Prepared in cooperation with the South Dakota Department of Transportation and the National Weather Service

Thunderstorms and Flooding of August 17, 2007, with a Context Provided by a History of Other Large Storm and Flood Events in the Black Hills Area of South Dakota

Scientific Investigations Report 2010–5187

U.S. Department of the Interior
U.S. Geological Survey

Front cover. Center: Site 435112103163700, un-named tributary to Deadman Gulch near Hermosa (table 1; drainage area = 0.678 square mile), where a flow of 2,000 cubic feet per second occurred on August 17, 2007. Photograph by Dan Driscoll.
Lower left: U.S. Geological Survey personnel checking field notes.
Lower right: This trailer was moved and damaged by the waters of the August 2007 flood event in the Hermosa area. Photograph by Mark T. Anderson.
Background: Aftermath of May 17, 1883, flood in Deadwood. Photographs courtesy of Adams Museum, Deadwood, SD (used with permission).

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U.S. Geological Survey
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Conversion Factors and Datums

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)
knot	1.852	kilometer/hour (km/hr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
inch per hour (in/h)	0.0254	meter per hour (m/h)
inch per day (in/d)	0.6096	meter per day (m/h)
mile per hour (mi/h)	1.609	kilometer per hour (km/h)
	Pressure	
atmosphere (atm)	1,013.25	millibar (mb)

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) or North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Altitude, as used in this report, refers to distance above the vertical datum of NGVD 29 unless otherwise specified.

Water year (WY) 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, 2006, is called the “2006” water year.

Under the downstream order system for streamflow-gaging stations, station numbers increase in the downstream direction.

Abbreviations and Acronyms

α	significance criterion
KUDX WSR–88D	South Dakota Weather Surveillance Radar-1988 Doppler, station KUDX
MDT	Mountain Daylight Time
NWS	National Weather Service
p-value	probability value
r	Pearson’s correlation coefficient
r^2	coefficient of determination
SDDOT	South Dakota Department of Transportation
STP	storm-total precipitation
USGS	U.S. Geological Survey
WY	water year

This residential area of Hermosa was inundated by flooding along Battle Creek during the August 17, 2007, storm (photograph by Mark T. Anderson).

Thunderstorms and Flooding Of August 17, 2007, with a Context Provided by a History of Other Large Storm and Flood Events in the Black Hills Area of South Dakota

By Daniel G. Driscoll[1], Matthew J. Bunkers[2], Janet M. Carter[1], John F. Stamm[1], and Joyce E. Williamson[1]

Abstract

The Black Hills area of western South Dakota has a history of damaging flash floods that have resulted primarily from exceptionally strong rain-producing thunderstorms. The best known example is the catastrophic storm system of June 9–10, 1972, which caused severe flooding in several major drainages near Rapid City and resulted in 238 deaths. More recently, severe thunderstorms caused flash flooding near Piedmont and Hermosa on August 17, 2007. Obtaining a thorough understanding of peak-flow characteristics for low-probability floods will require a comprehensive long-term approach involving (1) documentation of scientific information for extreme events such as these; (2) long-term collection of systematic peak-flow records; and (3) regional assessments of a wide variety of peak-flow information. To that end, the U.S. Geological Survey cooperated with the South Dakota Department of Transportation and National Weather Service to produce this report, which provides documentation regarding the August 17, 2007, storm and associated flooding and provides a context through examination of other large storm and flood events in the Black Hills area.

The area affected by the August 17, 2007, storms and associated flooding generally was within the area affected by the larger storm of June 9–10, 1972. The maximum observed 2007 precipitation totals of between 10.00 and 10.50 inches occurred within about 2–3 hours in a small area about 5 miles west of Hermosa. The maximum documented precipitation amount in 1972 was 15.0 inches, and precipitation totals of 10.0 inches or more were documented for 34 locations within an area of about 76 square miles.

A peak flow of less than 1 cubic foot per second occurred upstream from the 2007 storm extent for streamflow-gaging station 06404000 (Battle Creek near Keystone); whereas, the 1972 peak flow of 26,200 cubic feet per second was large, relative to the drainage area of only 58.6 square miles. Farther downstream along Battle Creek, a 2007 flow of 26,000 cubic feet per second was generated entirely within an intervening drainage area of only 44.4 square miles. An especially large flow of 44,100 cubic feet per second was documented for this location in 1972. The 2007 peak flow of 18,600 cubic feet per second for Battle Creek at Hermosa (station 06406000) was only slightly smaller than the 1972 peak flow of 21,400 cubic feet per second. Peak-flow values from 2007 for three sites with small drainage areas (less than 1.0 square mile) plot close to a regional envelope curve, indicating exceptionally large flow values, relative to drainage area.

Physiographic factors that affect flooding in the area were examined. The limestone headwater hydrogeologic setting (within and near the Limestone Plateau area on the western flank of the Black Hills) has distinctively suppressed peak-flow characteristics for small recurrence intervals. Uncertainty is large, however, regarding characteristics for large recurrence intervals (low-probability floods) because of a dearth of information regarding the potential for generation of exceptionally strong rain-producing

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[1] U.S. Geological Survey.

[2] National Weather Service.

thunderstorms. In contrast, the greatest potential for exceptionally damaging floods is around the flanks of the rest of the Black Hills area because of steep topography and limited potential for attenuation of flood peaks in narrow canyons.

Climatological factors that affect area flooding also were examined. Area thunderstorms are largely terrain-driven, especially with respect to their requisite upward motion, which can be initiated by orographic lifting effects, thermally enhanced circulations, and obstacle effects. Several other meteorological processes are influential in the development of especially heavy precipitation for the area, including storm cell training, storm anchoring or regeneration, storm mergers, supercell development, and weak upper-level air flow. A composite of storm total precipitation amounts for 13 recent individual storm events indicates (1) a propensity for heavy precipitation to occur east of the major axis of the Black Hills, from the northern hills (near Spearfish) toward the southeast through the eastern foothills near Hermosa, and (2) a proclivity for short-duration but intense convective precipitation events. The largest gradients in topography lie along the foothills, as opposed to over the higher altitudes, and this helps favor heavy precipitation. Additionally, a pronounced escarpment with several hundred feet of relief exists along the eastern edge of the Limestone Plateau, and orographic lifting associated with this escarpment can occur with a southeasterly air flow. However, to the west of this escarpment, relief is relatively small and localized, and the potential for orographic lifting is minimal. Moreover, moisture-laden air masses mostly originate from the Gulf of Mexico, which strongly affects the eastern Black Hills. Finally, the westerly mean air flow causes storm complexes to drift eastward, which generally coincides with a down-basin direction for most drainages along the eastern flanks of the Black Hills, and also favors convergent patterns along the eastern slopes of the Black Hills. Collectively these factors enhance the probability of exceptional rainstorms along the eastern Black Hills, relative to the highest terrain.

A chronology of historical storm and flood events was examined to provide a context regarding exceptional events for the Black Hills area. Consideration of the comprehensive flood history indicated that most of the especially large flows for smaller drainages in the Black Hills area have resulted from strong thunderstorms, rather than from more general storm systems. Of the 13 events that were included in a climatological analysis of recent large area storms, 10 occurred between late May through early July, which probably is reasonably representative of most of the strong localized storm events contained in a tabulation of historical storm and flood accounts. In contrast, many of the large storm and flood events for the Fall River have occurred in August and September.

Statistical analyses of peak-flow trends were performed for two streamflow-gaging stations, and a statistically significant trend (downward) was quantified for one (station 06402500 along Beaver Creek). However, consideration of historical flood accounts qualitatively supports a hypothesis that exceptionally large flood events may be somewhat “under-represented” in peak-flow records subsequent to 1972 (which includes a preponderance of modern peak-flow records) for relatively small area drainages that include the Fall River, Beaver Creek, Rapid Creek, Spearfish Creek, Whitewood Creek, and Bear Butte Creek.

The combination of climatological factors, systematic peak-flow records, and historical accounts strongly supports a conclusion that potential for generation of exceptional thunderstorms is much smaller west of the major axis of the Black Hills than east of the axis, especially relative to areas with the most robust history of large-scale events along the eastern flank. For areas just east of the escarpment that lies along the eastern extent of the Limestone Plateau, accounts of large peak-flow events are not completely absent, but generally are sparse relative to records and historical accounts for areas around the periphery of the Black Hills. A conclusion of increased potential for especially heavy precipitation from convective storms, relative to areas west of the escarpment, is strongly supported by systematic records, historical accounts, and climatological theory. Drainages within the northern Black Hills were qualitatively determined to be considerably more subject to effects from wet antecedent conditions (including snowpack) and from storms involving prolonged precipitation than drainages within the central and southern Black Hills.

Final interpretations are offered that further refine the potential for exceptionally strong storms and associated flooding. Storm and flood potential are smallest on the relatively flat top of the Limestone Plateau, but increase in southerly and northerly directions commensurate with increasing topographic relief. Storm and flood potential also increase in easterly and westerly directions owing primarily to increasing relief. Storm and flood potential are largest along the eastern and northeastern flanks of the Black Hills, with maximum flood potential occurring in confined canyons with especially steep topography nearby. Storm potential generally decreases in moving around the periphery of the Black Hills towards the western flank because of reduced potential for orographic lifting and decreasing effects from moisture-laden air masses originating from the Gulf of Mexico.

Introduction

The Black Hills area of western South Dakota has a history of damaging flash floods that have resulted primarily from exceptionally strong rain-producing thunderstorms. The best known example is the catastrophic storm system of June 9–10, 1972, which caused the most exceptional known flooding in several major drainages near Rapid City and resulted in 238 deaths and 3,057 injuries (Carter and others, 2002).

A system of severe thunderstorms on August 17, 2007, caused heavy precipitation and flash flooding in and near the communities of Hermosa and Piedmont (fig. 1; Holm and Smith, 2008). The 2007 storm system caused some of the most substantial flooding in the Black Hills area since 1972 and resulted in a peak flow along Battle Creek near Hermosa that was only slightly smaller than the record flood that occurred at the same location during 1972.

Estimating the probability of occurrence of large and infrequent floods such as those in 2007 and 1972 is a difficult task. Statistical approaches for flood-frequency analysis generally are based on relatively short-term, peak-flow records and inherently have large uncertainty associated with especially large recurrence intervals (that is, 100-, 500- or 1,000-year return periods, which have annual exceedance probabilities of 1.0, 0.2, and 0.1 percent, respectively). A flood magnitude with an annual exceedance probability of 1.0 percent means there is 1 chance in 100 for that magnitude to be exceeded in any given year.

Various investigators have worked to attain improved knowledge of the frequency of occurrence of large floods for the Black Hills area. Sando and others (2008) developed a “regional mixed-population approach” to address complications associated with consideration of “high-outlier” floods in performing peak-flow frequency analyses for the Black Hills area. A reconnaissance-level study to evaluate the applicability of paleoflood surveys for improving knowledge of extreme floods was performed by the U.S. Geological Survey (USGS) in cooperation with the Research Program of the South Dakota Department of Transportation (SDDOT). Results of that study indicated that evidence of extreme floods predating systematic peak-flow records is preserved in many locations throughout the Black Hills area (O’Connor and Driscoll, 2007). A subsequent cooperative study to improve peak-flow frequency relations for selected drainage basins using paleoflood evidence has been implemented by USGS and SDDOT. Compilation of information regarding particularly large storm and flood events for the Black Hills area is one component of this ongoing paleoflood study, which has partially supported preparation of this report. Other support has been provided by the Bridge Program of SDDOT, and by the National Weather Service (NWS), which has cooperated in authorship of this report. Specific purposes of this report are to (1) provide documentation regarding the August 17, 2007, storms and associated flooding, and (2) provide a context through examination of the history of other large storm and flood events in the Black Hills area.

Many private citizens were instrumental in making this publication possible, and many citizens in the Hermosa area are acknowledged for providing valuable information regarding precipitation amounts for the August 17, 2007, storm. Moreover, many area landowners graciously provided permission for accessing private land for subsequent indirect measurements of peak flow. The Hot Springs Public Library is acknowledged for providing assistance in compiling historical information and numerous entities are acknowledged for providing permission for reproduction of historical documentation including the Adams Museum, Antiques & Art, City of Deadwood Historic Preservation Commission, Fall River County Historical Society, Hot Springs Star, Rapid City Journal, and Tri-State Museum. Retired USGS employee Ken Lindskov is recognized for assisting with data collection for indirect measurements of peak flow and for providing rigorous reviews of associated computations. Finally, local historians Ellen Bishop, John Honerkamp, Peggy Sanders, and David Schnute are gratefully acknowledged for their many efforts in helping to assemble historical flood information for the Black Hills area.

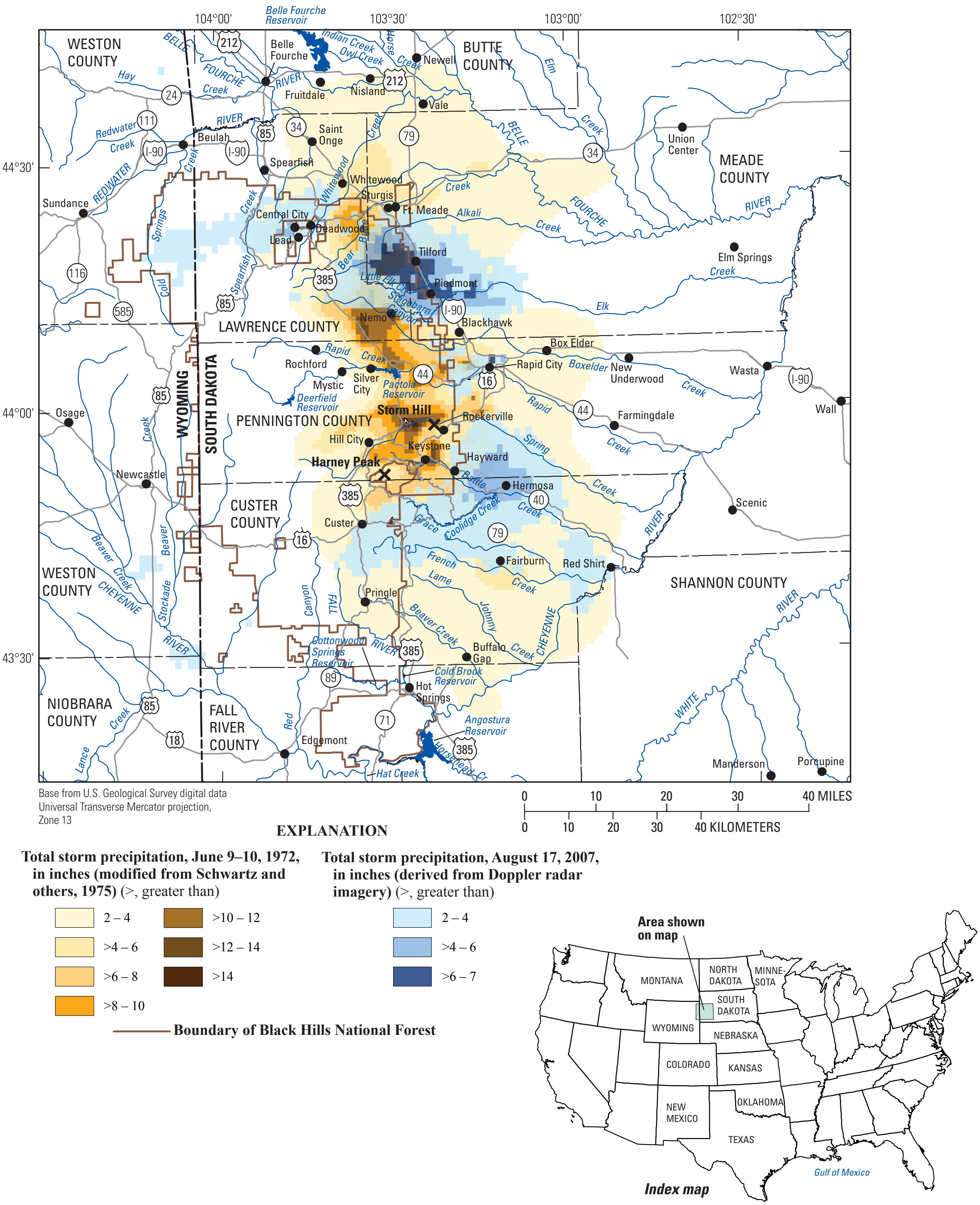


Figure 1. Location of study area and general extent of 1972 and 2007 thunderstorms (2007 storm plotted with transparency over 1972 storm).

The 2007 Storms and Flooding, with Comparisons to the 1972 Storms and Flooding

The area affected by the August 17, 2007, storms and associated flooding generally was encompassed within the area affected by the larger storm system of June 9–10, 1972 (fig. 1). The 1972 storms and associated flooding were thoroughly documented by Schwarz and others (1975). Numerous other accounts of various aspects of this exceptional event have been provided in other scientific publications and in many other non-scientific venues such as newspapers, magazines, and books. This section of the report provides details regarding the 2007 storms and associated flooding and also includes comparisons with the 1972 storms and associated flooding.

Photograph of 11-inch rain gage at a location west of Hermosa where 10.50 inches of precipitation was measured on August 17, 2007 (photograph by Robert D. Jarrett).

The Storms

Precipitation totals for the 2007 storms in the Hermosa area were determined by NWS for 30 locations through a survey of area residents. Site locations and precipitation totals were reported by Holm and Smith (2008), who also provided numerous other details regarding the 2007 storm system. Observed precipitation totals are shown in figure 2, which also shows isohyets (lines of equal precipitation) for the 2007 storm. The maximum observed precipitation totals were 10.50, 10.44, and 10.00 inches (in.), which were measured in three rain gages located just north of Battle Creek between Hayward and Hermosa. These totals occurred within a period of about 3 hours (Holm and Smith, 2008); however, various observers reported that most of the precipitation occurred within about 2 hours.

Schwarz and others (1975) provided numerous details regarding the 1972 storm, which was documented extensively because of the extreme storm magnitude and resulting damage from the associated flooding. Precipitation totals were reported for 24 NWS observing stations and for 258 additional locations where precipitation amounts were measured and reported by private and government sources. The maximum documented precipitation amount was 15.0 in. near Nemo (fig. 1), and precipitation totals that equaled or exceeded 10.0 in. were documented for 34 locations (compared with 3 locations for the 2007 storms), with all storm totals generally occurring within a 6-hour period. Schwarz and others (1975) also provided a context for the general rarity of extreme storms through a comparison with information for 132 other exceptional storms that had been documented for the northwestern Great Plains States of North Dakota, South Dakota, Kansas, Montana, Wyoming, and Colorado. Of these, 10 storms had point precipitation totals of 10 in. or more in 6 hours, and two storms exceeded 15 in. in 6 hours.

An isohyetal map for the 1972 storm is shown in figure 3, which was reproduced by Carter and others (2002) from an original map by Schwarz and others (1975). Figure 1 shows gridded precipitation totals for the 1972 storm, along with radar-estimated storm-total precipitation (STP) for the 2007 storm. The STP amounts were derived using a totaling algorithm applied to a time series of radar imagery from the South Dakota Weather Surveillance Radar-1988 Doppler (WSR–88D) that is located just north of New Underwood. For this algorithm, the power returned to the radar is converted to an instantaneous rainfall rate, which subsequently is totaled for a 4.1-minute interval. The 2007 STP dataset includes estimated storm totals for another storm cell that produced heavy precipitation farther north near Piedmont during the same timeframe. Hail damage in the Piedmont area was especially severe, as evidenced by visual observations and reports from numerous area residents. Holm and Smith (2008) reported that for areas near Hermosa with the heaviest precipitation, the STP estimates are lower than observed amounts. The radar-derived STP data for the Piedmont area probably were

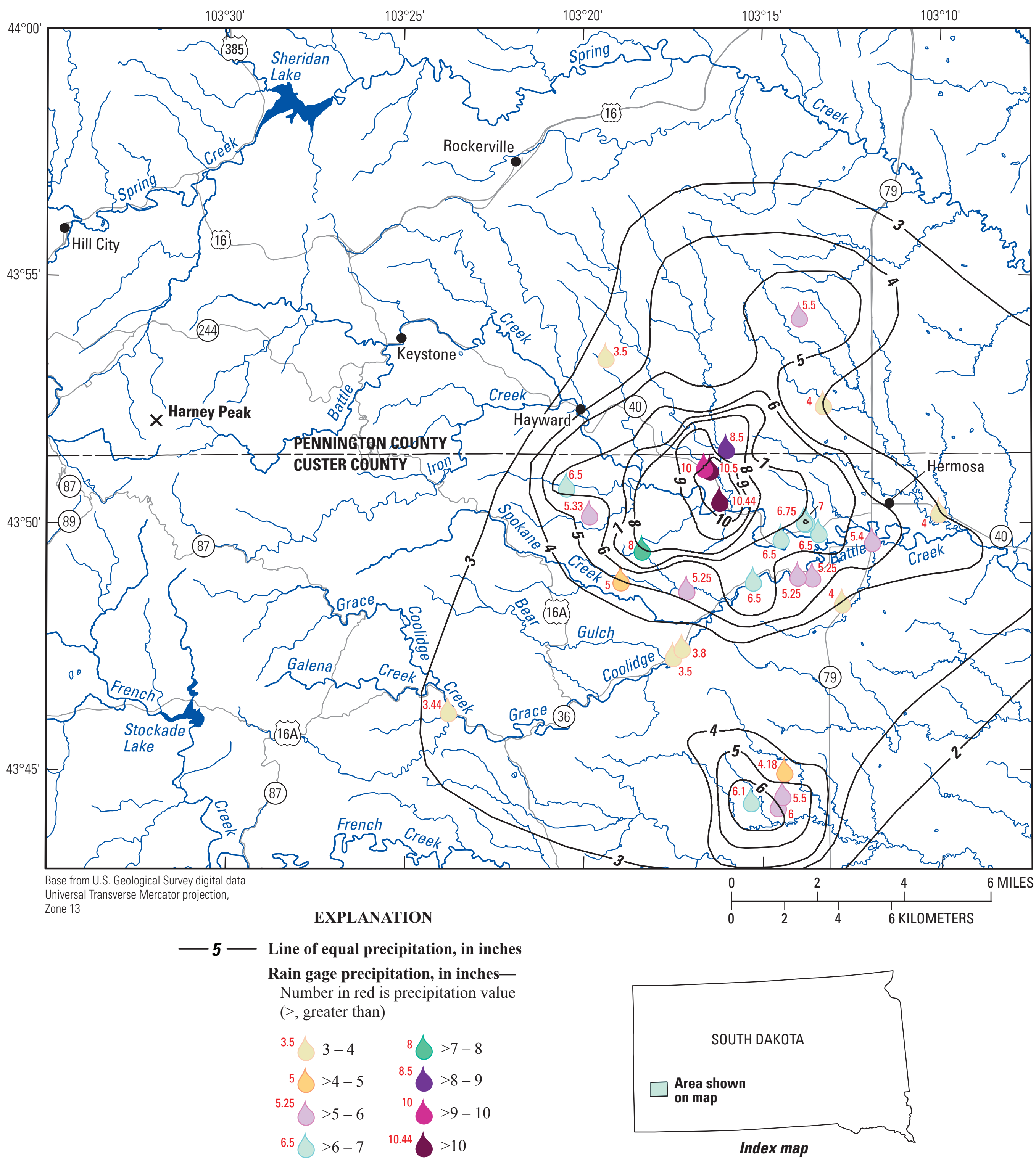


Figure 2. Isohyetal map for the 2007 storm in the Hermosa area.

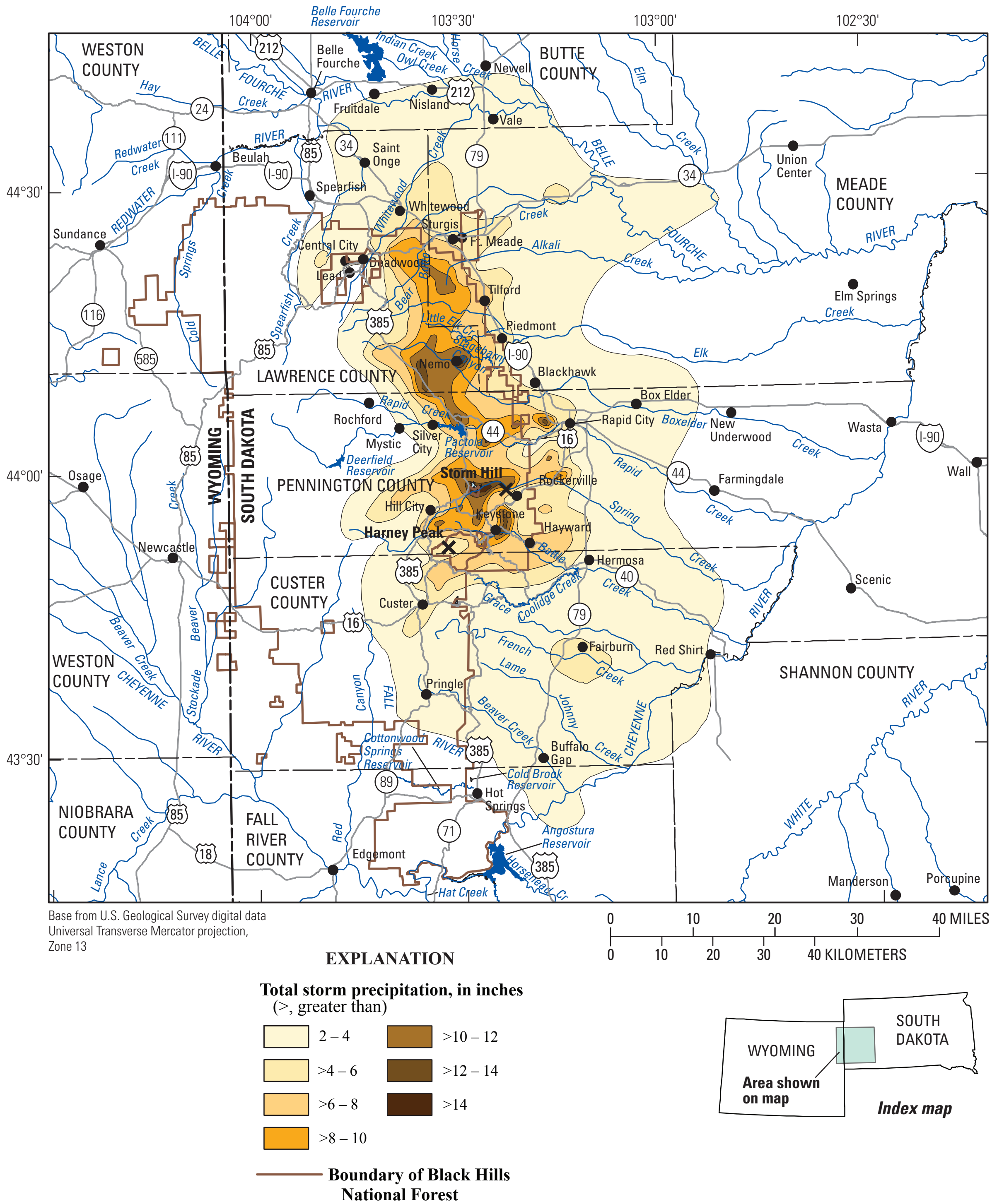


Figure 3. Isohyetal map for the 1972 storm (from Schwarz and others, 1975).

overestimated because of interference from large hail (Baeck and Smith, 1998).

The 1972 storm was exceptional in terms of precipitation totals, intensity, and areal extent, which can be illustrated by comparisons with national precipitation intensity data (Hershfield, 1961). The maximum return period listed in that publication is for a 100-year (1-percent annual exceedance probability) storm, and the 100-year, 6-hour precipitation for any given location in the general vicinity of the 1972 storm is about 3.5 to 4.0 in. Thus, the largest precipitation totals for the 1972 storm exceeded this precipitation depth by a factor of about 3 to 4. For estimating storm totals over larger areas, Hershfield (1961) provided a graph indicating that the 6-hour precipitation estimates should be reduced by a factor of about 0.85 for areas of about 100 to 400 square miles (mi^2). For the 1972 storm, the area encompassed by the 4-in. isohyet (fig. 3) is about 870 mi^2, with most of this area receiving considerably more than 4 in. of total precipitation. The probable maximum precipitation estimate is for a 6-hour duration storm covering 10 mi^2 and is about 20 in. for the Black Hills area. The 1972 storm produced about 50 percent of this amount (10 in.) over an area of about 76 mi^2 and about 70 percent of this amount (14 in.) over an area of about 2 mi^2.

Holm and Smith (2008) compared the 1972 and 2007 storms and identified some similarities between the large-scale atmospheric features for the two events. In terms of areal extent (fig. 1), the two storms are most similar for the smaller precipitation footprints, for which the 1972 footprint exceeds the 2007 footprint by about 300 percent for the 2–4 in. range and by about 270 percent for the 4–6 in. range. However, the 1972 footprint is much larger than the 2007 footprint for precipitation greater than 6 in. with 1972 exceeding 2007 by about 680 percent. The intensity of the 2007 storm was exceptional, with most precipitation occurring within about 2 to 3 hours. Thus, maximum precipitation intensities for some areas during the 2007 storm may have exceeded the maximum intensities that occurred during the 1972 storm (6-hour duration). Another noteworthy aspect of the 2007 storm was that the large-scale "parent" storm system continued to track to the east and later caused heavy precipitation and flooding across parts of southeastern Minnesota and southern Wisconsin (National Oceanic and Atmospheric Administration, 2009). A storm total of 16.27 in. was recorded near Hokah in Houston County, Minn. (in the southeastern corner of Minnesota, about 640 mi east of Rapid City, S. Dak.) of which 15.10 in. fell within 24 hours. This is the largest 24-hour rainfall total recorded by NWS in Minnesota (Minnesota Climatology Working Group, 2009).

Photograph of hailstones from the August 17, 2007, storm near Piedmont (photograph by Caroline Struwe, contributed through the Rapid City Journal).

Photographs of the 1972 flood

Water rose and flowed more than 4 feet deep over the entire length of Victoria Dam near Rapid City. Fortunately, the concrete arch dam held.

This bridge on Sheridan Lake Road was washed out. The estimated flood damage for roads and bridges was more than $22 million.

Houses floated downstream and lodged on Canyon Lake Dam.

The wreckage of homes stacked up against bridge abutments. This picture was taken on the morning after the flood when many bodies were being found in debris such as this.

Photographs by Perry H. Rahn, South Dakota School of Mines and Technology.

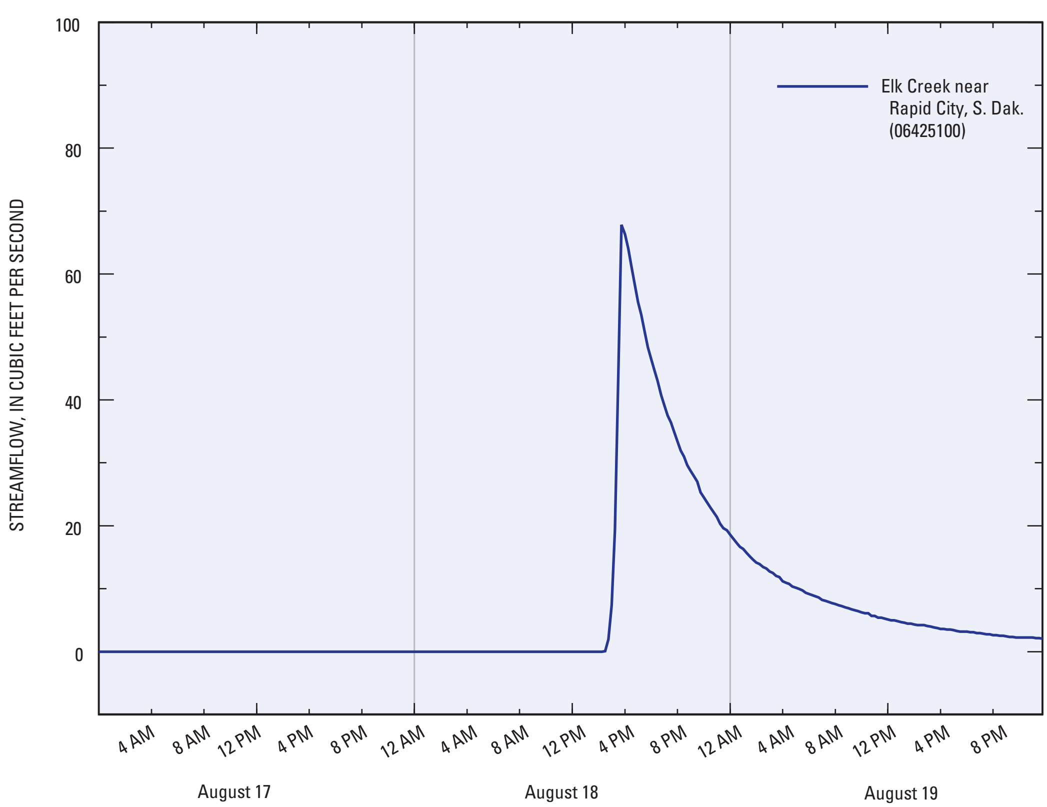
The Flooding

Flooding in the Piedmont area was localized. A maximum flow of only 68 cubic feet per second (ft^3/s) was recorded on August 18, 2007, for USGS streamflow-gaging station 06425100, Elk Creek near Rapid City (fig. 4), which is located about 10 miles (mi) downstream from Piedmont (fig. 5, map number 62). The drainage area for this station (211 mi^2) includes a large part of the area covered by the 2007 storm in the Piedmont area. Field inspections indicated that flows considerably greater than 68 ft^3/s occurred in many small drainages in the Piedmont area, and a flow of 1,600 ft^3/s was documented for Stagebarn Canyon (drainage area = 17.2 mi^2) (fig. 5, station 441233103215300). Thus, substantial attenuation of many localized flood peaks apparently occurred in moving downstream from Piedmont through extensive channel networks with large alluvial deposits.

The most severe flooding during 2007 occurred in the Hermosa area, where low-lying areas in the southern and southeastern parts of this small community (population of 335 in 2005; U.S. Census Bureau, 2009) were inundated by flooding along Battle Creek. A railroad grade was breached just south of town, and several downstream houses were washed from their foundations (fig. 6). The flood peak attenuated substantially downstream from Hermosa, and flood damage in this primarily agricultural area generally was not severe. Highway 79 (fig. 7) was inundated for most of the distance between Battle Creek and Highway 36, and extensive low-lying areas were inundated upstream from Highway 79, with substantial inundation extending to the west into Grace Coolidge Creek and Battle Creek upstream from Grace Coolidge Creek. Land use in this area primarily is a mix of "semi-agricultural" and low-density housing, and some houses and outbuildings experienced flood damage. Numerous area roads incurred damage related to plugging, overtopping, or washing out of culverts, bridges, or stream crossings. Two bridge foundations about 2–3 mi west of Hermosa along Highway 40 incurred scour damage (fig. 8), and considerable damage to the highway grade occurred in several locations.

Peak-flow determinations for the Hermosa area associated with the 2007 flooding, along with peak-flow determinations for 1972 (where available), are included on table 1. The 2007 peak flow of 18,600 ft^3/s for station 06406000 (Battle Creek at Hermosa) was only slightly smaller than the 1972 peak flow of 21,400 ft^3/s, despite considerably smaller areal extent of exceptionally heavy precipitation within the watershed during 2007 than in 1972. Peak-flow determinations for most of the larger flows were made using various methods of "indirect measurements" (Dalrymple and Benson, 1967) that utilize hydraulic analyses involving channel geometry and associated high-water marks that were performed after the passage of the flood peaks.

Figure 4. Hydrograph for 2007 flooding for streamflow-gaging station 06425100, Elk Creek near Rapid City, S. Dak.



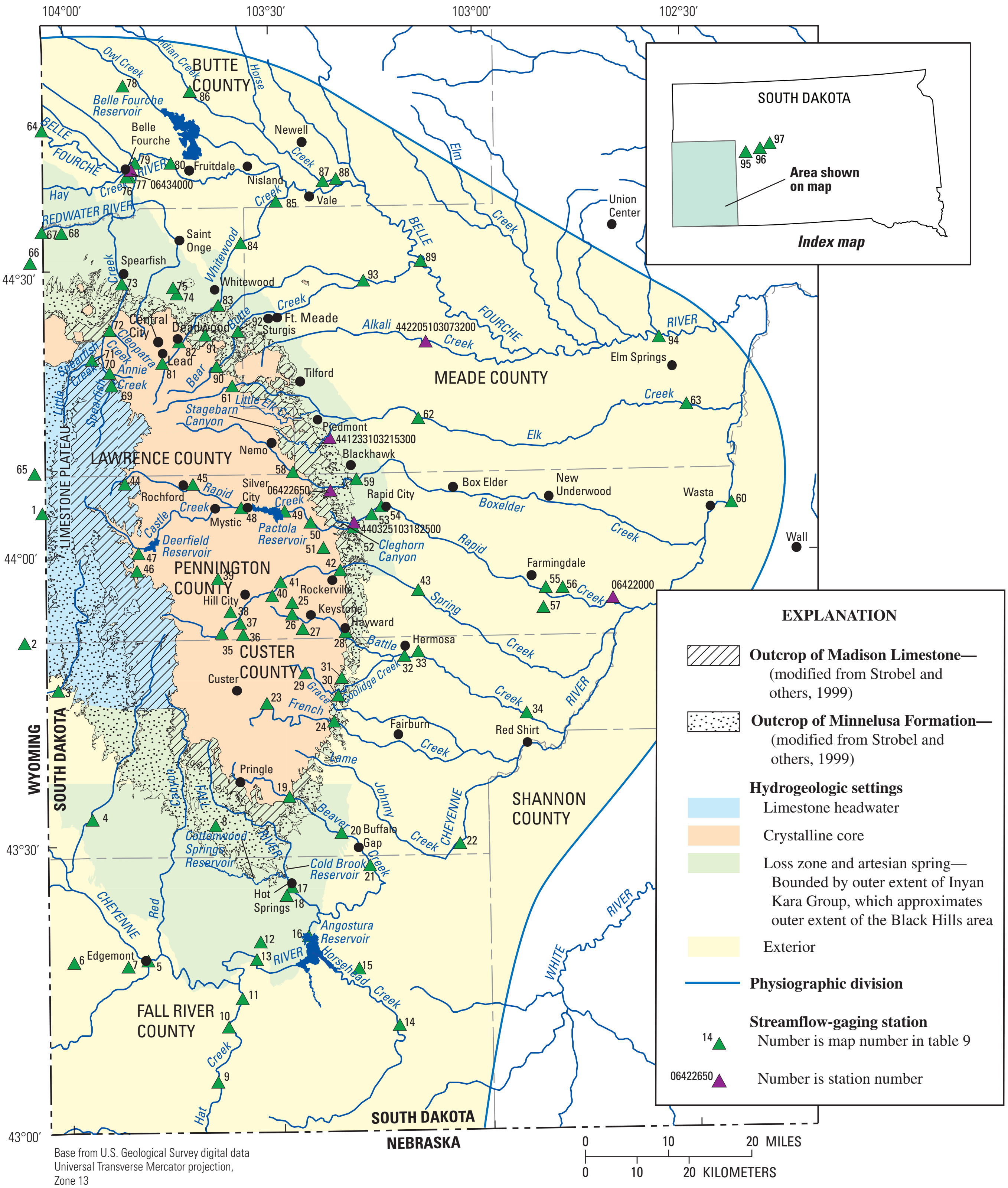


Figure 5. Hydrogeologic settings for the Black Hills area (modified from Sando and others, 2008) and locations of selected streamflow-gaging stations.

Figure 6. Photographs showing damages to houses and the railroad grade in the Hermosa area from flooding on August 17, 2007 (photographs by Mark T. Anderson).

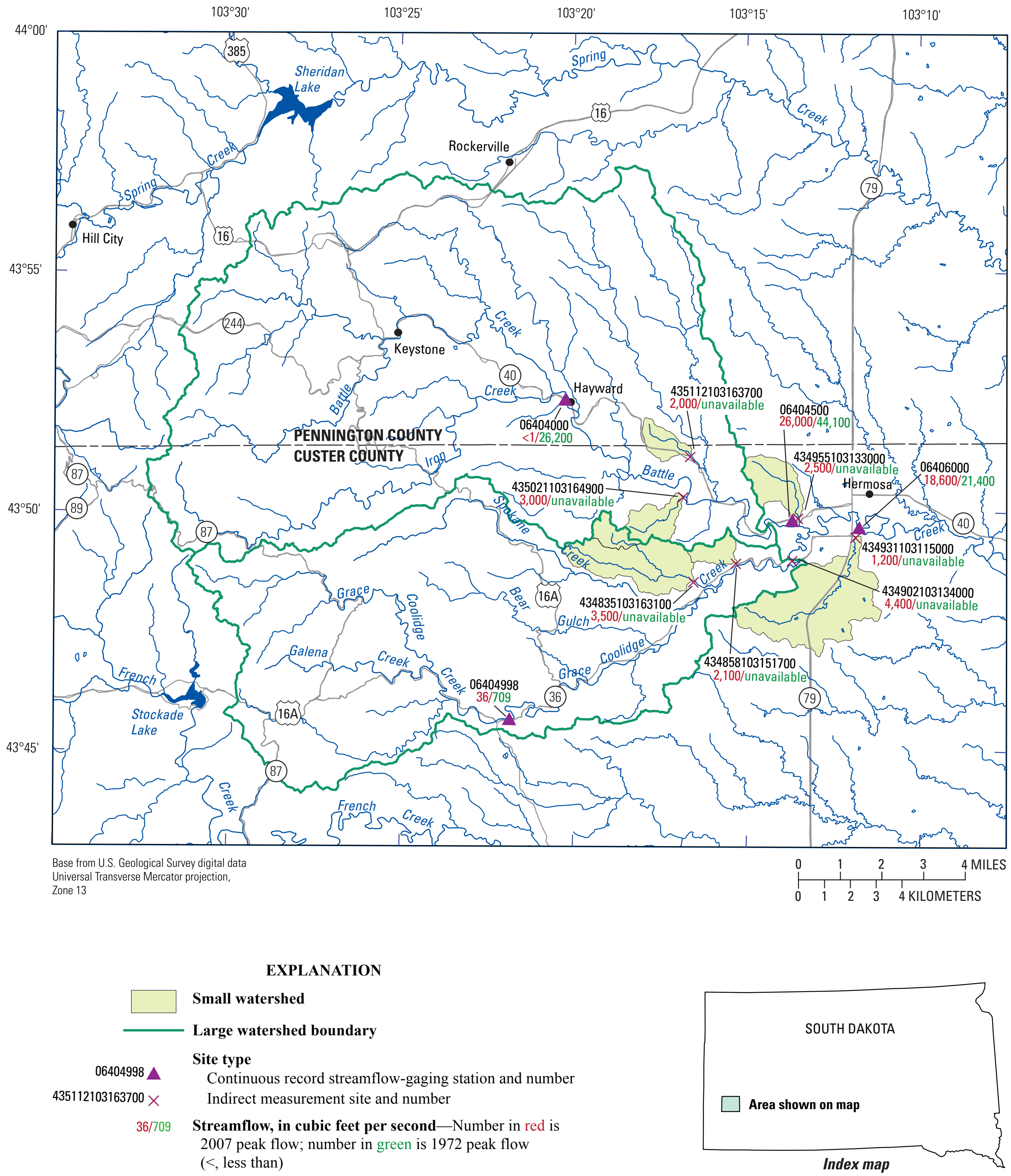


Figure 7. Comparison of 2007 and 1972 peak flows for selected locations in the Hermosa area.

Figure 8. Photographs showing scour from flooding on August 17, 2007, at a bridge site along Highway 40 about 2 to 3 miles west of Hermosa, S. Dak. Photographs by Mark T. Anderson.

Table 1. Peak-flow data for selected sites resulting from storms during 2007 (August 17), 1972 (June 9–10), and 1957 (July 28).

[mi², square miles; <, less than; --, not determined; e, estimated value derived from critical-flow computation (Grant, 1997)]

Station number	Station name	Drainage area (mi²)	Peak flow (cubic feet per second) for selected year		
			2007	1972	1957
Sites along main-stem reaches of Battle and Grace Coolidge Creeks					
06404000	Battle Creek near Keystone, S. Dak.	58.6	<1.0	26,200	--
06404500	Battle Creek near Hermosa, S. Dak.	103	26,000	44,100	--
[1]06404998	Grace Coolidge Creek near Game Lodge near Hermosa, S. Dak.[1]	26.9	36	709	--
434902103134000	Grace Coolidge Creek at Highway 36 bridge above Hermosa, S. Dak.	61.5	4,400	--	--
06406000	Battle Creek at Hermosa, S. Dak.	169	18,600	21,400	1,950
06406500	Battle Creek below Hermosa, S. Dak.	285	1,850	--	--
Sites along small tributaries to Battle and Grace Coolidge Creeks					
435112103163700	Un-named tributary to Deadman Gulch near Hermosa, S. Dak.	0.678	e2,000	--	--
435021103164900	Un-named tributary (right bank) to Battle Creek above Hermosa, S. Dak.	.977	e3,000	--	--
434955103133000	Un-named tributary (left bank) to Battle Creek above Hermosa, S. Dak.	1.36	2,500	--	--
434835103163100	Un-named tributary (lower Ghost Canyon) to Grace above Hermosa, S. Dak.	2.73	e3,500	--	2,660
434858103151700	Un-named tributary (left bank) to Grace Coolidge Creek above Hermosa, S. Dak.	.565	e2,100	--	--
434931103115000	Un-named tributary (right bank) to Battle Creek at Hermosa, S. Dak.	4.92	1,200	--	1,150
Selected sites reported by Schwarz and others (1975) and considered by Crippen and Bue (1977)					
440325103182500	Cleghorn Canyon at Rapid City, S. Dak.	7.0	--	12,600	--
06422650	Boxelder Creek at Doty School near Blackhawk, S. Dak.	116	--	51,600	--

[1]Data before 1977 were collected at station 06405000 (Grace Coolidge Creek near Custer), which was operated just downstream from station 06404998.

The 2007 peak flows for sites in the Hermosa area, along with 1972 peak flows for applicable sites are shown in figure 7. Six of the sites listed in table 1 are located along main-stem reaches of Battle Creek or Grace Coolidge Creek, and peak flows for 1972 were determined at four of the six sites (fig. 7). Differences in peak flows between 1972 and 2007 are consistent with the differences in storm patterns (figs. 2 and 3). During 1972, the heaviest precipitation was north of Grace Coolidge Creek, and the peak flow for upstream station 06404998 (Grace Coolidge Creek near Game Lodge near Hermosa; 709 ft^3/s) was relatively small, but about 20 times larger than during 2007 (36 ft^3/s). Farther downstream along Grace Coolidge Creek, a 2007 peak flow of 4,400 ft^3/s was determined for station 434902103134000, located just upstream from the confluence with Battle Creek. The 1972 peak flow for this location was not determined by USGS; however, Schwarz and others (1975) stated that "Grace Coolidge Creek did not experience heavy flooding." This account was corroborated by several area residents with distinct recollections of 1972 flooding who reported that the 2007 flooding was much larger along lower Grace Coolidge Creek, which is consistent with the storm patterns.

During 2007, the heaviest precipitation along Battle Creek was limited to areas downstream from station 06404000 (Battle Creek near Keystone), for which a peak flow of less than 1 ft^3/s was recorded (table 1). The 1972 peak flow of 26,200 ft^3/s for this station was very large, relative to the drainage area of only 58.6 mi^2. Farther downstream along Battle Creek (station 06404500, located just upstream from the confluence with Grace Coolidge Creek), a 2007 peak flow of 26,000 ft^3/s was determined, which was generated entirely within the intervening drainage area of only 44.4 mi^2. In moving downstream to the next station (06406000; Battle Creek at Hermosa), the 2007 peak flow (18,600 ft^3/s) was attenuated by about 30 percent. In comparison, in 1972 an especially large peak flow of 44,100 ft^3/s was documented for station 06404500, which attenuated to a peak flow of 21,400 ft^3/s at downstream station 06406000 (Battle Creek at Hermosa). The Battle Creek flood plain broadens considerably within this reach, and filling of large volumes of storage is the primary mechanism for attenuation of flood flows within this reach. Heavier precipitation and associated tributary inflows within this reach (including a larger peak flow for Grace Coolidge Creek) probably contributed to less attenuation during 2007, relative to 1972.

Hydrographs for stations 06406000 (Battle Creek at Hermosa) and 06406500 (Battle Creek below Hermosa) for August 17–19, 2007, are presented as figure 9, which show that the peak flow attenuated between the two stations from 18,600 to 1,850 ft^3/s. For the upstream station, the entire rise of about 14 ft occurred in about 2.5 hours, and 12.37 ft of this rise occurred in 65 minutes. For the downstream station, a very small rise occurred about 10 p.m. on August 17, which is about 2 hours after the peak at the upstream station, and presumably resulted from minor localized runoff. The main rise began at 11:15 a.m. on August 18 (about 15 hours after the main rise upstream), and although the peak flow had attenuated by about 17,000 ft^3/s (90 percent), the main rise of almost 8 ft occurred within only about 90 minutes.

Schwarz and others (1975) presented data for the 1972 flooding (reproduced as fig. 10) that show Rapid Creek above Canyon Lake near Rapid City (station 06412500) rising by about 14 ft in 3 hours, with about 11 ft of rise within 2 hours, during the fastest part of the rise. Flow increased by about 28,000 ft^3/s during this timeframe, and farther downstream (Rapid Creek at Rapid City; station 06414000) flow increased by about 45,000 ft^3/s in about 1 hour. Flow attenuated substantially farther downstream because the flood plain in the intervening reach broadens substantially, and the peak flow at Rapid Creek near Farmingdale (station 06421500) was only 7,320 ft^3/s. The 2007 and 1972 hydrographs illustrate how quickly area streams can rise, and that rises to catastrophic flood stages can occur within extremely short timeframes, such that time available for providing warnings can be very short. Both storms occurred late in the day, which is typical for many exceptionally severe convective storms, and the associated flood events extended into darkness hours, which can further complicate warning efforts and increase dangers relative to injury and loss of life.

Alternative frequency curves from Sando and others (2008) for station 06406000 (Battle Creek near Hermosa) are shown in figure 11. The magnitudes and estimated recurrence intervals for the 2007 and 1972 peak flows are shown relative to the “Black Hills regional mixed-population frequency curve” that was developed by Sando and others (2008) to address complications associated with “high-outlier” peaks such as these. The estimated recurrence intervals for the 2007 and 1972 peak flows (18,600 and 21,400 ft^3/s, respectively; table 1) are about 400 and 450 years, respectively, which correspond with annual exceedance probabilities of about 0.0025 and 0.0022. Sando and others (2008) cautioned that especially large uncertainty exists for estimation of low-probability events such as those of 2007 and 1972, which is well illustrated by the fact that two low-probability floods have occurred at this station within a period of record dating back to 1950. The most realistic interpretation of the frequency analyses is that (1) meaningful estimates of exceedance probabilities for such low-probability events cannot be made at this time; and (2) even with many tens of years of additional peak-flow records, large uncertainties for low-probability events may still remain for any given streamflow-gaging station. Obtaining a thorough understanding of peak-flow characteristics for low-probability events will require a comprehensive long-term approach involving (1) collection and documentation of scientific information for extreme events, such as those of 2007 and 1972; (2) continued long-term collection of systematic peak-flow records for many locations; and (3) regional assessments of a wide variety of information that includes all available systematic peak-flow records, historical flood information, paleoflood information (which pre-dates historical information), and climatic information.

Flooding associated with the 1972 storm was extensive throughout the Black Hills area. Schwarz and others (1975) documented peak flows associated with the 1972 storm for 49 locations, of which 37 are locations of USGS streamflow-gaging stations where systematic peak-flow records were being collected, previously had been collected, or subsequently have been collected. The 1972 peak flows represent peak-of-record flows for 17 of the 37 stations (including record peak flows for 4 stations that did not yet have systematic records). The five largest annual peak flows for each of 97 selected streamflow-gaging stations are listed in table 9 in the back of this report; locations of stations are shown in figure 5. This table includes only stations with 10 or more years of peak-flow record; however, this criterion encompasses most stations in the Black Hills area and almost all stations with systematic peak-flow records that include 1972. Of the 97 stations in table 9, 53 stations have records available for 1972, of which 27 annual peak flows were associated with the June 9–10 storm; 16 were record flows as of 1972, and 14 remain as record flows (through water year 2009).

Six of the sites listed in table 1 are located along small tributaries (drainage areas ranging from 0.565 to 4.92 mi^2) to either Battle Creek or to Grace Coolidge Creek (fig. 7). These six sites are located in drainage basins where especially heavy precipitation occurred during 2007 (fig. 2) and sites were selected for field measurements because of especially large peak flows and conditions that were reasonably favorable for determination of peak flow. Peak-flow determinations were not obtained during 1972 for any of these six sites, and peak flows during 1972 presumably were much smaller than during 2007 for all six because of considerably lighter precipitation during 1972 (figs. 2 and 3). Previous peak-flow determinations were made for two of the sites following localized flooding that occurred in the area on July 28, 1957 (table 1), when the fifth largest peak-of-record flow (1,950 ft^3/s, table 9) was recorded for Battle Creek at Hermosa (station 06406000).

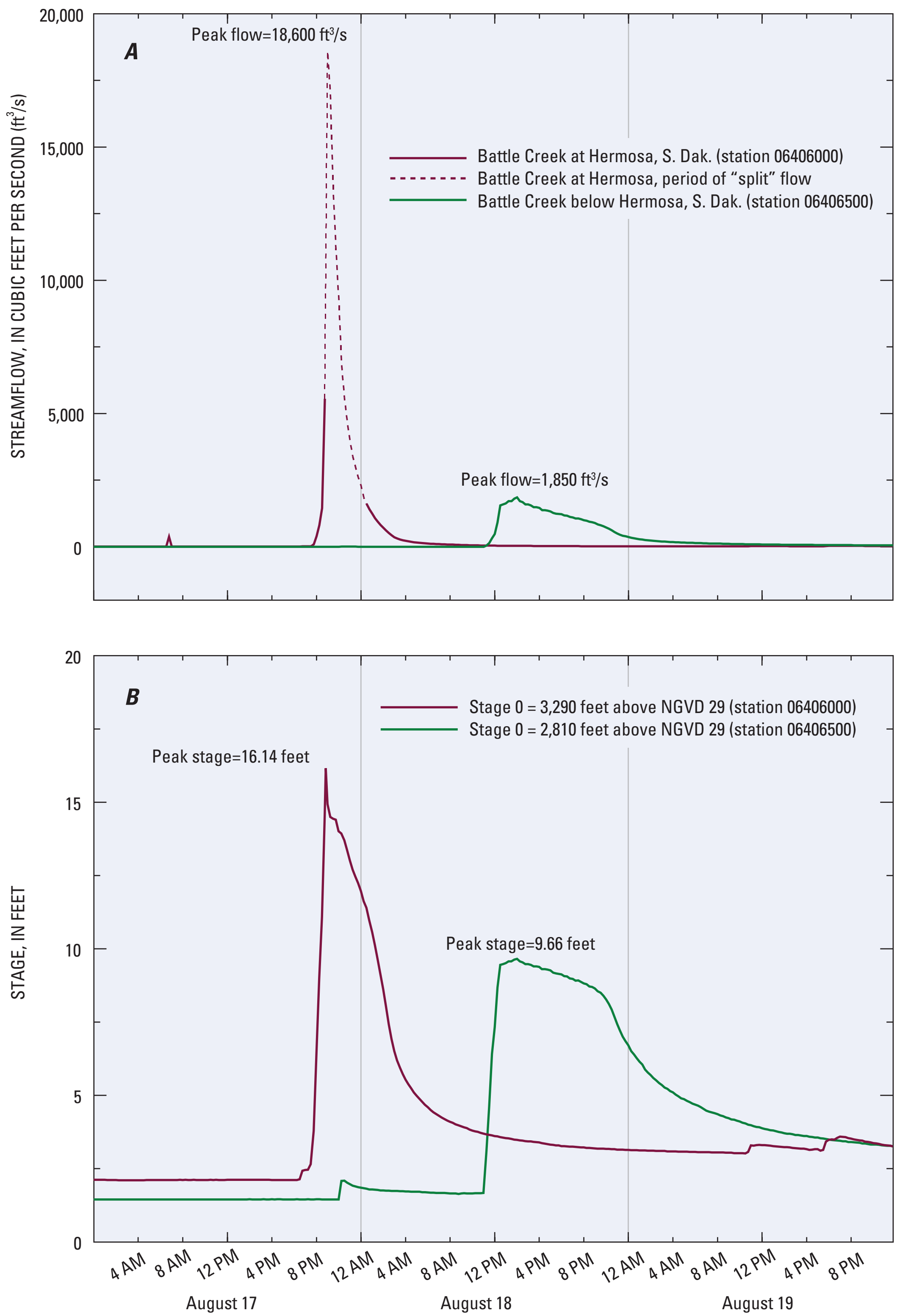


Figure 9. Hydrographs for 2007 flooding for two streamflow-gaging stations along Battle Creek. *A*, streamflow, dashed line indicates period when flow was split between the main channel at a railroad bridge at station 06406000 (Battle Creek at Hermosa, S. Dak.) and a breach in the railroad grade about one-quarter mile north of the station; and *B*, stage.

Figure 10. Hydrographs for 1972 flooding for three streamflow-gaging stations along Rapid Creek (modified from Schwarz and others, 1975).

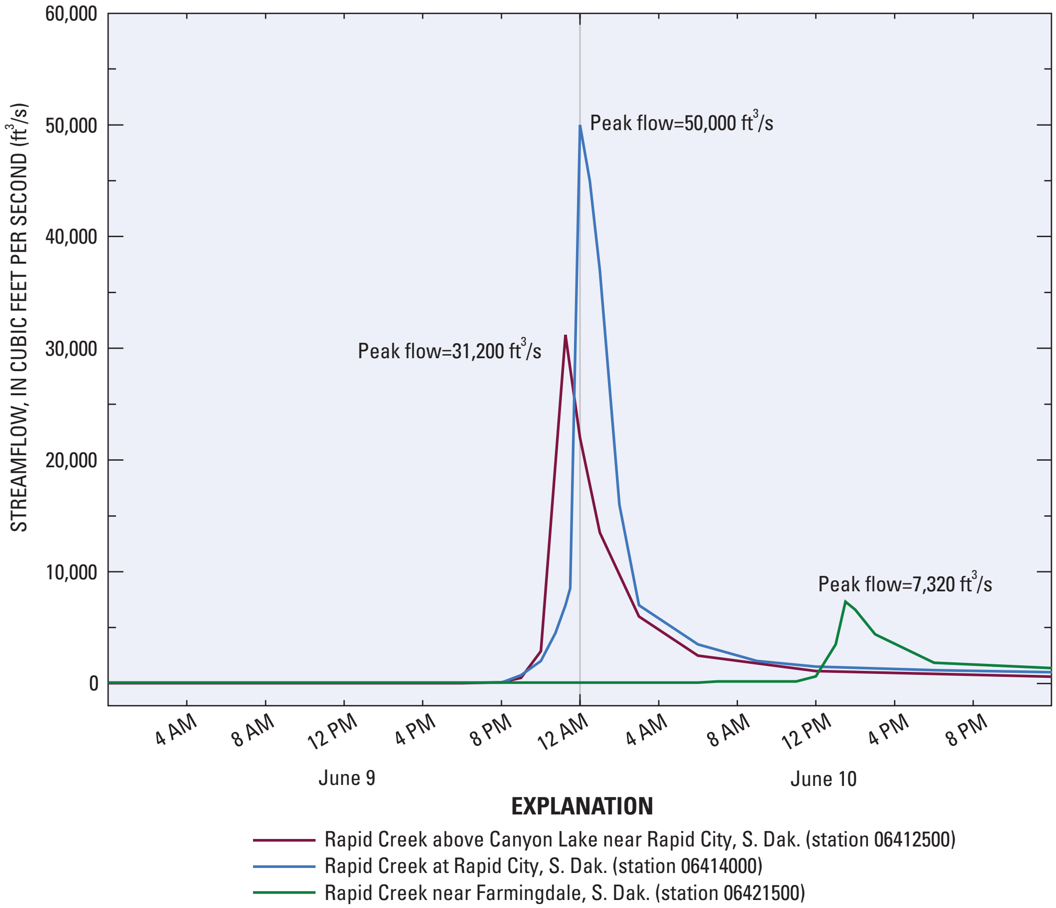
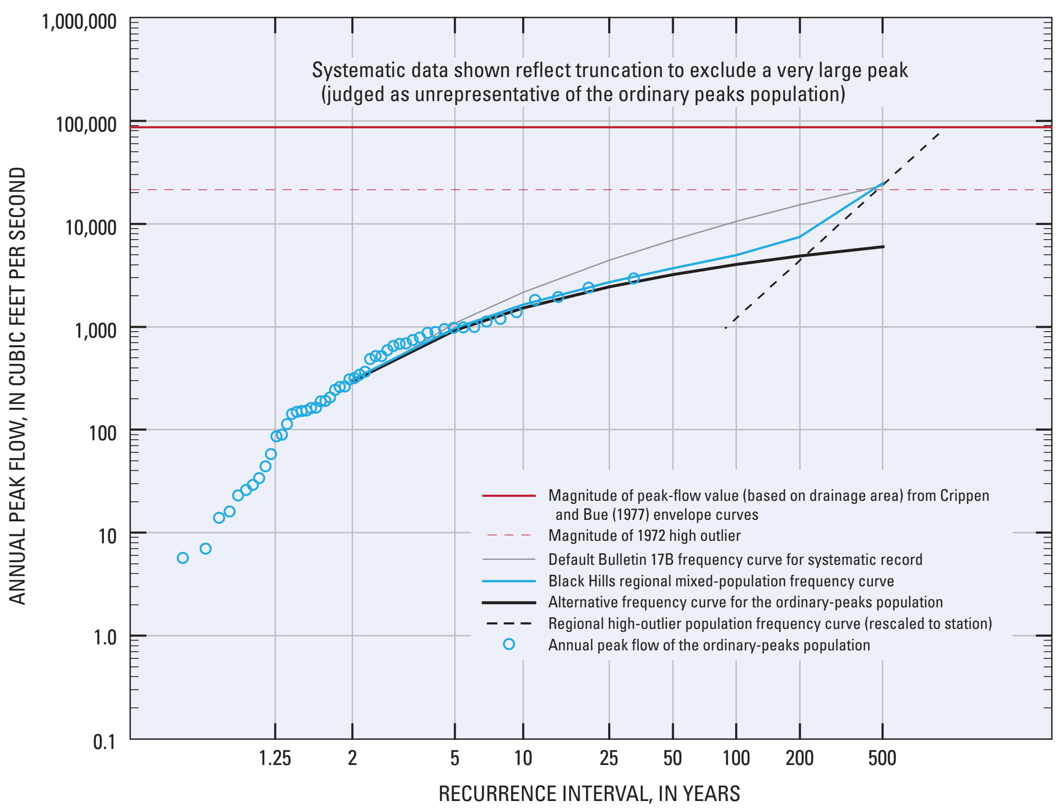


Figure 11. Frequency curve (modified from Sando and others, 2008) for Battle Creek at Hermosa, S. Dak. (streamflow-gaging station 06406000).



A perspective on the relative magnitudes of the 2007 peak flows for the six small tributary sites is shown in figure 12, which shows these six values plotted with an "envelope curve" that was developed by Crippen and Bue (1977) for a region that includes the Black Hills area. Crippen and Bue (1977) intended the envelope curve "to serve as a guide for making rule-of-thumb estimates of the magnitude of high flood discharges," and the envelope curve is closely approached by three of the peak-flow values for sites with the smallest drainage areas (<1.0 mi²), indicating exceptionally large flow values, relative to drainage area. Values for the four main-stem sites from table 1 where relatively large 2007 peak flows (1,850 to 26,000 ft³/s) were recorded are shown in figure 12. The largest of these four values is for station 06404500 (Battle Creek near Hermosa, drainage area = 103 mi²). The 1972 peak flow for this site (44,100 ft³/s; table 1) also is shown and plots fairly close to the envelope curve. Two other 1972 values from table 1 that were reported by Schwarz and others (1975) and considered by Crippen and Bue (1977) are shown in figure 12. A peak flow of 51,600 ft³/s for Boxelder Creek (station 06422650) coincides with one of the points plotted by Crippen and Bue (1977), and a peak flow of 12,600 ft³/s for Cleghorn Canyon at Rapid City (station 440325103182500, fig. 5) was listed by Crippen and Bue (1977) in a summary table, but was not plotted on their original envelope curve. It is noted that that peak-flow magnitudes generally do not increase linearly with increasing drainage area. This is reflected by the shape (exponential decay) of the envelope curve, which generally is consistent with an exponent of 0.6 that was used by Sando and others (2008) in normalizing "high-outlier" peak flows relative to drainage area.

Values for three sites in the Castle Creek Basin with peak-flow values for July 28, 1955, that were listed by Crippen and Bue (1977) but not plotted in their analysis, are shown in

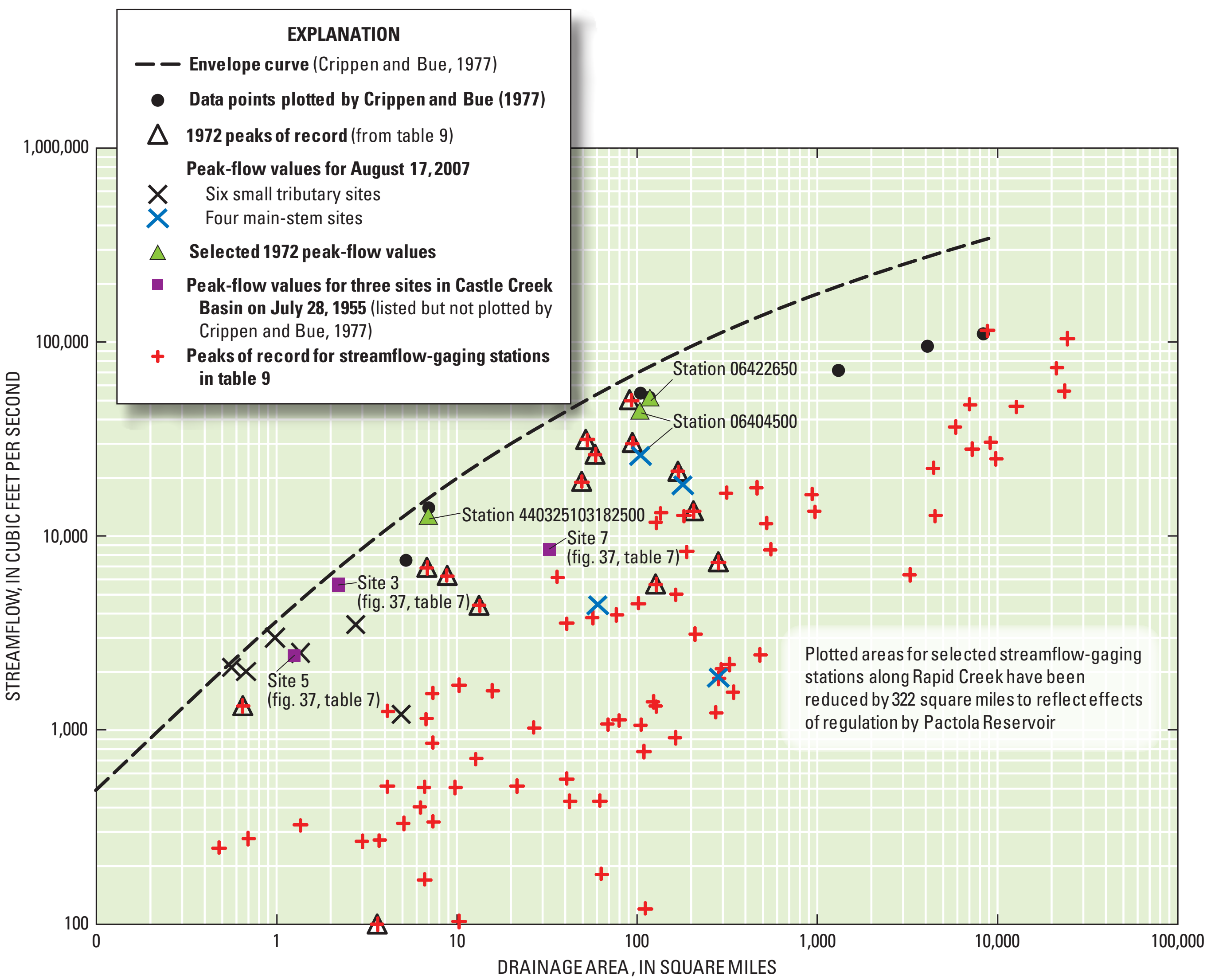


Figure 12. Regional envelope curve (modified from Crippen and Bue, 1977) and comparison with selected peak-flow values for the Black Hills area.

figure 12. One of these values is for a site for which the drainage area exceeds 30 mi^2, but the peak flow is well below the envelope curve. The other two sites have much smaller drainage areas (<3 mi^2) but their peak-flow values plot closer to the envelope curve. Additional details regarding this storm and flood event are provided in a subsequent section of this report titled "Upper Rapid Creek."

Also shown in figure 12 are peak-of-record flows that exceed 100 ft^3/s for stations listed in table 9. Fourteen of these values (denoted by open triangles) are associated with the June 9–10, 1972, storm, which had exceptionally large areal coverage, as described in the previous section titled "The Storms." The flooding was exceptional in that extremely large flows were generated in many relatively large drainage areas. Five of the sites with 1972 peak-of-record flows have drainage areas of 50 to 100 mi^2 with flow values that plot close or fairly close to the envelope curve. Additionally, two sites (stations 06404500 and 06422650) with drainage areas slightly larger than 100 mi^2 have 1972 peak-flow values that plot close to the envelope curve (fig. 12). In comparison, most sites with peak-flow values for 1955 and 2007 that plot close to the envelope curve have small drainage areas (<3 mi^2).

Schwarz and others (1975) listed peak-flow values for 16 other sites that are not shown in figure 12, and some of the values are fairly large, relative to drainage area. The preponderance of large peak flows generated by the 1972 storm provides a clear indication that the resulting flooding overwhelms the areal extent and magnitude of other flood events in the Black Hills area for which extensive peak-flow data are available (table 9).

A peak flow of 18,600 cubic feet per second was measured at U.S. Geological Survey streamflow-gaging station 06406000 (Battle Creek at Hermosa) (photograph by Mark T. Anderson).

Factors Affecting Flooding in the Black Hills Area

Flooding and the potential for flooding in the Black Hills area can be affected by many factors. Most factors generally can be categorized as physiographic or climatological, as described in this section of the report.

Physiographic Factors

Within the Black Hills physiographic region that encompasses the study area, four "hydrogeologic settings" (fig. 5) that can affect peak-flow characteristics, as well as the potential for flooding, were identified by Sando and others (2008). A distinction between peak flows and flood flows is important. The annual series of maximum instantaneous peak flows at any given site is the most commonly used dataset for peak-flow frequency analysis. Many sites can experience entire years of low-flow or zero-flow conditions; thus, peak flows are not necessarily synonymous with flood flows. Flooding generally implies an overabundance of water, which in terms of streamflow could range from localized overtopping of low-water channel banks to major flooding involving large areas.

Sando and others (2008) identified the "limestone headwater" hydrogeologic setting (fig. 5) as having distinctively "suppressed" peak-flow characteristics, with annual peak flows that consistently are much smaller, relative to drainage area, than annual peak flows for streamflow-gaging stations within the other hydrogeologic settings identified for the Black Hills area. High infiltration capacities of the predominant geologic outcrops (Madison Limestone and Minnelusa Formation) and generally low topographic relief within the "Limestone Plateau" area (which generally coincides with the limestone headwater setting, fig. 5) were cited as primary contributing causes of the suppressed peak-flow potential for this area. Sando and others (2008) noted that the suppressed characteristics are well defined for peak flows with small recurrence intervals (that is, 2-year through about 25- or 50-year return periods, which have annual exceedance probabilities of 50, 4, and 2 percent, respectively), but uncertainty regarding peak-flow estimates is especially large for larger recurrence intervals (that is, low-probability flood events).

A primary reason for the aforementioned uncertainty is a dearth of information regarding the potential for generation of exceptionally strong rain-producing thunderstorms within and near the Limestone Plateau area. O'Connor and Driscoll (2007) noted that decreasing potential for exceptionally heavy precipitation with increasing altitude (generally altitudes higher than about 7,500 ft) has been documented for other mountainous areas (Jarrett and Costa, 1988; Jarrett, 1993); however, documentation is minimal for the Black Hills, which has maximum land-surface altitudes of about 7,200 ft. From analysis of peak-flow records, effects of this possible climatological factor cannot necessarily be differentiated from the aforementioned physiographic factors. Thus, a detailed examination of potential climatological effects, as presented in the following section "Climatological Factors and a Climatology of Recent Large Black Hills Storms" is critical to a better understanding of flooding potential and peak-flow characteristics for the Black Hills area.

Flooding potential can be affected by various other physiographic factors, most of which have been well documented within the literature, and some of which can have utility in flood forecasting, assuming that forecasters have access to sufficiently detailed information. Antecedent moisture conditions can be an important factor, and the existence of substantial antecedent moisture commonly is considered in short-term flooding predictions. Storm motion directed in a down-basin direction also can contribute to increased peak flow because the storm essentially is moving with the flood peak. With the general exception of drainages along the South Dakota/Wyoming border, most of the larger drainages in the Black Hills tend to have at least somewhat of a west to east drainage orientation, which tends to parallel primary tracking directions for many storms.

Flood potential can be affected by various soil conditions such as type and thickness; however, soil conditions throughout the Black Hills area are highly variable and site specific. Flood risk generally decreases with increasing soil thickness because of increasing potential for storage of water. Soil thicknesses generally decrease with increasing slope, which can further increase higher flood potential associated with steeper topography. Sparse vegetation cover provides another mechanism for increased flood potential, and dramatically increased flood potential in the aftermath of forest fires has been well documented (for example, Agnew and others, 1997). Driscoll and others (2004) documented hydrologic effects following the 1988 Galena Fire, which occurred within the Battle Creek watershed, and provided numerous references regarding this subject matter.

The potential for exceptionally damaging floods probably is the greatest within upstream parts of the "loss zone and artesian spring" hydrogeologic setting that occurs around the flanks of the rest of the Black Hills area (fig. 5). Within and near outcrops of the Madison Limestone and Minnelusa Formation, narrow canyons are common, which have limited potential for attenuation of flood peaks because of limited floodplain storage potential. Steep topography within canyon reaches and associated tributaries also contributes to increased flood potential. Conversely, Sando and others (2008) noted that relatively small flood peaks can be diminished within this hydrogeologic setting as flows reach what frequently are dry channels downstream from loss zones. This hydrogeologic effect probably was a primary factor in diminishing localized flood peaks associated with the 2007 storm near Piedmont, as described in the previous section "The Flooding."

Climatological Factors and a Climatology of Recent Large Black Hills Storms

Most of the severe flooding in relatively small Black Hills drainages probably has been caused by exceptionally strong rain-producing thunderstorms, such as the 1972 and 2007 storms that were described in the section "The 2007 Storm and Flooding, with Comparisons to the 1972 Storm and Flooding." Prolonged precipitation from large-scale storm systems generally becomes progressively more influential with increasing drainage area, and large-scale storm systems tend to be the primary drivers for flooding in main-stem reaches of the Belle Fourche and Cheyenne Rivers. A proclivity for short-duration but intense convective precipitation events, including supercell thunderstorms, has been observed for the Black Hills area (for example, Dennis and others, 1973; Bunkers, 1997a,b; Holm and Smith, 2008). The following sections describe (1) climatological factors affecting thunderstorm generation for the Black Hills area and (2) a climatology of recent large Black Hills storms.

Climatological Factors Affecting Thunderstorm Generation for the Black Hills Area

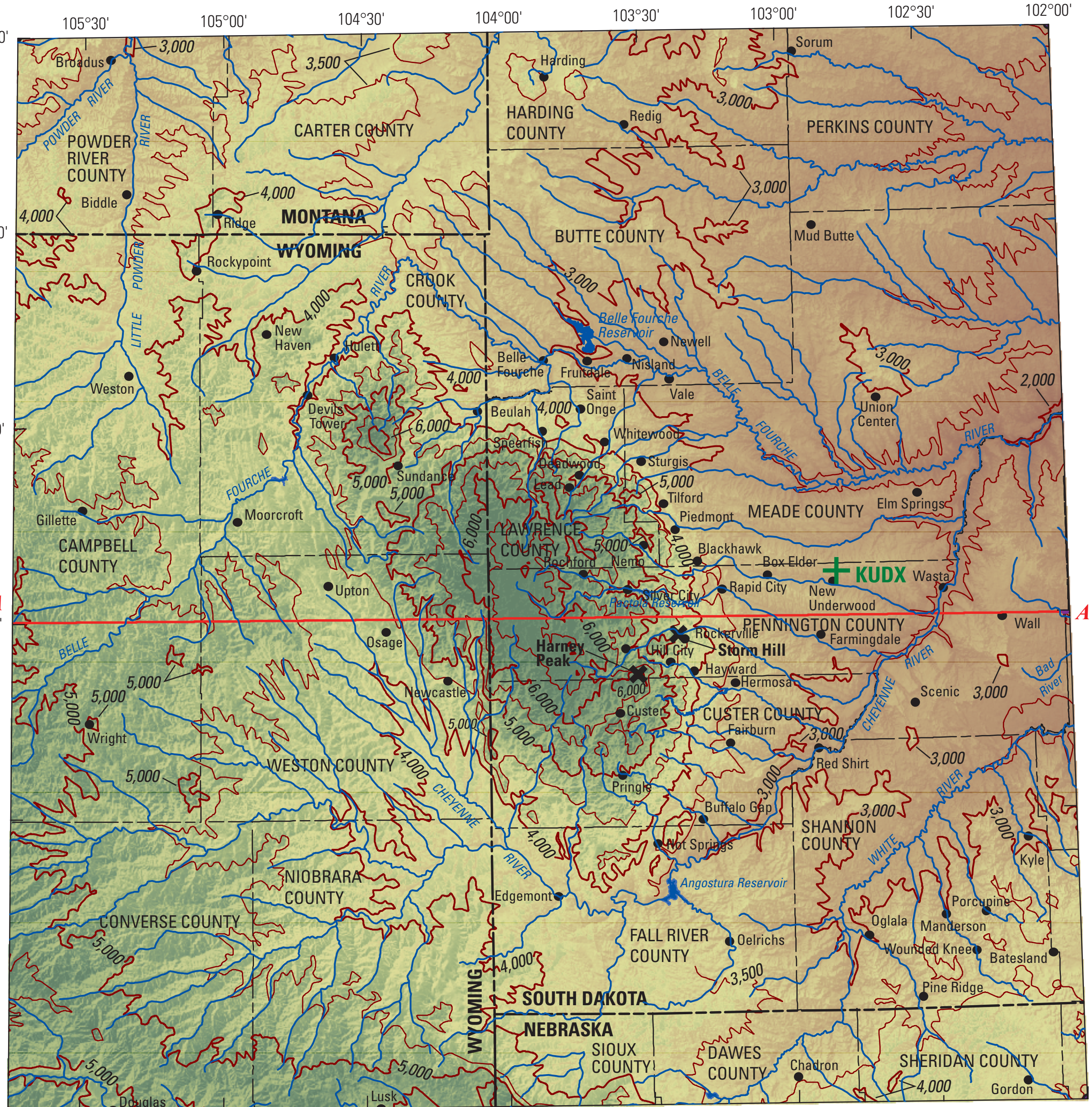
The Black Hills, with altitudes ranging from about 3,000 to 7,200 ft, plateau about 3,000 ft above the surrounding terrain, and slope gently downward from west to east (figs. 13*A* and 13*B*). The Black Hills are ellipsoidal in shape, with the major axis running from north-northwest to south-southeast (fig. 13*A*). The largest gradients in topography lie along the foothills, as opposed to over the higher altitudes, and this helps favor heavy precipitation in some of these areas, as described later in this section. Decreasing potential for exceptionally heavy precipitation with increasing altitude has been documented for other high-altitude areas, as described in the previous section "Physiographic Factors." However, within the moderate altitudes and relatively small areal extent of the Black Hills, several factors probably have a greater effect than altitude in thunderstorm generation, as described within this section.

Thunderstorms require moisture, instability, and upward motion for development; the upward motion helps initiate or "trigger" thunderstorms by bringing moist air parcels to the level of free convection. Thunderstorms that form over and around the Black Hills are largely terrain-driven, especially with respect to the requisite upward motion for initiation (Kuo and Orville, 1973; Banta, 1990). This terrain-enhanced phenomenon is fairly well understood, and has occurred in several other locations (for example, Schroeder 1977; Caracena and others, 1979; Schaaf and others, 1988; Akaeda and others, 1995; Petersen and others, 1999; Pontrelli and others, 1999; Lin and others, 2001; Lyman and others, 2005).

According to Banta (1990) and Hjelmfelt and others (1994), the Black Hills can provide lift through (1) orographic lifting effects, (2) thermally enhanced circulations, and (3) obstacle effects (fig. 14). All three of these processes are modulated by atmospheric stability. Orographic lifting effects are mechanical and occur when air is forced up the mountain—whether it is up a uniform slope or channeled through a canyon—where the resulting upward motion can lift moist air parcels to a level of free convection (fig. 14*A*); however, if the air mass is too dry, clouds may not develop from this process because the level of free convection either does not exist or is well above the mountain-top. In addition, if the air mass is too stable, the air will not ascend the mountain appreciably, and in fact may go around it. Because considerable moisture approaches the Black Hills from the Gulf of Mexico, this orographic lifting effect is most pronounced on the eastern slopes of the hills; whereas, the often dry westerly flow is less effective at producing deep moist convection on the western slopes of the hills. Also, the altitude change along the western slopes of the Black Hills is about 1,500 ft less than along the eastern slopes (fig. 13*B*), which further reduces convective potential because of orographic lifting along the western slopes.

Thermally enhanced circulations (thermal forcings) are most noticeable during daylight hours because of differential heating of a smaller volume of air over the mountains, relative to the plains. This produces low pressure and unstable/warmer conditions over the mountains, resulting in upslope flow over the elevated terrain with descending motion over the plains (fig. 14*B*)—the so-called mountain-plain circulation. Other areas of thermally driven upslope flow can occur where the underlying surface is dark (for example, a pine forest or a dark rock outcrop). When the large-scale tropospheric flow is greater than about 10 to 16 feet per second (ft/s), convergence of the upslope currents will be displaced to the lee side of the mountain axis (that is, to the right of the mountain peak in fig. 14*B*). In this case, the thermally induced convergence zone typically forms by late morning downwind of the mountain peak (or ridge line) because of the combination of surface heating and mixing of the large-scale westerly winds from above (Banta, 1984, 1990). Furthermore, this thermal circulation is stronger for drier soils/arid regions than for wet soils/non-arid regions because less energy is used for latent heating (that is, evapotranspiration) and more is used for sensible heating (that is, warming up the boundary layer)—hence creating a greater density difference between the mountains and plains. For the Black Hills, a consequence of this thermal forcing and climatological westerly winds at ridge-top level is a lee-side convergence zone that commonly extends east of the major axis of the Black Hills (fig. 15). Although not formally documented, this thermally induced circulation/convergence zone appears to be a common afternoon feature over the Black Hills on mostly sunny days in the warm season, generally

A



Base from U.S. Geological Survey digital data
Universal Transverse Mercator projection, Zone 13
Shaded relief from the National Elevation Dataset (*http://ned.usgs.gov*).
Altitude is portrayed as a range of colors, from orange for low altitudes to dark green for high altitudes

0 10 20 30 40 MILES

0 10 20 30 40 KILOMETERS

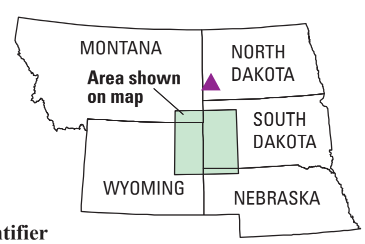
EXPLANATION

—5,000— **Land-surface altitude contour**—Contour interval 500 feet. Datum is North American Vertical Datum of 1988

A —— *A'* **Trace of cross section**

KUDX + **National Weather Service radar station and identifier**

▲ **U.S. Geological Survey streamflow-gaging station 06336000 in North Dakota**



Index map

Figure 13. *A*, Generalized topography for the Black Hills area, and *B*, topographic cross section for the Black Hills area along cross section *A*–*A'*.

from east of Spearfish to west of Rapid City and to east of Custer (based on anecdotal operational forecaster experience). In figure 15, surface observations indicate an easterly wind flow to the east of the convergence boundary and a westerly wind flow to the west of the convergence boundary. The weak shower shown in figure 15 initiated along the convergence zone, but was not sustained as it moved southeast because the level of free convection was well above the altitude of the Black Hills.

Obstacle effects (fig. 14*C*) also can be substantial for the Black Hills in terms of promoting thunderstorm development. Kuo and Orville (1973) studied four summers of radar data for June to August 1967–70 and determined that when the flow just above ridge-top level was from the southwest (or northwest), maximum echo frequency was over the northeastern (or southeastern) slopes of the Black Hills. This was attributed to some of the low-level airflow going around the Black Hills and converging or reversing direction on the downwind/lee side, thus helping produce upward motion to initiate thunderstorms. These results are consistent with Schaaf and others (1988), who determined this lee-side effect was noticeable for the Sangre de Cristo Mountains of southern Colorado and northern New Mexico. Hjelmfelt and Farley (1992) simulated idealized airflow for the Black Hills using a numerical model with horizontal grid spacing of about 5 mi, and confirmed the observational results of Kuo and Orville (1973), whereby convergence, flow reversal, and lee-side vortices were simulated downwind from the Black Hills. Furthermore, Hjelmfelt and Farley (1992) indicated this effect was greatest with a westerly wind component; an easterly wind component produced considerably weaker or nonexistent lee-side vortices to the west of the Black Hills.

Collectively, these three terrain-induced processes (fig. 14) indicate that convective initiation and thunderstorm occurrence should be favored to the east of the major axis of the Black Hills, down through the foothills. First, orographic lift and moisture availability and depth are greatest when the surface flow is from the southeast through the northeast. Given the topography of the Black Hills area, as illustrated in a cross section about 5 mi south of Rapid City (fig. 13*B*), this would give moist air parcels a relatively good chance to reach a level of free convection before ascending to the ridge line. Second, the thermally induced circulation—which is a focus for convective initiation—tends to set up to the east of the major axis of the Black Hills (fig. 15). And third, the obstacle effect has its greatest effect when wind near the ridge-top flows from a westerly direction, producing lee-side convergence on the northeastern–southeastern slopes of the Black Hills. Last, all three of these terrain-induced processes are affected by advection, which usually is toward the east because of the mean tropospheric flow, which favors thunderstorm formation and maintenance to the east of the major axis of the Black Hills.

Even though the amount of tropospheric water vapor at the highest altitudes of the Black Hills averages about three-fourths of that at the lower altitudes, this does not necessarily dictate less potential for exceptionally heavy precipitation at the higher altitudes. An example of extreme precipitation at relatively high altitude is a 1935 storm that produced as much as 24 in. of precipitation (6-hour duration) at an altitude of about 6,000 ft near Cherry Creek in northeastern Colorado (Schwarz and others, 1975; located about 400 mi southwest of Rapid City, S. Dak.). For the 1976 Big Thompson Canyon flood (west of Loveland in north-central Colorado; about 380 mi southwest of Rapid City, S. Dak.), the heaviest rain occurred mid-slope, around altitudes of 7,500 ft (Maddox and others, 1978; Caracena and others, 1979), which is above the highest altitudes of the Black Hills. Yoshizaki and Ogura (1988) studied the Big Thompson event with a numerical model to investigate why the higher mountains (above approximately 8,500 ft) were devoid of intense precipitation. They determined that when air with large water-vapor content was advected westward from the plains toward the mountain slopes, the heavy precipitation occurred mid-slope. If the moisture uniformly was distributed in the horizontal direction, then heavy rains occurred over the higher terrain. In summary, if moisture continually is supplied to higher altitudes, then heavy precipitation should occur there; however, water vapor commonly condenses into clouds and thunderstorms before reaching the higher altitudes.

In addition to the three aforementioned terrain-induced processes that affect thunderstorm generation in the Black Hills area, several other meteorological processes can greatly affect the development of especially heavy precipitation for the area, but are not necessarily specific to the Black Hills area. The first is a process called a “train echo” pattern, or cell training, in which showers and thunderstorms will repeatedly

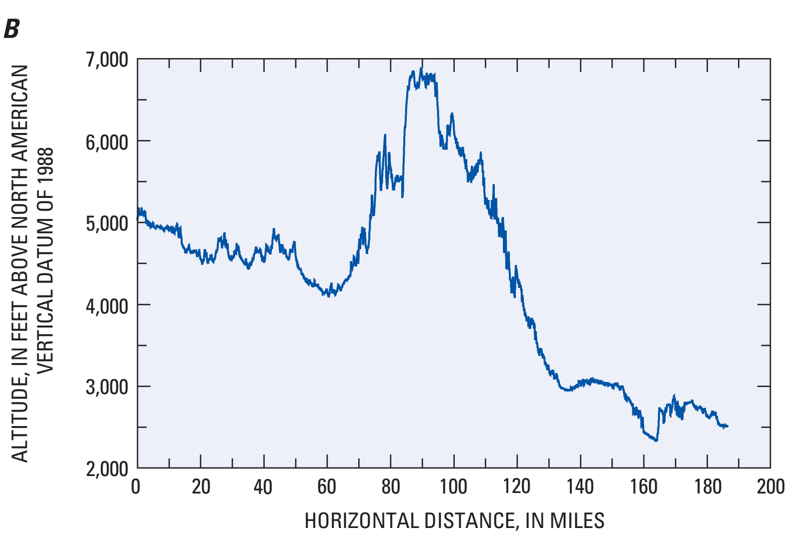


Figure 13. *A*, Generalized topography for the Black Hills area, and *B*, topographic cross section for the Black Hills area along cross section *A–A′*.—Continued

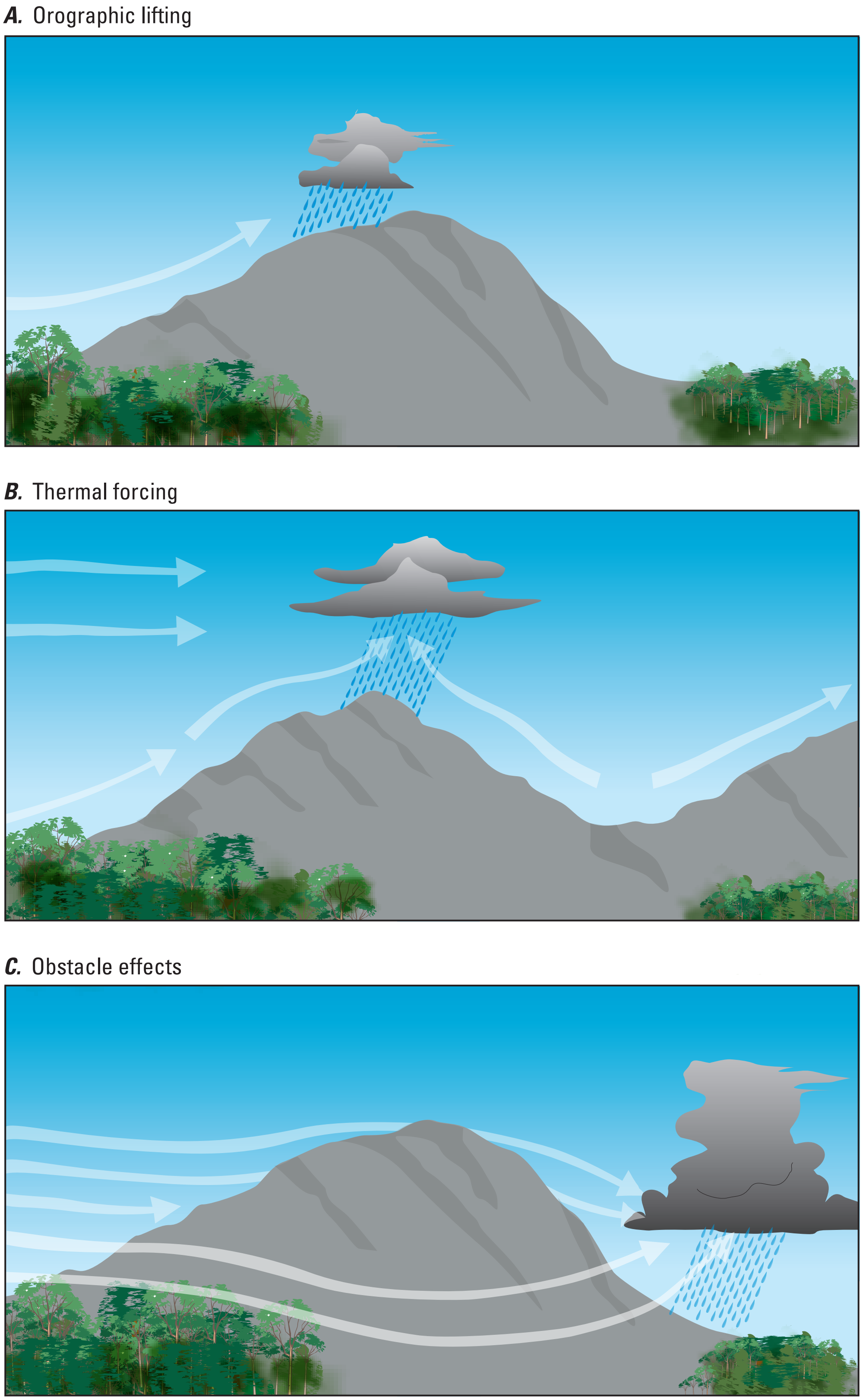


Figure 14. Schematic diagram illustrating terrain-induced processes of *A*, orographic lifting; *B*, thermal forcing; and *C*, obstacle effects on convective cloud development (modified from Banta, 1990).

track over the same area (for example, Schwartz and others, 1990). Although these storms may be relatively fast moving, the fact that several of them repeatedly travel over the same area increases the probability for heavy precipitation, and can further contribute to flood potential, especially when storm motion is directed in a down-basin direction. A second and somewhat related process occurs when a thunderstorm, or group of thunderstorms, are slow-moving and “anchored” in place for several hours as they are supplied with a continuous, low-level feed of moist and unstable air (for example, Chappell, 1986). A key to quasi-stationary thunderstorms—or “anchoring”—is storm regeneration, which can result from any of the terrain-induced convergence processes by promoting thunderstorm development and cell training in a persistent location. This effect appears to be strongest when the mean wind is relatively weak (less than about 33 ft/s) such that a mesoscale convergence pattern can become well established (Banta, 1990), and also so that potential storms are not advected away from the source of mesoscale convergence. In this scenario, new cells continually may develop in these favored convergence regions as old ones slowly advect away, leading to continual development on a preferred flank such that the system motion is near zero (for example, Schroeder, 1977; Akaeda and others, 1995; Bunkers, 1997a). Nearby storms that are not affected by mountainous terrain may have a substantial motion relative to those being affected by the orography. Finally, supercells are well-organized thunderstorms that possess persistent rotation about a vertical axis throughout much of their updraft, and because of this rotation move differently than ordinary thunderstorms (Bunkers and others, 2000). Their organization and potential for high precipitation rates makes them a candidate for producing flash floods. A hodograph, which is a plot of winds with height, can be used to evaluate the likelihood of slow-moving or stationary supercells, which helps estimate the potential for supercells to produce locally heavy precipitation. Chappell and Rodgers (1988) examined a case where supercell motion was nearly stationary, and the result of this supercell was a devastating storm and flash flood on August 1, 1985, near Cheyenne in southeastern Wyoming (about 310 miles southwest of Rapid City, S. Dak.).

A Climatology of Recent Large Black Hills Storms

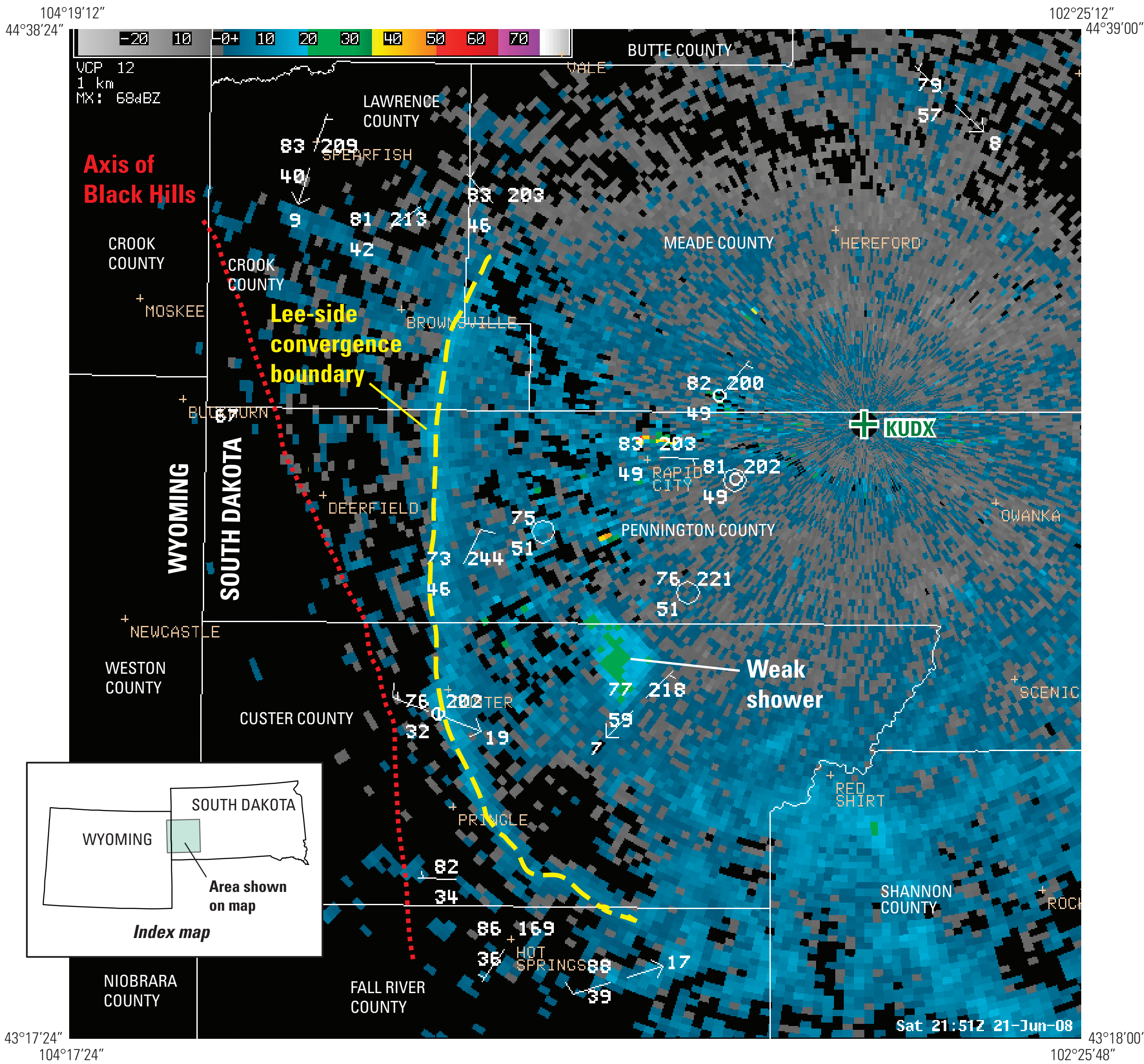
The WSR-88D radar installation near New Underwood (KUDX, fig. 13*A*) has operated since late 1995, allowing for nearly 14 years of data collection on Black Hills rainstorms. From these data, a limited climatology of 13 recent heavy precipitation events (table 2) was constructed. For the purpose of this report, these 13 events were selected based on local NWS records of heavy precipitation and reports of associated flooding. Using the KUDX WSR-88D, cases were selected where the radar-derived STP was greater than or equal to 2.66 in. in the vicinity of the Black Hills (fig. 16). This does not necessarily include all such events because a thorough investigation for each day was not undertaken. Furthermore, it is noted that radar-derived STP estimates are inherently imperfect because of (1) imperfect relations between radar reflectivity and precipitation, (2) hail contamination, and (3) other factors (Baeck and Smith, 1998). Given these limitations, caution should be used when viewing absolute values of radar-derived STP presented in this report; however, spatial patterns of STP are relatively robust compared to absolute values of STP.

Thirteen events were selected from 1996–2008 that fit the previously mentioned quantitative and spatial criteria of radar-derived STP (table 2; fig. 16); 4 of the 13 events had 2 “storm areas” of interest. In some cases, substantial precipitation also was observed well away from the Black Hills over the adjacent plains (for example, June 14, 1997, and May 6–7, 2005). The lightest events, with maximum STP estimates of 2.66–5.33 in., were mostly small in areal extent and located over the Black Hills; only one of these events (June 21, 2007) occurred to the west of the major axis of the Black Hills. The heaviest events (STP estimates of 5.33–7 in.), plus the extreme event on June 14, 1996 (maximum STP of 12 in.), were largely confined to the northern and eastern foothills and immediately adjacent plains. An exception to this is the July 6–7, 2008, storm (northwest of Rochford), which had anomalously high precipitation totals very near the major axis of the Black Hills.

A composite image showing summed precipitation increments of 6 in. and larger (fig. 17) was created by summing the radar-derived STP estimates for the 13 individual events shown in figure 16. This figure illustrates the propensity for heavy precipitation to occur east of the major axis of the Black Hills from the northern through eastern foothills. Thunderstorms over mountainous terrain tend to form in preferred “hot spots” because of orographic effects. Banta (1990) noted that such locations commonly are known by local residents, and many mountain peaks across the United States have been given names like “Storm Mountain” or “Storm King.” Perhaps not surprisingly, the Black Hills has a peak named “Storm Hill” that is located about 10 mi southwest of Rapid City (fig. 17) amidst the active thunderstorm zone along the eastern slopes; however, details regarding the specific history of the name are not known.

The exceptional 1972 thunderstorm produced a precipitation footprint (fig. 3) in a location generally similar to the composite for the 13 recent heavy precipitation events (fig. 17). Precipitation increments of 6 in. and larger for the 1972 storm are overlain with the composite of 13 recent events (from fig. 17) in figure 18. This figure shows that the 1972 storm footprint is perhaps at a slightly higher altitude than the 13-event composite. Moreover, the total volume of 6 in. increments and larger for the 1972 storm is about one-fourth the comparable volume for the composite.

Radar data were reviewed for each of the 13 recent events to understand the evolution of the thunderstorms, and possibly to put them into perspective with respect to the exceptional 1972 storm system. This analysis revealed several common



EXPLANATION

83 203
49

Standard station plot—Upper left number is air temperature in degrees Fahrenheit; lower left number is dew point in degrees Fahrenheit; upper right number (if available) is mean sea-level pressure times 10 with first two numbers omitted in millibars (the pressure for the example is 1,020.3 millibars); barb and tick mark indicate wind direction (calm if no barb is shown; the wind direction for the example is 90 degrees blowing from east to west); tick mark on the barb represents wind speed from the originating wind direction (short tick = 5 knots; long tick = 10 knots; wind speed for the example is 5 knots); circle (if shown) represents fractional cloud cover (not shown for the example)

-20 10 -0+ 10 20 30 40 50 60 70

Radar reflectivity, in decibels of Z (dBZ)—Returns less than 20 dBZ generally represent clear-air echoes; returns of about 20 dBZ and greater generally represent clouds and precipitation (for example, the weak shower indicated on image); returns of 50 dBZ and greater generally indicate strong precipitation and generally are associated with thunderstorms

KUDX **National Weather Service radar station and identifier**

Figure 15. Radar image for the Black Hills area for June 21, 2008, at 3:51 p.m. Mountain Daylight Time (image provided by the National Weather Service).

themes associated with many of the events, as summarized in table 2. In particular, thunderstorms tended to be regenerative and train over a particular area, resulting in a quasi-stationary convective system, and thus setting the hydrologic stage for potential flooding. In fact, all 13 events considered in this report displayed training thunderstorms. After this preconditioning occurred, a single larger storm, a group of smaller storms, or a line of storms, often approached and merged with the existing thunderstorm(s) over the area of interest. Although only 6 of the 13 events were associated with substantial mergers, the average maximum STP (from table 2) was 7.5 in. for the events with mergers, compared to an average of 5 in. for the events without mergers—implying the importance of substantial storm mergers for precipitation production. All but 2 of these 13 events had thunderstorms that also traveled down-basin—thus potentially exacerbating the effects of the heavy precipitation.

A representative example of the evolution of short-duration, intense precipitation events is given in figure 19 for the July 6–7, 2008, storm near Rochford. Note how a single supercell storm (denoted by (i) in fig. 19*A*) existed early in the event. After this storm moved eastward, it was followed (about 2 hours later) by a second supercell storm (ii) that showed signs of back-building to its west (fig. 19*B*). This storm also eventually moved east and weakened. About an hour later, a third and larger storm (iii) approached Rochford, while yet another storm (iv) began to merge on its southern flanks (fig. 19*C*). At the same time a broken line of storms (v) was approaching from the west (fig. 19*C*), and eventually this line merged with the existing thunderstorms over the Rochford area (fig. 19*D*). The maximum radar-derived STP for the overall storm system was about 7 in. (fig. 16; table 2), and the storm caused flooding along parts of upper Rapid Creek, as described in a subsequent section titled "History of Large Storm and Flood Events in the Black Hills Area." This type of scenario tends to be a prolific rain producer. Smith and others (2001) documented a similar pattern for a May 5–6, 1995, storm near Dallas in northeastern Texas (about 1,060 mi southeast of Rapid City, S. Dak.) that caused 16 deaths and about 1 billion dollars in property damage.

With respect to the exceptional storm of June 9–10, 1972, Schwarz and others (1975) provided detailed descriptions of the storm history from a combination of radar imagery, precipitation recordings, and visual observations, as paraphrased in this paragraph. The earliest signs of convective activity began about 1330 Mountain Daylight Time (MDT) about 60 mi west-northwest of Rapid City. Additional cells developed during the next 3–4 hours along the eastern edge of the Black Hills about 25 mi north of Rapid City and began building farther south. At about 1500 MDT (almost simultaneously with cell development north of Rapid City), a line of thunderstorms developed to the southeast and moved toward the west-northwest with subsequent cells forming on the trailing end of the line. These cells increased markedly in intensity, and by 1800 MDT the line of thunderstorms had become almost solid. Between 1800 and 1930 MDT, the gap filled in between the line of thunderstorms to the south and the initial thunderstorm development northwest of Rapid City. The large-scale system appeared to drift slowly eastward after about 2200 MDT, although light showers persisted to the west of Rapid City for several hours. Most of the heavy precipitation occurred between 1830 MDT on June 9 and 0030 MDT on June 10.

From the accounts of Schwarz and others (1975), it is apparent that the 1972 storm exhibited substantial merging of storm cells, and Dennis and others (1973) indicated that training of thunderstorms was clearly evident. Individual cell movement was to the west-northwest (generally in an up-basin direction for most of the drainages that were affected by the storm), but because of the ongoing regeneration of storm cells, the storm system essentially was anchored along the eastern slopes of the Black Hills. Storm movement was slowly eastward (generally down-basin) in the final stages of the storm as the parent low-pressure system moved east of the Black Hills. Unusually light upper-level winds were an important factor in the general stagnation of the storm system (Schwarz and others, 1975).

A final consideration for Black Hills rainstorms is the presence of supercell thunderstorms, which appear to be fairly common (table 2). For example, a further analysis of the radar data for the August 17, 2007, storm reveals that a nearly stationary supercell was present for at least 1 hour before a substantial storm merger occurred. In addition, the hodograph (or vertical wind shear profile) constructed for this storm (fig. 20) using the Rapid Update Cycle forecast model (Benjamin and others, 2004) was such that it favored slow-moving supercells; that is, the forecast storm motion for right-moving supercells was less than 10 miles per hour (mi/h). This slow motion resulted because as the storm began to rotate, it deviated to the right of the wind shear profile, which worked against the mean wind that steered the storm; the net effect was that the two components cancelled each other, resulting in a very slow storm motion. When this type of storm and motion can be anticipated, forecasts of heavy precipitation and potential flooding can be improved. Note that for the hodograph in figure 20, wind speed data are plotted every 1,600 ft above land surface, but markers (open circles or squares) are shown only at intervals of 3,200 ft. The long, stretched-out vertical wind shear profile between the near-surface layer and 19,200 ft above land surface (wind shear vector) indicates relatively large wind shear, which is required for supercell thunderstorm development.

Interestingly, a proximity hodograph for the 1972 storm (fig. 21) indicated that the predicted right-moving supercells (V_{RM}) would move slower than nonsupercells (mean wind speed; V_{mw})—toward the west-northwest at approximately 14 mi/h. The close plotting of points along the vertical wind shear profile (between about 5,000 ft and 25,000 ft above land surface) in figure 21 indicates smaller wind shear than during the 2007 storm, which, based on current research, indicates only a modest probability of supercells. Unfortunately, radar data are not available for the 1972 storm, and thus it is not known if supercells occurred. Dennis and others (1973) reported storm tops at altitudes of 45,000–50,000 ft above the National Geodetic Vertical Datum of 1929 (NGVD 29), which is indicative of intense thunderstorms. They also stated that storm motions were from the southeast at 23–35 mi/h, which is consistent with the motion of nonsupercell thunderstorms based on the comparison between the observed storm motion and the mean wind speed (fig. 21). Nevertheless, calculations based on figure 8 in Dennis and others (1973) indicate that some storms on June 10, 1972, had speeds of about 14 mi/h, which is the same as the predicted supercell motion from the hodograph. Could it be that some of the intense precipitation during the 1972 Rapid City flood was produced by supercell thunderstorms? Although this may never be unequivocally known, the occurrence of supercells is possible based on the recent history of Black Hills rainstorms and our knowledge of supercell processes.

Table 2. Maximum precipitation and radar characteristics for 13 recent strong rain-producing thunderstorm events in the Black Hills area.

[--, not applicable; Max precip, maximum radar-derived storm-total precipitation. Radar characteristics: Train, training cells; Merge, substantial storm mergers; DBM, down-basin storm movement; Super, supercell occurrence; --, not applicable]

Storm event number	Date	General location of primary storm cell	Color coding (fig. 16)	Max precip (inches)	Radar characteristics			
					Train	Merge	DBM	Super
1	May 30, 1996	South of Rapid City, S. Dak.	Lime green	6	Yes	No	Yes	Yes
2	June 14, 1996	East of Sturgis, S. Dak.	Yellow/brown	12	Yes	Yes	Yes	Yes
3	June 14, 1997	East-southeast of Sturgis, S. Dak.	Pale green	5	Yes	No	Yes	Yes
4	June 23, 1998	East of Sturgis, S. Dak. (north of storm 3)	Yellow/tan	6	Yes	Yes	Yes	Yes
5	June 18, 1999	East of Hill City, S. Dak.	Bright pink	3	Yes	No	Yes	No
6	August 7, 1999	Northwest of Custer, S. Dak.	Salmon	5	Yes	No	Yes	No
7	July 5, 2003	Cell 1 – southeast of Rockerville, S. Dak. Cell 2 – south and west of Nemo, S. Dak.	Orange/red Orange/red	6	Yes Yes	No No	Yes Yes	Yes No
8	May 6–7, 2005	Cell 1 – northeast of Hot Springs, S. Dak. Cell 2 – southeast of Red Shirt, S. Dak.	Dark green Dark green	7	Yes Yes	Yes Yes	Yes Yes	Yes[1] Yes
9	May 19, 2007	Cell 1 – southwest of Lead, S. Dak. Cell 2 – southwest of Rochford, S. Dak. (small)	Dark gray/black Dark gray/black	5	Yes Yes	No No	No No	Yes[1] Yes[1]
10	May 28, 2007	Cell 1 – northeast of Lead, S. Dak.	Pink	6	Yes	Yes	Yes	Yes
11	June 21, 2007	Northeast of Newcastle, Wyo.	Light gray	5	Yes	No	No	Yes
12	August 17, 2007	Cell 1 – centered around Hermosa, S. Dak. Cell 2 – centered around Piedmont and Tilford, S. Dak.	Blue Blue	[2]7	Yes Yes	Yes Yes	Yes Yes	Yes Yes
13	July 6–7, 2008	Northwest of Rochford, S. Dak.	Purple	7	Yes	Yes	Yes	Yes
Fraction and percentage of storm events exhibiting specified radar characteristic			Fraction Percentage	--	13/13 100	6/13 46	11/13 84	11/13 84

[1]Duration of supercell stage of thunderstorm was less than 1 hour.

[2]Maximum observed precipitation total was 10.5 inches.

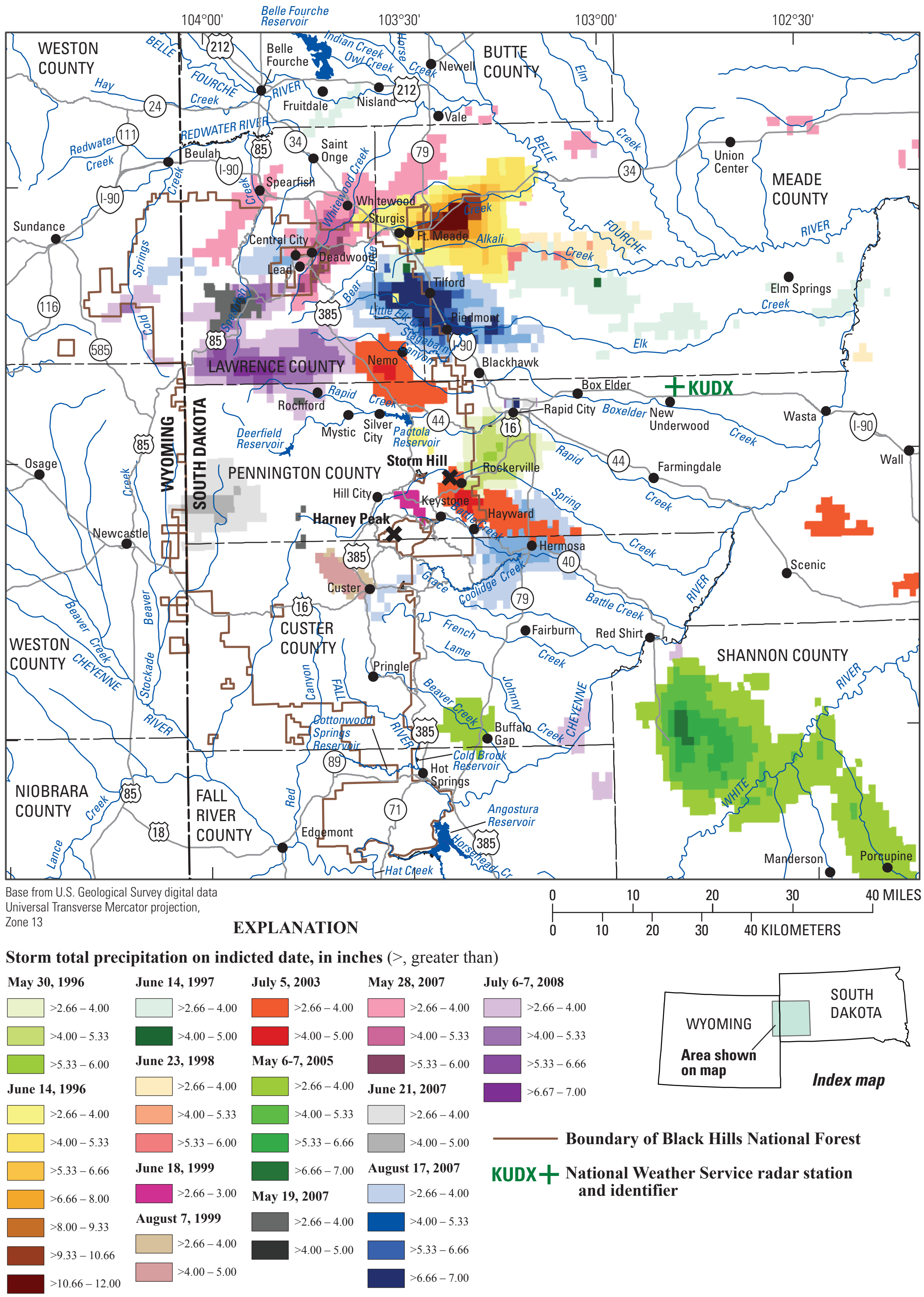


Figure 16. Radar-derived storm-total precipitation for 13 recent, separate events for which totals were greater than 2.66 inches.

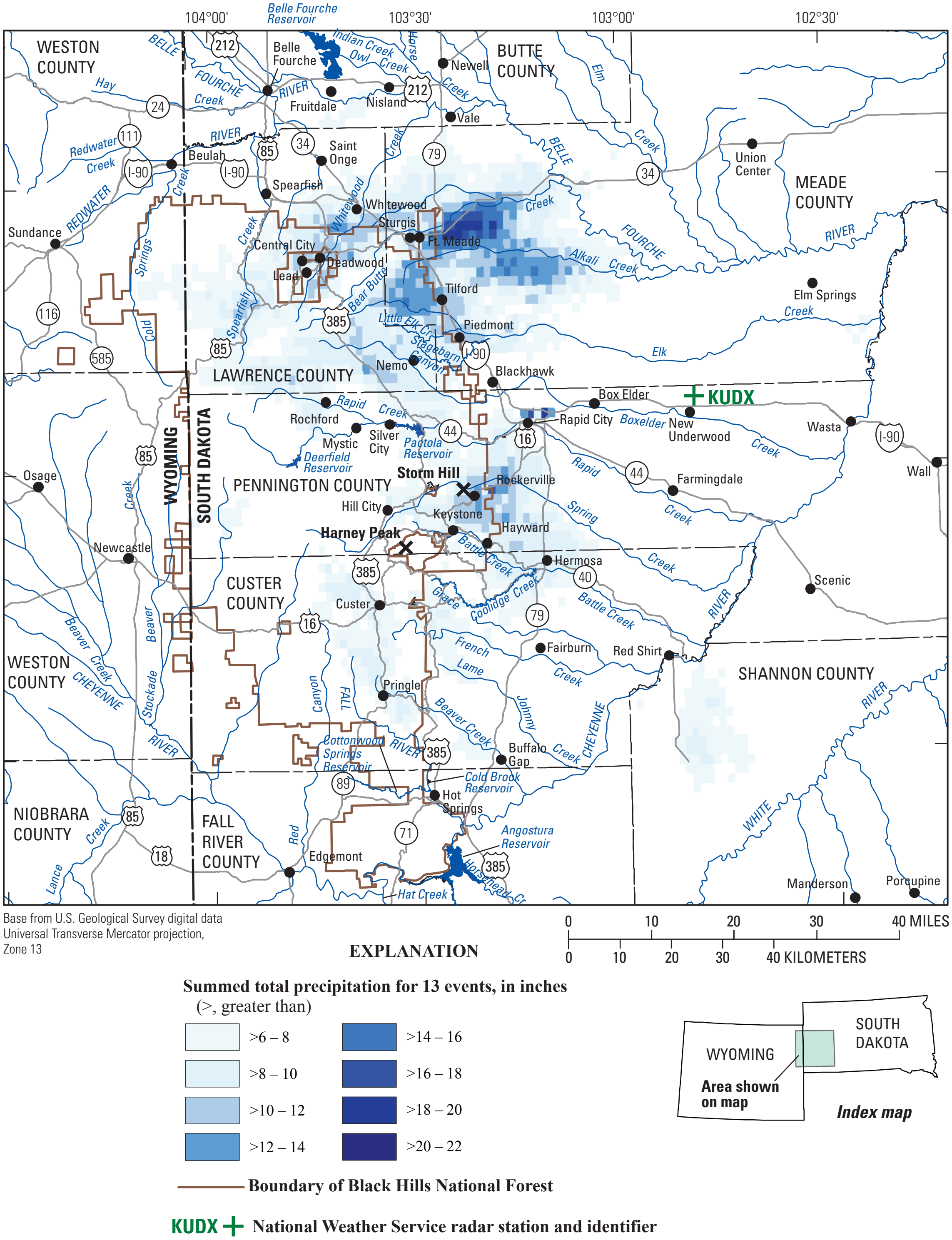


Figure 17. Summation of the radar-derived storm-total precipitation for the 13 events displayed in figure 16.

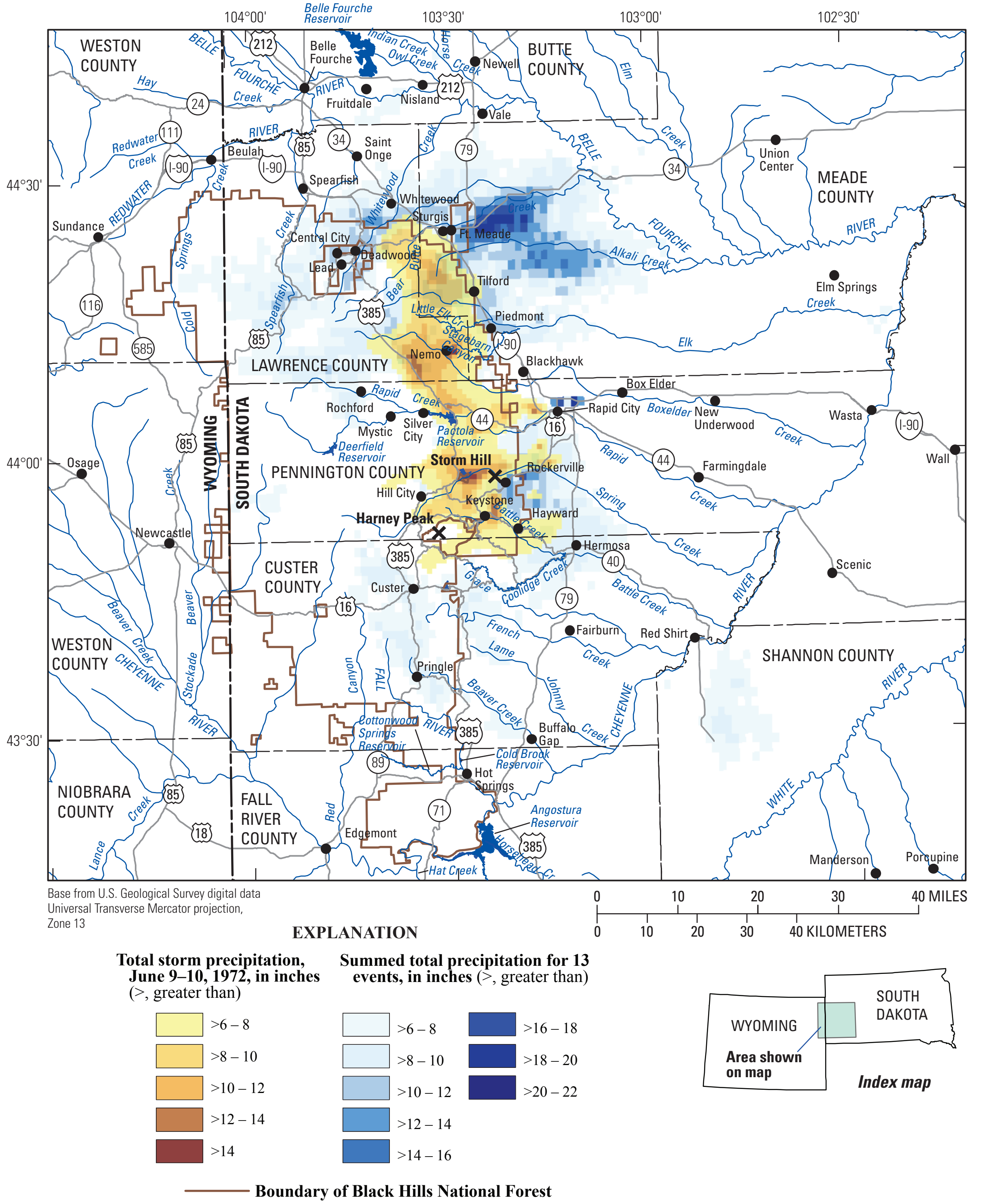
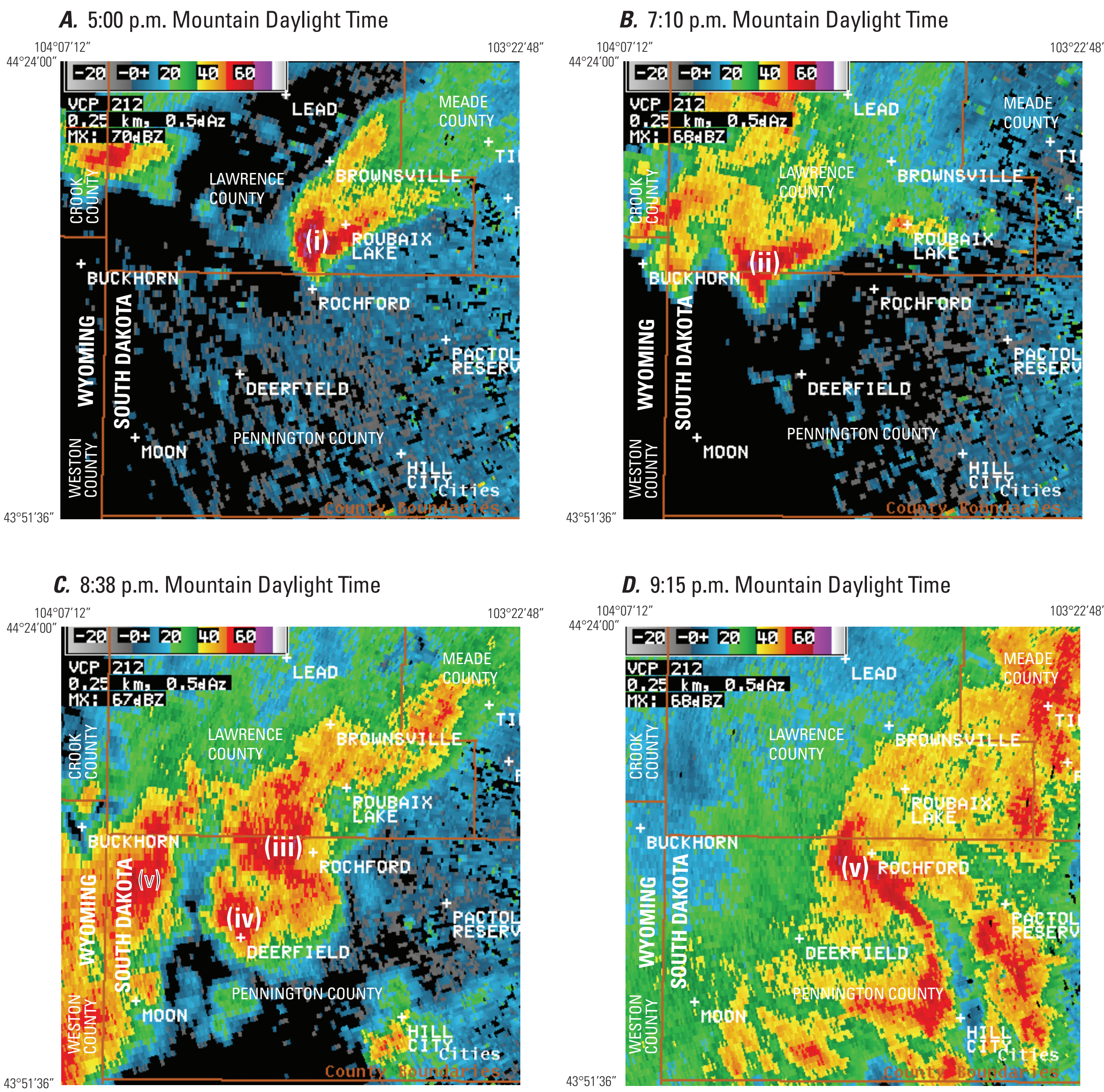


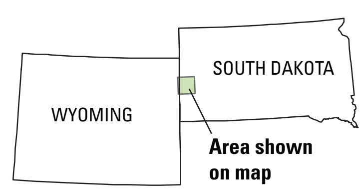
Figure 18. Precipitation totals for 1972 storm superimposed on the summed composite of 13 events displayed in figure 17.



EXPLANATION

-20 -0+ 20 40 60 **Radar reflectivity, in decibels of Z (Dbz)**—Returns less than 20 dBZ generally represent clear-air echoes; returns of about 20 dBZ and greater generally represent clouds and precipitation; returns of 50 dBZ and greater generally indicate strong precipitation and generally are associated with thunderstorms

(i) First thunderstorm (a supercell)
(ii) Second thunderstorm (a supercell)
(iii) Third, larger thunderstorm
(iv) Fourth, merging thunderstorm
(v) Line of thunderstorms, which eventually merged with and overtook storms (iii) and (iv)



Index map

Figure 19. Radar reflectivity (lowest 0.5° scan) for the July 6–7, 2008, storm system near Rochford (images provided by the National Weather Service).

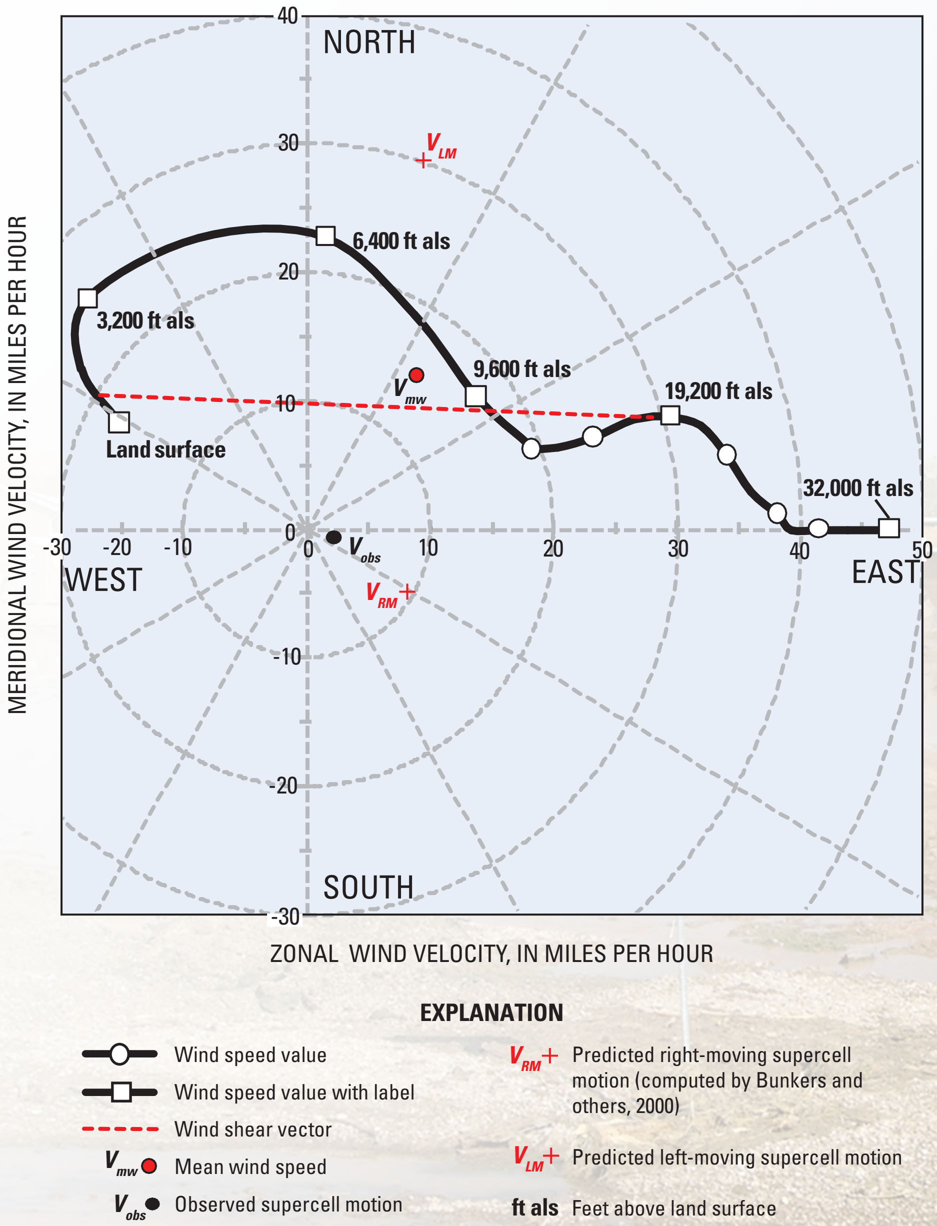


Figure 20. Model-derived hodograph for Hermosa, valid 5 p.m. Mountain Daylight Time, August 17, 2007.

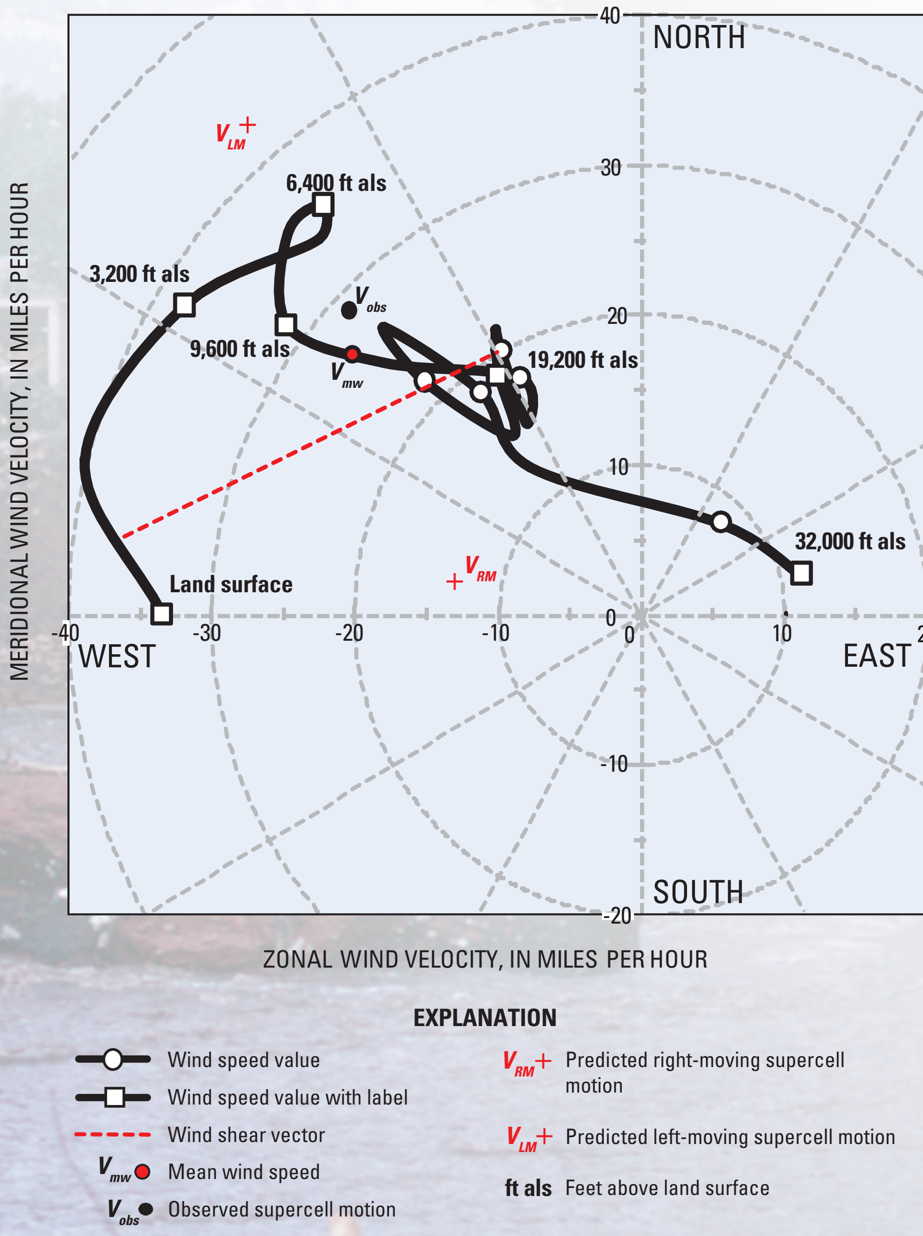


Figure 21. Model-derived hodograph for Rapid City, valid 6 p.m. Mountain Daylight Time, June 10, 1972.

Synopsis of Factors Affecting Flooding in the Black Hills Area

Flooding, and the potential for flooding in the Black Hills area, can be affected by various physiographic or climatological factors. The largest flood potential generally occurs in canyon reaches around the periphery of the Black Hills because of steep topography and minimal potential for attenuation of flood flows within the confined canyons. Distinctively suppressed peak-flow characteristics have been identified for low-probability floods in the limestone headwater hydrogeologic setting, partially because of generally low topographic relief and high infiltration capacities of the predominant geologic outcrops. Decreasing potential for exceptionally heavy precipitation with increasing altitude has been offered as another possible explanatory factor, and other investigators (Jarrett and Costa, 1988; Jarrett, 1993) have documented this effect for other higher-altitude settings in the Rocky Mountains. However, within the more moderate altitudes and relatively small areal extent of the Black Hills, several other climatological factors probably are considerably more influential.

Important factors contributing to development of exceptionally strong rain-producing thunderstorms are (1) the climatology of moisture and winds and (2) topographic effects for the Black Hills area. The largest gradients in topography lie along the foothills, as opposed to over the higher altitudes, and this helps favor heavy precipitation. Additionally, a pronounced escarpment with several hundred feet of relief exists along the eastern edge of the limestone headwater hydrogeologic setting (fig. 5), and orographic lifting associated with this escarpment can occur with a southeasterly air flow. However, to the west of this escarpment, relief is relatively small and localized, and the potential for orographic lifting is minimal. Moreover, moisture-laden air masses mostly originate from the Gulf of Mexico, which greatly affects the eastern Black Hills. Finally, the westerly mean flow causes storm complexes to drift eastward, which generally coincides with a down-basin direction for most drainages along the eastern flanks of the Black Hills, and also favors convergent patterns along the eastern slopes. Collectively these factors enhance the probability of exceptional rainstorms along the eastern Black Hills, relative to the highest terrain.

Several other meteorological processes are important in the development of especially heavy precipitation for the area, but are not necessarily specific to the Black Hills area. These processes include storm cell training, storm anchoring or regeneration, storm mergers, and supercell development. Additionally, weak upper-level air flow (similar to conditions of June 9–10, 1972, along the eastern flanks of the Black Hills) can allow heavy rainfall to remain almost stationary, which can exacerbate flooding potential.

Flood waters from Battle Creek smashed down grass in the agricultural area near Hermosa (photograph by Mark T. Anderson).

History of Large Storm and Flood Events in the Black Hills Area

A chronology of selected large storm and flood events for the Black Hills area is provided in table 10 in the back of this report. There is a rich history of large storm and flood events for the Black Hills area, and compilation of a comprehensive chronology of large events will, with time, contribute to improved knowledge of the relative frequency of occurrence of exceptionally large and damaging events for the area. One foundation piece for this chronology was provided by a list of historical Black Hills floods that was developed by the NWS office in Rapid City (National Oceanic and Atmospheric Administration, 2008). Another foundation piece is a chronological set of typed newspaper excerpts for 1878 through 1947 that was compiled at some previous unknown time by staff from the USGS office in Rapid City (U.S. Geological Survey, 2010a). The chronology has been supplemented by information from various other sources including (1) a chronology from Miller (1986) for the Rapid City area; (2) excerpts from additional newspaper articles; (3) various books with historical information; (4) photographs; and (5) USGS peak-flow data (U.S. Geological Survey, 2009).

A Web site on the history of flooding in the Black Hills has been developed by the U.S. Geological Survey (2010a) to host (1) the chronology that is provided in table 10, and (2) a large amount of the original source documentation for the chronology (newpaper articles, photographs, and other information). The Web site can be updated as additional information regarding large storms and flood events becomes available; thus, additional entries to the original chronological listing presented in this report (table 10) may become available with time (U.S. Geological Survey, 2010a).

Quantitative information regarding the approximate magnitude of flood flows tends to become progressively less reliable for progressively older flood reports. The most reliable quantitative information generally is provided by USGS peak-flow determinations; however, USGS data collection primarily has been limited, with a general exception of a handful of exceptional events, to sites of systematic (routine) data collection. A list of continuous-record streamflow-gaging stations for the Black Hills area provided by Miller and Driscoll (1998) indicates systematic streamflow records are most abundant for the most recent decades (subsequent to the 1980s) and are sparse before the mid-1940s. Additional systematic peak-flow data are available from several networks of partial-record, crest-stage gages that have been operated, including (1) two older networks that were operated during general timeframes of 1956–80 and during the 1970s (Becker, 1980); and (2) a newer network for which the number of crest-stage gages increased beginning in the mid- to late-1990s. USGS peak-flow records for some sites include historical records of peak stage that most commonly were derived from anecdotal reports from nearby residents of maximum water-surface altitude, relative to the gage datum. Such records are inherently less accurate, relative to stage and date of occurrence, than records based on recording devices. Although capabilities for determination of peak-flow magnitude have improved with time, early peak-flow records typically constitute the best quantitative peak-flow information available for that period.

Despite the limitation that peak-flow magnitudes generally cannot be determined or estimated from historical flood accounts, such accounts can be useful, primarily because of relatively widespread availability, as opposed to a paucity or complete absence of “official” peak-flow records. There may be somewhat of a bias towards “overstatement” of early flood accounts, relative to later accounts. Conversely, some historical accounts contain reports of “walls of water,” which given the hydrographs that were provided in figures 9 and 10, may truly be indicative of extraordinary flood events in many cases. The earliest available news accounts date back to the late 1870s and are associated with the onset of extensive European settlement involving the gold rush that began in the late 1870s, soon after the Custer Expedition of 1874 (Tallent, 1899). Many of the early flood reports (table 10) are tied to accounts of railroad damage, which initially tended to be common during high-water periods, but gradually became less common with time as developing rail infrastructure progressively was constructed to be more resistant to floods. Developing settlements also tended to move progressively farther from stream channels in response to iterative, damaging floods. Lastly, reports along the lines of “the worst known flooding to date” are quite common in many of the earliest news accounts available for the area, but generally become less common with time, as relative magnitudes of “floods of record” have become progressively larger and more difficult to surpass.

A final consideration is that USGS peak-flow records are tied to specific locations, as opposed to the more general locations associated with news accounts. An excellent example is presented in table 1 in the previous section titled “The Flooding.” The 2007 peak flow along Battle Creek at Hermosa (station 06406000) was about 87 percent as large as that which resulted from the much larger 1972 storm; however, the 2007 peak flow at an upstream station along Battle Creek was only about 59 percent of that in 1972. Furthermore, the 2007 peak flow along lower Grace Coolidge Creek is believed to have been larger than in 1972, although a peak-flow determination was not made for the site in 1972. Extraction of detailed quantitative data such as these obviously would not be possible from historical accounts.

Despite the drawbacks associated with historical flood accounts, the historical information has excellent potential to substantially supplement the knowledge of especially large floods for the Black Hills area. Photographic evidence could be especially useful for approximating stages associated with historical flood events and in some cases it might also be possible to use detailed historical descriptions as indicators of approximate stage. To help provide a qualitative indication of the relative magnitude of storm and flood events, a five-category rating system was used in table 10 to describe the relative magnitude of the event as (1) extreme, (2) severe, (3) moderate, (4) minor, and (5) very minor. In many cases, a single account may be rated in multiple categories in recognition of the inherent difficulty in assigning a single specific rating or because of overlap among multiple events within an account. In some cases, such as extremely broad accounts, ratings were not assigned.

The following sections of this report provide descriptions of some of the more noteworthy storm and flood events for the Black Hills area. An initial section provides a chronological overview and a subsequent section provides more detailed histories specific to several streams. A final section provides a synopsis of some of the most noteworthy events.

Chronological Overview of Storm and Flood Events

This section provides a chronological overview of major storm and flood events for the Black Hills area and generally follows (and refers to) the chronological listing that is provided in table 10 in the back of this report. In many cases, additional references also are made to the source documentation and newspaper articles (available from U.S. Geological Survey, 2010a) that were used in developing the chronological listing. When applicable, descriptions of the flood events include USGS peak-flow data (U.S. Geological Survey, 2009), which were previously summarized in table 9 for most stations (those with 10 or more years of record). The primary focus of the previous sections of this report was to examine especially large singular events, where flooding could be directly related to a single storm, or storm system. For many of the historical accounts (table 10), it cannot necessarily be determined whether flooding was caused primarily by a singular large storm, by prolonged precipitation, or by a combination of the two.

Presettlement Years

Thomson (1961) provided information regarding flood events that substantially pre-date the earliest (1877) accounts available in table 10. Exceptional snowfall and spring precipitation during 1852–53 were reported for Fort Laramie, Wyo. (located about 150 mi southwest of the Black Hills), and anecdotal reports were provided of Indian tribes enduring exceptionally harsh winter conditions and deep snowpack during the same period in the Black Hills area. Thomson (1961) hypothesized that these conditions (1) caused buffalo to permanently migrate away from the Black Hills area, and (2) probably caused substantial flooding in the Black Hills area. Thomson (1961) also provided various anecdotal reports of other flood events for the area. One particularly noteworthy report was given by a Mr. Art Petty of "an old Indian chief" who "had seen water slushing in and out of two caves in the sandstone cliff" that were situated "about 50 ft above the creek bed" of the Fall River in Hot Springs. Mr. Petty further related that as a boy he "had found driftwood in the caves in such size as no animals could have carried it there." Interestingly, a similar account is provided in an article by the Rapid City Journal and Hot Springs Evening Star on June 21, 1937, following an exceptionally large flood on June 17–18, 1937, in Hot Springs (table 10).

1877 through 1890

The oldest account listed in table 10 is for 1877 when a strong rainstorm caused flooding in Deadwood. Several floods are documented for 1878 and include a peak flow of 7,500 ft^3/s on Rapid Creek that was noted by Miller (1986) as the largest of four floods that year in Rapid City. Miller (1986) referenced the U.S. Army Corps of Engineers (1973) as the source of this peak-flow estimate and for three other estimates that pre-date available USGS peak-flow records for streamflow-gaging stations along Rapid Creek; however, additional details regarding these peak-flow estimates are not known. Flooding also occurred in 1878 in the Deadwood area. Flooding along Beaver Creek caused 11 deaths in June 1879. A rise of 25 ft was reported for "confined places" along the Redwater River in August 1882, and details provided in the Black Hills Journal on August 4, 1882, although sketchy, allude to transport of "rocks weighing hundreds of pounds" that indicate the possibility of an exceptionally large flood.

"Benchmark" flooding occurred in May of 1883, with extremely high flows reported throughout the northern and central Black Hills area that resulted from heavy rainfall on top of snowmelt. Substantial flood damage occurred in Spearfish on May 17–18, 1883, and flooding on the same dates in the Deadwood area was especially severe (fig. 22). A May 20, 1883, article in the Black Hills Daily Times indicated that flooding in Deadwood probably was exacerbated by large volumes of mine tailings that had substantially altered local stream channels. A severe forest fire had occurred in the watershed on September 25, 1879 (Tallent, 1899), and also might have exacerbated the flooding. Within the central Black Hills, high water was reported from Battle Creek to Elk Creek, with northern areas incurring the heaviest damage. Miller (1986) reported a peak flow of 8,400 ft^3/s for Rapid Creek on May 17, 1883. Subsequent flash flooding occurred around June 15, 1883, along Rapid, Boxelder, and Elk Creeks following strong thunderstorm activity. Although details regarding the 1883 flooding are somewhat sparse, this year frequently is referred to as a benchmark flood year for many streams in numerous ensuing news accounts for many subsequent years.

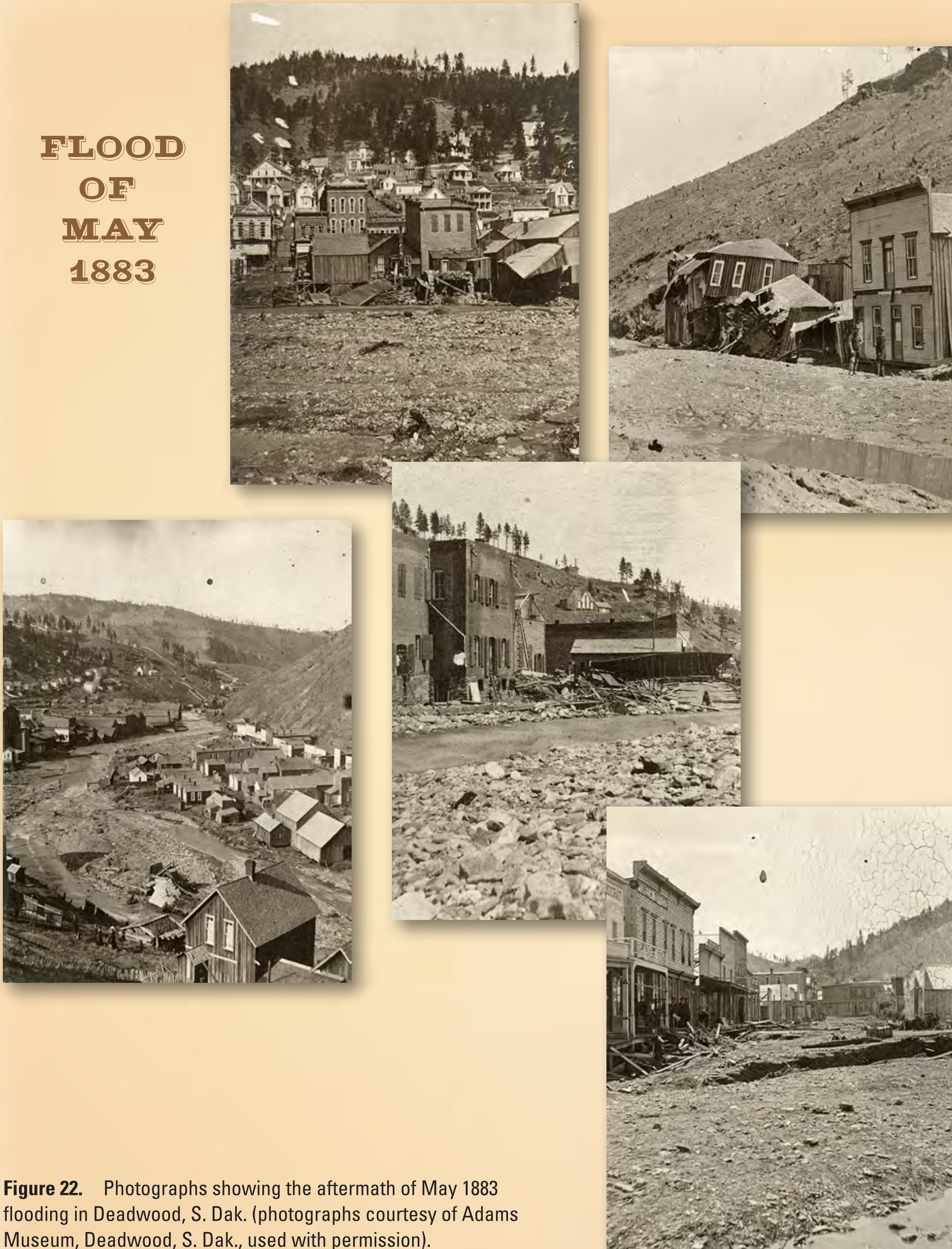


Figure 22. Photographs showing the aftermath of May 1883 flooding in Deadwood, S. Dak. (photographs courtesy of Adams Museum, Deadwood, S. Dak., used with permission).

Design documents (U.S. Army Corps of Engineers, 1950, 1966) for the flood-control dams on Cold Brook and Cottonwood Springs Reservoirs within the Fall River Basin provide accounts of historical high-water marks for a flood of August 27, 1884, that are 6 to 7 ft higher than the maximum recorded stage for the 1938 peak-of-record flow at USGS streamflow-gaging station 06402000 (Fall River at Hot Springs). To date (2010), additional historical information has not been located regarding the 1884 event.

Several articles by the Rapid City Journal and the Black Hills Daily Times describe flooding in June 1890. Details are quite sketchy and some reports (South Dakota Historical Society, 1960) refer to widespread flooding in the Black Hills area. Various articles in subsequent years occasionally refer to 1890 as somewhat of a year of benchmark flooding.

1891 through 1900

Historical flood reports available for the 1890s are sparser than for most other decades (table 10). A lone account by the Rapid City Journal (June 2, 1891) for 1891 describes fairly substantial flooding in the Deadwood and Lead areas and a fairly severe storm that caused flooding along the Fall River in Hot Springs. A flood that occurred along Spearfish Creek on July 30, 1895, was reported in an August 1, 1895, article in the Rapid City Journal as "higher than it has been since the well remembered flood of 1883." News coverage was quite extensive for storms that apparently began on about June 6, 1896, and resulted in flooding throughout much of the Black Hills. Rail damage in the southern Black Hills was extensive and additional flood damages were reported as far north as Belle Fourche.

In addition to the previously mentioned flood in 1891, the Hot Springs area had several floods in the 1890s. Twomey and Magee (1983) described an "unprecedented" storm during July 1895 for the Hot Springs area and provided a subsequent account of a damaging storm in June 1896 that was followed by additional severe storms that year. One of the additional 1896 storms occurred on September 12, 1896, and substantial flooding occurred again the next year (August 6–7, 1897). Reprints of articles about these two storms and associated flooding were included with reprints of four other articles in a recount of "Six Great Floods of Hot Springs" that was printed April 18, 1946, by the Hot Springs Weekly Star. The 1946 article announced construction plans for three U.S. Army Corps of Engineers flood control projects that included channel improvements along the Fall River and construction of Cold Brook and Cottonwood Springs Dams, which have regulated flows since September 1952 and June 1969, respectively (Miller and Driscoll, 1998). The six articles had previously been assembled as a primary exhibit in an October 19, 1937, hearing on flood control that was instrumental in securing Congressional authorization in 1941. Additional information regarding the robust and complicated flood history for the Fall River is provided in a subsequent section titled "Fall River and Beaver Creek."

1901 through 1910

Many floods were reported from 1901 through 1910, which may be one of the most active decades for flooding in the Black Hills area. Fairly widespread flooding was reported for June 1901, with the heaviest flooding reported for the northern parts of the Black Hills and areas north of Belle Fourche. Articles in the Rapid City Journal and Belle Fourche Bee (June 13, 1901) reported that on June 11, 1901, Hay Creek had been "the highest ever known." Flood damage occurred in the small former town of Cascade (located about 10 mi southwest of Hot Springs) in 1893 for an unknown date in July 1901 (Twomey and Magee, 1983).

Widespread flooding occurred again in the northern Black Hills in June 1904 (fig. 23*A*), with reports indicating fairly severe flooding in some areas. This is one of the earliest years for which quantitative information is available from USGS streamflow records (table 9); however, availability is limited to about a dozen stations with sporadic records within a general time frame of about 1903–06 (Miller and Driscoll, 1998). A peak flow of 5,000 ft^3/s was recorded on June 5, 1904, for station 06431500 (Spearfish Creek at Spearfish; map number 73 in fig. 5), which is one of the first large floods recorded at a USGS streamflow-gaging station in the Black Hills area and through 2009 remains as the peak-of-record flow for this station. A peak flow of 8,050 ft^3/s for the same date was reported for short-term station 06434000 (Redwater Creek at Belle Fourche; fig. 5) located about 20 mi downstream along the Redwater River. Larger peak flows through 2009 for the Redwater River include only peaks of 16,400 ft^3/s in 1962 and 8,480 ft^3/s in 1965, which were recorded at long-term station 06433000 (Redwater River above Belle Fourche; table 9; map number 76 in fig. 5), which is located about one-quarter mi farther upstream, and upstream from Hay Creek. The contribution to the 1904 peak from Hay Creek cannot be determined, but probably is much smaller than the uncertainty associated with determination of the peak flow for the Redwater River.

Substantial flooding occurred in Hot Springs during two separate weeks in June 1905, and a severe storm also was reported in the Edgemont area in June. Water was reported to be 15 ft deep in bottom areas in Sundance, Wyo. (location shown in fig. 13*A*), following a severe storm on July 11, 1905, and extensive rail damage occurred throughout the Black Hills area during the month (table 10). A peak flow of 13,000 ft^3/s was recorded on July 30, 1905, during the first year of USGS data collection at station 06395000 (Cheyenne River at Edgemont; table 9; map number 5 in fig. 5), which is an unusually large peak for this time of year and provides an indication of probable widespread high-water conditions because of the large drainage area (7,204 mi^2) involved. A peak flow of 9,150 ft^3/s was recorded on August 12, 1905, during the first year of USGS data collection at station 06400000 (Hat Creek near Edgemont; map number 11 in fig. 5). Larger peak flows (through 2009) have been measured only in 1954 (9,430 ft^3/s) and 1967 (13,300 ft^3/s; table 9).

The year 1907 is one of the most noteworthy years for flooding in the Black Hills area (fig. 23*B*). An initial indication of wet conditions is provided by an article in the Deadwood Pioneer Times on May 19, 1907, which recounts the 1883 flooding for the Deadwood area. Subsequent articles describe widespread disruptions to rail service and a rapidly rising stage of the Belle Fourche River at Belle Fourche that was the highest since 1883. An article on May 26, 1907, in the Deadwood Pioneer Times describes a record late snowfall of at least 2.5 ft in the Deadwood area that followed heavy rain over a previous period of 60 hours, with area streams subsiding somewhat because of the snowfall. A May 31, 1907, article in the Edgemont Express indicates generally wet but less severe conditions near Edgemont. A June 1, 1907, article in the Rapid City Journal indicates very high water and inundation of a "government gauge" on the lower Cheyenne River, with additional high water in the Bad River (heads on east-central edge of area shown in fig. 13*A*) and White River contributing to a large rise in the Missouri River (not shown in figures, located in central South Dakota). A June 1, 1907, article in the Custer Chronicle indicates bridge damage in Custer County and loss of 20 bridges along French Creek during "one freshet" in the previous year (1906).

The NWS office at Rapid City (station 396947) recorded 8.09 in. of precipitation in May 1907, with a total of 6.11 in. recorded during May 23–25 (South Dakota State University, 2009). Unfortunately, the nearest applicable USGS streamflow records for 1907 are for the Little Missouri River at Medora, N. Dak. (station 06336000, index map of fig. 13*A*), for which a peak flow of 29,000 ft^3/s was recorded on June 24 and monthly averages of 2,500, 4,160, and 1,820 ft^3/s were recorded for May, June, and July, respectively (U.S. Geological Survey, 2010b). These data indicate prolonged wet conditions west and north of the Black Hills.

The widespread wet conditions that persisted through at least the end of May 1907 might have been a contributing factor to severe and large-scale flooding in the Black Hills that developed beginning the afternoon of Wednesday, June 12. Quantitative information for this event is sparse, relative to the storm and flooding of 1972 and other recent large events; however, abundant qualitative information was available from the extensive news accounts that ensued. A June 13, 1907, article in the Deadwood Pioneer Times indicated that the June 12 storm might have been connected with a larger-scale system that "had been raging in Montana and Wyoming and was expected here, but not until today [June 13]." Several news articles indicate that the June 1907 storm probably produced especially heavy rainfall over an area north and west of Rapid City (table 10), and on the basis of the accounts, might have approached the severity and proportions of the 1972 storm and flooding. Honerkamp (1978) provided numerous details that indicated the storm activity probably was centered at least partially over the drainage area for Stagebarn Canyon, where flooding was especially severe, with very severe flooding also reported to the north in the Little Elk and Elk Creek drainages (fig. 24). Honerkamp's (1978) accounts are consistent with numerous news articles (table 10) and with a report by Miller (1986) of a 24-hour rainfall total of 7.1 in. for June 12, 1907, at Ft. Meade. The NWS office at Rapid City (station 396947) recorded only 3.24 in. of precipitation in June 1907, with a daily total of 1.25 in. on June 12 (South Dakota State University, 2009), which indicates that Rapid City probably did not receive exceptionally heavy precipitation. A peak flow of 13,000 ft^3/s was estimated for Rapid Creek for the June 1907 storm (U.S. Army Corps of Engineers, 1973; Miller, 1986), which certainly indicates heavy precipitation upstream (west) from Rapid City.

A peak flow of 16,000 ft^3/s occurred on June 12, 1907, at station 06422500 (Boxelder Creek near Nemo; table 9; map number 58 in fig. 5), from which it is apparent that heavy precipitation occurred upstream from this station, which is located just south of the headwaters of Stagebarn Canyon, Little Elk Creek, and Elk Creek. A June 19, 1907, article in the Black Hills Press described "a wall of water judged to have been fifteen feet in height coming down the [Stagebarn] canyon," which is similar to a report by Honerkamp (1978) of flood debris that was found 18.5 ft above the floor of Stagebarn Canyon. Honerkamp (1978) also reported complete devastation of the rail line in Elk Creek canyon, indicating a large peak flow. A June 22, 1907, article in the Custer Chronicle reported that "throughout the southern Hills" there was damage to "wagon and railroad bridges," which indicates that heavy precipitation probably was widespread. Another June 22, 1907, article in the Custer Chronicle reported "the heavy rains and resulting floods" as "the most widespread and damaging of any which have ever occurred in the Black Hills." A July 27, 1907, article in the Custer Chronicle indicated substantial railroad damage along Rapid Creek that might have extended as far upstream as Mystic, which provides another possible indication of extensive storm coverage.

In summary for the June 1907 storm system, quantitative information is insufficient for detailed comparisons between the storms and flooding of 1907 and those of 1972 and more recent years. However, a large body of evidence indicates that the 1907 storms and flooding probably are among the most substantial that have been experienced in the Black Hills area since European settlement and that 1907 flood severity may have rivaled that of 1972 in some drainages.

In 1908, Hot Springs had substantial flooding from heavy rainfall on May 31 that was exacerbated by saturated conditions from prolonged rains of the previous week. In 1946, the Hot Springs Weekly Star reprinted an article from June 5, 1908, that stated that the peak stage that occurred on June 1, 1908, was reported within about 3 ft of a bridge that marked high water from two previous larger floods (August 1897 and June 1905).

In late May and early June 1909, widespread flooding from prolonged rains occurred in many streams in the northern Black Hills, with flooding along Spearfish Creek reported as

A. FLOOD OF 1904

B. FLOOD OF 1907

Figure 23. Photographs of flood damage in the Deadwood, S. Dak., area during 1904 and 1907. *A*, Between Deadwood and Pluma and in Deadwood in 1904; and *B*, in Deadwood and Central City in 1907 (photographs courtesy of Adams Museum, Deadwood, S. Dak., used with permission).

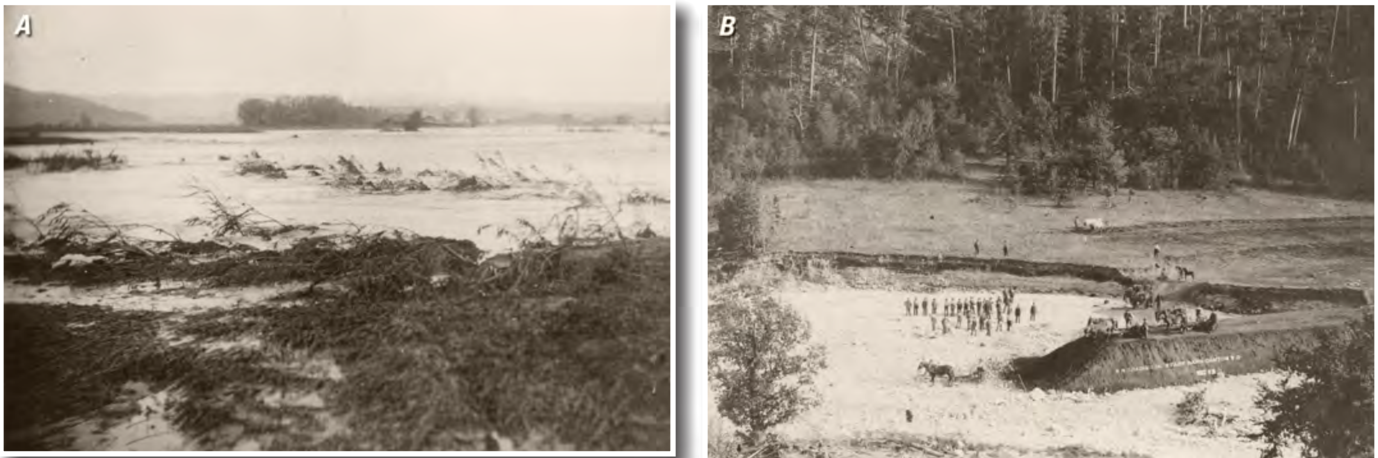


Figure 24. Photographs of the June 12, 1907, flood and aftermath in the Piedmont, S. Dak., area. *A*, Flood waters covered the floor of Elk Creek valley; *B*, the railroad grade damaged in Stagebarn Canyon during the 1907 flood was rebuilt in 1908 (photographs courtesy of John Honerkamp).

some of the most damaging (table 10). Additional flooding occurred in the Spearfish area on June 8, 1909, from a strong storm system that produced heavy rainfall and damage along the eastern fringe of the Black Hills and extended at least as far to the southeast as New Underwood, where especially severe storm effects were reported. Substantial flooding occurred in New Underwood again on June 10, with additional flooding reported from the Belle Fourche and Sturgis areas to as far south as Rapid Creek. A June 12 article in the Deadwood Pioneer Times provided a report that "more than twenty inches of water on the level fell" near Pactola (former town at current location of Pactola Reservoir); however, damage reports were not indicative of a large-scale storm with precipitation amounts of this general magnitude. The June 12 article also reported Boxelder Creek to be "seven feet higher than the record mark," which would indicate flooding substantially exceeding that of June 1907, when extensive railroad damage was reported (Rapid City Journal article of June 15, 1907).

A historical postcard shows that flooding occurred on the Belle Fourche River in 1910 (fig. 25). No other reports of flooding for 1910 were located.

1911 through 1920

Several reports of flooding are available for the years 1911–13 (table 10), with most of the news accounts reporting high water along the Belle Fourche and Cheyenne Rivers. Both 1915 and 1920 were exceptional in terms of prolonged wet conditions with widespread flooding. The southern Black Hills area was especially wet during May and June 1915, with numerous reports of flooding that ranged from localized to widespread and included many accounts of the worst flooding in many years for many locations. A June 17, 1915, article in the Oelrichs Advocate provided an account for Horsehead Creek of the worst known flooding to date, which surpassed the previous known flood of record that occurred 23 years previously. A June 19, 1915, article in the Buffalo Gap Gazette reported that the same storm system caused flooding that surpassed a previous high-water mark for Beaver Creek near Buffalo Gap before tracking towards Horsehead Creek. Numerous news articles (table 10) provided continuing accounts of strong storms through August 1915, with most reports for the southern Black Hills.

The year 1920 may constitute some of the most substantial and widespread flood conditions that have occurred since European settlement in western South Dakota and the Black Hills area. Two April 2, 1920, articles (White Owl Oracle and Wasta Gazette) described flooding conditions in early spring for the Belle Fourche and Cheyenne Rivers and for several tributaries in the Black Hills area. Miller (1986) noted a 24-hour rainfall total of 7.1 in. for Custer on April 7, 1920; however, NWS records (National Oceanic and Atmospheric Administration, 1920) indicate that April 17 was the correct date and that heavy snowfall (amounts ranging from 1 to 4 ft) was recorded at other stations throughout the Black Hills. Miller (1986) and the National Oceanic and Atmospheric Administration (2008) documented substantial flooding along Rapid Creek for May 10–12, and the widespread nature of flood conditions is described in numerous ensuing news accounts (table 10). A peak flow of 114,000 ft^3/s was recorded on May 12, 1920, at station 06400500 (Cheyenne River near Hot Springs; fig. 26; map number 13 in fig. 5), which is the largest peak flow ever recorded anywhere along the Cheyenne River (table 9). A record stage of 18.9 ft also is documented for the next day (May 13) at station 06439500 (Cheyenne River near Eagle Butte; map number 97 on index map of fig. 5), which is located on the Cheyenne River about 75 mi downstream from the confluence of the Belle Fourche River. The stage for this station was determined from information provided by local residents and probably represents the largest documented flood for the station; however, the magnitude of

Figure 25. Photograph of the Belle Fourche River in 1910 (photograph courtesy of James Aplan, Antiques & Art, Piedmont, S. Dak.).

Figure 26. The Cheyenne River near Hot Springs, S. Dak., flooded on May 12, 1920. A peak flow of 114,000 cubic feet per second was recorded on May 12, 1920, at station 06400500 (Cheyenne River near Hot Springs, S. Dak.), which is the largest peak flow ever recorded anywhere along the Cheyenne River (photograph courtesy of Fall River County Historical Society).

the peak flow is not known. Articles on May 14, 1920, in the Ardmore American and Edgemont Express provided accounts of the worst known flooding in the history of Hat Creek in the southern Black Hills, which claimed seven lives on May 12, 1920. Although many of the 1920 articles focus on flooding in the southern Black Hills, northern areas also had substantial flooding, as evidenced by a May 15 article in the Rapid City Journal reporting that “Newell suffered the heaviest rainfall ever known” and that flooding had occurred for the third time of the season in Belle Fourche. A June 4, 1920, article in the White Owl Oracle reported that Boxelder Creek “was fully four feet higher than ever known before” and “was over three miles wide.” A sense of the widespread nature of the 1920 flooding was provided by a May 29, 1920, article in the Oelrichs Advocate that reported severe railroad damage along the Bad and White Rivers.

1921 through 1930

In 1922, flooding occurred throughout much of the Black Hills area from a storm that began on May 10 and produced heavy precipitation (including rain, hail, sleet, and snow in different areas) from west of Edgemont (Cottonwood Creek and Cheyenne River) to west of Belle Fourche (Hay Creek) to Saint Onge to Rapid City. A May 12, 1922, article in the Rapid City Journal reported 3.79 in. of precipitation in Lead, and a following article on May 17 reported “approximately nine inches of water fell during less than twenty hours.” The specific location of the precipitation measurement was not provided, but the article described flooding in Spearfish. Precipitation totaling 6.08 in. during 24 hours “of the worst period of the storm” was reported at the end of the article that again seemed to refer to the Spearfish area. A May 11, 1922, article in the Deadwood Telegram described flooding of a power plant along the Redwater River and reports that “the flood at that point is the highest ever known, being three feet higher than the highest previously known, in 1916.” A May 22 article in the Weekly Pioneer Times reported “the highest water in the history of” Saint Onge, and numerous articles described widespread flooding in the northern Black Hills area and extending at least as far south as Sturgis. A severe thunderstorm on August 3, 1922, caused considerable damage to railroad bridges in one of the many large floods along the Fall River (fig. 27).

In 1923, high flows occurred along the Belle Fourche and Cheyenne Rivers on several occasions between April and October, with moderate to substantial flooding along one or both of these rivers. Flooding in 1924 was especially severe in the Belle Fourche area (fig. 28), and an April 10 article in the Black Hills Press noted that the Belle Fourche River was “still higher than any previous high water mark” after receding by about 18 in. A record peak flow of 22,400 ft^3/s occurred on April 9, 1924, at station 06435500 (Belle Fourche River near Belle Fourche; table 9; map number 79 in fig. 5).

Widespread flooding occurred in much of western South Dakota during 1927, following exceptionally heavy snowpack and heavy rains in early May (National Oceanic and Atmospheric Administration, 2008). A May 13, 1927,

Figure 27. Photograph of damage to a railroad bridge during the August 3, 1922, flood along the Fall River near Hot Springs, S. Dak. (photograph courtesy of Fall River County Historical Society).

article in the White Owl Oracle reported that Sulphur Creek (location unknown) was “higher by almost eight feet than during any other high water.” A record stage of 21.8 ft for an unknown date in May 1927 (table 10) is documented for station 06438000 (Belle Fourche River near Elm Springs; map number 94 in fig. 5), which is located about 15 mi upstream from the confluence with the Cheyenne River. The stage was determined from information provided by local residents and the magnitude of the peak flow is not known. The next largest known stages for the station are for the same gage datum and are about 20 ft on an unknown date in 1933 and 19.73 ft in 2008, for which the associated peak flow was 47,500 ft^3/s (table 9). Large peak flows occurred in 1927 (8,250 ft^3/s), 1928 (9,660 ft^3/s), and 1929 (15,000 ft^3/s) for station 06435500 (Belle Fourche River near Belle Fourche); however, all are substantially exceeded by the 1924 peak flow of 22,400 ft^3/s (table 9).

A stage of 18.0 ft is documented for station 06402500 along Beaver Creek near Buffalo Gap (map number 21 in fig. 5) for an unknown date in 1927 (table 10). The stage was determined from information provided by local residents and exceeded a stage of 16.46 ft (associated peak flow was 11,700 ft^3/s) that occurred during the first year of operation (1938) of a streamflow-gaging station at the location.

Figure 28. Photographs of the April 9, 1924, flood along the Belle Fourche River in Belle Fourche, S. Dak. (photographs courtesy of Tri-State Museum, Belle Fourche, S. Dak.).

1931 through 1940

On May 6, 1932, a peak flow of 16,000 ft^3/s was recorded at station 06422000 (Rapid Creek at Creston; fig. 5; table 10) along Rapid Creek. This station is located about 8 mi downstream from station 06421500 (Rapid Creek near Farmingdale; map number 55 in fig. 5), where a peak flow of 7,320 ft^3/s was recorded on June 10, 1972 (table 9). The 1972 peak had attenuated by almost an order of magnitude in moving downstream along Rapid Creek. News accounts of the 1932 flooding have not been located and streamflow-gaging stations 06411500 (Rapid Creek below Pactola Dam) and 06412000 (Rapid Creek at Big Bend near Rapid City) (map numbers 49 and 50, respectively, in fig. 5), which are located upstream from Rapid City, did not have large peak flows (U.S. Geological Survey, 2009). However, a peak-of-record flow of 46,300 ft^3/s was recorded on the same date (table 9) for downstream station 06423500 (Cheyenne River near Wasta; map number 60 in fig. 5). Daily mean flow values recorded for May 5–12, 1932, for this station were 650, 14,600, 5,390, 5,250, 3,770, 2,480, 1,760, and 773 ft^3/s (U.S. Geological Survey, 2010c). In comparison, daily mean flow values recorded for June 9–16, 1972, for this station were 138, 1,390, 9,240, 5,780, 3,700, 2,210, 1,600, and 1,370 ft^3/s and the peak flow for June 11, 1972, was only 11,800 ft^3/s. The average daily flows for these 8-day periods were 4,330 and 3,180 ft^3/s for 1932 and 1972, respectively, which provide a useful perspective regarding the 1932 storm system that apparently produced heavy rainfall over a relatively large area primarily downstream from Rapid City.

A storm system occurred throughout a large part of the Black Hills area on May 22–23, 1933. A tornado occurred between Mystic and Rochford, and severe storm conditions were reported from Custer to Newell. Lead reported 4.8 in. of precipitation in 12 hours and severe flooding was reported along Spearfish Creek (May 23, 1933, article in the Lead Call), with additional reports of high water for many other area streams. A peak flow of 1,540 ft^3/s was recorded on May 24 for station 06411500 (Rapid Creek below Pactola Dam; table 9), which is downstream from where Pactola Dam now exists.

Belle Fourche experienced considerable damage from two separate floods along Hay Creek on July 10 and 12 of 1937. A July 13 article in the Belle Fourche Bee described the July 10 flood as the worst along Hay Creek since 1923 and the worst in Belle Fourche since flooding of the Belle Fourche River in 1924.

Severe flooding occurred in Hot Springs along the Fall River on June 17, 1937 (fig. 29) and on September 4, 1938, when a peak flow of 13,100 ft^3/s was recorded during the first year of record for station 06402000 (Fall River at Hot Springs; table 9; map number 17 in fig. 5). Also on September 4, 1938, a very large peak flow of 11,700 ft^3/s was recorded for station 06402500 (Beaver Creek near Buffalo Gap). A September 24, 1938, article in the Rapid City Journal reported that flooding on the same date farther north along Lame Johnny Creek "was the worst in 35 years." This article, in combination with the known magnitudes of the other two large peak flows, provides an indication of a strong storm system over a relatively large area that produced some of the most substantial flooding that has been documented for the Black Hills area.

1941 through 1950

Moderate to severe flooding occurred at station 06402000 (Fall River at Hot Springs) in 1941 (peak flow of 4,700 ft^3/s) and 1947 (peak flow of 8,300 ft^3/s; table 9; fig. 30). These were the last substantial floods before construction of two flood-control reservoirs within the Fall River Basin.

Substantial flooding occurred in May 1946 in various streams in the northern Black Hills, which resulted from prolonged, heavy precipitation. Articles for May 2, 3, and 4 in the Rapid City Journal described flooding along Bear Butte Creek, and a May 31 article in the Lead Call reported that Spearfish Creek was as high as it had been during the flood of 1933 when the railroad bed in Spearfish Canyon was washed out. A peak flow of 9,800 ft^3/s was recorded on May 24, 1946, at station 06437500 (Bear Butte Creek near Sturgis; map number 93 in fig. 5) about 15 mi northeast of Sturgis. A summary of monthly precipitation totals (extracted from Driscoll and others, 2000) for May and June 1946 (and other selected years with especially wet conditions) for selected NWS stations in the northern Black Hills area (fig. 31) is provided in table 3. The table shows a monthly total of 18.61 in. in Deadwood for May 1946, with large monthly totals for other stations in the northern Black Hills. Examination of peak-flow records (Burr and Korkow, 1996) for station 06438000 (Belle Fourche River near Elm Springs) indicates a series of peak flows during May and June 1946 that are fairly large (as much as 25,500 ft^3/s) but do not approach record flows that exceed 40,000 ft^3/s.

1951 through 1960

Table 10 contains very few listings for historical floods for years after 1947, which is the last year for the chronological set of typed newspaper articles that was compiled by staff

Figure 29. Photograph of the June 17, 1937, flood along the Fall River in and near Hot Springs, S. Dak. (photograph courtesy of David Bachelor).

Figure 30. The 1947 flood along the Fall River caused severe damage in Hot Springs (photograph courtesy of Fall River County Historical Society). During this flood, a peak flow of 8,300 cubic feet per second occurred on June 20, 1947, at station 06402000 (Fall River at Hot Springs, S. Dak.).

from the USGS office in Rapid City (U.S. Geological Survey, 2010a). Chronological listings after 1947 primarily consist of entries from the National Oceanic and Atmospheric Administration (2008) Web site and U.S. Geological Survey (2009) peak-flow records. USGS peak-flow records are especially sparse before about 1938 and availability of peak-flow records begins to increase considerably in the 1940s, which coincides conveniently (and perhaps not necessarily coincidentally) with the aforementioned set of typed newspaper articles.

High flows occurred along Rapid Creek and many other streams throughout much of the Black Hills area in late May 1952. A peak flow of 2,540 ft^3/s occurred on May 23 on Rapid Creek at station 06414000 (Rapid Creek at Rapid City; map number 54 in fig. 5), and a peak flow of 1,770 ft^3/s occurred on May 24 at station 06421500 (Rapid Creek near Farmingdale; table 9) east of Rapid City. An aerial photograph taken on May 23 shows flooding for a reach of Rapid Creek in western Rapid City (fig. 32). A relatively large peak flow of 24,700 ft^3/s occurred on May 22 at station 06423500 (Cheyenne River near Wasta) (U.S. Geological Survey, 2009), indicating widespread high water throughout the southern Black Hills area during May 1952.

A peak flow of 9,430 ft^3/s occurred on May 23, 1954, at station 06400000 (Hat Creek near Edgemont). The 1954 peak flow for this station is second only to a peak flow of 13,300 ft^3/s on June 16, 1967 (table 9).

A strong storm near Rochford on July 28, 1955, caused flooding along Castle Creek. Additional details about this flood are provided in a subsequent section titled “Upper Rapid Creek.”

1961 through 1970

Notable storms and flooding occurred along the northeastern flanks of Black Hills in 1962, following about a decade of extended and severe drought conditions (Driscoll and others, 2000). Articles of May 23 and June 6, 1962, in the Sturgis Tribune described moderately high water in the Sturgis area following a week of prolonged rain, which was proclaimed to be the end of the drought. These were followed by two June 16 articles (Sturgis Tribune and Rapid City Journal) that described severe flooding during June 15–16 along the northeastern flank of the Black Hills (Rapid City to Sturgis to Whitewood), with the most severe flooding in the Sturgis area. Rapid City subsequently suffered additional but less severe flooding from another storm the next day. The worst flooding of 1962 along Rapid Creek occurred several weeks later (July 13) and resulted in a peak flow of 3,300 ft^3/s for station 06414000 (Rapid Creek at Rapid City). This is the second largest peak flow for this station, but is dwarfed by the 1972 peak flow of 50,000 ft^3/s (table 9). An exceptional peak flow of 2,920 ft^3/s (Larimer, 1973; U.S. Geological Survey, 2009) was determined for July 13, 1962, for station 440325103182500 (Cleghorn Canyon at Rapid City), which is a small drainage (area = 7.0 mi^2) in western Rapid City (fig. 5) that incurred flood damage (fig. 33). A June 23, 1962, article in the Sturgis Tribune described the aftermath of flooding that occurred on June 16–17, 1962, in the Sturgis area. The article also reported that 14 in. of rain during a 6-hour period on June 15 in Whitewood, which provides an indication of possible extreme storms in the area that is corroborated by examination of peak-flow records. A peak-of-record flow of 12,700 ft^3/s occurred on June 16, 1962, at station 06437500 (table 9) along Bear Butte Creek about 15 mi northeast of Sturgis. Another peak-of-record flow occurred on June 16 at station 06433000 (16,400 ft^3/s; drainage area = 930 mi^2) along the Redwater River upstream from Belle Fourche. An annual peak flow of only 2,340 ft^3/s occurred on the same date at upstream station 06430500 (Redwater River at Wyoming/South Dakota line; drainage area = 481 mi^2), which is located near the Wyoming/South Dakota border (map number 67 in fig. 5), and the 1962 peak flow of 830 ft^3/s for station 06431500 (Spearfish Creek at Spearfish; drainage area = 165 mi^2) occurred several weeks earlier on May 22. Thus, most of the large peak flow (16,400 ft^3/s) on June 16, 1962, was generated within an area of only 284 mi^2 downstream from stations 06430500 and 06431500, indicating that the flow must have resulted from a strong individual storm system, rather than from prolonged precipitation. Another large peak flow (3,120 ft^3/s) occurred on June 17, 1962, at station 06425500 (Elk Creek near Elm Springs; map number 63 in fig. 5; Burr and Korkow, 1996); however, the peak flow for the year (7,040 ft^3/s) occurred on May 29 and another large peak flow of 6,320 ft^3/s occurred on May 21 (U.S. Geological Survey, 2010c). The peak-of-record flow for this station (8,540 ft^3/s) occurred on March 29, 1952 (table 9).

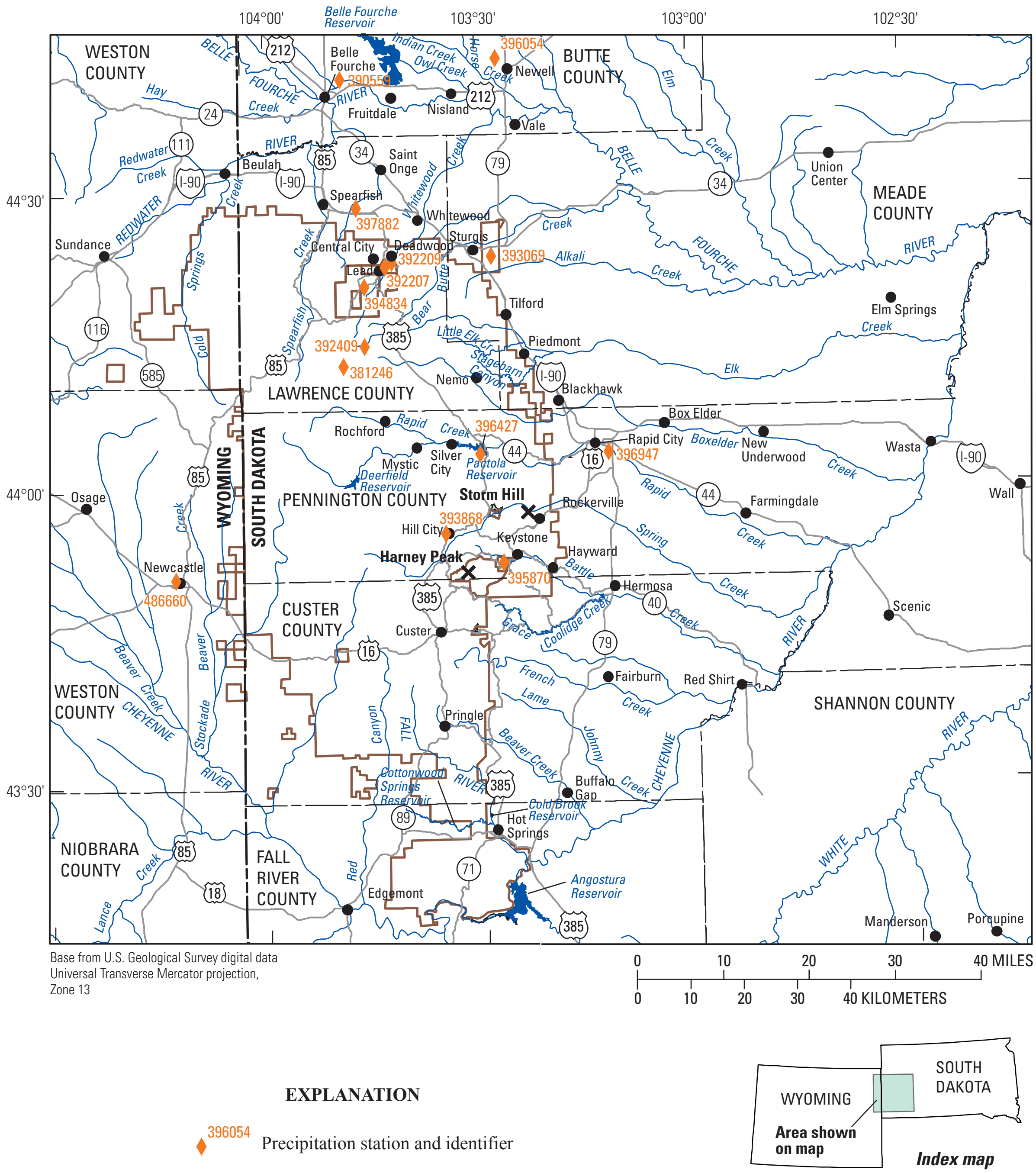


Figure 31. Location of selected National Weather Service precipitation stations in the Black Hills area.

Table 3. Summary of selected precipitation information for the Black Hills (from Driscoll and others, 2000).

[NWS, National Weather Service; NA, not available]

NWS station name (number) or area	Month	Monthly precipitation total (inches)							
		1946	1962	1965	1976	1982	1995	Average for selected years[1]	Average for 1931–98
Belle Fourche (390559)	May	7.63	7.23	5.96	2.31	10.70	7.99	6.97	NA
	June	4.71	4.66	3.46	9.36	2.31	4.57	4.85	NA
Buskala Ranch (381246)	May	13.20	9.70	8.20	4.08	6.72	8.79	8.45	NA
	June	4.37	4.84	4.82	6.39	4.05	3.75	4.70	NA
Deadwood (392207)	May	18.61	12.10	13.96	3.64	15.99	13.32	12.94	NA
	June	7.71	7.05	4.45	12.43	3.30	5.82	6.79	NA
Fort Meade (393069)	May	[2]14.15	11.20	6.67	2.62	8.73	8.50	8.65	NA
	June	[2]5.89	6.41	5.70	11.45	2.03	6.00	6.25	NA
Lead (394834)	May	15.31	13.52	14.84	3.10	12.26	10.73	11.63	NA
	June	5.38	8.57	4.13	11.88	3.33	4.13	6.24	NA
Newell (396054)	May	9.35	8.60	6.25	1.53	8.10	5.58	6.57	NA
	June	4.75	4.85	3.80	4.63	3.72	3.55	4.22	NA
Rapid City (396947)	May	7.35	9.21	7.30	4.03	6.09	6.13	6.69	NA
	June	5.37	7.48	3.42	7.35	2.38	4.41	5.07	NA
Spearfish (397882)	May	13.07	10.01	[2]11.08	2.77	14.11	7.77	9.80	NA
	June	7.36	5.28	[2]4.11	14.01	2.83	6.42	6.67	NA
Butte County	May	8.51	8.59	6.54	2.11	10.33	7.35	7.24	2.83
	June	4.78	4.83	3.91	8.12	2.94	4.49	4.85	3.25
Lawrence County	May	12.64	10.74	10.63	3.31	10.96	9.35	9.61	3.74
	June	5.60	6.48	4.53	10.56	3.25	4.53	5.83	3.83
Meade County	May	10.41	10.20	7.78	2.98	8.36	8.12	7.98	3.37
	June	5.21	6.46	4.77	8.58	2.70	4.61	5.39	3.52
Pennington County	May	7.71	8.75	8.42	3.55	5.80	6.66	6.82	3.27
	June	4.23	5.86	4.80	6.45	3.74	4.32	4.90	3.45
Custer County	May	7.24	6.99	6.81	2.81	5.44	6.51	5.97	3.12
	June	3.20	4.39	4.49	4.92	4.49	5.17	4.44	3.25
Fall River County	May	6.96	5.62	5.45	2.55	5.50	4.73	5.14	2.91
	June	3.07	4.51	3.41	3.09	4.54	4.40	3.84	2.93
All Black Hills	May	4.36	8.15	7.54	2.94	7.11	6.89	6.17	3.21
	June	4.00	5.29	4.34	6.42	3.83	4.64	4.75	3.35

[1]Selected years are 1946, 1962, 1965, 1976, 1982, and 1995.

[2]Estimated amount by Driscoll and others (2000).

Precipitation totals for May 1962 were especially large for Deadwood, Fort Meade, and Lead (table 3), which presumably contributed to generally high flows and wet antecedent conditions in the northern Black Hills. Selected monthly precipitation totals that were compiled by Driscoll and others (2000) for counties in the Black Hills area also are shown in table 3. Monthly totals for May for Butte, Lawrence, Meade, and Pennington Counties are especially large relative to 1931–98 averages, and provide a good indication of the areal extent of the exceptionally wet conditions. Precipitation totals for June 1962 are not exceptional, which indicates that the large June 16–17 peak flows recorded for several streamflow-gaging stations probably resulted from especially strong rain-producing thunderstorms, as opposed to more widespread precipitation.

A large peak flow of 3,040 ft^3/s occurred at station 06431500 along Spearfish Creek on June 9, 1964 (table 9). Daily mean flow values for this station for June 7–10 are 59, 80, 1,480, and 493 ft^3/s, respectively, and the June 7 and 8 daily mean flow values are similar to the long-term (1947–2009) June average of 79.8 ft^3/s for the station (U.S. Geological Survey, 2010c). These data indicate that the peak flow resulted from a strong storm during a relatively low- to moderate-flow period. The storm apparently produced heavy rainfall over a large area, as indicated by a summary of precipitation data that is provided in table 4.

Flooding occurred on May 15, 1965, in Deadwood (fig. 34), Spearfish, and Sturgis from heavy rain falling on as much as 30 in. of snow (National Oceanic and Atmospheric Administration, 2008). A peak flow of 4,240 ft^3/s occurred along Spearfish Creek at Spearfish (station 06431500), and farther downstream a peak flow of 8,480 ft^3/s occurred along the Redwater River above Belle Fourche (station 06433000; table 9). On May 15, a peak-of-record flow of 2,060 ft^3/s was recorded for station 06410500 (Rapid Creek above Pactola Reservoir at Silver City; map number 48 in fig. 5).

Figure 32. Aerial photograph of flooding along Rapid Creek on May 23, 1952, near Canyon Lake in Rapid City, S. Dak.; the bridge in center of photograph is Evergreen Drive (U.S. Geological Survey photograph).

1971 through 1980

Severe and widespread flooding occurred along many streams in the central Black Hills on June 9–10, 1972 (fig. 35). Nearly 15 in. of rain fell in about 6 hours near Nemo, and more than 10 in. of rain fell over an area of 60 mi^2. The resulting floods left 238 people dead and 3,057 people injured (Carter and others, 2002). Battle, Spring, Rapid, and Boxelder Creeks experienced the largest flooding with smaller floods along Elk and Bear Butte Creeks. Record flows were recorded for many USGS streamflow-gaging stations, and the 1972 peak flows remain (through water year 2009) as peak-of-record flows for 14 streamflow-gaging stations (table 9).

Figure 33. Photograph of a mobile home that was washed down Cleghorn Canyon in western Rapid City, S. Dak., by a 6-foot wall of water on July 13, 1962 (photograph courtesy of the Rapid City Journal). A family was inside the home as it was washed down the canyon but was able to escape with the aid of neighbors.

Flooding was especially severe along Rapid Creek, where a peak-of-record flow of 50,000 ft^3/s was recorded at Rapid City (station 06414000) and where many of the 238 known flood victims perished. Additional details regarding the 1972 storm and flooding was provided in the previous section "The 2007 Storm and Flooding, with Comparisons to the 1972 Storm and Flooding," and numerous other details regarding the 1972 flooding have been extensively documented in many other venues; thus, no additional details are provided here.

Prolonged heavy rainfall occurred throughout parts of the northern Black Hills on June 13–15, 1976, and many USGS streamflow-gaging stations in the Black Hills area recorded annual peak flows for 1976 associated with this storm. Sando and others (2008) provided peak-flow data (in table 8 of that report) for 70 streamflow-gaging stations along unregulated tributaries to the Cheyenne and Belle Fourche Rivers that were used in developing a mixed-population analysis for the Black Hills area. Of these 70 stations, 41 have peak-flow data for 1976, and the annual peak flow for 30 of the 41 stations occurred during June 15–17. This included all stations within and north of the Grace Coolidge and Battle Creek Basins. Noteworthy peak flows (table 9) in 1976 included 3,870 ft^3/s along Spearfish Creek at Spearfish (station 06431500), 6,780 ft^3/s farther downstream along the Redwater River above Belle Fourche (station 06433000), and 16,700 ft^3/s at Indian Creek near Arpan (station 06436700; map number 86 in fig. 5).

1981 through 1990

The northern Black Hills were very wet in May 1982 (table 3), and peak-of-record flows were recorded for stations along Horse Creek and the Belle Fourche River (table 9). Large peak flows also were recorded along Spearfish Creek, Redwater River, and Whitewood Creek. In general, precipitation was low in all Black Hills counties during the late 1980s (Driscoll and others, 2000), which corresponds with a general dearth of large peak flows during this period.

1991 through 2000

Widespread wet conditions prevailed throughout much of the Black Hills area for several years during the 1990s with sustained high flows occurring in many area streams (Driscoll and Carter, 2001). Driscoll and others (2000) provided a ranking (number 1 being the wettest of 68 years) for annual precipitation over the Black Hills area for water years 1931–98, and the wettest years include 1993 (6), 1995 (1), 1996 (8), 1997 (2), and 1998 (7). Most of the associated flooding during the 1990s generally was not especially severe, however. A peak-of-record flow of 8,270 ft^3/s occurred at station 06400875 (Horsehead Creek at Oelrichs; table 9; map number 14 in fig. 5) during 1991, before the onset of the especially wet conditions. Relatively large precipitation totals were recorded for many stations in May 1995 (table 3), and

Table 4. Summary of precipitation data for selected National Weather Service stations in the northern Black Hills for June 8–9, 1964.

[Data provided by Dennis Todey, South Dakota State Climatologist, written commun., 2010]

Date	Daily precipitation total (inches) for selected stations (station number)				
	Buskala Ranch (381246)	Dumont 2ENE (392409)	Deadwood (392207)	Lead (394834)	Spearfish (397882)
June 8, 1964	2.89	2.30	2.30	2.27	2.80
June 9, 1964	2.05	2.90	3.48	3.28	5.03

Figure 34. Photographs of damage in Deadwood, S. Dak., following a flood on May 15, 1965 (photographs courtesy of the City of Deadwood Historic Preservation Commission).

Figure 35. Photographs of damage in Rapid City, S. Dak., following the flood of June 9–10, 1972 (upper photograph courtesy of Norm Dewald; bottom photograph courtesy of the Rapid City Journal).

a strong storm system caused relatively large flows during May 8–10, 1995, for many streams in the central and northern Black Hills. Peak-of-record flows were recorded at 13 stations for these dates (between station numbers 06403300 (French Creek above Fairburn; map number 24 in fig. 5) and 06437020 (Bear Butte Creek near Deadwood; map number 90 in fig. 5), inclusive, in table 9).

Most of the entries in table 10 for 1996 and later are associated with the 13 storm events that were described in a previous section titled “A Climatology of Recent Large Black Hills Storms.” Entries with USGS peak-flow information are provided for five of the storm events; however, applicable peak-flow data are not available for the other eight storms. One of the most notable of these storms (storm number 2 in table 2) occurred June 14, 1996, and resulted in a peak flow of 16,900 ft^3/s (U.S. Geological Survey, 2009) along Alkali Creek (fig. 5, station 442205103073200) about 10 mi east of Sturgis. A smaller peak flow of 6,910 ft^3/s was recorded on May 30, 1996 (storm number 1 in table 2), for station 06408500 (Spring Creek near Hermosa; map number 43 in fig. 5); however, the only larger flow recorded for this station occurred June 10, 1972 (13,400 ft^3/s; table 9).

2001 through 2009

On August 17, 2007, substantial flooding occurred primarily in the Hermosa area, and flooding in the Piedmont area generally was of a localized nature, as stated previously in the section “The 2007 Storms and Flooding, with Comparisons to the 1972 Storm and Flooding.” A peak flow of 18,600 ft^3/s occurred on this date at station 06406000 (Battle Creek at Hermosa; map number 32 in fig. 5), which was second only to the 1972 peak flow of 21,400 ft^3/s (table 9).

The northern Black Hills experienced prolonged heavy rains in June 2008, which resulted in a peak-of-record flow (47,500 ft^3/s) at station 06438000 (Belle Fourche River near Elm Springs; table 9). A strong storm on July 7, 2008 (storm number 13 from table 2), caused flash flooding along upper Rapid Creek, and a peak flow of 1,640 ft^3/s was recorded on July 8 at station 06410500 (Rapid Creek above Pactola Reservoir at Silver City). A peak flow of 400 ft^3/s occurred at station 06408850 (Silver Creek near Rochford; map number 45 in fig. 5); the next largest peak flow for this station is only 14 ft^3/s (table 9).

Widespread wet conditions occurred again in 2009 in many parts of the northern Black Hills from melting of heavy snowpack and subsequent rains; however, annual peak flows for most streamflow-gaging stations were not exceptional. A peak flow of 29,500 ft^3/s was recorded on April 13, 2009 (U.S. Geological Survey, 2009) for the Belle Fourche River near Elm Springs (station 06438000).

Stream-Specific Storm and Flood Histories

Examination of histories of storm and flood events for specific streams provides an opportunity to evaluate previous events in a collective fashion. Within this section, histories are examined for selected streams (Fall River, Beaver, Rapid, Spearfish, and Whitewood Creeks) that provide particularly useful perspectives regarding peak-flow characteristics for the Black Hills area.

Fall River and Beaver Creek

Available peak-flow records for the Fall River and Beaver Creek (stations 06402000 and 06402500, respectively) extend back to 1938 (table 9) and are among the longest records available for the Black Hills area. Exceptionally large peak flows (13,100 and 11,700 ft^3/s, respectively) were recorded at both stations on September 4, 1938, during the first year of gage operation. Flooding reported as “the worst in 35 years” also occurred on the same date farther north along Lame Johnny Creek (table 10; article on September 24, 1938, in the Rapid City Journal), and collectively this information provides an indication of an exceptionally strong storm system with large areal extent.

The Fall River and Beaver Creek had rich flood histories prior to the availability of the systematic peak-flow records. For Beaver Creek, a reported stage for an unknown date in 1927 is higher than that of the 1938 peak stage, and there are various other historical accounts of substantial flooding (table 10). Four moderately large peak flows (between 1,000 and 3,000 ft^3/s) occurred between 1947 and 1966 on Beaver Creek; however, peak flows exceeding 1,000 ft^3/s have not been recorded since 1966 (U.S. Geological Survey, 2009). A trend analysis of the log of peak-flow values for Beaver Creek near Buffalo Gap (station 06402500; period of record 1938–2009) was performed in S-PLUS (TIBCO Software, Inc., 2008) using the Kendall’s tau with the Sen estimate of slope function (Slack and others, 2003), where Sen’s slope is the median of all slopes of possible pairs of data (Helsel and Hirsch, 1992). A statistically significant downward trend was indicated by a probability value (p-value) of 0.0388 using a significance criterion (α) of 0.05. The probability of this trend resulting strictly from chance is only 3.88 percent. However, no known changes in land use have occurred within the basin to which this downward trend in peak-flow characteristics can be attributed; thus, an absence of exceptionally strong rain-producing storms since 1966 is hypothesized as the primary cause.

Large uncertainty commonly exists regarding magnitudes of large flows before the availability of systematic peak-flow records, as exemplified by conflicting historical information regarding the Fall River. Design documents for the Cold Brook and Cottonwood Springs Reservoirs (U.S. Army Corps of Engineers, 1950, 1966) provide similar, but not identical, flood histories for the Fall River. A flood of June 17–18, 1937, was reported as slightly larger than the flood of September 4, 1938, which is the largest flood (13,100 ft^3/s) of the systematic record for station 06402000 (Fall River at Hot Springs; table 9). Details provided by the Hot Springs Weekly Star (September 6, 1938) indicate that the 1938 water level exceeded that of 1937 by about 1 ft in Hot Springs; however, farther down the canyon, the 1937 water level exceeded that of 1938 by about 3 ft. Unpublished USGS documentation (R.E. West, U.S. Geological Survey, written commun., 1954) that was compiled after the earliest U.S. Army Corps of Engineers (1950) document indicates that (1) the 1938 stage exceeded the 1937 stage by 4.4 ft at the location and datum of where the USGS streamflow-gaging station was established in 1938; (2) indirect determinations of the 1937 peak flow were made by the U.S. Army Corps of Engineers (16,000 ft^3/s) and the Bureau of Reclamation (8,000 ft^3/s), which indicates large uncertainty based on the difference between the determinations; and (3) large uncertainty also exists in the USGS peak-flow determination for 1938, for which the final value of 13,100 ft^3/s was revised in 1954 from an original value of 8,400 ft^3/s. In spite of the somewhat conflicting reports, consideration of the collective information indicates that (1) the floods of 1937 and 1938 were both very large and probably produced substantially different peak stages at different locations along the Fall River; (2) the stage for the 1938 flood probably exceeded that of the 1937 flood at the location of the USGS streamflow-gaging station; and (3) the stage for the 1937 flood may well have exceeded that of the 1938 flood downstream from the station. The relative magnitude of the 1937 storm is unknown, but may have been smaller than the 1938 storm, which also caused large flows farther north along Beaver and Lame Johnny Creeks.

In the U.S. Army Corps of Engineers (1950, 1966) design documents, floods of 1897, 1905, and 1908 were reported as approximately equal to each other, and all were about 4 ft higher than the flood of 1937. A flood of August 27, 1884, also was reported as the largest known flood in the history of the town, with a stage that exceeded the 1937 stage by about 7 ft (3 ft higher than the 1897, 1905, and 1908 floods). In an article on June 5, 1908, the Hot Springs Weekly Star provided a report that is somewhat unclear, but is interpreted to mean that the 1908 flood waters were about 3 ft lower than the 1897 and 1905 high-water marks. Many details regarding the historical flood accounts will never be known with certainty; however, obtaining additional information regarding previous large floods would be useful.

Construction of the two flood-control reservoirs (Cold Brook in 1952 and Cottonwood Springs in 1969) precludes a statistical analysis of trends for the Fall River. However, examination of available peak-flow records indicates a distinctive downward trend, beyond what turns out to be a negligible effect from the reservoirs on the occurrence of especially large peak flows. Table 9 shows the five largest peak-flow values for station 06402000 (Fall River at Hot Springs) for 1938–52, when the Fall River was completely unregulated; and also for 1953–2009, which includes periods of regulation by one reservoir (1953–69) and both reservoirs (1970–2009). Substantially large inflows have not occurred to either reservoir since construction (Tim Temeyer, U.S. Army Corps of Engineers, oral commun., 2009), which can be ascertained by examination of reservoir inflow records (available only as daily mean values) provided by the U.S. Army Corps of Engineers (Tim Temeyer, written commun., 2009) that are summarized in table 5. The two largest peak flows recorded for station 06402000 (Fall River at Hot Springs) since regulation began in 1952 are 2,060 and 1,590 ft^3/s (U.S. Geological Survey, 2009), for which daily mean flow values are 164 and 64 ft^3/s, respectively (U.S. Geological Survey, 2010c). Daily mean inflows for Cold Brook Reservoir account for only about 40 and 14 percent, respectively, of the corresponding daily mean values for station 06402000. Cottonwood Springs Reservoir was not constructed yet in 1961 and also had no effect (zero inflow) on the downstream peak flow for 2005. The largest daily mean inflow for the period of record for each reservoir also is shown in table 5 (74 ft^3/s for Cold Brook Reservoir in 1962 and 52 ft^3/s for Cottonwood Springs Reservoir in 1993), along with corresponding streamflow data for station 06402000. These data indicate that in the absence of the two flood control reservoirs, the largest peak flow for the Fall River during the 57 years of post-regulation record (1953–2009) probably would have been considerably smaller than the second (8,300 ft^3/s in 1947) and third largest peak flows (4,700 ft^3/s in 1941) during the 15 years of pre-regulation record (1938–52) (table 9). Notwithstanding some of the uncertainties regarding historical flood events, it is apparent that a series of numerous large flood events occurred along the Fall River before construction of the two flood-control reservoirs, which has been coincidentally followed in the post-construction period by a dearth of especially large storm events with capabilities for generating large floods.

Rapid Creek

Flood histories for two reaches of Rapid Creek are examined within this section. Histories are examined for lower Rapid Creek, which is considered herein to be that part of the drainage basin downstream from Pactola Dam (fig. 5), and for upper Rapid Creek, which is upstream from Pactola Reservoir.

Rapid Creek is one of the largest drainage basins in the Black Hills area, and Rapid City developed as a population center early in the settlement of the area, with extensive utilization and management of water resources. Thus, more streamflow-gaging stations have been operated within the Rapid Creek Basin than in any other drainage basins in the area (Miller and Driscoll, 1998). Peak-flow records dating back to the 1940s are available for several streamflow-gaging stations; however, earlier records are sparse (table 9).

Table 5. Summary of selected peak-flow data for streamflow-gaging station 06402000 (Fall River at Hot Springs, S. Dak.) and mean daily inflow values for Cold Brook and Cottonwood Springs Reservoirs.

[Daily mean inflow values provided by the U.S. Army Corps of Engineers; USGS, U.S. Geological Survey; NA, not applicable]

Date	USGS station 06402000		Daily mean inflow values	
	Peak flow	Daily mean flow	Cold Brook Reservoir	Cottonwood Springs Reservoir
July 7, 1961	2,060	164	65	NA
July 13, 1962	392	36	74	NA
August 19, 1993	354	34	7.5	52
August 12, 2005	1,590	64	9.2	0

Lower Rapid Creek

The longest peak-flow records available for lower Rapid Creek are for station 06414000 (Rapid Creek at Rapid City), which has records for 1905–06 and 1943–2009 (table 9). Peak flows along Rapid Creek are regulated by two large reservoirs constructed by the Bureau of Reclamation. Storage in Deerfield Reservoir began in December 1945, and storage in Pactola Reservoir began in August 1956 (Sando and others, 2008). Regulated drainage areas for the Deerfield and Pactola Reservoirs are 92.4 and 322 mi^2, respectively. Inspection of data for streamflow-gaging stations located just upstream from the two reservoirs (table 9) indicates that the reservoirs have not substantially affected the history of especially large peak flows for lower Rapid Creek. The largest recorded flow for Rapid Creek (50,000 ft^3/s) occurred at station 06414000 on June 9, 1972, and is about 15 times larger than the next largest recorded peak flow. The annual peak flow for 1972 for a station just upstream from Pactola Reservoir (station 06410500) was 252 ft^3/s and was not associated with the storm of June 9–10, 1972. This station has records for 1954–2009 and the peak-of-record flow is 2,060 ft^3/s.

A few peak-flow records before construction of Pactola Dam are available for two stations located downstream from the dam and upstream from Rapid City (table 9). Stations 06411500 (Rapid Creek below Pactola Dam) and 06412000 (Rapid Creek near Big Bend) collectively provide records for 1915–17 and 1929–42. Collectively, the largest recorded peak flow (1,570 ft^3/s) occurred on May 24, 1933, and is coincident with widespread flooding throughout much of the Black Hills area (table 10). On June 26, 1915, a maximum daily mean flow of 616 ft^3/s was recorded for station 06412000. The instantaneous peak flow is not known, but probably is similar to the 1933 peak flow of 1,570 ft^3/s.

Miller (1986) summarized four relatively large floods for Rapid Creek at Rapid City that were previously reported by the U.S. Army Corps of Engineers (1973). The four floods are listed in table 10 and consist of 7,500 ft^3/s (June 10–11, 1878), 8,400 ft^3/s (May 17, 1883), 13,000 ft^3/s (June 12–13, 1907), and 8,000 ft^3/s (May 11–12, 1920). The 1878 flood was one of four floods reported for the year and the 1883 flood was coincident with widespread flooding throughout the Black Hills area. The 1907 flood followed wet antecedent conditions in the area and was associated with what is believed to have been an anomalously strong storm system that caused exceptionally large peak flows in many area streams. A 1968 flood inundation map for the Rapid City area (City of Rapid City, 1968) shows that the area affected by the 1907 flooding was more extensive than for subsequent floods of 1920, 1927, 1949, 1952, and 1962. The 1920 flood was associated with substantial widespread flooding throughout the Black Hills and western South Dakota. Damage to homes, roads, railroads, and other infrastructure along Rapid Creek was severe.

During 1962, relatively severe storms and flooding occurred in the Rapid City area on the night of June 15, with less severe storms and flooding the following night. These thunderstorms were associated with a large low pressure system across the southwestern United States, and caused exceptionally large peak flows for several streams (tables 9 and 10). The largest peak flow along Rapid Creek during 1962 (3,300 ft^3/s) occurred several weeks later on July 13 at station 06414000, and an exceptional peak flow of 2,920 ft^3/s occurred in Cleghorn Canyon at station 440325103182500 (fig. 5; drainage area = 7.0 mi^2) in western Rapid City.

The storms and flooding of June 9–10, 1972, were especially severe west of Rapid City, although no severe hail, wind, or tornadoes were reported. Peak-of-record flows were recorded at three streamflow-gaging stations on lower Rapid Creek during this flood (table 9): 31,200 ft^3/s at station 06412500 (Rapid Creek above Canyon Lake near Rapid City), 50,000 ft^3/s at station 06414000 (Rapid Creek at Rapid City), and 7,320 ft^3/s for station 06421500 (Rapid Creek near Farmingdale (map numbers 52, 54, and 55 in fig. 5, respectively).

Upper Rapid Creek

Sando and others (2008) identified "suppressed" peak-flow characteristics for the limestone headwater hydrogeologic setting, which comprises a large part of the headwaters of upper Rapid Creek (fig. 5), as described in a previous section titled “Physiographic Factors.” Various climatological factors indicate reduced potential for generation of exceptionally strong rain-producing storms in the high-altitude parts of the basin, relative to lower Rapid Creek, as described in a previous section titled “Climatological Factors Affecting Thunderstorm Generation for the Black Hills Area.” Thus, examination of the peak-flow history for upper Rapid Creek relative to these factors is especially useful.

Peak-flow records for station 06410500 (Rapid Creek above Pactola Reservoir) are affected by storage within Deerfield Reservoir, which has regulated about one-third of the drainage area since December 1945. However, examination of peak-flow data (table 9) for this station and station 06409000 (Castle Creek above Deerfield Reservoir; map number 47 in fig. 5) indicates that (1) especially large peak flows have not been recorded for either station; and (2) Deerfield Reservoir has not prevented the occurrence of especially large peak flows for station 06410500. The peak-of-record flow for station 06409000 (1,120 ft^3/s) occurred on May 22, 1952, before construction of Pactola Reservoir and the period of record for station 06410500. Moderately large peak flows (approximately 2,100 to 2,600 ft^3/s) occurred within the next day at two streamflow-gaging stations along lower Rapid Creek (stations 06411500 and 06412500) and coincided with heavy rains in other parts of the northern Black Hills (National Oceanic and Atmospheric Administration, 2008). The peak-of-record flow for station 06410500 (2,060 ft^3/s) occurred on May 15, 1965, about 1 month before the annual peak flow for station 06409000 (906 ft^3/s on June 17, 1965) (table 9).

Figure 36 shows annual peak flows for stations 06409000 and 06410500, which illustrate distinctive differences in peak-flow characteristics. The 79.3-mi^2 drainage area for the Castle Creek station (06409000) is primarily within the limestone headwater hydrogeologic setting, and the peak-flow record is dominated by relatively small flows, many of which are only slightly larger than the relatively large base flow for this station (Driscoll and Carter, 2001). In comparison, the peak-flow record for station 06410500 indicates larger variability and larger peak flows, relative to drainage area, which is typical of the crystalline core hydrogeologic setting (Sando and others, 2008) that comprises most of the drainage area downstream from Deerfield Reservoir. For station 06410500, the mean annual peak flow relative to the unregulated part of the drainage area (203 mi^2) is 1.81 cubic feet per second per square mile ($ft^3/s/mi^2$), compared with 1.23 $ft^3/s/mi^2$ for station 06409000 for the period of concurrent record (1954–2009).

Two of the largest peak flows recorded for station 06410500 (Rapid Creek above Pactola Reservoir) occurred in July (table 9), which is somewhat later than is typical for most stations in the Black Hills. In contrast, of the largest peak flows recorded for Castle Creek (station 06409000), only one occurred in June (1965) and was coincident with widespread flooding throughout the central and northern Black Hills (table 10) from heavy rains and snowmelt (National Oceanic and Atmospheric Administration, 2008). All of the other largest peak flows for Castle Creek have occurred during March through May and are indicative of snowmelt or prolonged wet conditions, as opposed to primary effects from strong individual storms. Historical accounts exist for floods along Castle Creek for May 17, 1883, and June 17, 1885 (table 10). The location of the 1883 flood, relative to the streamflow-gaging station, cannot be determined from

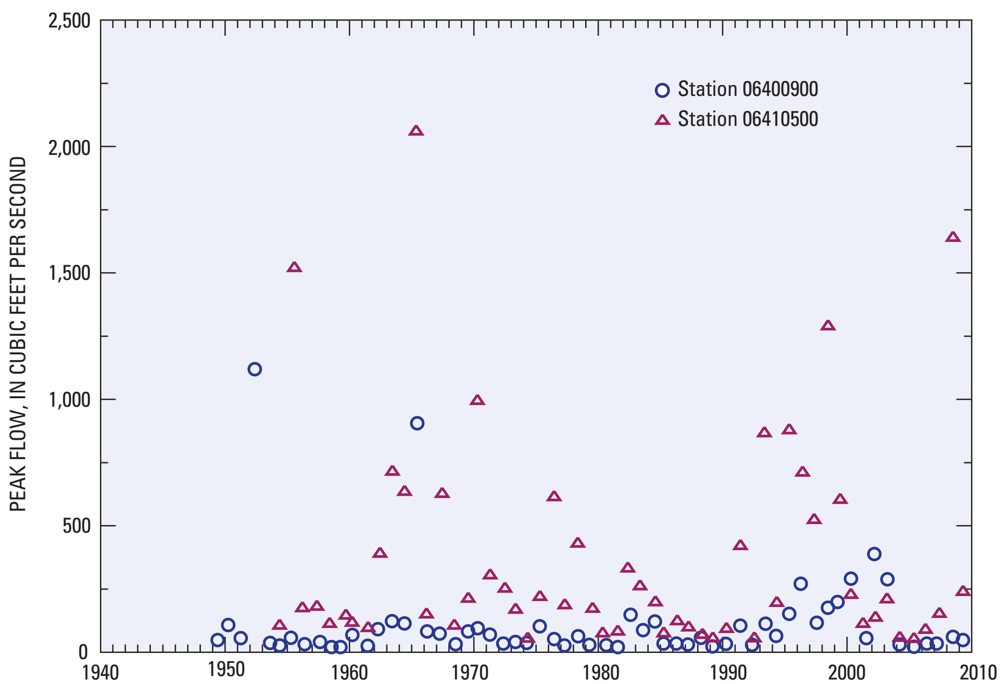


Figure 36. Annual peak flows for streamflow-gaging stations 06409000 (Castle Creek above Deerfield Reservoir near Hill City, S. Dak.) and 06410500 (Rapid Creek above Pactola Reservoir at Silver City, S. Dak.).

the short news account; however, it can be determined that the 1885 flooding caused damage along lower Castle Creek, upstream from the confluence with Rapid Creek.

A peak flow of 1,640 ft³/s was recorded for station 06410500 on July 7, 2008 (table 9), and resulted from a series of strong rain-producing thunderstorms that began late in the afternoon of the previous day and is listed as storm event number 13 in table 2. Precipitation totals ranged from about 1.5 to 5.5 in., and the duration was about 1.5 to 2 hours (fig. 37), as reported by several area residents in a survey conducted by NWS staff (Melissa Smith, National Weather Service, written commun., 2008). Precipitation totals were much smaller for NWS cooperative stations in the surrounding area, as shown in table 6. Antecedent moisture conditions may have contributed somewhat to generation of storm runoff, as showers had been prevalent throughout the area for July 2–4, with the heaviest reported amount of 0.80 in. for July 3 in Newcastle, Wyo. (table 6), which is about 35 mi southwest of Rochford.

A peak flow of 400 ft³/s from the July 6–7, 2008, storm occurred along Silver Creek (station 06408850; drainage area of 6.24 mi²; fig. 37) near the eastern extent of where heavy precipitation (fig. 16) and associated runoff occurred. This peak flow is about 30 times larger than the next largest peak flow for this station, for which other records are available only for 1969–79 (table 9). Silver Creek is a tributary to Rapid Creek about 5 mi northwest of the confluence with Castle Creek and about 10 mi upstream from station 06410500. In many parts of this long reach, Rapid Creek has a fairly well-developed alluvial floodplain with relatively large

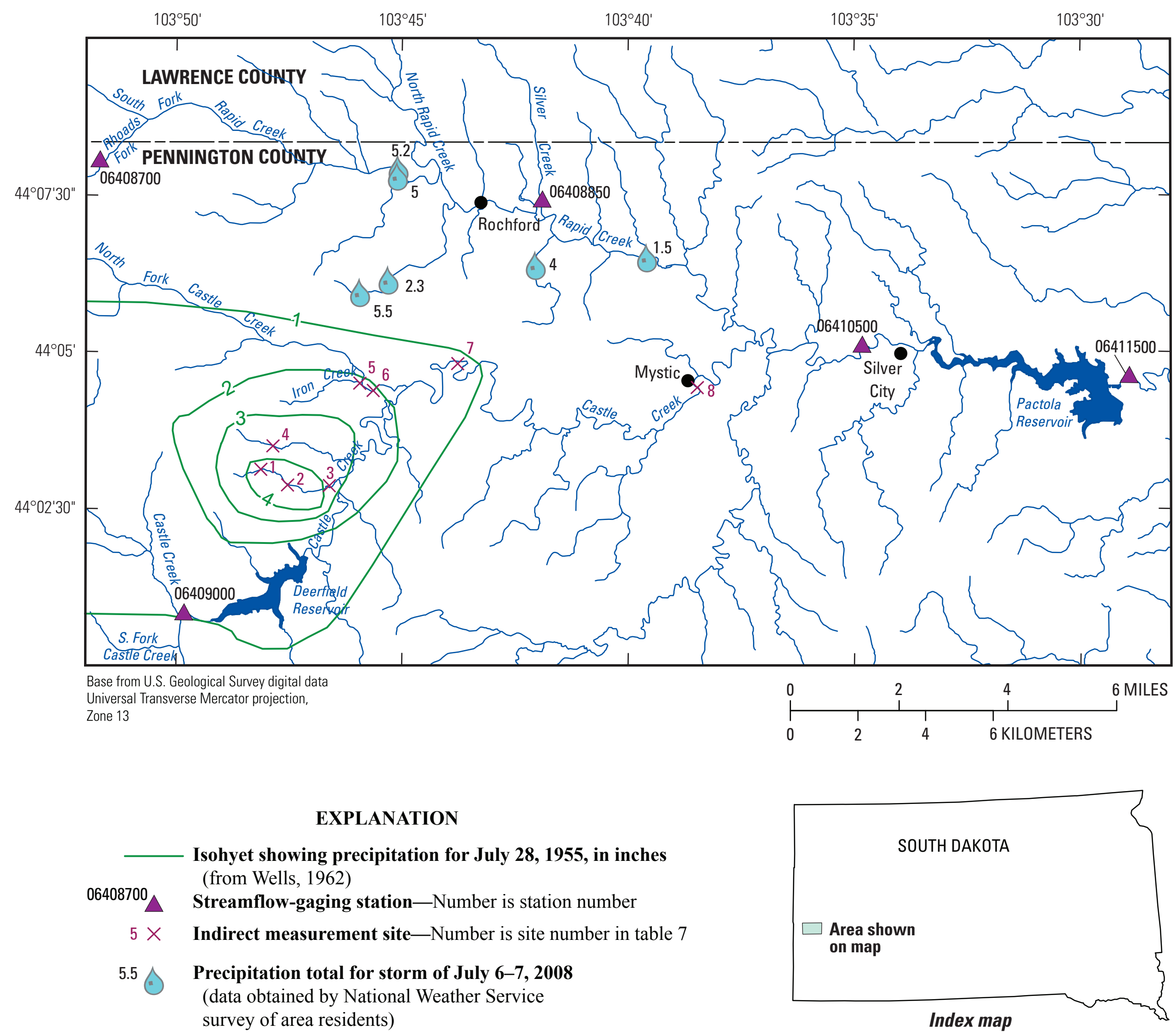


Figure 37. Locations of sites for peak-flow determinations and isohyets for storm of July 28, 1955, and precipitation totals for storm of July 6–7, 2008, in the upper Rapid Creek drainage basin.

storage capacity (fig. 38); thus, substantial attenuation probably occurred as upstream flows were routed downstream to station 06410500.

Evidence of heavy runoff in many other tributaries to Rapid Creek upstream from Silver Creek was observed by the lead author during field inspections on July 7 and 9, 2008 (fig. 39). Runoff was minimal within Rhoads Fork (a western headwater tributary to Rapid Creek shown in figure 37) as indicated by visual observation and a recorded annual peak flow for July 6 of only 15 ft^3/s for station 06408700 (Rhoads Fork near Rochford; drainage area = 7.82 mi^2). Visual evidence indicated that runoff increased markedly in a downstream direction from Rhoads Fork, which is consistent with radar imagery for the storm (fig. 16). Collective evidence indicated that lack of substantial runoff in Rhoads Fork resulted from lack of substantial precipitation, as opposed to effects of physiographic factors (topography and geology). This is the third largest peak flow for this station (table 9), which has 28 years of peak-flow record dating back to 1982. This station typifies suppressed peak-flow characteristics for the limestone headwater hydrogeologic setting (Sando and others, 2008), as shown by the comparison between annual mean flows and annual peak flows that is presented in figure 40.

A storm that occurred on July 28, 1955 (table 10) probably was of a generally similar scale to that of the 2008 storm. Wells (1962) reported that “as much as 5 inches of rain fell in 2 hours in the storm center 6.5 miles southwest of Rochford,” and provided an isohyetal map (reproduced in figure 37) that was “based on data from Weather Bureau and Forest Service precipitation stations, from unofficial rain gages, and from information given by residents.” This storm caused high flows along Castle Creek downstream from Deerfield Reservoir and caused the third largest annual peak flow (1,520 ft^3/s) for station 06410500 (Rapid Creek above Pactola Reservoir; table 9). Indirect determinations of peak flow were obtained by USGS for eight other sites in the Castle Creek Basin upstream from the confluence with Rapid Creek (fig. 37, table 7).

The 1955 event is noteworthy in that (1) the largest peak flows (sites 3, 6, and 7) are by far the largest flows that have been documented within upper Rapid Creek; and (2) the peak flows for sites 3, 5, and 7 were considered by Crippen and Bue (1977) in developing a regional envelope curve. Those three peak-flow values are shown in figure 12. Costa and Jarrett (2008) evaluated the validity of indirect determinations of peak flow for extraordinary floods in the United States, and they reported a sound overall approach for site 4, which was one of 30 floods considered in development of a national envelope curve. Furthermore, measurements for all eight of the Castle Creek sites were closely scrutinized as part of this effort, with no identification of problems.

Examination of peak-flow rates expressed as inches of runoff per hour (in/h) relative to total drainage area (table 7) indicates that for site 4, the runoff rate largely exceeded the maximum precipitation rate of about 2.5 in/h reported by Wells (1962). This is not implausible for the small drainage area of 0.192 mi^2 (equivalent to 12.3 acres) and because extremely high precipitation rates are not uncommon for small areas within high-intensity storms. A more “outstanding” flow rate actually was for site 3, for which an equivalent runoff rate of 3.96 in/h is calculated for a much larger drainage area of 2.20 mi^2. Flow rates normalized relative to drainage area raised to the 0.6 power, which was the method used by Sando and others (2008) for normalizing peak flow rates for the Black Hills area, are shown in table 7. The normalized flow rate for site 3 is about 1.5 times as large as the next largest normalized value (site 5). The associated peak-flow value for site 3 plots close to the regional envelope curve (fig. 12), and the drainage area for this site is about two to three times larger than the areas associated with three peak-flow values for August 17, 2007 (table 1) that also plot close to the regional envelope curve. The equivalent runoff rate of 0.40 in/h for site 7 is small, relative to sites 1 through 5, which have much smaller drainage areas; however, the peak flow of 8,500 ft^3/s (table 7) is quite large for the unregulated drainage area of

Table 6. Daily precipitation amounts for selected precipitation stations for July 1–7, 2008.

[Data from South Dakota State University, 2010. NWS, National Weather Service]

Date in July 2008	Daily precipitation total (inches) for selected NWS stations (station number)					
	Deadwood 2NE (392209)	Hill City (393868)	Lead (394834)	Mt. Rushmore National Memorial (395870)	Newcastle (486660)	Pactola Dam (396427)
1	0.00	0.00	0.00	0.00	0.00	0.00
2	.00	.10	.00	.07	.02	.00
3	.03	.13	.03	.07	.80	.07
4	.50	.00	.06	.00	.00	.00
5	.00	.00	.00	.00	.00	.00
6	.31	.00	.00	.00	.25	.69
7	.15	.53	.25	.50	.70	.45

32.6 mi^2 and is the largest peak flow measured for a drainage area of this size at a comparable altitude for the Black Hills area.

The western extent for the 1955 and 2008 storm events in upper Rapid Creek generally was just east of a pronounced escarpment (fig. 41) that constitutes the eastern extent of the Limestone Plateau area (fig. 5) and would correspond with a horizontal distance of about 95 to 100 mi on the X-axis of figure 13*B*. The escarpment generally aligns with the major axis of the Black Hills (fig. 15) and is essentially the westernmost orographic barrier to westerly (up-slope) air flow that could be a factor in genesis of most large-scale convective storms. Castle Creek (fig. 5) is incised into the Limestone Plateau (draining to the east, but west of the escarpment shown on figure 41), which could contribute to limited potential for development of large-scale convective storms within the Castle Creek Basin.

Consideration of various peak-flow information can be used to conclude that there have been no exceptionally large peak flows at the location of station 06410500 (Rapid Creek above Pactola Reservoir) since 1920. The available peak-flow records for station 06410500, which begin in 1954, essentially can be supplemented using available records for pre-construction periods of 1929–42 and 1947–53 for station 06411500 (Rapid Creek below Pactola Dam). The largest peak flow for station 06411500 was 2,170 ft^3/s in 1952 (table 9). The associated peak flow at the location of the upstream station (station 06410500) might have been somewhat larger than the peak-of-record flow (2,060 ft^3/s in 1965), but would not have been exceptional. Similarly, a peak flow of 1,540 ft^3/s on May 24, 1933, at station 06411500 resulted from a strong storm reported by the Rapid City Journal (May 23, 1933); however, the flow at location of station 06410500 probably was not exceptional. Records are available for 1943–46 for station 06414000 (Rapid Creek at Rapid City) and none of the annual peak flows exceed 1,000 ft^3/s (U.S. Geological Survey, 2009). Substantially larger flows at the location of the upstream station may have occurred during at least several

Figure 38. Photograph showing floodplain storage potential along a reach of Rapid Creek downstream from Silver Creek (photograph courtesy of Dan Driscoll).

Figure 39. Photograph showing evidence of heavy runoff from storm of July 6–7, 2008, in the upper Rapid Creek drainage basin (photograph courtesy of Dan Driscoll).

Figure 40. Annual mean and annual peak flows for streamflow-gaging station 06408700 (Rhoads Fork near Rochford, S. Dak.).

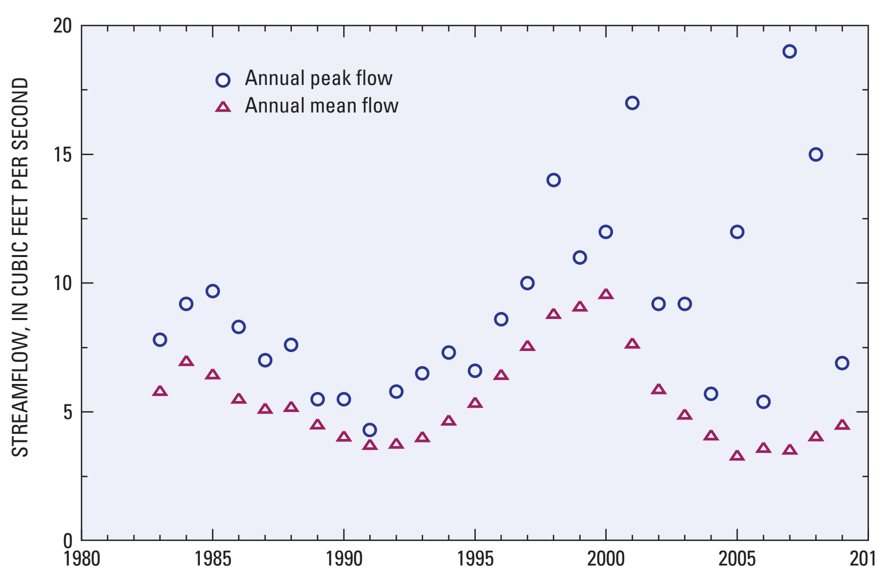


Table 7. Summary of peak-flow determinations for flooding of July 28, 1955.

[Modified from Wells (1962). mi^2, square mile; ft^3/s, cubic feet per second; in/h, flow rate expressed as inches of runoff per hour from entire drainage area; normalized, normalized by dividing by drainage area raised to the 0.6 power]

Site number (fig. 37)	Stream and place of determination	Drainage area (mi^2)	Peak flow		
			ft^3/s	in/h	Normalized
1	Castle Creek tributary near Rochford, S. Dak.	1.25	2,190	2.71	1,920
2	Castle Creek tributary near Rochford, S. Dak.	1.75	1,720	1.52	1,230
3	Castle Creek tributary near Rochford, S. Dak.	2.20	5,620	3.96	3,500
4	Castle Creek tributary near Rochford, S. Dak.	.0192	98.9	7.98	1,060
5	Iron Creek near Rochford, S. Dak.	1.25	2,410	2.99	2,110
6	North Fork Castle Creek near Rochford, S. Dak.	14.6	4,490	.48	900
7	Castle Creek near Rochford, S. Dak.	[1]32.6	8,500	.40	1,050
8	Castle Creek at Mystic, S. Dak.	52.2	2,360	.07	220
06410500	Rapid Creek above Pactola Reservoir at Silver City, S. Dak.	[1]196	1,520	.01	64.0

[1]Excludes drainage area upstream from Deerfield Dam. During flood, flow of Castle Creek from Deerfield Dam was 3 ft^3/s (Wells, 1962).

Figure 41. Three-dimensional depiction (viewed south to north) of the Black Hills (from Newton and Jenney, 1880). The limestone plateau area is the low-relief area west of the generally north-south trending escarpment along the major axis of the Black Hills.

years with large flood events prior to 1929, including some years for which reports of rail damage extended to parts of upper Rapid Creek (table 10). The largest potential for large flows probably was during four years (1878, 1883, 1907, and 1920) for which especially large floods in Rapid City (7,500, 8,400, 13,000, and 8,000 ft^3/s, respectively) were reported by the U.S. Army Corps of Engineers (1973). Examination of all available peak-flow data and historical flood accounts further indicates that even in the absence of the two main-stem dams (Deerfield and Pactola), none of these four aforementioned peak flows would have been exceeded in the Rapid City area during 1921–42, during which time peak-flow records were sparse or non-existent.

Spearfish and Whitewood Creeks

Examination of peak-flow histories for Spearfish and Whitewood Creeks provides useful insights regarding peak-flow trends and the effects of hydrogeologic settings on peak-flow characteristics in the northern Black Hills. Peak-flow records are summarized in table 9 for five streamflow-gaging stations within the Whitewood Creek Basin, which heads primarily within the crystalline core hydrogeologic setting (fig. 5). Figure 42 shows annual peak flows for three of these stations (those farthest downstream, with drainage areas ranging from 56.7 to 102 mi^2) plotted with data for station 06431500 (Spearfish Creek at Spearfish), for which the drainage area (165 mi^2) is considerably larger and is primarily within the limestone headwater hydrogeologic setting.

Of the four largest peak flows for Spearfish Creek, all exceeded 3,000 ft^3/s (fig. 42), and all occurred before the availability of peak-flow records for Whitewood Creek. As described in a previous section titled “1961 through 1970,” the 1964 peak flow resulted from a localized storm system during a relatively low to moderate flow period, as opposed to prolonged precipitation as a primary cause for the other three large flow events. During periods of concurrent record between Spearfish Creek and Whitewood Creek, the two largest peak flows for Spearfish Creek (2,110 ft^3/s on May 22, 1982, and 1,900 ft^3/s on May 8, 1995) occurred during months with especially large precipitation totals (table 3) and were exceeded by about 1,000–2,000 ft^3/s by peak flows along Whitewood Creek that occurred on the same, or nearly the same dates. In contrast, relatively small peak flows occurred along Spearfish Creek in 1986, 1991, 1993, and 1999 and were exceeded by an order of magnitude, or larger, by peak flows that occurred along Whitewood Creek during various dates unrelated to the dates for Spearfish Creek (U.S. Geological Survey, 2009).

These datasets clearly illustrate the suppressed nature of peak-flow characteristics for Spearfish Creek, relative to Whitewood Creek, which given the proximity of the drainage areas (fig. 5), certainly must be attributed at least partially to hydrogeologic factors, rather than solely to the effect of storm patterns. This does not necessarily indicate, however, that distinctive differences in storm patterns may not exist for the Spearfish and Whitewood Creek drainage basins. Spearfish Creek generally lies along the major axis of the Black Hills (fig. 13*A*), and the basin headwaters may be less subject to strong individual storms than Whitewood Creek because of the typical eastward motion of thunderstorms, as described in a previous section titled “Climatological Factors Affecting Thunderstorm Generation for the Black Hills Area.”

A possible downward trend in peak-flow values for Spearfish Creek is indicated by figure 42; however, a trend analysis using the Kendall’s tau with the Sen estimate of slope function (Slack and others, 2003) in S-PLUS (TIBCO Software, Inc., 2008), indicates statistical non-significance (p-values of 0.144 and 0.262, respectively) for periods of record including and excluding 1904. The trend analysis does not consider any of several relatively large peak flows that have been documented in news accounts (table 10) for which peak-flow magnitudes cannot be estimated. Substantial flood damage occurred in Spearfish in May 1883, coincident with severe flooding along Whitewood Creek. Damage in the Spearfish area probably was less extensive in June 1890, which was associated with widespread flooding in the northern Black Hills. Flooding that occurred July 30, 1895, was reported as the highest water level since 1883. A strong storm system on June 8, 1909, caused flooding in Spearfish; however, flooding probably was more severe on May 23, 1933, based on a May 31, 1946, article in the Lead Call that referred to damage to the railroad bed in Spearfish Canyon in 1933. In that article, Spearfish Creek was reported as being as high in May 1946 as in 1933.

In light of the comparison between peak flows for Spearfish and Whitewood Creeks, it probably would be reasonable to hypothesize that recorded peak flows in the short available period of record for Whitewood Creek have been exceeded by several of the flood events chronicled in table 10. Most of the historical accounts of flooding for Whitewood Creek are for upstream reaches in the Deadwood and Lead areas. One of the more outstanding flood events for Whitewood Creek, however, may be that of June 15–16, 1962, when strong thunderstorms caused severe flooding along the northeastern flank of the Black Hills.

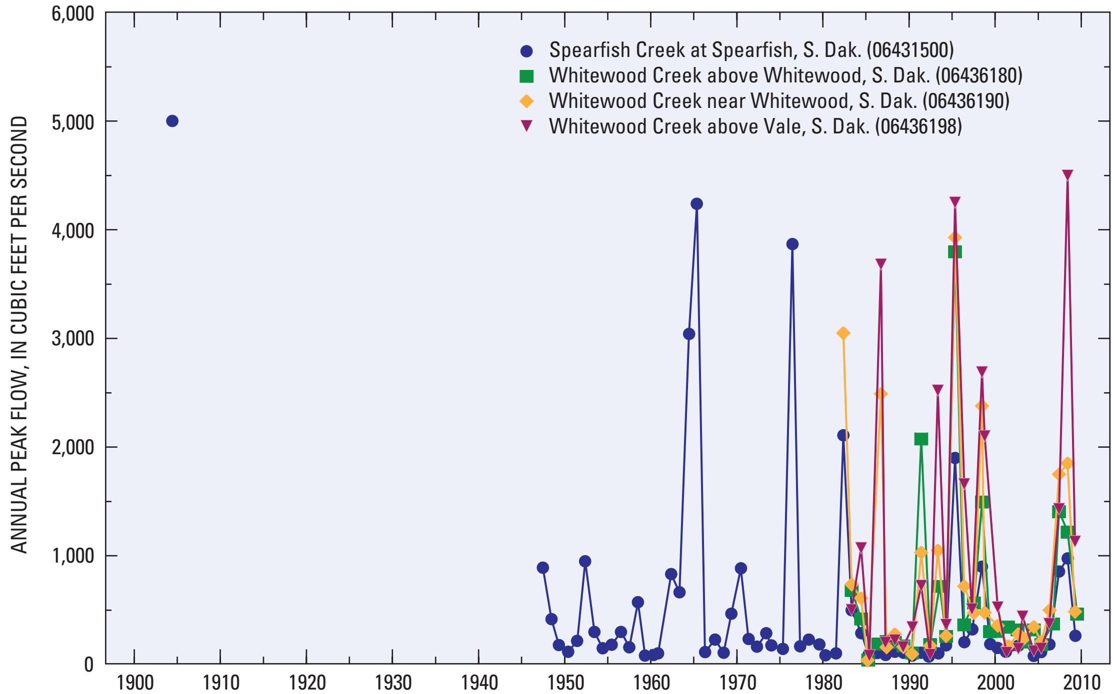


Figure 42. Time series of annual peak flows for one streamflow-gaging station on Spearfish Creek and three stations along Whitewood Creek.

Synopsis and Hydrologic Implications of Historical Storm and Flood Events

This section provides a brief synopsis of the most noteworthy storm and flood events for the Black Hills area, which provides an opportunity to examine some of the most substantial events in a collective context. Associated hydrologic implications also are described.

Chronological Synopsis

The year 1883 was a year of benchmark flooding, with large flood events in the Deadwood and Spearfish areas, substantial flooding in other parts of the northern Black Hills, and fairly widespread flooding throughout much of the Black Hills area. The year 1890 also is referred to as somewhat of a benchmark year because of widespread flooding; however, historical accounts for 1883 are much more abundant than for 1890, which probably indicates more severe flooding in 1883.

A large flood reported for the Fall River on August 27, 1884, was the first, and perhaps the largest, of many large floods for the Hot Springs area, based on documentation provided by the U.S. Army Corps of Engineers (1959, 1966). Other relatively large floods occurred in the Hot Springs area in 1800s including 1891, 1895, 1896, and 1897.

On June 5, 1904, a peak flow of 5,000 ft^3/s was recorded along Spearfish Creek at Spearfish (station 06431500), which through 2009 remains as the peak-of-record flow for this station (table 9). A large flow of 8,050 ft^3/s was recorded farther downstream along the Redwater River (station 06434000; table 10) and indicates that heavy precipitation probably occurred over a widespread area.

The year 1907 was noteworthy, with wet antecedent conditions and widespread flooding that persisted through at least the end of May. These conditions may have exacerbated severe and large-scale flooding that developed on June 12 as part of a larger-scale system moving in from Montana and Wyoming. Flooding was especially severe in Stagebarn Canyon, with severe flooding also reported in drainages to the north and a 24-hour rainfall total of 7.1 in. measured at Ft. Meade (table 10; Miller, 1986). Widespread flooding and damage also occurred throughout much of the southern Black Hills. The U.S. Army Corps of Engineers (1973) estimated a peak flow of 13,000 ft^3/s for Rapid Creek, and a peak flow of 16,000 ft^3/s occurred along Boxelder Creek near Nemo (station 06422500). Quantitative information for 1907 is insufficient for detailed comparisons between the storm and flood events of 1907, and those of 1972 and more recent years. However, quantitative and historical information for the 1907 events is more abundant than for other events in the area, and the collective information indicates that the 1907 events are among the most severe that have been experienced in the Black Hills area since European settlement.

On May 31, 1908, Hot Springs experienced flooding from heavy rainfall that was exacerbated by saturated conditions from prolonged rains of the previous week. On June 8, 1909, a strong storm system caused flooding in Spearfish and produced heavy rainfall and damage along the eastern fringe of the Black Hills and extended at least as far to the southeast as New Underwood, where especially severe storm effects were reported.

In 1915, the southern part of the Black Hills experienced widespread wet conditions, with Horsehead Creek experiencing the worst known flooding to date. The year 1920 may constitute the most substantial and widespread flood conditions that have occurred since European settlement in western South Dakota and the Black Hills area, with substantial flooding on the Belle Fourche, Cheyenne, Bad, and White Rivers. Flooding also was documented for Hat Creek in the southern Black Hills, Rapid and Boxelder Creeks in the central part of the Black Hills, and the Newell area in the northern Black Hills. An exceptional 24-hour precipitation total of 7.1 in. for Custer was recorded on April 17, 1920, as part of a storm that produced heavy snowfall throughout the Black Hills. A peak flow of 114,000 ft^3/s was recorded on May 12, 1920, at station 06400500 (Cheyenne River near Hot Springs), which is the largest peak flow recorded anywhere along the Cheyenne River (table 9). A record stage of 18.9 ft also is documented for the next day (May 13) at station 06439500 (Cheyenne River near Eagle Butte), which is located on the Cheyenne River about 75 mi downstream from the confluence of the Belle Fourche River.

In 1922, flooding occurred throughout much of the Black Hills area from a large storm system that began on May 10 and produced exceptionally heavy precipitation from west of Edgemont to west of Belle Fourche to Saint Onge to Rapid City. Flooding of a power plant along the Redwater River was reported in a May 11, 1922, article in the Deadwood Telegram as “the highest ever known, being three feet higher than the highest previously known,” and “the highest water in the history of” Saint Onge also was reported in association with this storm system in a May 1922 article in the Weekly Pioneer Times. Flooding in 1924 and 1927 was especially severe in the Belle Fourche area. A peak-of-record flow of 22,400 ft^3/s occurred on April 9, 1924, at the Belle Fourche River near Belle Fourche (station 06435500; table 9), and a record stage of 21.8 ft for an unknown date in May 1927 is documented for the Belle Fourche River near Elm Springs (station 06438000; table 10).

A large peak flow of 16,000 ft^3/s was recorded on May 6, 1932, along Rapid Creek at station 06422000 about 20 mi downstream from Rapid City. Flows recorded at two streamflow-gaging stations upstream from Rapid City were not large. However, a peak-of-record flow of 46,300 ft^3/s was recorded on the same date farther downstream along the Cheyenne River near Wasta (station 06423500), indicating a storm system that apparently produced heavy rainfall over a relatively large area primarily downstream from Rapid City.

Severe flooding occurred in Hot Springs along the Fall River on June 17, 1937, and was instrumental in securing Congressional authorization for construction of Cold Brook and Cottonwood Springs Dams, which have regulated flows since September 1952 and June 1969, respectively. Large flows were recorded on September 4, 1938, for the Fall River (13,100 ft^3/s; station 06402000) and Beaver Creek (11,700 ft^3/s; station 06402500), which in combination with reported heavy flooding for Lame Johnny Creek, provide an indication of a storm system that produced some of the most substantial flooding for which peak-flow records are available. Relatively large floods also occurred along the Fall River in 1941 and 1947. Widespread flooding occurred in May 1946 throughout the northern Black Hills. A monthly precipitation total of 18.61 in. was recorded in Deadwood for May 1946 (Driscoll and others, 2000), with large monthly totals for other precipitation stations in the northern Black Hills (table 10).

Notable flooding occurred June 15–16, 1962, in areas from Rapid City to Sturgis to Whitewood, with the most severe flooding in the Sturgis area. In Whitewood, 14 in. of rain during a 6-hour period was reported for June 15 in a June 23, 1962, article in the Black Hills Press, and peak-of-record flows (table 9) were recorded along Bear Butte Creek (12,700 ft^3/s; station 06437500) about 15 mi northeast of Sturgis and along the Redwater River above Belle Fourche (16,400 ft^3/s; station 06433000). An exceptional peak flow of 2,920 ft^3/s occurred July 13 in Cleghorn Canyon in west Rapid City (station 440325103182500), and farther downstream the second largest peak-of-record flow (3,300 ft^3/s) was recorded for station 06414000 along Rapid Creek.

The most outstanding flooding documented in the Black Hills area since European settlement occurred on June 9–10, 1972. Nearly 15 in. of rain fell in about 6 hours near Nemo, and more than 10 in. of rain fell over an area of 60 mi^2. The resulting floods left 238 people dead and 3,057 people injured (Carter and others, 2002). Battle, Spring, Rapid, and Boxelder Creeks experienced the largest flooding with smaller floods along Elk and Bear Butte Creeks. Record flows were recorded for many USGS streamflow-gaging stations, and the 1972 peak flows remain (through water year 2009) as peak-of-record flows for 14 streamflow-gaging stations (table 9). Flooding was especially severe along Rapid Creek, where a record peak flow of 50,000 ft^3/s was recorded at Rapid City (station 06414000) and where many of the 238 known flood victims perished.

Prolonged heavy rainfall occurred throughout parts of the northern Black Hills on June 13–15, 1976. Annual peak flows for the year at many USGS streamflow-gaging stations in the Black Hills resulted from this storm. Especially large peak flows were recorded in 1976 and 1982 along Indian Creek and Horse Creek (table 9).

Since 1982, at least four strong storm events that were listed in table 2 have caused noteworthy peak flows in the Black Hills area. Two of these storms occurred in 1996 (storm numbers 1 and 2), and storm numbers 12 and 13 occurred in 2007 and 2008, respectively (table 2).

Stream-Specific Synopsis

The Fall River and Beaver Creek have unique peak-flow histories that have important implications for regional peak-flow characterization. A statistically significant downward trend in peak-flow magnitudes was identified for Beaver Creek. A similar downward trend is apparent for the Fall River, but could not be tested for statistical significance because of the coincidental effect of two flood-control reservoirs. Especially when considering the numerous historical floods that pre-date the available systematic peak-flow records, the Fall River stands out as having one of the most robust flood histories in the Black Hills area in terms of relatively large peak flows. This observation is important relative to the regional mixed-population analysis developed by Sando and others (2008), which was used to address complications related to high outliers that for many streamflow-gaging stations are about an order of magnitude larger than the next largest peak flows. Many stations have a conspicuous "under-representation" of moderately large peak flows in their periods of record, which are essentially mid-range between small peak flows that represent the "ordinary peaks population" and the much larger peak flows that represent the "high-outlier population." The Fall River, possibly with an "over-representation" of relatively large peak flows in the period of record, represents an opposing end of this spectrum.

Flooding of June 9–10, 1972, was especially severe along lower Rapid Creek (downstream from Pactola Reservoir), where a peak-of-record flow of 50,000 ft^3/s was recorded at station 06414000 (Rapid Creek at Rapid City; table 9). Flood storage in Pactola Reservoir was inconsequential, as flooding was isolated within the downstream reach. The U.S. Army Corps of Engineers (1973) provided historical peak-flow estimates for four other relatively large floods for the Rapid City area that pre-date USGS systematic peak-flow records and the construction of Pactola Dam. All of the peaks flows are small (7,500, 8,400, 13,000, and 8,000 ft^3/s in 1878, 1883, 1907, and 1920, respectively) relative to the 1972 peak flow.

The peak-flow history for upper Rapid Creek (upstream from Pactola Reservoir) was examined in detail relative to differentiation between hydrogeologic and climatological effects on peak-flow characteristics. Long-term records (dating back to 1949) exist for station 06409000 (Castle Creek above Deerfield Reservoir), which is located primarily within the limestone headwater hydrogeologic setting and for which the peak-flow record is dominated by relatively small peaks, many of which are only slightly larger than the relatively large base flow for this station (Driscoll and Carter, 2001). In comparison, records for station 06410500 (Rapid Creek above Pactola Reservoir) indicate larger variability and larger peak flows, relative to drainage area, which is typical of the crystalline core hydrogeologic setting (Sando and others, 2008) that comprises most of the drainage area downstream from Deerfield Reservoir. Most of the largest peak flows for station 06409000 have occurred during March through May and are indicative of snowmelt or prolonged wet conditions, as opposed to primary effects from strong individual storms. Consideration of various peak-flow information indicates that no exceptionally large peak flows at the location of station 06410500 have occurred since 1920. Detailed documentation is available for two relatively large storm and flood events that have occurred upstream from station 06410500. A peak flow of 1,640 ft^3/s was recorded for station 06410500 on July 7, 2008, and resulted from strong rain-producing thunderstorms that are listed as storm event number 13 in table 2. Another storm system of generally similar scale occurred somewhat farther south on July 28, 1955, and resulted in a peak flow of 8,500 ft^3/s along Castle Creek (table 7), upstream from Rapid Creek, with large flows documented in several other locations (Wells, 1962).

The flood history for Spearfish Creek is dominated by flows resulting from some combination of prolonged precipitation and wet antecedent conditions. A June 9, 1964, flow of 3,040 ft^3/s at station 06431500 (Spearfish Creek at Spearfish) was not particularly large relative to drainage area (165 mi^2), but approaches the record of 5,000 ft^3/s for this station (table 9), and is the only quantified large flow that has resulted from a localized storm system, as opposed to effects of prolonged precipitation or wet antecedent conditions. More typical is a flow of 3,870 ft^3/s following 3 days of heavy rainfall during June 1976 that caused large flows in many other streams in the northern Black Hills.

Peak-flow histories relative to effects of hydrogeologic settings were examined for Spearfish and Whitewood Creeks, which are composed primarily of the limestone headwater and crystalline core hydrogeologic settings (fig. 5), respectively. Various datasets clearly illustrate the suppressed nature of peak-flow characteristics for Spearfish Creek, relative to Whitewood Creek, which can be at least partially attributed to hydrogeologic factors. However, distinctive differences in storm patterns may exist because Spearfish Creek generally lies along the major axis of the Black Hills, and the basin headwaters may be somewhat less subject to strong thunderstorms than (1) Whitewood Creek and (2) downstream parts of the Spearfish Creek Basin. The largest recorded flows at station 06431500 (Spearfish Creek at Spearfish; map number 73 in fig. 5; drainage area = 165 mi^2) are quite small, relative to most other drainages of comparable size around the periphery of the Black Hills (table 9). The distinctive effect of the limestone headwater hydrogeologic setting is exemplified by peak-flow records (table 9) for headwater stations 06430770 (Spearfish Creek near Lead; map number 69 in fig. 5) and 06430850 (Little Spearfish Creek near Lead; map number 71 in fig. 5) for which the peak-of-record flows (181 ft^3/s and 90 ft^3/s, respectively) are especially small, relative to drainage areas (65.0 and 27.8 mi^2, respectively). In contrast, Annie Creek (station 06430800; drainage area = 3.73 mi^2; map number 70 in fig. 5) and Cleopatra Creek (station 06430898; drainage area = 7.32 mi^2; map number 72 in fig. 5), which are small tributaries within the crystalline core hydrogeologic setting, have much larger peak-of-record flows

(270 ft^3/s and 860 ft^3/s, respectively). The effect of topography and geology on the contrasting peak-flow characteristics is certain; however, effects resulting from potential climatological factors cannot necessarily be distinguished. Annie and Cleopatra Creeks are located along the northern flank of the hills where steeper relief (figs. 5 and 13*A*) may tend to favor heavier convective precipitation, relative to the higher-altitude limestone headwater setting. Future resolution of this question could have important implications for peak-flow characterization of Spearfish Creek.

Hydrologic Implications of Historical Events

Extraction of definitive information regarding storm and flood events that occurred before systematic peak-flow records can be difficult for various reasons beyond the simple passage of time. Scientific documentation of events was not a societal priority, streamflow-gaging networks were sparse or nonexistent, and precipitation-gaging networks were sparse. Furthermore, like today, homeowner precipitation gages could be broken, over-topped, or were not necessarily available in locations where exceptionally heavy precipitation occurred, or measurements simply were not always recorded for posterity. Historical news accounts frequently provide general information regarding precipitation amounts, but seldom contain information that can be used to quantify magnitudes of flood peaks, which can vary considerably along stream reaches. Likewise, before the advent of radar data, it is difficult to ascertain prior storm morphology and evolution with confidence. Another important consideration is that some strong rain-producing thunderstorms undoubtedly have been largely unnoticed because of occurrence in areas where population or damage was minimal or not recorded.

Despite these drawbacks, continued collection and examination of historical accounts has excellent potential to contribute to a need for improved knowledge of especially large flood events for the Black Hills area, where potential exists for extreme damage and loss of lives in rapidly developing areas. As an example, an August 4, 1882, article in the Black Hills Journal (table 10) reported that “Redwater (River) rose in confined places, twenty-five feet, and rocks weighing hundreds of pounds were carried for miles.” Verification of this report more than a century later may never be possible; however, it might be possible to eventually find additional evidence of what might be an extraordinary event that might not necessarily have caused much damage, or associated consternation, given the limited extent of settlement and associated infrastructure at that time.

Statistical analyses of peak-flow trends were performed for only two stations. A statistically significant downward trend was quantified for station 06402500 (Beaver Creek near Buffalo Gap); however, a downward trend for station 06431500 (Spearfish Creek at Spearfish) was not statistically significant at the 5-percent confidence level. Statistical analyses of peak-flow trends cannot incorporate historical flood accounts; however, consideration of historical accounts qualitatively supports a hypothesis that exceptionally large flood events may be somewhat “under-represented” in peak-flow records subsequent to 1972 for relatively small drainages in the Black Hills area that include the Fall River, Beaver Creek, Rapid Creek, Spearfish Creek, Whitewood Creek, and Bear Butte Creek, which could have important implications for assessing peak-flow characteristics for the area. Systematic peak-flow records for the area are strongly affected by record flows for the exceptional 1972 storm event. Since 1972, the most noteworthy events that have been documented (U.S. Geological Survey, 2009) are for 2007 (peak flows of 26,000 and 18,600 ft^3/s for two locations along Battle Creek; table 1) and a 1996 peak flow of 16,900 ft^3/s for Alkali Creek (storm number 2 from table 2; drainage area = 102 mi^2; station 442205103073200).

Consideration of historical accounts indicates that histories of exceptional events for many streams probably are much richer before 1972 than after 1972, which includes a preponderance of “modern” peak-flow records. For the Fall River, peak flows that were recorded for 1938, 1941, and 1947 clearly surpass any flows that could have occurred subsequent to 1952, when the first of two flood control reservoirs in the basin was built. The storm of 1938 also caused substantial flooding farther north in Beaver and Lame Johnny Creeks. Historical USGS information indicates that the 1938 stage at the location of the streamflow-gaging station may have been higher by several feet than for a severe flood in 1937; however, newspaper accounts indicate that the 1937 flood probably was more severe in locations downstream from where the station was established in 1938. Documentation provided by the U.S. Army Corps of Engineers (1950, 1966) indicates that 1937 and 1938 flood stages probably were exceeded by about 7 ft in 1884 and other historical accounts indicate substantial floods in 1891, 1895, 1896, and 1897. Detailed examination of peak-flow information for Rapid Creek indicates that moderately large peaks at Rapid City in 1878, 1883, 1907, and 1920 (7,500, 8,400, 13,000, and 8,000 ft^3/s, respectively) have been exceeded only by the 1972 flooding, and that flood control storage in Deerfield and Pactola Reservoirs (initiated in 1945 and 1956, respectively) has been inconsequential relative to this interpretation.

As previously stated in section titled “Spearfish and Whitewood Creeks,” a downward trend for Spearfish Creek (station 06431500) was not statistically significant; however, four of the five largest peak flows (table 9) occurred before 1976 for a peak-flow record that includes 1904 and 1947–2009. Historical accounts indicate that moderate to substantial flooding probably occurred along Spearfish Creek in 1883, 1890, 1895, 1909, 1933, and 1946. Peak-flow records for other streamflow-gaging stations in the northern Black Hills generally are short. Records for Bear Butte Creek near Sturgis include 1946–72 and 1990–2001; three of the five largest peaks are from the earlier period and largely exceed those from the latter period. The earliest systematic records for Whitewood Creek date back only to 1982 and comparisons provided in a previous section titled “Spearfish and

Whitewood Creeks" indicate under-representation of large peak flows, relative to the longer-term systematic records for Spearfish Creek. If quantitative data could be extracted from historical accounts, the under-representation of large peak flows for Whitewood Creek presumably would be even more pronounced.

Although a formal analysis was not performed, consideration of the comprehensive flood history clearly indicates that most of the especially large peak flows for relatively small drainages in the Black Hills area have resulted from strong thunderstorms, as postulated in a previous section titled "Climatological Factors and a Climatology of Recent Large Black Hills Storms," and including those such as the 2007 event near Hermosa and the exceptional 1972 event. This is well known for many recent storms, and the storms that are listed in table 2 provide good examples. The most noteworthy example is the 1972 storm event, for which exceptionally large peak flows were generated in many small to moderate-sized drainages. Of these, an outstanding example is the peak flow of 50,000 ft^3/s along Rapid Creek at station 06414000, for which the unregulated drainage area is 93 mi^2. In comparison, for station 06438000 (Belle Fourche River near Elm Springs; drainage area = 7,029 mi^2) the peak-of-record flow is 47,500 ft^3/s set in June 2008 (table 9). For large drainages such as this, large flows most commonly have resulted from some combination of wet antecedent conditions and prolonged precipitation over widespread areas, although exacerbation by especially heavy localized precipitation undoubtedly has contributed to some of the more exceptional flows. An example is a large flow of 16,000 ft^3/s that was recorded on May 6, 1932, along Rapid Creek (station 06422000), about 20 mi downstream from Rapid City (fig. 5). Driscoll and others (2000) reported 4.10 and 5.02 in. of precipitation for April and May, respectively, for NWS weather station 396947 at Rapid City. The 1932 annual peak flow of 682 ft^3/s for streamflow-gaging station 06411500 (Rapid Creek below Pactola Dam) occurred on April 24 (table 9) and is indicative of generally high flows and wet antecedent conditions; however, indications are that a strong storm provided the final ingredient for the large May 6, 1932, flow.

Although a statistical analysis for dates of exceptionally strong localized storm events has not been performed, examination of the 13 storm events listed in table 2 shows that 4 occurred in May (6–7, 19, 28, and 30), 5 occurred in June (as did the 1972 event), 2 occurred in July (5 and 6–7), and 2 occurred in August. Thus, the most frequent time frame for the occurrence of these events is late May through early July, which probably is reasonably representative of most of the strong storm events in the Black Hills area for the historical accounts listed in table 10. In addition, May and June clearly stand out as predominant months for general storms with large areal extent and heavy prolonged precipitation.

In contrast, the Fall River flood history indicates that a disproportionately large number of the large storm and flood events have occurred in August and September. Dates for the 10 largest known events for the Fall River are shown in table 8, and one-half of these events occurred in August or September.

Table 8. Dates for the 10 largest known storm/flood events for the Fall River.

Year	Approximate date
1884	August 27
1896	September 12
1897	August 6
1905	June 17
1908	May 31/June 1
1922	August 3
1937	June 17
1938	September 4
1941	August 6
1947	June 20

Water standing in the ditch alongside the railroad tracks near Hermosa after the 2007 flood (photograph by Mark T. Anderson).

Storm and Flood Potential Based on Climatological Factors and Historical Events

Previous examination of climatological factors for the Black Hills area in the section titled “Climatological Factors and a Climatology of Recent Large Black Hills Storms,” indicated that (1) the largest gradients in topography lie along the foothills, as opposed to over the higher altitudes, and this helps favor heavy precipitation in foothills areas; and (2) greater potential exists for generation of exceptional thunderstorms for areas east (as opposed to west) of the major axis of the Black Hills area. Collective consideration of all available accounts for exceptional storm and peak-flow events supports development of a hypothesis of generally increasing potential for exceptionally strong rain-producing thunderstorms in an easterly direction from the escarpment that lies along the eastern extent of the Limestone Plateau, with maximum potential occurring within an area in figure 18 that can be generally defined by the combination of the footprint for the 1972 storm and the largest precipitation increments (generally approaching or exceeding 10 in.) for the “composite” footprint. The areas near Sturgis with the largest precipitation increments (as much as 20 in.) may be somewhat biased by the short-term nature of the available radar dataset, but generally coincide with some of the most exceptional historical storm accounts. Detailed examination of numerous 1907 historical accounts indicates a storm footprint that although undefinable, may resemble the 1972 footprint, albeit with considerably less precipitation in the Rapid Creek drainage basin and most likely with less precipitation in the southern Black Hills.

The general area from Rapid City to Keystone to Hermosa has a robust recent (1972 and later) storm history (fig. 16), including events of 1996 and 2007 that produced exceptional flows for small drainage areas. The area between Hermosa and Hot Springs may be somewhat under-represented by the general absence of large precipitation increments in figure 18. The outstanding 1938 event caused exceptionally large flows (in systematic records) along the Fall River and Beaver Creek, with historical accounts of exceptional flows along Lame Johnny Creek. The statistically significant downward trend in peak flows for Beaver Creek indicates an under-representation of large flows since about 1966, which would be amplified by consideration of historical accounts. An even more pronounced under-representation of recent large flows was identified for the Fall River.

The combination of climatological factors, systematic peak-flow records, and historical accounts strongly supports a conclusion that potential for generation of exceptional thunderstorms is much smaller west of the major axis of the Black Hills than east of the axis, especially relative to areas with the most robust history of large-scale events along the eastern flank. Available peak-flow records for the Limestone Plateau area are short and spatially sparse (fig. 5); however, especially large peak-flow events originating from exceptional convective storms are absent in the systematic records. Furthermore, no historical accounts of exceptional storms or high flows for this area have been located to date; nevertheless, it needs to be recognized that the potential for bias exists because this is the least populated part of the Black Hills area.

For areas just east of the escarpment that lies along the eastern extent of the Limestone Plateau, systematic records

Low-lying areas in the southern and southeastern parts of Hermosa were inundated by flooding along Battle Creek during the August 17, 2007, storm (photograph by Mark T. Anderson).

and historical accounts of large peak-flow events are not completely absent, but generally are sparse relative to records and historical accounts for areas around the periphery of the Black Hills. A conclusion of increased potential for especially heavy precipitation from convective storms, relative to areas west of the escarpment, is strongly supported by systematic records, historical accounts, and climatological theory. The interpretation of reduced potential relative to the periphery of the Black Hills is somewhat less conclusive and must be qualified by a cautionary note that systematic peak-flow records and population densities in this area have historically been much sparser than for the peripheral areas.

Although a formal analysis was not performed, collective consideration of numerous datasets presented within this report indicates that drainages within the northern Black Hills are considerably more subject to effects from wet antecedent conditions (including snowpack) and from storms involving prolonged precipitation than drainages within the central and southern Black Hills. Table 3 indicates a greater propensity for northern than southern drainages for large precipitation during May, which is the most common month for substantial flooding associated with widespread conditions. This also is consistent with trends in winter precipitation (Driscoll and others, 2000) and associated accumulation of snowpack.

After consideration of all available information, the following final interpretations are offered relative to potential for exceptionally heavy precipitation (storm potential), and the associated potential for severe flooding:

- Storm and flood potential are smallest on the relatively flat “top” of the Limestone Plateau, which generally is represented by the part of the limestone headwater hydrogeologic setting (fig. 5) that is within Pennington County. Storm potential increases in southerly and northerly directions (moving into Custer and Lawrence Counties) with increasing topographic relief, and flood potential increases further, commensurate with increasing relief.

- Storm potential increases just to the east of the Limestone Plateau, because of the orographic effect of a pronounced escarpment, and to the west of the South Dakota/Wyoming border, because of increasing topographic relief. Flood potential in both areas increases further, commensurate with increasing relief.

- Storm potential is greatest along eastern and northeastern flanks of the Black Hills, with maximum potential generally coinciding with the largest precipitation increments in figure 18. The greatest flood potential generally occurs in canyon reaches within this area and is because of steep topography and minimal potential for attenuation of flood flows within the confined canyons.

- Storm potential generally decreases in moving around the periphery of the Black Hills towards the western flank, because of reduced potential for orographic lifting and decreasing effects from moisture-laden air masses originating from the Gulf of Mexico.

Summary

The Black Hills area of western South Dakota has a history of damaging flash floods that have resulted primarily from exceptionally strong rain-producing thunderstorms. The best known example is the catastrophic storm system of June 9–10, 1972, which caused severe flooding in several major drainages near Rapid City and resulted in 238 deaths. More recently, severe thunderstorms caused heavy precipitation and flash flooding near Piedmont and Hermosa on August 17, 2007. Various investigators have worked to attain improved knowledge of the frequency of occurrence of large (low-probability) flood events such as these for the Black Hills area. To that end, the U.S. Geological Survey (USGS) cooperated with the South Dakota Department of Transportation and National Weather Service (NWS) and to produce this report, the purposes of which are to (1) provide documentation regarding the August 17, 2007, storm and associated flooding, and (2) provide a context through examination of the history of other large storm and flood events in the Black Hills area.

The area affected by the August 17, 2007, storms and associated flooding generally was encompassed within the area affected by the larger storm of June 9–10, 1972. The maximum observed 2007 precipitation totals of between 10.00 and 10.50 inches (in.) occurred within about 2–3 hours and were measured within a small area about 5 miles (mi) west of Hermosa. In contrast, the maximum documented precipitation amount in 1972 was 15.0 in. near Nemo, and precipitation totals that equaled or exceeded 10.0 in. were documented for 34 locations within an area of about 76 square miles (mi^2), with storm totals generally occurring within a 6-hour interval.

Hail damage in the Piedmont area during 2007 was especially severe; however, flooding was localized. A peak flow of 1,600 cubic feet per second (ft^3/s) was determined for a site in Stagebarn Canyon (drainage area = 17.2 mi^2); however, moderately high flows in many relatively small drainages such as this attenuated in moving downstream through extensive channel networks, and a peak flow of only 68 ft^3/s was recorded for USGS streamflow-gaging station 06425100 (Elk Creek near Rapid City; drainage area = 211 mi^2), which is located about 10 mi farther downstream along Elk Creek. Substantial flooding occurred in the Hermosa area, where low-lying areas were inundated by flooding along Battle Creek, a railroad grade was breached, several houses just downstream from the breach were washed from their foundations, and area roads incurred damage. The 2007 peak flow of 18,600 ft^3/s for station 06406000 (Battle Creek at Hermosa) was only slightly smaller than the 1972 peak flow of 21,400 ft^3/s, despite considerably smaller areal extent of exceptionally heavy precipitation within the watershed during 2007 than in 1972.

In 1972, the heaviest precipitation was north of Grace Coolidge Creek, and the peak flow (709 ft^3/s) for upstream station 06404998 (Grace Coolidge Creek near Game Lodge) was relatively small, but about 20 times larger than during 2007 (36 ft^3/s). Farther downstream along Grace Coolidge Creek (and just upstream from the confluence with Battle Creek), a 2007 peak flow of 4,400 ft^3/s was determined. The 1972 peak flow for this location was not determined, but perhaps was considerably smaller than in 2007, based on information from various sources. During 2007, a peak flow of less than 1 ft^3/s was recorded for station 06404000 (Battle Creek near Keystone). The 1972 peak flow of 26,200 ft^3/s for this station was very large, relative to the drainage area of only 58.6 mi^2. Farther downstream along Battle Creek (and just upstream from the confluence with Grace Coolidge Creek), a 2007 peak flow of 26,000 ft^3/s was determined, which was generated entirely within the intervening drainage area of only 44.4 mi^2. An especially large peak flow of 44,100 ft^3/s was documented for this location in 1972.

A previous study of regional peak-flow frequency characteristics provides a perspective on the relative infrequency of extreme events such as these; however, readers are cautioned that especially large uncertainty exists for estimation of such low-probability events. Obtaining a thorough understanding of peak-flow characteristics for low-probability events will require a comprehensive long-term approach involving (1) collection and documentation of scientific information for extreme events, such as those of 2007 and 1972; (2) continued long-term collection of systematic peak-flow records for many locations; and (3) regional assessments of a wide variety of information that includes all available systematic peak-flow records, historical flood information, paleoflood information (which pre-dates historical information), and climatic information.

A perspective on the relative magnitudes of large peak flows for the 2007 and 1972 flooding was provided through a comparison with a regional envelope curve that had been developed by previous investigators. Peak-flow values from 2007 for three sites with small drainage areas (<1.0 mi^2) plot close to the envelope curve, indicating exceptionally large flow values, relative to drainage area. Flooding in 1972 was exceptional in that extremely large peak flows (approaching the regional envelope curve) were generated in many relatively large drainage areas.

Physiographic factors that affect flooding in the Black Hills area were examined. The limestone headwater hydrogeologic setting on the western flank of the Black Hills has distinctively suppressed peak-flow characteristics, with annual peaks that are consistently small, relative to drainage area, for peak flows with small recurrence intervals (that is, 2-year through about 25- or 50-year return periods—equating to annual exceedance probabilities of 50, 4, and 2 percent).

Uncertainty is large, however, regarding peak-flow characteristics for larger recurrence intervals (low-probability flood events) because of a dearth of information regarding the potential for generation of exceptionally strong rain-producing thunderstorms within and near the Limestone Plateau area in the limestone headwater setting. In contrast, the greatest potential for exceptionally damaging floods is around the flanks of the rest of the Black Hills area because of steep topography and limited potential for attenuation of flood peaks in narrow canyons.

Climatological factors that affect flooding in the Black Hills area also were examined. Area thunderstorms are largely terrain-driven, especially with respect to their requisite upward motion, which can be initiated by orographic lifting effects, thermally enhanced circulations, and obstacle effects. Several other meteorological processes are influential in the development of especially heavy precipitation for the area, including storm cell training, storm anchoring or regeneration, storm mergers, and supercell development. A composite of summed precipitation amounts for 13 recent individual storm events indicates (1) a propensity for heavy precipitation to occur east of the major axis of the Black Hills, from the northern hills (near Spearfish) toward the southeast through the eastern foothills near Hermosa, and (2) a proclivity for short-duration but intense convective precipitation events.

The largest gradients in topography lie along the foothills, as opposed to over the higher altitudes, and this helps favor heavy precipitation. Additionally, a pronounced escarpment with several hundred feet of relief exists along the eastern edge of the Limestone Plateau, and orographic lifting associated with this escarpment can occur with a southeasterly air flow. However, to the west of this escarpment, relief is relatively small and localized, and the potential for orographic lifting is minimal. Moreover, moisture-laden air masses mostly originate from the Gulf of Mexico, which strongly affects the eastern Black Hills. Finally, the westerly mean air flow causes storm complexes to drift eastward, which generally coincides with a down-basin direction for most drainages along the eastern flanks of the Black Hills, and also favors convergent patterns along the eastern slopes of the Black Hills. Collectively these factors enhance the probability of exceptional rainstorms along the eastern Black Hills, relative to the highest terrain. Additionally, weak upper-level air flow (similar to conditions of June 9–10, 1972, along the eastern flanks of the Black Hills) can allow heavy rainfall to remain almost stationary, which can exacerbate flooding potential.

A chronology of historical storm and flood events was examined to provide a context regarding exceptional events for the Black Hills area. Both 1883 and 1890 were early years of benchmark flooding for much of the area, with especially noteworthy flooding in 1883 for the Deadwood area and other parts of the northern Black Hills. A large flood in 1884 is the first, and perhaps the largest, of many historical floods that pre-date USGS peak-flow records for Fall River. A peak flow of 5,000 ft^3/s was recorded along Spearfish Creek during 1904 (one of the earliest USGS records in the area) and through 2009 remains a record for this station. The year 1907 was one of the most noteworthy flood years for the area with wet antecedent conditions, widespread flooding, and severe flooding from a strong storm system that produced a 24-hour rainfall total of 7.1 in. at Ft. Meade on June 12. A peak flow of 13,000 ft^3/s was estimated for Rapid Creek, and a peak flow of 16,000 ft^3/s occurred along Boxelder Creek. Collective information indicates that the events of 1907 are among the most severe experienced in the area since European settlement.

In 1915 and 1920, the Black Hills experienced widespread flooding, and 1920 may constitute the most substantial and widespread flooding in the larger streams draining western South Dakota since European settlement. During 1922, flooding occurred throughout much of the Black Hills area from a storm system that began on May 10 and produced exceptionally heavy precipitation from west of Edgemont to west of Belle Fourche to Saint Onge to Rapid City. Flooding in 1924 and 1927 was especially severe along the Belle Fourche River.

A large peak flow of 16,000 ft^3/s was recorded on May 6, 1932, along Rapid Creek about 20 mi downstream from Rapid City. Flows recorded at two streamflow-gaging stations upstream from Rapid City were not large. However, a peak-of-record flow of 46,300 ft^3/s was recorded farther downstream along the Cheyenne River near Wasta (station 06423500), indicating a storm system that apparently produced heavy rainfall over a relatively large area primarily downstream from Rapid City.

Severe flooding occurred in Hot Springs along the Fall River on June 17, 1937, and was instrumental in securing Congressional authorization for construction of Cold Brook and Cottonwood Springs Dams, which have regulated flows since September 1952 and June 1969, respectively. Large flows were recorded on September 4, 1938, for the Fall River (13,100 ft^3/s) and Beaver Creek (11,700 ft^3/s), which in combination with reported heavy flooding for Lame Johnny Creek, provide an indication of a storm system that produced some of the most substantial flooding for which peak-flow records are available. Relatively large floods also occurred along the Fall River in 1941 and 1947.

Notable flooding occurred along the northeastern flanks of Black Hills in 1962, with the most severe flooding in the Sturgis area. In Whitewood, 14 in. of rain during a 6-hour period was anecdotally reported for June 15, and record flows occurred the next day along Bear Butte Creek (12,700 ft^3/s) about 15 mi northeast of Sturgis and along the Redwater River above Belle Fourche (16,400 ft^3/s).

The most outstanding flooding documented in the Black Hills area since European settlement occurred on June 9–10, 1972. Battle, Spring, Rapid, and Boxelder Creeks experienced the largest flooding with smaller floods along Elk and Bear Butte Creeks. Record flows were recorded for many USGS streamflow-gaging stations, and the 1972 peak flows remain (through water year 2009) as peak-of-record flows for 14 streamflow-gaging stations. Flooding was especially severe along Rapid Creek where many of the 238 known flood victims perished.

The Fall River stands out as having one of the most robust flood histories in the area in terms of relatively large peaks, which are “over-represented” relative to the general abundance of especially large peak flows for many other area streams. A statistically significant downward trend in peak-flow magnitudes was identified for Beaver Creek, and a similar downward trend is apparent for the Fall River, but could not tested for statistical significance because of the coincidental effect of the two flood control reservoirs.

Flooding in 1972 was especially severe along Rapid Creek, where a peak-of-record flow of 50,000 ft^3/s was recorded at Rapid City. Flood storage upstream in Pactola Reservoir was inconsequential, as flooding was isolated within the reach downstream from the reservoir. Historical peak-flow estimates exist for four other relatively large floods that predate USGS systematic peak-flow records and the construction of Pactola Dam. All of the peaks flows are small (7,500, 8,400, 13,000, and 8,000 ft^3/s in 1878, 1883, 1907, and 1920, respectively) relative to the 1972 peak flow.

The peak-flow history for upper Rapid Creek (above Pactola Reservoir) was examined in detail relative to differentiation between hydrogeologic and climatological factors on peak-flow characteristics. A long-term peak-flow record for Castle Creek, which is located primarily within the limestone headwater hydrogeologic setting, is dominated by relatively small peak flows, many of which are only slightly larger than the relatively large base flow for this station. Most of the largest peak flows occurred during March through May and are indicative of snowmelt or prolonged wet conditions, as opposed to primary effects from strong individual storms. Farther downstream, a peak-flow record for Rapid Creek above Pactola Reservoir indicates larger variability and larger peak flows, relative to drainage area, which is typical of the crystalline core hydrogeologic setting that comprises most of the unregulated drainage area. Consideration of various peak-flow information indicates there have been no exceptionally large peak flows at the location of station 06410500 since 1920, and effects of storage in Deerfield Reservoir (located upstream) on especially large peaks in downstream reaches has been inconsequential. The largest documented peak flow in this intervening reach was 8,500 ft^3/s in 1955 along Castle Creek, upstream from Rapid Creek.

The flood history for Spearfish Creek is dominated by flows resulting from some combination of prolonged precipitation and wet antecedent conditions. A 1964 flow of 3,040 ft^3/s is the only quantified large flow that has resulted from a localized storm system.

Peak-flow histories relative to effects of hydrogeologic settings were examined for Spearfish and Whitewood Creeks, which are composed primarily of the limestone headwater and crystalline core hydrogeologic settings, respectively. Various datasets clearly illustrate the suppressed nature of peak-flow characteristics for Spearfish Creek, relative to nearby Whitewood Creek, which can be at least partially attributed to hydrogeologic factors. However, distinctive differences in storm patterns may exist because Spearfish Creek generally lies along the major axis of the Black Hills, and the basin headwaters may be somewhat less subject to strong thunderstorms than (1) Whitewood Creek and (2) downstream parts of the Spearfish Creek Basin.

Statistical analyses of peak-flow trends were performed for only two streamflow-gaging stations, and a statistically significant trend (downward) was quantified for one (station 06402500; Beaver Creek near Buffalo Gap). However, consideration of historical flood accounts qualitatively supports a hypothesis that exceptionally large flood events may be somewhat “under-represented” in peak-flow records subsequent to 1972 (which includes a preponderance of modern peak-flow records) for relatively small drainages in the area that include the Fall River, Beaver Creek, Rapid Creek, Spearfish Creek, Whitewood Creek, and Bear Butte Creek.

Consideration of the comprehensive flood history indicated that most of the especially large flows for smaller drainages in the Black Hills area have resulted from strong thunderstorms, rather than from more general storm systems. Of the 13 events that were included in a climatological analysis of recent large area storms, 10 occurred between late May through early July, which probably is reasonably representative of most of the strong localized storm events contained in a tabulation of historical storm and flood accounts. In contrast, many of the large storm and flood events for the Fall River have occurred in August and September.

The combination of climatological factors, systematic peak-flow records, and historical accounts strongly supports a conclusion that potential for generation of exceptional thunderstorms is much smaller west of the major axis of the Black Hills than east of the axis, especially relative to areas with the most robust history of large-scale events along the eastern flank. For areas just east of the escarpment that lies along the eastern extent of the Limestone Plateau, systematic records and historical accounts of large peak-flow events are not completely absent, but generally are sparse relative to records and historical accounts for areas around the periphery of the Black Hills. A conclusion of increased potential for especially heavy precipitation from convective storms, relative to areas west of the escarpment, is strongly supported by systematic records, historical accounts, and climatological theory. Drainages within the northern Black Hills were qualitatively determined to be considerably more subject to effects from wet antecedent conditions (including snowpack) and from storms involving prolonged precipitation than drainages within the central and southern Black Hills.

Final interpretations are offered that further refine the potential for exceptionally strong storms and associated flooding. Storm and flood potential are smallest on the relatively flat top of the Limestone Plateau, but increase in southerly and northerly directions commensurate with increasing topographic relief. Storm and flood potential also increase in easterly and westerly directions primarily because of increasing topographic relief. Storm and flood potential are largest along eastern and northeastern flanks of the Black Hills, with maximum flood potential in confined canyons with especially steep topography nearby. Storm potential generally decreases in moving around the periphery of the Black Hills towards the western flank, because of reduced potential for orographic lifting and decreasing effects from moisture-laden air masses originating from the Gulf of Mexico.

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A large tree was deposited on the back of this truck by the flood waters of August 17, 2007, near Hermosa (photograph by Mark T. Anderson).

Supplemental Tables

Table 9. Station information and listing of five largest annual peak flows during selected periods for selected streamflow-gaging stations with 10 or more years of peak-flow record, and peak flows recorded during water year 1972, but outside of the five largest.

[Data from U.S. Geological Survey (2009). 1972 column: NRA, no records available for 1972; Other 1972, annual peak flow occurred outside of June 9–12, 1972, and is one of the five largest peak flows for the station through water year 2009; June 9–12, annual peak flow occurred during June 9–12, 1972, and is one of the five largest peak flows for the station through water year 2009; OPORC, 1972 is outside of the period of record considered for the station; --, not available]

Map number (fig. 5)	Station number	Station name	Drainage area[1] (square miles)	Period and number of years considered		Date of annual peak flow and annual peak flow (cubic feet per second)					
				Period of record (water years)[2]	Number of years	Largest	Second largest	Third largest	Fourth largest	Fifth largest	1972
1	06392900	Beaver Creek at Mallo Camp near Four Corners, Wyo.	10.3	1975–82, 1991–2009	26	04/22/1994 103	03/25/1999 87	06/07/1993 75	06/18/1998 48	10/31/1996 31	NRA
2	06392950	Stockade Beaver Creek near Newcastle, Wyo.	110	1975–82, 1991–2009	26	07/17/1993 776	08/12/2005 374	03/13/1996 373	08/29/1999 137	06/16/1977 107	NRA
3	06394300	Redbird Canyon near Newcastle, Wyo.	62.1	1991–2009	11	08/12/2005 431	07/05/2002 111	05/01/2003 106	04/05/1999 28	06/22/1905 0	NRA
4	06394450	Pass Creek near Dewey, S. Dak.	36.1	1991–2009	11	07/18/2008 6,130	08/12/2005 5,240	06/13/2009 1,610	--/--/1999 1,430	07/05/2000 811	NRA
5	06395000	Cheyenne River at Edgemont, S. Dak.	7,204	1905, 1929–32, 1947–2009	69	05/20/1978 28,000	05/25/1971 13,800	06/17/1962 13,500	07/30/1905 13,000	06/03/1929 10,500	06/17/1972 750
6	06396200	Fiddle Creek near Edgemont, S. Dak.	.71	1956–80	25	06/15/1980 275	08/04/1961 68	08/09/1977 44	07/20/1958 43	05/24/1957 41	02/29/1972 1
7	06396300	Cottonwood Creek tributary near Edgemont, S. Dak.	.09	1956–80	25	07/19/1965 86	07/18/1969 75	08/09/1977 51	06/15/1980 48	07/20/1958 41	--/--/1972 4
8	06396350	Red Canyon Creek tributary near Pringle, S. Dak.	.20	1970–79	10	05/03/1971 30	09/02/1973 12	02/29/1972 7	04/08/1975 7	--/--/1970 5	Other 1972
9	06399300	Hat Creek tributary near Ardmore, S. Dak.	4.11	1956–59, 1961–79	23	03/16/1963 510	07/20/1976 338	06/21/1964 320	06/09/1968 320	05/23/1971 310	05/10/1972 1
10	06399700	Piney Creek near Ardmore, S. Dak.	7.34	1956–75	20	06/09/1968 1,550	07/23/1965 1,540	06/16/1962 1,440	06/17/1956 1,110	07/13/1959 1,110	07/26/1972 820
11	06400000	Hat Creek near Edgemont, S. Dak.	962	1905, 1951–2009	60	06/16/1967 13,300	05/23/1954 9,430	08/12/1905 9,150	05/17/1991 7,870	04/23/2000 6,210	07/22/1972 310
12	06400497	Cascade Springs near Hot Springs, S. Dak.	.48	1977–96	20	08/09/1996 247	07/04/1977 49	06/05/1982 31	08/14/1993 28	12/30/1977 25	NRA
13	06400500	Cheyenne River near Hot Springs, S. Dak.	8,757	1915–20, 1943–72	36	05/12/1920 114,000	06/12/1915 39,200	07/14/1918 19,000	05/22/1917 16,100	06/18/1962 15,500	03/05/1972 4,460
14	06400875	Horsehead Creek at Oelrichs, S. Dak.	188	1983–2009	27	05/11/1991 8,270	06/11/1986 5,620	04/22/2000 2,170	06/03/1997 1,690	06/14/2005 644	NRA

Table 9. Station information and listing of five largest annual peak flows during selected periods for selected streamflow-gaging stations with 10 or more years of peak-flow record, and peak flows recorded during water year 1972, but outside of the five largest.—Continued

[Data from U.S. Geological Survey (2009). 1972 column: NRA, no records available for 1972; Other 1972, annual peak flow occurred outside of June 9–12, 1972, and is one of the five largest peak flows for the station through water year 2009; June 9–12, annual peak flow occurred during June 9–12, 1972, and is one of the five largest peak flows for the station through water year 2009; OPORC, 1972 is outside of the period of record considered for the station; --, not available]

Map number (fig. 5)	Station number	Station name	Drainage area[1] (square miles)	Period and number of years considered		Date of annual peak flow and annual peak flow (cubic feet per second)					
				Period of record (water years)[2]	Number of years	Largest	Second largest	Third largest	Fourth largest	Fifth largest	1972
15	06400900	Horsehead Creek tributary near Smithwick, S. Dak.	1.62	1969–79	11	07/18/1969 90	06/12/1970 3	05/23/1971 12	07/21/1972 1	--/--/1973 7	Other 1972
16	06401500	Cheyenne River below Angostura Dam, S. Dak.	[1]9,136	1946–2009	64	05/20/1978 30,300	06/18/1962 20,500	05/25/1971 17,900	06/17/1967 10,300	06/22/1947 9,520	06/20/1972 1,290
17	06402000	Fall River at Hot Springs, S. Dak. (pre-regulation period)	[1]136	[3]1938–52	32	09/04/1938 13,100	06/20/1947 8,300	08/06/1941 4,700	08/13/1948 1,720	04/27/1940 691	OPORC
		Fall River at Hot Springs, S. Dak. (post-regulation period)		[4]1953–2009		07/07/1961 2,060	08/12/2005 1,590	07/19/1997 1,170	08/20/1998 1,090	06/06/1963 805	06/09/1972 145
18	06402100	Fall River tributary at Hot Springs, S. Dak.	3.82	1970–79	10	07/04/1977 53	08/15/1978 46	07/27/1970 40	06/16/1979 29	06/19/1975 19	06/25/1972 3
19	06402430	Beaver Creek near Pringle, S. Dak.	45.7	1991–2009	19	06/10/1995 90	06/08/1993 28	05/26/1999 28	07/08/2006 26	07/09/2001 23	NRA
20	06402470	Beaver Creek above Buffalo Gap, S. Dak.	111	1990–2004	13	06/19/1999 120	07/19/1997 59	07/03/1995 56	08/01/1996 26	10/07/1990 21	NRA
21	06402500	Beaver Creek near Buffalo Gap, S. Dak.	127	1938–2009	72	09/04/1938 11,700	08/10/1955 2,750	06/07/1963 1,440	07/14/1966 1,430	06/20/1947 1,240	06/10/1972 829
22	06402600	Cheyenne River near Buffalo Gap, S. Dak.	[1]9,833	1969–80, 2008–09		05/21/1978 25,000	05/25/1971 17,600	07/21/1969 8,620	06/10/1972 2,750	07/09/1977 1,590	June 9–12
23	06402995	French Creek above Stockade Lake near Custer, S. Dak.	68.6	1991–2009	19	08/07/1999 1,070	05/08/1995 408	08/17/2007 340	08/06/1991 320	06/18/1998 317	NRA
24	06403300	French Creek above Fairburn, S. Dak.	[1]105	1982–2009	28	05/08/1995 1,060	08/08/1999 572	03/07/1987 329	06/19/1998 323	06/04/1991 304	NRA
25	06403800	Battle Creek tributary near Keystone, S. Dak.	.65	1956–80	25	06/09/1972 1,330	06/23/1967 16	07/04/1979 15	05/25/1965 9	06/16/1962 5	June 9–12
26	06403810	Battle Creek above Keystone, S. Dak.	6.8	1998–2009	12	06/18/1999 1,140	06/18/1998 134	05/24/2008 35	05/17/2000 15	05/24/2009 13	NRA

Table 9. Station information and listing of five largest annual peak flows during selected periods for selected streamflow-gaging stations with 10 or more years of peak-flow record, and peak flows recorded during water year 1972, but outside of the five largest.—Continued

[Data from U.S. Geological Survey (2009). 1972 column: NRA, no records available for 1972; Other 1972, annual peak flow occurred outside of June 9–12, 1972, and is one of the five largest peak flows for the station through water year 2009; June 9–12, annual peak flow occurred during June 9–12, 1972, and is one of the five largest peak flows for the station through water year 2009; OPORC, 1972 is outside of the period of record considered for the station; --, not available]

Map number (fig. 5)	Station number	Station name	Drainage area[1] (square miles)	Period and number of years considered: Period of record (water years)[2]	Number of years	Date of annual peak flow and annual peak flow (cubic feet per second): Largest	Second largest	Third largest	Fourth largest	Fifth largest	1972
27	06403850	Grizzly Bear Creek near Keystone, S. Dak.	8.86	1972, 1998–2009	13	06/09/1972 6,230	07/11/2001 713	06/18/1998 423	05/24/2008 309	06/18/1999 192	June 9–12
28	06404000	Battle Creek near Keystone, S. Dak.	58.6	1946–47, 1962–2009	50	06/09/1972 26,200	06/18/1999 2,000	05/08/1995 1,690	06/18/1998 1,520	06/15/1976 1,260	June 9–12
29	06404800	Grace Coolidge Creek near Hayward, S. Dak.	7.41	1989–2009	21	05/08/1995 337	06/03/1991 210	05/29/1990 168	06/07/1993 141	06/18/1998 126	NRA
30	06404998	Grace Coolidge Creek near Game Lodge near Custer, S. Dak.	[1]26.9	[5]1946–47, [5]1967–2009	45	09/07/1989 1,030	06/15/1976 980	05/08/1995 765	06/10/1972 709	08/03/1988 621	June 9–12
31	06405800	Bear Gulch near Hayward, S. Dak.	4.15	1989–2009	21	09/07/1989 1,250	05/08/1995 169	04/30/2009 120	05/24/2008 118	06/07/1993 115	NRA
32	06406000	Battle Creek at Hermosa, S. Dak.	169	1950–2009	60	06/10/1972 21,400	08/17/2007 18,600	05/22/1952 2,950	05/08/1995 2,400	07/28/1957 1,950	June 9–12
33	06406100	Battle Creek tributary near Hermosa, S. Dak.	3.61	1970–79	10	06/10/1972 100	--/4/1970 25	04/20/1973 20	06/15/1976 20	--/4/1978 20	June 9–12
34	06406500	Battle Creek below Hermosa, S. Dak.	285	1989–2009	21	08/18/2007 1,850	05/09/1995 1,360	05/27/1997 995	06/20/1999 954	05/10/1991 948	NRA
35	06406700	Spring Creek at Oreville near Hill City, S. Dak.	42.4	1998–2009	12	06/18/1998 430	08/01/1999 112	07/13/2001 79	04/24/2000 63	04/06/2002 61	NRA
36	06406740	Sunday Gulch below Johnson Canyon near Hill City, S. Dak.	5.14	1998–2009	12	06/18/1998 91	05/24/2008 54	10/28/1998 26	04/19/2000 24	06/30/2001 22	NRA
37	06406750	Sunday Gulch near Hill City, S. Dak.	6.63	1956–69	14	07/19/1965 170	--/4/1957 59	04/10/1963 45	06/09/1964 24	06/12/1967 23	NRA
38	06406760	Reno Gulch near Hill City, S. Dak.	3.75	1998–2009	12	06/18/1998 99	07/31/1999 17	04/24/2000 11	04/24/2001 4	07/19/2002 2	NRA
39	06406800	Newton Fork near Hill City, S. Dak.	8.17	1969–79	11	07/27/1977 58	05/19/1978 51	07/18/1974 50	06/15/1976 45	06/15/1972 27	Other 1972

Table 9. Station information and listing of five largest annual peak flows during selected periods for selected streamflow-gaging stations with 10 or more years of peak-flow record, and peak flows recorded during water year 1972, but outside of the five largest.—Continued

[Data from U.S. Geological Survey (2009). 1972 column: NRA, no records available for 1972; Other 1972, annual peak flow occurred outside of June 9–12, 1972, and is one of the five largest peak flows for the station through water year 2009; June 9–12, annual peak flow occurred during June 9–12, 1972, and is one of the five largest peak flows for the station through water year 2009; OPORC, 1972 is outside of the period of record considered for the station; --, not available]

Map number (fig. 5)	Station number	Station name	Drainage area[1] (square miles)	Period and number of years considered		Date of annual peak flow and annual peak flow (cubic feet per second)					
				Period of record (water years)[2]	Number of years	Largest	Second largest	Third largest	Fourth largest	Fifth largest	1972
40	06406900	Palmer Creek near Hill City, S. Dak.	13.3	1956–80	25	06/09/1972 4,370	06/16/1962 385	07/17/1969 265	04/23/1970 240	05/25/1965 140	June 9–12
41	06406920	Spring Creek above Sheridan Lake near Keystone, S. Dak.	127	1972, 1991–2004	15	06/09/1972 5,630	06/18/1999 809	05/08/1995 740	06/02/1997 566	06/18/1998 553	June 9–12
42	06407500	Spring Creek near Keystone, S. Dak.	[1]163	1904–05, 1946–47, 1987–2009	24	05/09/1995 913	06/23/1947 865	05/30/1996 642	06/03/1997 516	06/20/1998 306	NRA
43	06408500	Spring Creek near Hermosa, S. Dak.	[1]206	1950–2004	55	06/10/1972 13,400	05/30/1996 6,910	06/07/1967 772	05/23/1952 580	07/18/1995 540	June 9–12
44	06408700	Rhoads Fork near Rochford, S. Dak.	7.82	1982–2009	28	07/25/2007 19	07/09/2001 17	07/06/2008 15	06/18/1998 14	07/02/2000 12	NRA
45	06408850	Silver Creek near Rochford, S. Dak.	6.24	1969–79, 2008	12	07/07/2008 400	06/15/1976 14	05/18/1978 14	09/09/1969 13	06/12/1970 10	06/19/1972 5
46	06408900	Heeley Creek near Hill City, S. Dak.	4.88	1969–79	11	04/08/1975 20	05/03/1969 15	04/17/1971 15	05/18/1978 14	06/12/1970 10	05/11/1972 5
47	06409000	Castle Creek above Deerfield Reservoir near Hill City, S. Dak.	79.3	1949–2009	61	05/22/1952 1,120	06/17/1965 906	03/09/2002 388	04/19/2000 291	03/31/2003 288	05/10/1972 34
48	06410500	Rapid Creek above Pactola Reservoir at Silver City, S. Dak.	[1]294	1954–2009	56	05/15/1965 2,060	07/07/2008 1,640	07/28/1955 1,520	06/18/1998 1,290	04/19/1970 995	07/06/1972 252
49	06411500	Rapid Creek below Pactola Dam, S. Dak. (pre-regulation period)	[1]322	1929–42, [6]1947–56	24	05/22/1952 2,170	05/24/1933 1,540	06/23/1947 954	06/03/1929 794	04/24/1932 682	OPORC
		Rapid Creek below Pactola Dam, S. Dak. (post-regulation period)		[7]1956–2009	54	05/19/1965 547	10/01/1971 505	06/07/1996 450	06/21/1999 444	07/02/1998 443	Other 1972
50	06412000	Rapid Creek at Big Bend near Rapid City, S. Dak.	[1]339	1915–17, [6]1932–42	14	05/24/1933 1,570	06/26/1915 616	06/11/1941 552	05/01/1935 446	05/16/1942 417	OPORC

Table 9. Station information and listing of five largest annual peak flows during selected periods for selected streamflow-gaging stations with 10 or more years of peak-flow record, and peak flows recorded during water year 1972, but outside of the five largest.—Continued

[Data from U.S. Geological Survey (2009). 1972 column: NRA, no records available for 1972; Other 1972, annual peak flow occurred outside of June 9–12, 1972, and is one of the five largest peak flows for the station through water year 2009; June 9–12, annual peak flow occurred during June 9–12, 1972, and is one of the five largest peak flows for the station through water year 2009; OPORC, 1972 is outside of the period of record considered for the station; --, not available]

Map number (fig. 5)	Station number	Station name	Drainage area[1] (square miles)	Period and number of years considered		Date of annual peak flow and annual peak flow (cubic feet per second)					
				Period of record (water years)[2]	Number of years	Largest	Second largest	Third largest	Fourth largest	Fifth largest	1972
51	06412250	Victoria Creek below Victoria Dam near Rapid City, S. Dak.	6.83	1972, 1998–2009	13	06/09/1972 6,860	05/24/2008 130	06/15/1999 73	04/14/2009 19	06/18/1998 15	June 9–12
52	06412500	Rapid Creek above Canyon Lake near Rapid City, S. Dak.	[1]375	1947–2009	63	06/09/1972 31,200	05/23/1952 2,600	07/13/1962 1,310	06/02/1997 1,050	06/23/1947 950	June 9–12
53	06413650	Lime Creek at mouth at Rapid City, S. Dak.	9.81	1981–83, 1988–2002	18	06/02/1999 505	06/02/1997 365	09/13/1998 280	05/11/1991 210	08/24/1989 178	NRA
54	06414000	Rapid Creek at Rapid City, S. Dak.	[1]414	1905–06, 1943–2009	69	06/09/1972 50,000	07/13/1962 3,300	06/02/1997 3,190	05/23/1952 2,540	07/26/1905 2,500	June 9–12
55	06421500	Rapid Creek near Farmingdale, S. Dak.	[1]605	1947–58, 1960–2001	62	06/10/1972 7,320	05/27/1996 3,830	06/21/1947 2,640	05/26/1997 2,380	05/21/1962 2,030	June 9–12
56	06421750	Rapid Creek tributary near Farmingdale, S. Dak.	1.63	1970–79	10	04/25/1970 35	06/15/1976 18	03/25/1971 10	03/23/1973 10	04/28/1975 10	03/12/1972 8
57	06421800	Lindsey Draw near Farming-dale, S. Dak.	12.8	1998–2009	12	06/05/2008 710	04/26/2009 392	04/29/2000 370	05/12/2005 200	06/12/1999 195	NRA
58	06422500	Boxelder Creek near Nemo, S. Dak.	94.4	1907, 1946–47, 1966–2009	47	06/09/1972 30,100	06/12/1907 16,000	06/15/1976 1,460	05/02/1946 1,180	05/09/1995 1,140	June 9–12
59	06423010	Boxelder Creek near Rapid City, S. Dak.	127	[8]1904–05, [8]1946–47, 1981–2009	29	05/02/1946 1,320	05/10/1995 1,080	05/31/1996 1,060	07/02/1905 650	06/05/1904 620	NRA
60	06423500	Cheyenne River near Wasta, S. Dak.	[1]12,725	1915, 1929–32, 1934–2009	81	05/06/1932 46,300	05/12/1942 44,000	06/01/1935 43,000	06/22/1947 40,100	06/13/1915 34,200	06/11/1972 11,800
61	06424000	Elk Creek near Roubaix, S. Dak.	21.6	1946–47, 1992–2009	18	05/08/1995 515	05/02/1946 378	08/06/2008 300	05/22/1947 218	04/07/1997 200	NRA
62	06425100	Elk Creek near Rapid City, S. Dak.	211	1979–2009	31	05/27/1996 3,120	05/09/1995 2,860	04/13/2009 2,400	06/06/2008 2,390	05/20/1982 1,560	NRA
63	06425500	Elk Creek near Elm Springs, S. Dak.	549	1950–2009	60	03/29/1952 8,540	05/28/1996 7,660	05/29/1962 7,040	06/06/2008 7,000	06/08/1994 5,570	06/11/1972 1,880

Table 9. Station information and listing of five largest annual peak flows during selected periods for selected streamflow-gaging stations with 10 or more years of peak-flow record, and peak flows recorded during water year 1972, but outside of the five largest.—Continued

[Data from U.S. Geological Survey (2009). 1972 column: NRA, no records available for 1972; Other 1972, annual peak flow occurred outside of June 9–12, 1972, and is one of the five largest peak flows for the station through water year 2009; June 9–12, annual peak flow occurred during June 9–12, 1972, and is one of the five largest peak flows for the station through water year 2009; OPORC, 1972 is outside of the period of record considered for the station; --, not available]

Map number (fig. 5)	Station number	Station name	Drainage area[1] (square miles)	Period and number of years considered		Date of annual peak flow and annual peak flow (cubic feet per second)					
				Period of record (water years)[2]	Number of years	Largest	Second largest	Third largest	Fourth largest	Fifth largest	1972
64	06428500	Belle Fourche River at Wyoming-South Dakota State line	[1]3,248	1947–2009	63	05/10/1995 6,320	06/06/2008 5,190	03/14/1996 5,050	06/30/1993 4,550	06/18/1962 4,400	06/19/1972 2,330
65	06429500	Cold Springs Creek at Buckhorn, Wyo.	22.4	1976–82, 1991–2009	26	03/26/1999 42	04/11/2003 30	04/23/2006 19	04/01/1981 13	04/22/1980 12	NRA
66	06429905	Sand Creek near Ranch A near Beulah, Wyo.	275	1975–83, 1991–2009	28	05/08/1995 1,230	06/15/1976 700	05/16/1982 514	06/01/2007 294	06/06/2008 255	NRA
67	06430500	Redwater Creek at Wyoming-South Dakota State line	481	1929–31, 1936–37, 1955–2009	60	08/22/1973 2,440	06/16/1962 2,340	07/17/1937 2,000	06/16/1984 1,960	05/09/1995 1,640	06/20/1972 251
68	06430532	Crow Creek near Beulah, Wyo.	40.8	1992–2009	18	06/05/2008 561	05/09/1995 530	06/18/1998 389	06/01/2007 326	06/08/1993 178	NRA
69	06430770	Spearfish Creek near Lead, S. Dak.	65.0	1989–2009	21	08/20/1998 181	05/08/1995 144	06/12/1999 132	07/24/1997 90	05/11/2000 75	NRA
70	06430800	Annie Creek near Lead, S. Dak.	3.73	1989–2009	21	05/08/1995 270	06/01/2007 151	06/18/1998 144	06/06/2008 56	04/06/1997 44	NRA
71	06430850	Little Spearfish Creek near Lead, S. Dak.	27.8	1989–2009	21	06/11/1999 90	05/10/1995 61	05/30/1996 45	06/18/1998 44	05/02/1997 36	NRA
72	06430898	Cleopatra Creek near Spearfish, S. Dak.	7.32	1989–2009	21	05/08/1995 860	06/01/2007 350	06/06/2008 313	06/18/1998 199	09/23/2006 101	NRA
73	06431500	Spearfish Creek at Spearfish, S. Dak.	165	1904, 1947–2001	56	06/05/1904 5,000	05/15/1965 4,240	06/15/1976 3,870	06/09/1964 3,040	05/22/1982 2,110	05/13/1972 163
74	06432200	Polo Creek near Whitewood, S. Dak.	10.2	1956–72	17	04/14/1967 1,700	05/14/1965 1,060	06/09/1964 794	06/19/1972 550	06/12/1970 370	Other 1972
75	06432230	Miller Creek near Whitewood, S. Dak.	5.05	1956–67	12	05/14/1965 330	06/09/1964 275	05/22/1962 180	07/02/1958 127	04/29/1963 64	NRA
76	06433000	Redwater River above Belle Fourche, S. Dak.	930	1946–2001	64	06/16/1962 16,400	05/15/1965 8,480	05/20/1982 6,920	06/15/1976 6,780	06/06/2008 5,440	06/18/1972 1,200

Table 9. Station information and listing of five largest annual peak flows during selected periods for selected streamflow-gaging stations with 10 or more years of peak-flow record, and peak flows recorded during water year 1972, but outside of the five largest.—Continued

[Data from U.S. Geological Survey (2009). 1972 column: NRA, no records available for 1972; Other 1972, annual peak flow occurred outside of June 9–12, 1972, and is one of the five largest peak flows for the station through water year 2009; June 9–12, annual peak flow occurred during June 9–12, 1972, and is one of the five largest peak flows for the station through water year 2009; OPORC, 1972 is outside of the period of record considered for the station; --, not available]

Map number (fig. 5)	Station number	Station name	Drainage area[1] (square miles)	Period and number of years considered		Date of annual peak flow and annual peak flow (cubic feet per second)					
				Period of record (water years)[2]	Number of years	Largest	Second largest	Third largest	Fourth largest	Fifth largest	1972
77	06433500	Hay Creek at Belle Fourche, S. Dak.	123	1954–96, 2008	44	06/06/2008 1,400	05/09/1995 1,280	06/19/1972 930	05/20/1982 926	06/15/1976 654	Other 1972
78	06434800	Owl Creek tributary near Belle Fourche, S. Dak.	2.98	1970–79	10	06/15/1976 267	06/10/1972 102	10/01/1977 73	06/17/1979 59	05/26/1905 50	June 9–12
79	06435500	Belle Fourche River near Belle Fourche, S. Dak.	[1]4,387	1924–43	18	04/09/1924 22,400	04/08/1929 15,000	03/12/1928 9,660	06/10/1941 8,960	05/13/1927 8,250	NRA
80	06436000	Belle Fourche River near Fruitdale, S. Dak.	[1]4,520	1946–2009	64	05/20/1982 12,700	06/15/1976 12,200	05/10/1995 12,200	06/06/2008 8,700	05/15/1965 8,100	06/19/1972 6,270
81	06436156	Whitetail Creek at Lead, S. Dak.	6.59	1989–2009	21	05/08/1995 507	06/18/1998 210	06/01/2007 188	07/24/1997 180	06/05/2008 125	NRA
82	06436170	Whitewood Creek at Deadwood, S. Dak.	40.7	1982–95	14	05/08/1995 3,540	05/15/1982 2,660	06/05/1991 2,500	07/20/1993 2,120	05/07/1983 715	NRA
83	06436180	Whitewood Creek above Whitewood, S. Dak.	56.7	1983–2009	27	05/08/1995 3,800	06/05/1991 2,080	06/18/1998 1,500	06/01/2007 1,410	06/06/2008 1,220	NRA
84	06436190	Whitewood Creek near Whitewood, S. Dak.	77.5	1982–2009	28	05/08/1995 3,930	05/20/1982 3,050	09/24/1986 2,490	06/18/1998 2,380	06/05/2008 1,850	NRA
85	06436198	Whitewood Creek above Vale, S. Dak.	102	1983–2009	27	06/05/2008 4,500	05/08/1995 4,250	09/24/1986 3,680	06/18/1998 2,690	05/05/1993 2,520	NRA
86	06436700	Indian Creek near Arpan, S. Dak.	313	1962–81	20	06/15/1976 16,700	05/08/1978 4,410	05/08/1967 2,690	05/26/1972 2,210	06/27/1975 1,940	Other 1972
87	06436760	Horse Creek above Vale, S. Dak.	461	1981–2009	29	05/21/1982 17,700	06/06/2008 15,100	05/10/1995 8,110	05/10/1986 7,410	05/28/1996 6,600	NRA
88	06436800	Horse Creek near Vale, S. Dak.	522	1962–80	19	06/16/1976 11,600	03/22/1978 3,540	05/26/1965 2,380	05/24/1962 2,280	10/04/1971 2,160	NRA
89	06437000	Belle Fourche River near Sturgis, S. Dak.	[1]5,821	1946–2008	64	05/21/1982 36,400	06/06/2008 36,100	05/10/1995 20,000	04/13/2009 19,700	06/15/1976 19,100	06/10/1972 7,060
90	06437020	Bear Butte Creek near Deadwood, S. Dak.	15.8	1989–2009	21	05/08/1995 1,590	06/05/1991 938	04/06/1997 350	05/30/1996 264	06/01/2007 256	NRA

Table 9. Station information and listing of five largest annual peak flows during selected periods for selected streamflow-gaging stations with 10 or more years of peak-flow record, and peak flows recorded during water year 1972, but outside of the five largest.—Continued

[Data from U.S. Geological Survey (2009). 1972 column: NRA, no records available for 1972; Other 1972, annual peak flow occurred outside of June 9–12, 1972, and is one of the five largest peak flows for the station through water year 2009; June 9–12, annual peak flow occurred during June 9–12, 1972, and is one of the five largest peak flows for the station through water year 2009; OPORC, 1972 is outside of the period of record considered for the station; --, not available]

Map number (fig. 5)	Station number	Station name	Drainage area[1] (square miles)	Period and number of years considered		Date of annual peak flow and annual peak flow (cubic feet per second)					
				Period of record (water years)[2]	Number of years	Largest	Second largest	Third largest	Fourth largest	Fifth largest	1972
91	06437100	Boulder Creek near Deadwood, S. Dak.	1.36	1956–80	25	06/14/1976 323	06/15/1962 210	06/12/1970 206	05/14/1965 202	06/09/1964 179	06/09/1972 59
92	06437200	Bear Butte Creek near Galena, S. Dak.	52.1	1972, [9]1998–2008	12	06/09/1972 19,000	06/06/2008 697	06/02/2007 545	06/18/1998 541	04/25/2000 199	June 9–12
93	06437500	Bear Butte Creek near Sturgis, S. Dak.	181	1946–72, 1990–2009	47	06/16/1962 12,700	05/24/1946 9,800	06/10/1972 7,220	06/06/2008 5,920	05/08/1995 4,310	June 9–12
94	06438000	Belle Fourche River near Elm Springs, S. Dak.	[1]7,029	1929–32, 1934–2009	81	06/06/2008 47,500	06/08/1964 45,100	05/21/1982 40,300	05/27/1996 39,900	05/28/1962 37,900	06/11/1972 9,810
95	06438500	Cheyenne River near Plainview, S. Dak.	[1]21,425	1951–81, 1995–2009	46	06/07/2008 73,200	05/28/1996 69,700	05/26/1957 41,700	03/30/1952 41,400	05/22/1962 38,600	06/11/1972 14,600
96	06439300	Cheyenne River at Cherry Creek, S. Dak.	[1]23,643	1961–94	34	05/22/1982 55,900	06/16/1967 43,800	05/09/1993 39,200	05/26/1965 38,400	05/23/1962 36,500	06/12/1972 17,000
97	06439500	Cheyenne River near Eagle Butte, S. Dak.	[1]24,311	1929–67, 2007–08	41	05/24/1933 104,000	06/07/2008 84,300	07/13/1937 64,400	06/11/1941 59,000	05/07/1932 53,000	NRA

[1]Includes entire drainage area, regardless of effects of regulation. Footnoted drainage areas are affected by one or more regulating structures or diversions listed in table 1 of Sando and others (2008).

[2]Includes entire period of available record, unless otherwise noted.

[3]Includes only records before construction of Coldbrook Dam.

[4]Includes only records subsequent to construction of Coldbrook Dam.

[5]Records for station 06404998 include records for station 06405000 (Grace Coolidge Creek near Custer, S. Dak.).

[6]Includes only records before construction of Pactola Dam.

[7]Includes only records subsequent to construction of Pactola Dam.

[8]Records for station 06423010 include records for station 06423000 (Boxelder Creek at Blackhawk, S. Dak.).

[9]Period of record for station extends through 2009; however, magnitude of 2009 peak has not been determined and is not considered within this table.

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.

[All locations in South Dakota unless otherwise specified. Peak of record flow is the maximum instantaneous peak flow that has been recorded for the period of record for the streamflow-gaging station. Relative magnitude of event: 1, extreme; 2, severe; 3, moderate; 4, minor; 5, very minor; ft^3/s, cubic feet per second; USGS, U.S. Geological Survey; X, indicates applicable magnitude; --, not applicable or unknown]

Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
July 13, 1877	July 13, 1877	--	--	--	--	X	Whitewood Creek	--
Apr. 16–17, 1878	Apr. 18, 1878	--	--	--	--	X	Rapid Creek	--
May 1878	May 22–23, 1878	--	--	--	X	X	Rapid Creek	Whitewood and Deadwood Creeks
--	June 10–11, 1878	--	--	X	--	--	Rapid Creek	--
--	1878	--	--	--	--	--	Whitewood Creek	Deadwood Creek
--	Apr.–June 1878	--	--	X	--	--	Rapid Creek	Whitewood Creek
--	July 12, 1878	--	--	--	--	X	Whitewood Creek	--
--	July 12, 1878	--	--	--	--	X	Rapid Creek	--
June 12, 1879	June 12–13, 1879	--	X	X	--	--	Beaver Creek	--
June 10, 1879	June 10–11, 1879	--	--	--	--	X	Rapid Creek	--
June 1879	June 1879	--	X	X	--	--	Beaver Creek	--
June 1879	June 1879	--	X	X	--	--	Beaver Creek	--
June 1879	June 1879	--	X	X	--	--	Beaver Creek	--
Mar. 4–5, 1882	Mar. 5, 1882	--	--	--	--	X	--	--
Apr. 1882	Apr. 1882	--	--	--	--	X	Cheyenne River	--
May 7, 1882	May 7, 1882	--	--	--	X	X	Spring Creek	--
July 5, 1882	July 5, 1882	--	--	--	X	X	Rapid Creek	--
July 5, 1882	July 5, 1882	--	--	--	X	X	Rapid Creek	--
July 28, 1882	July 28, 1882	--	--	--	X	--	Redwater River	--
May 1883	May 11, 1883	--	--	X	--	--	Whitewood Creek	Spearfish Creek
May 17–18, 1883	May 18–19, 1883	--	--	--	--	--	--	--
--	May 16, 1883	--	--	X	X	--	Whitewood Creek	--

Primary town or area	Secondary town or area	Description of event	Source of information[1]
Deadwood	--	Damage reported to roads and cabins from biggest storm yet chronicled in the Black Hills.	Black Hills Daily Times (July 13, 1877).
Rapid City	--	High water reported for Rapid Creek, with some damage in Rapid City.	Black Hills Journal (Apr. 20, 1878).
Rapid City	Deadwood	Flooding occurred in Rapid City and Deadwood.	Black Hills Journal (May 25, 1878).
Rapid City	--	Peak flow of 7,500 ft^3/s for Rapid Creek for June 10–11, 1878. Three other smaller floods reported during 1878.	Miller (1986).
Deadwood	--	Substantial flooding occurred on unknown date. Very heavy snows reported during winter months.	Tallent (1899).
Rapid City	Deadwood/Lead	Minor damage reported for April, May, and June 1878.	National Oceanic and Atmospheric Administration (2008).
Deadwood/Lead	--	Freight train (10 ox wagons) washed downstream.	National Oceanic and Atmospheric Administration (2008).
Rapid City	--	Rapid Creek rose 10 feet and one life was lost. Unclear if date was July 12 or June 10–11, 1878.	National Oceanic and Atmospheric Administration (2008).
Buffalo Gap	--	Eleven deaths reported from flooding along Beaver Creek near Buffalo Gap.	Black Hills Journal (June 14, 1879).
Rapid City	--	Flood damage reported in Rapid City area.	Black Hills Journal (June 15, 1879).
Buffalo Gap	--	Six bodies recovered from the flood near Buffalo Gap.	Black Hills Daily Times (June 17, 1879).
Buffalo Gap	--	Five victims still missing from flood near Buffalo Gap.	Black Hills Daily Times (June 18, 1879).
Buffalo Gap	--	At least four victims reported missing in flood near Buffalo Gap.	Black Hills Journal (June 21, 1879).
--	--	Northwestern coaches on Pierre Road delayed.	Black Hills Journal (Mar. 10, 1882).
--	--	Cheyenne River reported as being high for several days.	Black Hills Journal (Apr. 28, 1882).
--	--	Two reservoirs washed out along Spring Creek (near current location of Sheridan Lake).	Black Hills Journal (May 12, 1882).
--	--	Rapid Creek rose 5 feet in one-half hour. Same flood as reported by Miller (1986).	Black Hills Journal (July 7, 1882).
Rapid City	--	Rapid Creek rose 5 feet in one-half hour.	Miller (1986).
--	--	Storm reported as severe beyond precedent. Caused rise of 25 feet in confined places along Redwater River. Damage to crops and stock reported.	Black Hills Journal (Aug. 4, 1882).
Deadwood, Spearfish	Pennington	Heavy damage reported for Deadwood. About one-third of Spearfish washed away.	Deadwood Pioneer Times (May 18, 1883).
Deadwood	--	This 1907 article recounted events of the 1883 flood in Deadwood.	Deadwood Pioneer Times (May 19, 1907).
Deadwood	--	Photographs of Deadwood flood.	Adams Museum, Deadwood, S. Dak.

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

[All locations in South Dakota unless otherwise specified. Peak of record flow is the maximum instantaneous peak flow that has been recorded for the period of record for the streamflow-gaging station. Relative magnitude of event: 1, extreme; 2, severe; 3, moderate; 4, minor; 5, very minor; ft^3/s, cubic feet per second; USGS, U.S. Geological Survey; X, indicates applicable magnitude; --, not applicable or unknown]

Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
May 1883	May 17, 1883	--	--	X	X	--	Rapid Creek	--
May 1883	May 11, 1883	--	--	X	X	--	Rapid Creek	Whitewood Creek
May 17, 1883	May 18, 1883	--	--	X	X	--	Whitewood Creek	--
May 17–18, 1883	May 17–18, 1883	--	--	--	X	X	Spearfish Creek	--
May 17–18, 1883	May 17–18, 1883	--	--	--	X	X	Spearfish Creek	--
--	May 17, 1883	--	--	X	X	--	Whitewood Creek	--
May 17–18, 1883	May 17, 1883	--	--	X	X	--	Whitewood and Rapid Creeks	Elk, Boxelder, Castle, Spring, and Battle Creeks
May 17–18, 1883	May 17–18, 1883	--	--	--	X	X	Spearfish Creek	--
May 1883	May 1883	--	--	--	--	--	Numerous - Black Hills wide	--
June 15, 1883	June 15, 1883	--	--	X	X	--	Rapid Creek	Boxelder and Elk Creeks
--	Aug. 27, 1884	--	X	X	X	--	Fall River	--
June 17, 1885	June 17, 1885	--	--	--	--	X	Rapid Creek	--
June 17, 1885	June 17, 1885	--	--	--	--	X	Castle Creek	--

Primary town or area	Secondary town or area	Description of event	Source of information[1]
Rapid City	--	Peak flow of 8,400 ft^3/s occurred on Rapid Creek on May 17, 1883. Torrential rain and snowmelt occurred.	Miller (1986).
Rapid Valley	Deadwood	Considerable damage reported for Rapid Valley and in Deadwood.	Black Hills Journal (May 18, 1883).
Deadwood	--	Reported rising water from snow melt. Paragraph refers to a lengthier article.	Black Hills Daily Times (May 18, 1883).
Spearfish	--	Lower part of Spearfish reported to be flooded.	Black Hills Daily Times (May 20, 1883).
Spearfish	--	Heavy rainfall reported with flooding in Spearfish Creek.	Dakota Register (May 19, 1883).
Deadwood	--	Aftermath of Deadwood flood described. Article attributes exacerbation of flooding to accumulation of mine tailings in stream channels.	Black Hills Daily Times (May 20, 1883).
Deadwood, Rapid City	--	Severe flood destroyed most low-lying areas in Deadwood. Elk Creek was high, but minimal damage. Boxelder and Spring Creeks were higher than ever known. Probably the largest known flood to date in Rapid City (see Miller, 1986) with flooding reported along Castle Creek. Battle Creek reported as high. Cheyenne River reported at unprecedented height.	Black Hills Journal (May 25, 1883).
Spearfish	--	Article described flood damage in Spearfish Creek as worst in the brief history of the town, but not as bad as things might have been.	Dakota Register (May 26, 1883).
--	--	Article described heavy extended rain covering entire Black Hills area, with flooding throughout the entire region. Heavy floods reported for Rapid and Hat Creeks and that "water extended from bluff to bluff" on the Cheyenne River downstream from the Belle Fourche River.	Johnson (1949).
Rapid City	--	Very heavy storm occurred "5 to 8 miles west of the foothills." Rapid Creek reported as larger than in previous years, but May 17–18, 1883, not referenced. Very high flows reported along Boxelder and Elk Creeks, with substantial damage.	Black Hills Weekly Journal (June 22, 1883).
Hot Springs	--	The design document for Cottonwood Springs Dam indicates a report from "pioneer residents" of a peak stage in 1884 that was 6 feet higher than the 1938 flood. The design document for Cold Brook Dam indicates historical high-water marks for the same 1884 date that are 7 feet higher than in 1937, with the 1937 flow shown as about 15 percent larger than the 1938 flow.	U.S. Army Corps of Engineers (1950, 1966).
Rapid City	--	Heavy rain caused Rapid Creek to rise out of its banks.	Black Hills Weekly Journal (June 19, 1885).
--	--	Some bridges destroyed upstream from confluence with Rapid Creek.	Rapid City Journal (June 19, 1885).

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

[All locations in South Dakota unless otherwise specified. Peak of record flow is the maximum instantaneous peak flow that has been recorded for the period of record for the streamflow-gaging station. Relative magnitude of event: 1, extreme; 2, severe; 3, moderate; 4, minor; 5, very minor; ft^3/s, cubic feet per second; USGS, U.S. Geological Survey; X, indicates applicable magnitude; --, not applicable or unknown]

Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
June 20, 1885	June 20, 1885	--	--	--	--	X	Spearfish Creek	--
1885	1885	--	--	--	--	--	--	Rapid, Boxelder, and Elk Creeks
June 2, 1886	June 2, 1886	--	--	--	--	X	Unknown	--
July 12, 1886	July 12, 1886	--	--	--	--	X	Rapid Creek	--
--	July 30, 1886	--	--	--	--	--	Rapid Creek	--
May 1888	May 1888	--	--	--	--	X	Spring Creek	--
May 1888	May 1888	--	--	--	--	X	Unknown	--
May 1888	May 1888	--	--	--	--	X	Unknown	--
May 1888	--	--	--	--	--	--	--	--
Apr. 17, 1889	Apr. 19, 1889	--	--	--	--	X	Rapid Creek	--
July 18,19, 1889	July 19,20, 1889	--	--	--	--	X	--	--
Aug. 10, 1889	Aug. 10, 1889	--	--	--	--	X	Battle Creek	French and Battle Creeks
1890	1890	--	--	--	--	X	Gold Run Creek	--
--	Jan. 1890	--	--	--	--	X	Whitewood Creek	--
June 4–5, 1890	June 5, 1890	--	--	--	--	X	City and Whitewood Creeks	--
June 4–5, 1890	June 5, 1890	--	--	--	--	X	Whitewood Creek	--
June 4–5, 1890	June 5, 1890	--	--	--	--	X	Whitewood Creek	--
--	June 6, 1890	--	--	--	--	X	Whitewood Creek	Spearfish Creek
May and Aug. 1890	May and Aug. 1890	--	--	--	--	X	Various	Various
Aug. 10, 1890	Aug. 10, 1890	--	--	--	--	X	Rapid Creek	--
Aug. 10, 1890	Aug. 10, 1890	--	--	--	--	X	Rapid Creek	--
--	--	--	--	--	--	--	Numerous - Black Hills wide	--
May 31, 1891	June 1, 1891	--	--	--	X	--	Whitewood Creek	Fall River

Primary town or area	Secondary town or area	Description of event	Source of information[1]
Spearfish	--	Wave of water 4 to 6 feet high flooded Spearfish Creek.	Black Hills Daily Times (June 28, 1885).
--	--	More than $25,000 in flood damage reported. Date not specified, perhaps June 17, as reported by other news articles dated June 19, 1885.	National Oceanic and Atmospheric Administration (2008).
--	--	Several bridges washed out and other flood damage reported between Rapid City and Deadwood.	Rapid City Journal (June 8, 1886).
--	--	Sheriff waded Rapid Creek to catch woman who was later fined for indecent exposure.	Rapid City Journal (July 13, 1886).
Rapid City	--	One man drowned along Rapid Creek.	Miller (1986).
--	--	Spring Creek reported as being higher than ever before known.	Rapid City Journal (May 23, 1888).
--	--	Train tracks damaged near Chadron, Neb.	Rapid City Journal (May 27, 1888).
--	--	Another article that reported damaged train tracks.	Rapid City Journal (June 1, 1888).
--	--	Total precipitation in May was 6.01 inches (presumably in Rapid City).	Rapid City Journal (June 2, 1888).
--	--	Minor localized flooding of cellars and yards reported.	Rapid City Journal (Apr. 19, 1889).
Deadwood	Rapid City	Minor localized flooding reported for Deadwood.	Rapid City Journal (July 20, 1889).
--	--	Large storm system south and east of Rapid City caused widespread (minor) flooding.	Rapid City Journal (Aug. 13, 1889).
Deadwood	--	Photograph of the Deadwood Central Railroad tracks after the 1890 washout by Gold Run Creek	Fielder (1964)
Deadwood	--	Whitewood Creek reported as being out of its banks.	Rapid City Journal (Jan. 31, 1890).
Deadwood	--	Localized flooding in Deadwood and high water along Whitewood Creek reported.	Rapid City Journal (June 6, 1890).
Deadwood	--	Continued flooding reported for Whitewood Creek in Deadwood.	Rapid City Journal (June 7, 1890).
Deadwood	--	Reported that rain fell for 24 hours. Article indicated that storm was Black Hills wide.	Black Hills Daily Times (June 6, 1890).
Deadwood	Spearfish, Sturgis	Flow subsided in Whitewood Creek. Three dams at Spearfish went out with flood.	Black Hills Daily Times (June 7, 1890).
Various	Various	Various flooding reported for Deadwood and Rapid City.	National Oceanic and Atmospheric Administration (2008).
Rapid City	--	Minor localized flooding reported for Rapid City area.	Miller (1986).
Rapid City	--	Minor localized flooding reported for Rapid City area. Same event as reported by Miller (1986).	Rapid City Journal (Aug. 12, 1890).
--	--	1890 is noted with 1883 and 1907 as a year of “hills-wide” flooding.	South Dakota Historical Society (1960).
Deadwood, Lead	Hot Springs	Severe flood damage reported for Gold Run Gulch. Hot Springs area also had storm and flood damage.	Rapid City Journal (June 2, 1891).

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

[All locations in South Dakota unless otherwise specified. Peak of record flow is the maximum instantaneous peak flow that has been recorded for the period of record for the streamflow-gaging station. Relative magnitude of event: 1, extreme; 2, severe; 3, moderate; 4, minor; 5, very minor; ft³/s, cubic feet per second; USGS, U.S. Geological Survey; X, indicates applicable magnitude; --, not applicable or unknown]

Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
June 1892	June 1892	--	--	--	--	X	Various	Various
June 1892	June 1892	--	--	--	--	X	Various	Various
June 4–5, 1892	--	--	--	--	--	--	--	--
--	--	--	--	--	--	X	Various	Various
July 1892	July 1892	--	--	--	--	X	Beaver Creek	--
--	Mar. 1893	--	--	--	--	X	Belle Fourche River	Redwater River
Aug. 9, 1893	Aug. 9, 1893	--	--	--	X	X	Spring Creek	--
Apr. 30, 1895	Apr. 30, 1895	--	--	--	--	X	--	--
June 1895	June 1895	--	--	--	--	X	Indian Creek	--
June 22, 1895	June 22, 1895	--	--	--	--	X	Bear Butte Creek	--
July 22, 1895	July 22, 1895	--	--	--	--	X	--	--
July 22, 1895	July 22, 1895	--	--	--	X	--	Fall River	--
July 30, 1895	July 30, 1895	--	--	X	X	--	Spearfish Creek	--
May 1896	May 1896	--	--	--	X	--	Sand Creek	--
June 1896	June 1896	--	--	--	--	X	Battle Creek	--
June 6, 1896	June 6, 1896	--	--	--	X	X	French Creek	Various
June 6, 1896	June 6, 1896	--	--	--	X	X	--	--
June 6, 1896	June 6, 1896	--	--	--	X	X	Spring Creek	--
June 6, 1896	June 6, 1896	--	--	--	X	X	Middle Creek	Various
June 6, 1896	June 8, 1896	--	--	--	X	X	Spring and Battle Creeks	--

Primary town or area	Secondary town or area	Description of event	Source of information[1]
--	--	Rail damaged between Rapid City and Chadron, Neb. Rail damaged on way to Deadwood also.	Rapid City Journal (June 7, 1892).
--	--	Flood damaged railroads and roads on June 6, 1892. Prolonged rainfall reported 6 days later.	National Oceanic and Atmospheric Administration (2008).
Rapid City	--	Rain total for year “has been greater than in any previous year” since record keeping began.	Rapid City Journal (June 9, 1892).
--	--	Rail damaged near Oelrichs. Probably coincides with large flood along Horsehead Creek (approximately June 11–12, 1892) that was referenced in the Oelrichs Advocate article of June 17, 1915).	Rapid City Journal (June 17, 1892).
--	--	Bridges over Beaver Creek washed out (between Buffalo Gap and Hot Springs).	Rapid City Journal (July 4, 1892).
Belle Fourche	--	Belle Fourche River rose about 15 feet, taking out one span of the railroad bridge.	Rapid City Journal (Apr. 1, 1893).
--	--	Crops damaged along Spring Creek and heavy storm in Hermosa area.	Rapid City Journal (Aug. 10, 1893).
--	--	Train delayed from railroad washout east of Hay Springs, Neb.	Rapid City Journal (May 1, 1895).
--	--	Heavy rains caused high flows north of Belle Fourche.	Rapid City Journal (June 6, 1895).
Sturgis	Deadwood	Heavy rains and hail with flooding reported in and around Sturgis.	Rapid City Journal (June 23, 1895).
Hot Springs	--	Damage reported to rail yard, track, and bridges in Hot Springs.	Rapid City Journal (July 23, 1895).
Hot Springs	--	Article described “unprecedented” storm for Hot Springs area. Bridges destroyed during flooding.	Twomey and Magee (1983).
Spearfish	--	Spearfish Creek reported as highest since 1883 due to heavy rain upstream from Spearfish.	Rapid City Journal (Aug. 1, 1895).
Oelrichs	--	Damage along Sand Creek (north of Oelrichs) was reported as worst suffered to date by Elkhorn Railroad in the Black Hills area.	Rapid City Journal (May 10, 1896).
Keystone	--	Localized flooding reported along Battle Creek in Keystone from heavy rain.	Rapid City Journal (June 6, 1896).
--	--	Rail line damaged south of Rapid City. Worst damage near Fairburn.	Rapid City Journal (June 7, 1896).
--	--	Another report provided of rail damage south of Rapid City from flood on June 6, 1896.	Black Hills Press (June 9, 1896).
--	--	Irrigation dam damaged along Spring Creek.	Rapid City Journal (June 9, 1896).
Belle Fourche	--	Woman drowned in Middle Creek near Belle Fourche. Additional information provided on rail damage south of Rapid City.	Rapid City Journal (June 9, 1896).
--	--	Bridges destroyed along Spring and Battle Creeks by continued rain and flooding.	Rapid City Journal (June 9, 1896).

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

[All locations in South Dakota unless otherwise specified. Peak of record flow is the maximum instantaneous peak flow that has been recorded for the period of record for the streamflow-gaging station. Relative magnitude of event: 1, extreme; 2, severe; 3, moderate; 4, minor; 5, very minor; ft³/s, cubic feet per second; USGS, U.S. Geological Survey; X, indicates applicable magnitude; --, not applicable or unknown]

Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
June 6, 1896	June 6, 1896	--	--	--	X	X	Various	--
June 1896	June 1896	--	--	--	--	X	Fall River	--
July 1896	July 1896	--	--	--	--	X	--	--
Sept. 12, 1896	Sept. 12, 1896	--	--	--	X	--	Fall River	--
Mar. 31, 1897	Mar. 31, 1897	--	--	--	X	X	Belle Fourche River	--
June 1897	June 1897	--	--	--	--	X	--	--
June 1897	June 1897	--	--	--	--	X	Dry Creek	--
Aug. 6–7, 1897	Aug. 6–7, 1897	--	--	--	X	--	Fall River	--
Aug. 6, 1897	Aug. 6–7, 1897	--	--	--	X	--	Fall River	--
1897	1897	--	--	--	X	--	Fall River	--
May 29, 1898	May 30, 1898	--	--	--	--	X	Battle Creek	Grizzly Gulch
May 25, 1898	May 25, 1898	--	--	--	--	X	Boxelder Creek	--
May 19,20, 1899	May 21, 1899	--	--	--	--	X	Rapid Creek	Various
June 2, 1899	--	--	--	--	--	X	--	--
June 1, 1899	June 1–2, 1899	--	--	--	--	X	Rapid Creek	Spring Creek, many others
June 2, 1899	June 2, 1899	--	--	--	--	X	Rapid Creek	--
June 11, 1901	June 11, 1901	--	--	--	--	X	Rapid Creek	--
June 10–11, 1901	June 11, 1901	--	--	--	X	X	Hay Creek	Redwater and Belle Fourche Rivers
June 1901	June 1901	--	--	--	X	X	Various	Various

Primary town or area	Secondary town or area	Description of event	Source of information[1]
--	--	Railroad washouts reported south of Rapid City (north and south of Cheyenne River).	Rapid City Journal (June 11, 1896).
Hot Springs	--	Short account provided of several heavy storms and minor flooding in Hot Springs.	Twomey and Magee (1983).
--	--	Rail damage reported south of Rapid City.	Rapid City Journal (July 9, 1896).
Hot Springs	--	Heavy rain and hail reported. Flood damage was less extensive than from several previous floods.	Hot Springs Weekly Star (April 18, 1946 reprint of Sept. 18, 1896 article).
Belle Fourche, Newcastle, Edgemont, Spearfish, Deadwood	--	Belle Fourche River reported higher than ever before known. Water backed up 10 miles from ice jam.	Rapid City Journal (Apr. 1, 1897).
Belle Fourche	--	Cloudburst at Belle Fourche caused problems for camped troops.	Rapid City Journal (June 26, 1897).
--	--	One person drowned along or near Dry Creek (location unknown).	Rapid City Journal (June 26, 1897).
Hot Springs	--	Largest flood reported to date in Hot Springs history. Most bridges on Fall River destroyed.	Daily Independent-Deadwood (Aug. 7, 1897).
Hot Springs	--	Same flood as reported by Daily Independent (Aug. 7, 1897) above. Reported that “never in the history of Hot Springs have the ravages of high water been so serious as this year,” with additional accounts provided that indicate that this flood probably was the most severe in many years.	Hot Springs Weekly Star (April 18, 1946 reprint of Aug. 13, 1897 article).
Hot Springs	--	Statue at Hygeia Springs was destroyed. Same as reported by Daily Independent (Aug. 7, 1897) and Hot Springs Weekly Star (August 13, 1897) above.	Twomey and Magee (1983).
--	--	Bridges along Battle Creek were washed out.	Rapid City Journal (May 30, 1898).
--	--	Cloudburst and flooding reported along lower Boxelder Creek.	Rapid City Journal (May 28, 1898).
Rapid City	--	Very wet conditions reported for Rapid City. Some bridges were out to west and south.	Rapid City Journal (May 21, 1899).
Rapid City	--	Heavy rains occurred in Rapid City. Area trains were delayed.	Rapid City Journal (June 3, 1899).
--	--	Loss of cattle reported along lower Rapid Creek.	Rapid City Journal (June 4, 1899).
Farmingdale	--	House washed away along lower Rapid Creek.	Rapid City Journal (June 10, 1899).
Rapid City	--	Small rise in Rapid Creek occurred west of Rapid City.	Rapid City Journal (June 12, 1901).
Belle Fourche	--	Hay Creek was reported as the highest ever known to date. All streams near Belle Fourche reported to be high.	Rapid City Journal, Belle Fourche Bee (June 13, 1901).
Belle Fourche	Various	All streams north of Belle Fourche reported to be high.	Rapid City Journal, Pioneer Times (June 13, 1901).

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

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Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
June 1901	June 1901	--	--	--	X	X	Redwater	Various
June 19, 1901	June 19, 1901	--	--	--	--	X	--	--
June 19, 1901	June 19, 1901	--	--	--	--	X	--	--
June 19, 1901	June 19, 1901	--	--	--	--	X	Deadman Creek	--
--	July 22, 1901	--	--	--	--	X	Rapid Creek	--
--	July 1901	--	--	X	--	--	Cascade Creek	--
June 1904	June 5, 1904	--	--	X	--	--	Spearfish Creek	--
June 1904	June 5, 1904	--	--	X	--	--	Redwater River	--
June 4–5, 1904	June 4,5, 1904	--	--	X	X	--	Spearfish Creek	Beaver, Sand, Crow, Iron, and Whitewood Creeks
June 4–6, 1904	Apr.–June 1904	--	--	X	X	--	Bear Butte Creek	Various
June 8, 1904	Aug. 1904	--	--	--	X	X	Whitewood Creek	--
June 8, 1904	Aug. 1904	--	--	--	X	X	Whitewood Creek	Various
June 9, 1905	June 9, 1905	--	--	--	--	X	Fall River	Various
June 9, 1905	June 9, 1905	--	--	--	X	--	Fall River	--
June 17, 1905	June 17, 1905	--	--	--	X	--	Fall River	--
June 1905	June 9 and 17, 1905	--	--	--	X	--	Fall River	--
June 17, 1905	June 17, 1905	--	--	--	X	--	Cheyenne River	Cottonwood Creek
June 23, 1905	June 23, 1905	--	--	--	X	--	Fall River	--
July 1905	July 1905	--	--	--	--	X	--	--

Primary town or area	Secondary town or area	Description of event	Source of information[1]
Beulah, Wyo.	Sundance, Wyo.	Flooding reported in Beulah, Wyo. Many area bridges were out.	Rapid City Journal, Daily Independent-Deadwood (June 16, 1901).
Rapid City (?)	--	Very heavy rain reported with flooding of low-lying areas.	Rapid City Journal (June 20, 1901).
Rapid City	--	Article described aftermath from storm on June 19, 1901.	Rapid City Journal (June 21, 1901).
Sturgis	--	Heavy rain and flooding reported for Sturgis area.	Rapid City Journal (June 25, 1901).
Rapid City	--	Flooding of streets reported for Rapid City.	National Oceanic and Atmospheric Administration (2008).
Cascade	--	Hotel destroyed by flooding. Date unknown, but reported in July newspaper account.	Twomey and Magee (1983).
Spearfish	--	Peak flow of 5,000 ft^3/s recorded on June 5, 1904, during early period of USGS data collection (station 06431500; Spearfish Creek at Spearfish).	U.S. Geological Survey (2009).
Belle Fourche	--	Peak flow of 8,050 ft^3/s recorded during early period of USGS data collection (station 06434000; Redwater Creek at Belle Fourche).	U.S. Geological Survey (2009).
Spearfish	Deadwood, Sturgis, Terry, and Central	Reported as worst known flood as of date of article (1904) for Spearfish. All area streams were reported high. Four deaths occurred in Deadwood area, where damage was most severe since 1883.	Queen City Mail (June 8, 1904).
Sturgis	Various	Record rainfall reported for the Black Hills area. Very high water occurred in Sturgis area and much of northern Black Hills.	Black Hills Press (June 8, 1904).
Deadwood	--	Substantial flooding reported for Deadwood, probably the worst since 1883.	Weekly Pioneer Times (June 9, 1904).
Deadwood	--	This article appears to be a continuation of the previous article (Weekly Pioneer Times, June 9, 1904).	Weekly Pioneer Times (June 9, 1904).
Hot Springs	--	Heavy flood damage reported for Hot Springs and to railroad west of there.	Deadwood Pioneer Times (June 10, 1905).
Hot Springs	--	Same event described as reported by Deadwood Pioneer Times (June 10, 1905) above.	Custer Chronicle (June 17, 1905).
Hot Springs	--	Second major flood within 2 weeks reported. Perhaps more severe than the previous flood.	Hot Springs Weekly Star (April 18, 1946 reprint of June 23, 1905 article).
Hot Springs	--	Recount provided for two floods that damaged bridges.	Twomey and Magee (1983).
Edgemont	--	Heavy rain, hail, lightning, and flooding reported for Edgemont and upstream from Edgemont. Fourteen residents were knocked unconscious by lightning, and many sheep were killed by hail.	Edgemont Express (June 23, 1905).
Hot Springs	--	Article described same event as reported by Hot Springs Weekly Star (June 23, 1905) above.	Custer Chronicle (July 1, 1905).
--	--	Heavy rains reported throughout Black Hills area.	Black Hills Journal (July 5, 1905).

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

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Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
July 11, 1905	July 11, 1905	--	--	--	--	X	Sundance Creek	--
--	--	--	--	--	--	X	--	--
July 1905	July 26, 1905	--	--	--	--	X	Rapid Creek	--
July 1905	July 26, 1905	--	--	--	X	X	Rapid Creek	--
July 1905	July 30, 1905	--	--	--	X	X	Cheyenne River	--
--	Aug. 12, 1905	--	--	X	X	--	Hat Creek	--
Apr. 1906	Apr. 1906	--	--	--	--	X	Belle Fourche River	Hay Creek
--	Apr. 1906	--	--	--	--	X	Cheyenne River	--
May 1907	May 27, 1907	--	--	--	X	--	Cheyenne River	--
May 1907	May 25, 1907	--	--	X	X	--	Belle Fourche River	Various
May 25, 1907	May 26, 1907	--	--	--	X	X	Whitewood Creek	Spearfish Creek
May 1907	May 1907	--	--	--	--	X	Cottonwood Creek	Cheyenne River
May 1907	May 1907	--	--	--	X	--	Cheyenne River	Missouri, Bad, and White Rivers
May 1907	May 1907	--	--	--	--	X	French Creek	--
May 1907	May 1907	--	--	--	--	X	Belle Fourche River	--
June 12, 1907	June 12–13, 1907	--	--	--	--	--	Boxelder Creek	--

Primary town or area	Secondary town or area	Description of event	Source of information[1]
Sundance, Wyo.	--	Tornadoes, heavy rain, and flooding reported for Sundance, Wyo. Water in Sundance reported 15 feet deep in bottom areas.	Deadwood Pioneer Times (July 12, 1905).
--	--	Extensive damage throughout entire area prevented rail service for weeks.	Black Hills Press (July 26, 1905).
Rapid City	--	Peak flow of 2,500 ft^3/s occurred July 26, 1905, on for Rapid Creek.	Miller (1986).
Rapid City	--	Peak flow of 2,500 ft^3/s occurred on July 26, 1905, during early period of USGS data collection at station 06414000 (Rapid Creek at Rapid City).	U.S. Geological Survey (2009).
Edgemont	--	Peak flow of 13,000 ft^3/s on July 30, 1905, during early period of USGS data collection at station 06395000 (Cheyenne River at Edgemont).	U.S. Geological Survey (2009).
--	--	Peak flow of 9,150 ft^3/s on August 12, 1905, during early period of USGS data collection at station 06400000 (Hat Creek near Edgemont); exceeded only by peak flows of 9,430 ft^3/s (1954) and 13,300 ft^3/s (1967).	U.S. Geological Survey (2009).
Belle Fourche	--	Belle Fourche River reported as within a few feet of record stage.	Custer Chronicle (Apr. 14, 1906).
Oral	--	Bridge damaged from high water.	Twomey and Magee (1983).
Rapid City	Oelrichs	Heavy (record) rainfall and disruptions to rail service reported.	Rapid City Journal (May 28, 1907).
Belle Fourche	--	Belle Fourche River reported as nearing record stage of 1883 and still rising. Heavy rains and high flows reported throughout entire Belle Fourche River watershed.	Deadwood Pioneer Times (May 26, 1907).
Deadwood	Spearfish	Record snowfall (at least 2.5 feet) reported for May 25, 1907, which followed a prolonged rain.	Deadwood Pioneer Times (May 26, 1907).
Edgemont	--	High water reported for Cottonwood Creek and Cheyenne River with localized flooding.	Edgemont Express (May 31, 1907).
--	--	Reported that the “government river gauge” at Russo was inundated by extremely high flow in the Cheyenne River, which contributed to a rapid rise in the Missouri River.	Rapid City Journal (June 1, 1907).
--	--	High flows reported throughout Black Hills. During the previous year (1906), 20 bridges were destroyed along French Creek in one storm.	Custer Chronicle (June 1, 1907).
Belle Fourche	--	Belle Fourche River was reported as being very high, but was subsiding.	Custer Chronicle (June 8, 1907).
--	--	Peak flow of 16,000 ft^3/s occurred on June 12, 1907, at station 06422500 (Boxelder Creek near Nemo). Peak flow determination made from historical gage-height record and application of 1972 rating curve.	U.S. Geological Survey (2009).

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

[All locations in South Dakota unless otherwise specified. Peak of record flow is the maximum instantaneous peak flow that has been recorded for the period of record for the streamflow-gaging station. Relative magnitude of event: 1, extreme; 2, severe; 3, moderate; 4, minor; 5, very minor; ft³/s, cubic feet per second; USGS, U.S. Geological Survey; X, indicates applicable magnitude; --, not applicable or unknown]

Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
June 12, 1907	June 12–13, 1907	--	X	X	X	--	Whitewood Creek	--
June 12–13, 1907	--	--	--	--	--	--	--	--
June 12, 1907	June 12–13, 1907	--	X	X	X	--	Rapid and Boxelder Creeks	Elk Creek and others
June 12, 1907	June 12–13, 1907	--	X	X	X	--	Rapid Creek	Boxelder Creek
June 12, 1907	June 12–13, 1907	--	X	X	X	--	Elk and Boxelder Creeks	--
June 12, 1907	June 12–13, 1907	--	--	X	--	--	Rapid Creek	--
June 12, 1907	June 12–13, 1907	X	X	X	--	--	Various	Various
May 12, 1907	June 12–13, 1907	--	--	--	--	--	Rapid Creek	--
June 12, 1907	June 12–13, 1907	X	--	--	--	--	Stagebarn Canyon	Elk and Little Elk Creeks
June 12, 1907	June 12-13, 1907	--	X	--	--	--	Stagebarn Canyon, Little Elk Creek	Bear Butte Creek
June 12, 1907	June 12–13, 1907	X	--	--	--	--	Stagebarn Canyon	--
June 12, 1907	June 12–13, 1907	--	X	X	X	--	--	--

Primary town or area	Secondary town or area	Description of event	Source of information[1]
Deadwood	Lead	Record rainfall reported throughout much of Black Hills. Elk Creek was reported as highest ever as of date of article (1907) . Damage was not severe in Deadwood, but was more severe in many areas. Reported that the extent of damage will be unknown for some time.	Deadwood Pioneer Times (June 13, 1907).
--	--	Miller (1986) reported a 24-hour rainfall total of 7.1 inches for Ft. Meade.	Miller (1986).
Rapid City	Sturgis, Deadwood/Lead, Hill City	Massive damage reported throughout area. Elk Creek fared worse than Boxelder Creek. Rail was heavily damaged east of Rapid City, indicating probable high flows in Boxelder Creek. Heavy storm in Hill City area resulted in rail damage. More damage to north than south, but rail damage reported along Spring Creek and near Hermosa.	Rapid City Journal (June 14, 1907).
--	--	Article provided a recount of article from previous day (June 14, 1907), with additional accounts of damage. Rain east of the Black Hills apparently was not as heavy as in the central Black Hills, but all rail bridges were out along Boxelder Creek west of Owanka.	Rapid City Journal (June 15, 1907).
--	Custer	Additional damage reports provided. Heavy rain and hail reported for Custer.	Rapid City Journal (June 16, 1907).
Rapid City	--	Peak flow of 13,000 ft^3/s occurred on June 12, 1907, on Rapid Creek from 5 inches or more of rain in 6 hours. Antecedent moisture since May 26, 1907, also was noted.	Miller (1986).
Various	Various	Severe flooding reported along Rapid Creek and many other Black Hills locations.	National Oceanic and Atmospheric Administration (2008).
Rapid City	--	Various details regarding flooding along Rapid Creek were reported.	Johnson (1949).
Piedmont	Tilford	Detailed account provided for Stagebarn Canyon flood that caused three deaths. Dr. O'Hara (South Dakota School of Mines and Technology) reported debris 18.5 feet above floor of canyon.	Honerkamp (1978).
Piedmont	Rapid City, Mystic	Article recounts the severe flood on June 12, 1907, in Stagebarn Canyon. Between Rapid City and Mystic, "the Crouch Line Railroad had only five small bridges left out of a total of 110, with grades washed out and rails wrapped around trees."	Fielder (1964)
--	--	This is an account of the June 1907 storm and flood that was printed in November 1974.	Rapid City Journal (Nov. 8, 1949).
--	--	Storm in southern Black Hills was thought by many to be the heaviest ever, as of date of article (1907).	Custer Chronicle (undated).

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

[All locations in South Dakota unless otherwise specified. Peak of record flow is the maximum instantaneous peak flow that has been recorded for the period of record for the streamflow-gaging station. Relative magnitude of event: 1, extreme; 2, severe; 3, moderate; 4, minor; 5, very minor; ft^3/s, cubic feet per second; USGS, U.S. Geological Survey; X, indicates applicable magnitude; --, not applicable or unknown]

Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
June 12, 1907	June 12–13, 1907	X	--	--	--	--	Stagebarn Canyon	--
June 12, 1907	June 12–13, 1907	--	X	X	X	--	Stagebarn Canyon, Elk Creek	--
June 12, 1907	June 12–13, 1907	--	X	X	X	--	Elk and Boxelder Creeks	--
June 12, 1907	June 12–13, 1907	--	--	X	X	--	Rapid Creek	--
June 1, 1908	June 1, 1908	--	--	--	--	X	--	--
May–June 1908	May–June 1908	--	--	--	X	--	Fall River	Cold Brook and Hot Brook
May–June 1908	May–June 1908	--	--	--	X	--	Fall River	--
May–June 1908	May–June 1908	--	--	--	X	--	Fall River	--
May–June 1908	May–June 1908	--	--	--	X	--	Cheyenne River	--
June 1908	June 1908	--	--	--	--	X	--	Various
May 1909	May 1909	--	--	--	X	--	Belle Fourche River	Various
May 1909	May 31, 1909	--	--	--	X	X	Whitewood Creek	--
May 1909	May–June 1909	--	--	--	X	--	Spearfish Creek	--
May 1909	May–June 1909	--	--	--	X	--	Spearfish Creek	--
May 1909	May–June 1909	--	--	--	X	X	Whitewood Creek	--
May–June 1909	May–June 1909	--	--	--	X	X	--	Bear Butte Creek
May 31, 1909	May 31, 1909	--	--	X	X	--	Belle Fourche River	Many

Primary town or area	Secondary town or area	Description of event	Source of information[1]
Piedmont	--	Storm was reported as heaviest ever known in Sturgis area as of date of article (1907), but damage was less than in other areas. Wall of water estimated as 15 feet high in Stagebarn Canyon.	Black Hills Press (June 19, 1907).
Tilford	--	Five deaths reported from floods of June 12–13, 1907.	Custer Chronicle (June 22, 1907).
--	--	Additional details provided on the heavy rains and flooding of June 12–13, 1907, which were reported as the most widespread and damaging of any that had occurred in the Black Hills as of date of article (1907).	Custer Chronicle (June 22, 1907).
--	--	A dozen railroad bridges were washed out between Mystic and Rapid City.	Custer Chronicle (July 27, 1907).
Hot Springs	--	Heavy rains reported for Hot Springs area with rail damage and delays. Probably same flood as reported by Hot Springs Weekly Star (June 5, 1908) below.	Rapid City Journal (June 2, 1908).
Hot Springs	--	Heavy storm occurred on May 31, 1908, following a week of rain. Highest stage on June 1, 1908, was within about 3 feet of a bridge that marked high water from two previous larger floods (August 1897 and June 1905). Additional heavy rain occurred on June 2.	Hot Springs Weekly Star (April 18, 1946 reprint of June 5, 1908 article).
Hot Springs	--	Short story on flooding reported by Hot Springs Weekly Star (June 5, 1908) above.	Twomey and Magee (1983).
Hot Springs	--	Photos of June 1908 flooding.	Twomey and Magee (1983).
Hot Springs area	--	Young man drowned while crossing Cheyenne River at high flow.	Twomey and Magee (1983).
--	Various	Widespread rail damage and delays reported in South Dakota, Wyoming, and Montana.	Edgemont Express, Alliance Times (June 6, 1908).
Belle Fourche	Deadwood, Lead, Spearfish	Substantial damage reported for Belle Fourche.	National Oceanic and Atmospheric Administration (2008).
Deadwood	--	Flooding reported in Deadwood that was caused by two heavy rains during previous days.	Deadwood Telegram (June 1, 1909).
Spearfish	--	Worst flood reported since 1904. Substantial damage reported, including severe rail damage in Spearfish Canyon, which may indicate more severe flooding in Spearfish Canyon than in 1904.	Deadwood Telegram (June 2, 1909).
Spearfish	Deadwood, Lead	Additional details provided on flooding in Spearfish area.	Queen City Mail (June 2, 1909).
Deadwood	--	Widespread rail damage and delays reported.	Deadwood Telegram (June 2, 1909).
--	--	Flooding occurred from a week of rain. Bear Butte Creek reported to be very high.	Black Hills Press (June 3, 1909).
Belle Fourche	Many	Widespread flooding reported. Belle Fourche River reported as 4 feet higher than ever before at VVV ranch.	Northwest Post - Belle Fourche (June 3, 1909).

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

[All locations in South Dakota unless otherwise specified. Peak of record flow is the maximum instantaneous peak flow that has been recorded for the period of record for the streamflow-gaging station. Relative magnitude of event: 1, extreme; 2, severe; 3, moderate; 4, minor; 5, very minor; ft^3/s, cubic feet per second; USGS, U.S. Geological Survey; X, indicates applicable magnitude; --, not applicable or unknown]

Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
May 31, 1909	May 31, 1909	--	--	--	X	X	Whitewood Creek	--
June 8, 1909	June 8–9, 1909	--	--	--	X	--	Spearfish Creek	Redwater River
June 8, 1909	June 8,9, 1909	--	--	--	--	X	Spearfish Creek	Various
June 10–11, 1909	June 10–11, 1909	--	--	--	X	--	--	Hay Creek
June 10–11, 1909	June 10–11, 1909	--	--	--	X	--	Rapid Creek	Various
--	June 11, 1909	--	--	--	X	--	Bear Butte Creek	Various
June 11, 1909	June 11–12, 1909	--	--	--	X	--	Rapid Creek	--
June 11, 1909	June 11–12, 1909	--	--	--	X	--	Rapid Creek	Boxelder Creek
--	--	--	--	--	--	--	--	--
1910	Apr. 1910	--	--	X	--	--	Belle Fourche River	--
June 1911	June 1911	--	--	--	--	X	Cheyenne River	--
June 1911	June 1911	--	--	--	--	X	Boxelder Creek	--
Aug. 5–6, 1911	Aug. 6, 1911	--	--	--	X	--	Cheyenne River (?)	--
Aug. 5–6, 1911	Aug. 6–7, 1911	--	--	--	--	X	Cheyenne River	--
Sept. 5,6, 1911	Sept. 1911	--	--	--	--	X	Hawk Canyon	Cheyenne River
--	Apr. 1912	--	--	X	--	--	Belle Fourche River	--
--	Apr. 1912	--	--	X	--	--	Belle Fourche River	Various
Apr. 13–14, 1912	Apr. 1912	--	--	--	--	--	--	--

Primary town or area	Secondary town or area	Description of event	Source of information[1]
Deadwood	--	Flooding reported in Deadwood. Report of 12 inches of rain within about 1 week.	Deadwood Daily Pioneer Times (1), Weekly Pioneer Times (3) (June 1, 3, 1909).
Spearfish	--	Damage primarily downstream from Spearfish was reported. Flooding appears to be from storm of June 8, 1909, as reported by the Deadwood Pioneer Times article (June 9, 1909), rather than associated with flooding of previous week.	Queen City Mail (June 9, 1909).
Spearfish	New Underwood and various	Storm was perhaps heaviest in the Spearfish and New Underwood areas.	Deadwood Pioneer Times (June 9, 1909).
New Underwood	Belle Fourche	Second flood in New Underwood reported for the week. Another storm reported along Hay Creek in Belle Fourche.	Deadwood Pioneer Times (June 11, 1909).
Rapid City	--	Heaviest rain recorded at Weather Bureau in Rapid City as of date of article (1909). Same storm affected New Underwood (June 9, 1909, Deadwood Pioneer Times article) and other areas south of Rapid City.	Deadwood Pioneer Times (June 11, 1909).
--	--	Evacuation of 20 homes along Bear Butte Creek reported. Other damage reported elsewhere.	National Oceanic and Atmospheric Administration (2008).
Pactola	--	Report of 20 inches of rain at Pactola. Rail damage reported.	Deadwood Pioneer Times (June 12, 1909).
Pactola	New Underwood, Owanka	Boxelder Creek reported as 7 feet higher than previous record and Owanka in danger of being swept away	Deadwood Pioneer Times (June 12, 1909).
--	--	Progress reported on railroad repairs. Railroad wires (telegraph) were connected again.	Deadwood Daily Pioneer Times-Deadwood (June 16, 1909).
--	--	Photograph of 1910 flooding on postcard (from Rapid City Journal, March 25, 2009).	Rapid City Journal photo (March 25, 2009).
Wasta, Owanka	--	Moderately high flow in Cheyenne River reported from general rains.	Wasta Gazette (June 23, 1911).
Owanka, Wasta	--	Minor damage reported along Boxelder Creek.	Wasta Gazette (June 30, 1911).
Edgemont	--	Cheyenne (?) River thought to be highest within memory of oldest inhabitants (as of date of article).	Edgemont Express (Aug. 11, 1911).
Wasta	--	Heavy rain reported. Cheyenne River rose to high water mark for the year.	Wasta Gazette (Aug. 11, 1911).
Wasta	--	Heavy rain and high water reported, with some rail damage.	Wasta Gazette (Sept. 8, 1911).
Belle Fourche	--	Reported as highest stage for Belle Fourche River in 20 years.	Belle Fourche Bee (Apr. 11, 1912).
Belle Fourche	Various	Belle Fourche River peaked on Monday, April 11, 1912. Same flood as reported by Belle Fourche Bee (April 11, 1912). Many additional details provided.	Northwest Post - Belle Fourche (Apr. 11, 1912).
Newell, Vale, and Nisland	Belle Fourche	Heavy snow and some rain reported. Belle Fourche Dam reported as endangered.	Black Hills Press (Apr. 17, 1912).

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

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Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
July 4, 1912	July 4, 1912	--	--	--	X	--	Rapid Creek	--
Aug. 17, 1912	Aug. 17, 1912	--	--	--	--	X	Spearfish Creek	--
Aug. 18, 1912	Aug. 18, 1912	--	--	--	--	X	Whitewood Creek	--
Aug. 17–18, 1912	Aug. 18, 1912	--	--	--	X	X	Spring Creek	Bear Butte Creek
Aug. 30, 1912	Aug. 30, 1912	--	--	--	--	X	--	--
--	Mar.–Apr. 1913	--	--	--	--	X	Belle Fourche River	Redwater River
Aug. 7–8, 1913	Aug. 8, 1913	--	--	--	--	X	Cheyenne River	--
Apr.–May 1915	Apr.–May 1915	--	--	--	--	X	Horsehead and Lone Well Creeks	--
May 1915	May 1915	--	--	--	--	X	Cheyenne River	--
May 1915	May 1915	--	--	--	X	--	Cheyenne River	Fall River
May 25, 1915	May 25, 1915	--	--	--	--	X	Horsehead and Lone-well Creeks	--
May 25, 1915	May 25, 1915	--	--	--	--	X	--	--
May 25, 1915	May 25, 1915	--	--	--	--	X	French Creek	Beaver Creek, Cheyenne River
May 1915	May 26, 1915	--	--	--	--	X	Unknown	--
June 1915	June 1915	--	--	X	X	X	Various, Fall River	--
June 11, 1915	June 11, 1915	--	--	X	--	--	Fall River	--
June 11, 1915	June 11, 1915	--	--	X	X	X	Fall River	Horsehead Creek
June 1915	June 12, 1915	--	X	--	--	--	Cheyenne River	--
May–June 1915	May–June 1915	--	--	X	X	X	Cheyenne River	--
June 1915	June 1915	--	--	--	X	--	Fall River	--

Primary town or area	Secondary town or area	Description of event	Source of information[1]
Rapid City	--	Localized flooding reported for Rapid City. Rise of 15 feet reported in Dark Canyon.	Rapid City Journal (July 6, 1912).
Spearfish area	--	Heavy rain in Spearfish Canyon, with some damage reported.	Deadwood Telegram (Aug. 17, 1912).
Sturgis area	--	Heavy rain in Sturgis area with some rail damage reported. Whitewood Creek was out of banks.	Deadwood Telegram (Aug. 19, 1912).
Vale	Sturgis	Widespread hail with flood damage in some locations reported.	Black Hills Press (Aug. 21, 1912).
Sturgis	--	Heavy rains and some rail damage in Sturgis area reported.	Wasta Gazette (Aug. 30, 1912).
Belle Fourche	--	Lowland flooding reported from ice jam at diversion dam for canal to Belle Fourche Reservoir.	Northwest Post - Belle Fourche (Apr. 3, 1913).
--	--	High water from general rains reported.	Wasta Gazette (Aug. 15, 1913).
--	--	High water occurred from general rains with 7.2 inches of rain reported since April, plus heavy prior snow.	Oelrichs Advocate (May 6, 1915).
--	--	General rains occurred. Cheyenne River reported as highest in at least 8 years, perhaps 15 years.	Wasta Gazette (May 15, 1915).
Hot Springs	Buffalo Gap, Oelrichs, Pringle	Widespread rail damage reported. Cheyenne River reported as highest in 30 years.	Hot Springs Star (May 18, 1915).
Oelrichs	--	High water from general rains reported.	Oelrichs Advocate (May 27, 1915).
Fairburn	--	Rail damaged from heavy storm.	Custer Chronicle (May 29, 1915).
--	--	Rail damaged along French Creek. Rapid rises reported for other streams.	Buffalo Gap Gazette (May 29, 1915).
Climax, Grindstone	Pino	Three drowned in flooding at Climax from heavy storm.	Buffalo Gap Gazette (June 5, 1915).
Various, Hot Springs	--	Widespread rail damage reported throughout southern Black Hills and beyond. Severe flood occurred in Hot Springs.	Deadwood Telegram (June 12, 1915).
Hot Springs	--	Severe flood occurred in Hot Springs.	Deadwood Daily Pioneer Times (June 12, 1915).
Hot Springs	Oelrichs	Widespread rain, flooding, and rail damage reported. Severe flood occurred in Hot Springs.	Rapid City Journal (June 13, 1915).
--	--	Peak flow of 39,200 ft^3/s occurred on June 12, 1915, during first year of USGS data collection at station 06400500 (Cheyenne River near Hot Springs).	U.S. Geological Survey (2009).
--	--	Detailed report of streamflow conditions at USGS station 06400500 (Cheyenne River near Hot Springs). Flow peaked at 39,200 ft^3/s on June 12, 1915.	Hot Springs Star (June 14, 1915).
Oelrichs	--	Bridges destroyed during flooding. Reported as worst flood to date in Hot Springs.	Twomey and Magee (1983).

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

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Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
June 11, 1915	June 11–12, 1915	--	--	X	--	--	Horsehead Creek	All streams in area high
June 1915	June 1915	--	--	--	X	X	--	--
June 12, 1915	June 12, 1915	--	--	X	--	--	Cheyenne River	--
June 1915	June 1915	--	--	--	--	X	Sulphur Creek	--
June 1915	June 1915	--	--	--	X	--	Fall River	All streams in area high
June 1915	June 1915	--	--	--	X	--	Beaver Creek	--
June 11, 1915	June 11–12, 1915	--	--	X	--	--	Beaver Creek	Various
June 11–12, 1915	June 1915	--	--	--	--	X	--	--
June 1915	June 1915	--	--	--	--	--	Horsehead Creek	--
June 1915	June 1915	--	--	X	--	--	Belle Fourche River	Cheyenne River
July 15–20, 1915	July 1915	--	--	X	X	--	Red Owl and Sulphur Creeks	Many in Meade County
July 15–20, 1915	July 1915	--	--	X	X	--	--	--
July–Aug. 1915	July–Aug. 1915	--	--	--	--	X	Horsehead Creek	Cheyenne River
Aug. 1915	Aug. 1915	--	--	X	--	--	Bad River	Cheyenne River
Aug. 9–10, 1915	Aug. 9–10, 1915	--	--	--	--	X	--	--
Aug. 1915	Aug. 1915	--	--	--	--	X	Beaver Creek	--
Aug. 1915	Aug. 1915	--	--	--	--	X	Beaver Creek	--
Aug. 17, 1915	Aug. 17, 1915	--	--	--	--	X	False Bottom Creek	Polo Creek

Primary town or area	Secondary town or area	Description of event	Source of information[1]
Fall River County	--	Four inches of rain during saturated conditions caused "biggest flood in this country within the memory of the white man." Surpassed previous worst flooding that occurred 23 years prior, to the day (June 11 or 12, 1892).	Oelrichs Advocate (June 17, 1915).
--	--	Northern Black Hills was isolated for 6 days due to extensive rail damage.	Black Hills Press (June 17, 1915).
Wasta	--	Cheyenne River reported as highest for the year and for some unknown number of previous years.	Wasta Gazette (June 18, 1915).
White Owl	--	Sulphur Creek reported as highest in 6 years.	White Owl Oracle (June 18, 1915).
Hot Springs	--	High water reported throughout southwestern South Dakota. Severe flood occurred in Hot Springs.	Custer Chronicle (June 19, 1915).
Buffalo Gap	--	Crop damage and other damage reported along Beaver Creek.	Buffalo Gap Gazette (June 19, 1915).
Buffalo Gap	Various	Beaver Creek exceeded previous high water mark of several years ago. Horsehead Creek reported as highest in years. Cheyenne River exceeded all previous high water marks.	Buffalo Gap Gazette (June 19, 1915).
Custer	Hot Springs	Widespread flooding reported between Custer and Hot Springs.	Custer Chronicle (June 19, 1915).
Oelrichs	--	Streams reported as receding. Brief report provided on aftermath.	Oelrichs Advocate (June 24, 1915).
--	--	Belle Fourche and Cheyenne Rivers reported as remaining very high.	White Owl Oracle (June 25, 1915).
Faith, Dupree	--	All streams in eastern Meade County reported as very high from four heavy rains during previous week.	White Owl Oracle (July 23, 1915).
Faith	Various	Severe rail damage reported for east of Faith from flooding.	White Owl Oracle (July 30, 1915).
Oelrichs	Oral	Very wet conditions reported for time of year. Some crops damaged, harvest slowed. Horsehead Creek reported as high again.	Oelrichs Advocate (Aug. 5, 1915).
Midland, Ft. Pierre	Scenic	Extensive rail damage reported along the Bad River and other places. Cheyenne River reported as remaining high.	White Owl Oracle (Aug. 13, 1915).
Custer, Pringle	--	Bridges washed out on wagon road between Custer and Pringle. Rail damage reported near Custer.	Edgemont Express (Aug. 13, 1915).
Buffalo Gap	--	Heavy rains west of Buffalo Gap reported to have kept Beaver Creek at flood stage.	Buffalo Gap Gazette (Aug. 14, 1915).
Hot Springs	Pringle	Continued flooding reported along Beaver Creek. Many area bridges have been washed out.	Custer Chronicle (Aug. 15, 1915).
St. Onge	Beulah, Whitewood, Spearfish	Heavy rainfall reported. Rail damaged near St. Onge.	Deadwood Pioneer Times (Aug. 18, 1915).

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

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Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
Aug. 1915	Aug. 1915	--	--	--	--	X	French Creek	--
Aug. 16 and 18, 1915	Aug. 18–19, 1915	--	--	--	X	--	Beaver Creek	--
Aug. 18, 1915	Aug. 18, 1915	--	--	--	--	X	French Creek	--
Sept.–Oct. 1915	Sept.–Oct. 1915	--	--	--	--	X	Cheyenne River	--
July 27–28, 1916	July 27–28, 1916	--	--	--	X	--	Bear Butte Creek	--
June 22, 1918	June 22, 1918	--	--	--	X	X	Beaver Creek	--
July 11–15, 1918	July 1918	--	--	--	--	X	Fall River	Lone Well and Horse-head Creeks
July 13, 1918	July 13–14, 1918	--	--	--	--	X	Fall River	Beaver Creek
--	Aug. 8, 1918	--	--	--	--	X	Fall River	--
Mar., 1920	Mar., 1920	--	--	--	X	--	Sulphur Creek	Many
Mar., 1920	Mar., 1920	--	--	X	X	--	Belle Fourche and Cheyenne Rivers	Various
Mar., 1920	Mar., 1920	--	--	X	X	--	Belle Fourche and Cheyenne Rivers	Elk Creek
Apr. 7, 1920	1920	--	--	--	--	--	--	--
May 10–12, 1920	May 11–12, 1920	--	--	X	--	--	Rapid Creek	--
May 10–12, 1920	May 11–12, 1920	--	--	X	--	--	Rapid Creek	--
May 1920	May 10, 1920	--	--	X	X	--	Medicine Creek	--
May 10–11, 1920	May 10–11, 1920	--	--	X	--	--	Rapid Creek	Various
May 11–12, 1920	May 11–12, 1920	--	--	X	X	--	Many in Black Hills	Many

Primary town or area	Secondary town or area	Description of event	Source of information[1]
--	--	Damage reported to ranch along French Creek near mouth of Cheyenne River.	Buffalo Gap Gazette (Aug. 21, 1915).
Buffalo Gap	--	Rain total of 3.5 inches in 1.5 hours in Buffalo Gap. Beaver Creek reported to be nearly as high as record peak flow during spring. Rail damaged in Hot Springs.	Buffalo Gap Gazette (Aug. 21, 1915).
Custer	Pringle	Heavy rain reported west of Custer, with three bridges washed out along French Creek.	Custer Chronicle (Aug. 21, 1915).
Edgemont	--	Train delayed from damaged grade caused by rise of 8 feet in Cheyenne River.	Custer Chronicle (Oct. 2, 1915).
Sturgis	--	Reported as one of heaviest rains and highest water in Sturgis in 30 years.	Black Hills Press (Aug. 3, 1916).
Buffalo Gap	--	Crops, bridges, and roads damaged.	Buffalo Gap Gazette (June 28, 1918).
Hot Springs	--	Heavy rains reported in many parts of Fall River County with some damage reported.	Oelrichs Advocate (July 18, 1918).
Hot Springs	Buffalo Gap	Moderate damage reported along Fall River.	Buffalo Gap Gazette (July 19, 1918).
Hot Springs	--	Photographs show minor flooding of Hot Springs.	Photographs by Fall River County Historical Society.
Many	Many	Sulphur Creek reported as highest ever as of date of article (1920). Many bridges washed out throughout widespread area.	White Owl Oracle (Mar. 26, 1920).
Various	Various	Some streams reported as dropping. Belle Fourche and Cheyenne Rivers reported as highest ever as of date of article (1920). Much damage reported across widespread areas.	White Owl Oracle (Apr. 2, 1920).
Rapid City	New Underwood, Wasta	Widespread flooding reported.	Wasta Gazette (Apr. 2, 1920).
Custer	--	Miller (1986) reported a record 24-hour rainfall total of 7.1 inches for Custer.	Miller (1986).
Rapid City	--	Peak flow of 8,000 ft^3/s occurred on May 11-12, 1920, in Rapid Creek.	Miller (1986).
Rapid City	--	Rain (4.75 inches over 3 days) on melting snow reported. Eight deaths reported. All private and county bridges on Rapid Creek destroyed, and 20 rail bridges damaged or destroyed.	National Oceanic and Atmospheric Administration (2008).
Blunt	--	Reported as largest known flood along Medicine Creek east of Pierre as of date of article (1920). Very severe rail damage reported, with service expected to be out for 3 weeks.	Rapid City Journal (May 11, 1920).
Rapid City	Various	Rapid City inundated from very heavy storm and flooding. Widespread rail damage reported and virtually all train service disrupted or halted throughout a very large area. Rail line was under 5 feet of water near Hill City.	Deadwood Telegram (May 11, 1920).
Many	Many	Severe damage reported to rail lines throughout large area, with rain and snow continuing to exacerbate conditions.	Deadwood Telegram (May 12, 1920).

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

[All locations in South Dakota unless otherwise specified. Peak of record flow is the maximum instantaneous peak flow that has been recorded for the period of record for the streamflow-gaging station. Relative magnitude of event: 1, extreme; 2, severe; 3, moderate; 4, minor; 5, very minor; ft³/s, cubic feet per second; USGS, U.S. Geological Survey; X, indicates applicable magnitude; --, not applicable or unknown]

Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
May 11, 1920	May 11–12, 1920	--	--	X	--	--	Rapid, Boxelder, Spring, and Medicine Creeks	All streams in Black Hills
May 11, 1920	May 11–12, 1920	--	--	--	--	--	Rapid Creek	--
May 1920	May 12, 1920	X	--	--	--	--	Cheyenne River	--
May 9–12, 1920	May 11–12, 1920	--	--	--	X	--	Belle Fourche and Redwater Rivers	Hay Creek
May 11–12, 1920	May 11–12, 1920	--	--	X	--	--	Cheyenne River	Rapid Creek
May 10–13, 1920	May 1920	X	X	X	X	--	Cheyenne River	Fall River
May 10–13, 1920	May 11, 1920	X	X	X	X	--	Horsehead Creek, Cheyenne River	Lone Well Creek
May 8, 1920	May 8, 1920	--	--	--	X	--	Deadman’s Draw, Bear Butte Creek	Alkali Creek, others
May 11–12, 1920	May 11–12, 1920	--	--	X	--	--	Rapid Creek	--
May 1920	May 1920	--	--	X	X	--	Cheyenne and Belle Fourche Rivers	Sulphur Creek
--	May 13, 1920	--	X	X	X	--	Cheyenne River	--
May 1920	May 12–13, 1920	--	--	X	--	--	Rapid Creek	Whitewood Creek
May 11–12, 1920	May 11–12, 1920	--	X	--	--	--	Hat Creek	--

Primary town or area	Secondary town or area	Description of event	Source of information[1]
Rapid City, New Underwood, Box Elder, many others	--	Lengthy and detailed description of severe damage throughout widespread areas provided. Fifty families dislodged from low-lying area north of Rapid Creek.	Rapid City Journal (May 12, 1920).
Rapid City	--	Various details provided regarding flooding along Rapid Creek.	Johnson (1949).
--	--	Peak flow of 114,000 ft^3/s on May 12, 1920, at station 06400500 (Cheyenne River near Hot Springs). This peak flow is almost three times larger than the peak flow of June 12, 1915, and the most extraordinary peak flow ever recorded (relative to drainage area) along the Cheyenne River, through the current (2010) date.	U.S. Geological Survey (2009).
Belle Fourche, Nisland	Rapid City	Very heavy rain reported in Belle Fourche area. Area streams were out of banks.	Northwest Post - Belle Fourche (May 13, 1920).
Rapid City, Oral	--	Rail damage throughout area reported to be enormous.	Rapid City Journal (May 13, 1920).
Rapid City	Various	Heavy rain following heavy April snow reported. Cheyenne River reported as highest ever as of date of article (1920). Rapid City flooded from the May 10, 1920, storm.	Hot Springs Star (May 13, 1920).
Oelrichs	Various	Horsehead Creek reported as highest since 1915, which was second to only one previous flood. Note: previous Oelrichs Advocate article of June 17, 1915, reported 1915 as the largest known flood.	Oelrichs Advocate (May 13, 1920).
Sturgis	Rapid City, others	Heavy storm reported for Sturgis on May 9, 1920. Reported as wettest in 30 years by locals. Damage in Sturgis area was less severe than elsewhere. Article includes excerpts from Rapid City Journal article of May 12, 1920.	Black Hills Press (May 13, 1920).
Rapid City	--	A short excerpt from Rapid City Journal article of May 12, 1920, is provided.	Deadwood Telegram (May 3, 1920).
--	--	Sulphur Creek could not be crossed. Belle Fourche and Cheyenne Rivers reported as higher than ever before known.	White Owl Oracle (May 14, 1920).
--	--	Record stage of 18.9 feet on May 13, 1920, at station 06439500 (Cheyenne River near Eagle Butte).	U.S. Geological Survey (2009).
Rapid City	Deadwood	Rapid Creek reported as rising. A short account of 1883 flooding also is provided, with a notation that this is the largest known flooding for Deadwood, prior to or since then.	Black Hills Weekly Journal (May 14, 1920).
Ardmore, Bunker Hill	--	Worst known flood for Hat Creek occurred as of date of article (1920); creek reported as 4 feet higher than 1915. Seven deaths reported in Bunker Hill.	Ardmore American (May 14, 1920).

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

[All locations in South Dakota unless otherwise specified. Peak of record flow is the maximum instantaneous peak flow that has been recorded for the period of record for the streamflow-gaging station. Relative magnitude of event: 1, extreme; 2, severe; 3, moderate; 4, minor; 5, very minor; ft³/s, cubic feet per second; USGS, U.S. Geological Survey; X, indicates applicable magnitude; --, not applicable or unknown]

Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
May 10–13, 1920	May 13, 1920	X	--	--	--	--	Cheyenne River	Many
May 1920	May 1920	X	X	X	--	--	Cheyenne River	--
May 1920	May 11–12, 1920	--	--	X	--	--	Hat Creek	Cottonwood Creek, Cheyenne River
May 1920	May 1920	--	X	X	X	--	Cheyenne River, Rapid Creek	Various
May 1920	May 1920	--	X	X	X	--	Many	--
May 1920	May 1920	--	--	X	--	--	Cheyenne River	White River
May 1920	May 1920	--	--	--	--	X	--	--
May 1920	May 1920	--	--	X	X	--	Horsehead and Hat Creeks	--
May 1920	May 1920	--	--	--	--	X	--	--
May 24, 1920	May 1920	--	--	--	--	X	Lame Johnny and Beaver Creeks	--
May 1920	May 1920	--	X	X	X	--	Various	Various
--	May 1920	--	X	X	--	--	Cheyenne River	--
--	May 1920	--	--	X	X	--	Boxelder Creek	--
--	May–June 1920	--	X	X	--	--	Cheyenne River	--
--	June 1920	--	--	X	X	--	Cheyenne and Belle Fourche Rivers	--
June 25, 1920	June 25, 1920	--	--	--	--	X	Cold Springs Creek	--
June 28, 1920	--	--	--	--	--	X	New Underwood	--
June 1920	June 1920	--	--	--	--	X	Johnny and Brushie Creeks	--
Aug. 28, 1920	Aug. 28, 1920	--	--	--	--	X	Beaver and Cold Springs Creeks	--
--	Mar. 1921	--	--	--	--	X	Fall River	--

Primary town or area	Secondary town or area	Description of event	Source of information[1]
--	--	Reported as highest known flood stage for Cheyenne River as of date of article (1920).	Buffalo Gap Gazette (May 14, 1920).
Ardmore	--	Extensive rail damage reported. Brief report of flood deaths near Ardmore provided.	Rapid City Journal (May 14, 1920).
Ardmore	Edgemont	Article reported deaths near Ardmore involving 7-foot "body of water" on top of previous flood conditions. Conflicting reports provided on flood stages for Cheyenne River and Cottonwood Creek, relative to prior years. Old timers declared that water is highest in "their remembrance."	Edgemont Express (May 14, 1920).
Rapid City	Various	Recap of flood damage reported by several previous articles was provided.	Black Hills Weekly Journal (May 14, 1920).
Many	Newell	Article is primarily a report from travelers and other people in dealing with flood circumstances. Reported that "Newell suffered the heaviest rainfall ever known."	Rapid City Journal (May 15, 1920).
--	--	Report from traveler of flood damage south of Rapid City and along the White River provided.	Rapid City Journal (May 16, 1920).
Sturgis	--	Damage reported to Sturgis area cemeteries due to rain.	Black Hills Press (May 20, 1920).
--	--	Horsehead and Hat Creeks reported as very high. Debris carried across Cheyenne River by Hat Creek.	Hot Springs Star (May 20, 1920).
--	--	Short report of damage to a ranch house provided.	Buffalo Gap Gazette (May 21, 1920).
--	--	Lame Johnny Creek reported as "highest flood stage in years."	Buffalo Gap Gazette (May 26, 1920).
--	--	Many bridges destroyed on Bad and White Rivers. Hat Creek had "30 feet of raging water."	Oelrichs Advocate (May 29, 1920).
--	--	Record flows reported all along the Cheyenne River.	Buffalo Gazette (June 4, 1920).
--	--	Boxelder Creek reported as "fully 4 feet higher than ever known before" and "over 3 miles wide."	White Owl Oracle (June 4, 1920).
--	--	Reported that "all high water marks were broken" along the Cheyenne River.	Wasta Gazette (June 11, 1920).
--	--	Events and damage reported along the Cheyenne and Belle Fourche Rivers.	White Owl Oracle (June 20, 1920).
Pringle	--	Minor damage reported along Cold Springs Creek.	Custer Chronicle (June 26, 1920).
Wasta	--	Heavy rain and hail reported near New Underwood.	Wasta Gazette (July 2, 1920).
--	--	Bridge repairs reported along Johnny and Brushie Creeks.	White Owl Oracle (July 2, 1920).
--	--	Damage reported to roads and fences along Beaver and Cold Springs Creeks.	Custer Chronicle (Sept. 4, 1920).
Hot Springs	--	Melting of heavy snow caused damage to bridges and highways.	White Owl Oracle (Apr. 1, 1921).

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

[All locations in South Dakota unless otherwise specified. Peak of record flow is the maximum instantaneous peak flow that has been recorded for the period of record for the streamflow-gaging station. Relative magnitude of event: 1, extreme; 2, severe; 3, moderate; 4, minor; 5, very minor; ft^3/s, cubic feet per second; USGS, U.S. Geological Survey; X, indicates applicable magnitude; --, not applicable or unknown]

Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
June 1921	June 1921	--	--	--	--	X	Cheyenne and Belle Fourche Rivers	--
--	June 1921	--	--	--	--	X	Cheyenne and Fourche Rivers	--
May 10, 1922	May 10, 1922	--	--	--	--	X	Bear Butte Creek	Belle Fourche River
May 10, 1922	May 10, 1922	--	--	X	X	X	Redwater River	Spearfish Creek and many others
--	--	--	--	--	X	X	Cheyenne River	Cottonwood Creek and others in Wyoming
May 10, 1922	May 10–11, 1922	--	--	--	X	X	Rapid Creek	Belle Fourche River
May 10 to unknown date, 1922	May 10 to unknown date, 1922	--	--	X	X	--	Spearfish Creek	Various
May 10 to unknown date, 1922	May 10 to unknown date, 1922	--	--	X	X	--	Spearfish Creek	Various
May 10 to unknown date, 1922	May 10 to unknown date, 1922	--	--	X	X	--	Spearfish Creek	Redwater River and others
May 10 to unknown date, 1922	May 10 to unknown date, 1922	--	--	X	X	X	Redwater River, Spearfish and Hay Creeks	Various
May 10 to unknown date, 1922	May 10 to unknown date, 1922	--	--	X	X	X	Spearfish Creek	Belle Fourche River
May 1922	May 1922	--	--	--	X	X	Belle Fourche and Cheyenne Rivers	--
Aug. 3, 1922	Aug. 3, 1922	--	--	--	X	X	Fall River	--
Aug. 3, 1922	Aug. 3, 1922	--	--	--	X	X	Fall River	--

Primary town or area	Secondary town or area	Description of event	Source of information[1]
--	--	Cheyenne and Belle Fourche Rivers reported as higher than usual.	White Owl Oracle (June 17, 1921).
--	--	Cheyenne River reported as higher this week, with the Belle Fourche River not as high.	White Owl Oracle (June 24, 1921).
Sturgis	St. Onge	Reported as worst storm and high water in years. Bear Butte Creek was out of its banks and the Belle Fourche River was at bankfull.	Black Hills Press (May 11, 1922).
Belle Fourche	Many others	Redwater River was higher by 3 feet at power plant than previous high in 1916. Serious flooding occurred in Spearfish. High water reported in many other parts of northern Hills.	Deadwood Telegram (May 11, 1922).
Edgemont	--	Widespread flooding reported with substantial damage from large storm west of Edgemont.	Edgemont Express (May 12, 1922).
Rapid City	Lead, Belle Fourche	Minor flooding reported for Rapid City. Lead had 3.79 inches of precipitation before a foot of snow. Flooding reported in Belle Fourche.	Rapid City Journal (May 12, 1922).
Spearfish	St. Onge	Precipitation of 6.08 inches reported during a 24-hour period was reported for what seems to be the Spearfish area. The article also provides an earlier report that about 9 inches of water fell in less than 20 hours, with damage reports focusing on Spearfish and surrounding areas.	Rapid City Journal (May 17, 1922).
Spearfish	Deadwood, Lead, and St. Onge	Article provided detailed report of very heavy precipitation totals, but dates are unclear. Some precipitation came as snow and sleet, which helped reduce flood damage somewhat. Flooding reported in Spearfish.	Weekly Pioneer Times (May 18, 1922).
Spearfish, Belle Fourche	St. Onge	No report from Spearfish Valley provided, but severe damage implied. Belle Fourche reported as under water. St. Onge reported the highest water in the history of the town. Redwater River reported as highest known as of date of article (1922).	Weekly Pioneer Times (May 1922).
Belle Fourche	Various	Lowland flooding reported near confluence of Hay Creek and Belle Fourche and Redwater Rivers. Record flood reported on Redwater River at power house. Widespread damage reported.	Belle Fourche Bee (May 18, 1922).
Spearfish, Belle Fourche	--	Article provided a summary of same information provided in several previous articles.	Western Call (May 18, 1922).
--	--	Belle Fourche and Cheyenne Rivers reported as exceptionally high; perhaps as high as 2 years ago in this area. Heavy precipitation and flooding reported in the Black Hills area.	White Owl Oracle (May 19, 1922).
Hot Springs	--	First of several articles on heavy storm and associated flooding in Hot Springs.	Hot Springs Star (Aug. 3, 1922).
Hot Springs	--	Worst flood in many years destroyed 13 rail bridges and 2 highway bridges.	Buffalo Gap Gazette (Aug. 4, 1922).

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

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Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
Aug. 3, 1922	Aug. 3, 1922	--	--	--	X	X	Fall River	--
Aug. 3, 1922	Aug. 3, 1922	--	--	--	X	X	Fall River	--
--	Apr. 12, 1923	--	--	--	X	X	Cheyenne River	--
June 1923	June 6, 1923	--	--	--	--	X	Boxelder Creek	--
June 3–5, 1923	June 6, 1923	--	--	--	--	X	Cheyenne River	--
June 1923	June 1923	--	--	--	--	X	Cheyenne River	--
--	June 1923	--	--	--	--	X	Cheyenne River	--
July 1, 1923	July 1, 1923	--	--	--	--	X	Fall River	--
July 1, 1923	July 1, 1923	--	--	--	--	X	Fall River	--
July 9, 1923	July 9, 1923	--	--	--	X	X	French and Laughing Water Creeks	--
Sept. 1923	Sept. 29, 1923	--	--	X	X	--	Belle Fourche River	Spearfish Creek
Sept. 29–30, 1923	Oct. 1, 1923	--	--	--	X	--	Cheyenne River	--
Sept.–Oct. 1923	Sept.–Oct. 1923	--	--	--	--	X	Belle Fourche River	--
--	Feb. 13, 1924	--	--	--	--	X	Belle Fourche River	--
--	Feb., 1924	--	--	--	--	X	Belle Fourche River	--
--	Feb.–Mar. 1924	--	--	--	--	X	Belle Fourche River	--
--	Apr. 4–10, 1924	--	X	X	X	--	Belle Fourche River	--
--	Apr. 8–9, 1924	--	X	X	X	--	Belle Fourche River	--

Primary town or area	Secondary town or area	Description of event	Source of information[1]
Hot Springs	--	Report that eight rail bridges between Hot Springs and Buffalo Gap were washed out.	Black Hills Press (Aug. 10, 1922).
Hot Springs	--	More details provided on the August 3, 1922, flood. Water reported as 3 feet deep in power plant, which is ordinarily 13 feet above the water.	Hot Weekly Springs Star (April 18, 1946 reprint of Aug. 10, 1922 article).
Edgemont	--	Highway bridge over Cheyenne River at Edgemont was out of commission.	Hot Springs Star (Apr. 16, 1923).
New Underwood	--	Bridges near New Underwood damaged.	Owanka Bee (June 7, 1923).
Wasta	New Underwood	Cheyenne River was out of its banks. Rail damaged near New Underwood.	Wasta Gazette (June 7, 1923).
--	--	Rains help crops. Creeks reported as high. Cheyenne River reported as near stage of 3 years earlier.	White Owl Oracle (June 8, 1923).
--	--	Damage to crops reported along Cheyenne River.	Wasta Gazette (June 21, 1923).
Hot Springs	Deadwood	Heavy storm occurred in Deadwood. Moderate flooding reported in Hot Springs.	Rapid City Journal (July 2, 1923).
Hot Springs	--	Moderate flood damage reported in Hot Springs.	Rapid City Journal (July 3, 1923).
Custer	--	Reported as heaviest rain storm ever experienced as of date of article (1923). Bridge damage along French Creek initially reported as severe, but subsequent correction reported much less damage.	Custer Chronicle (July 14, 1923).
Belle Fourche	Whitewood	Belle Fourche River reported as highest ever experienced as of date of article (1923). Stage was nearing floor of American Legion building.	Deadwood Pioneer Times (Sept. 30, 1923).
Edgemont	--	Cheyenne River reported at highest point in many years.	Edgemont Express (Oct. 5, 1923).
--	--	High water reported in Belle Fourche River.	White Owl Oracle (Oct. 5, 1923).
--	--	Flooding from ice jam reported.	Wasta Gazette (Feb. 14, 1924).
--	Nisland	Flooding from ice jams reported. Nisland reported highest water in 15 years.	Black Hills Press (Feb. 21, 1924).
--	--	Continue flooding from ice jams reported along Belle Fourche River.	Wasta Gazette (Mar. 6, 1924).
Belle Fourche	--	Flood damage reported as worst in history of Belle Fourche as of date of article (1924). Flooding was caused by melting of heavy snow to the west and exacerbated by ice jamming. American Legion building partly submerged.	Deadwood Pioneer Times (Apr. 10, 1924).
Belle Fourche	--	Crest of Belle Fourche River was reported within 2 inches of American Legion Hall. Stage receded 18 inches on morning of April 10, 1924, but was “still higher than any previous high water mark.” Residents of Belle Fourche reported that this was the worst flood in history of the town as of date of article (1924).	Black Hills Press (Apr. 10, 1924).

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

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Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
--	Apr. 1924	--	X	X	X	--	Belle Fourche River	--
--	Apr. 1924	--	X	X	X	--	Belle Fourche River	--
--	Apr. 1924	--	X	X	X	--	Belle Fourche River	--
--	Apr. 9–10, 1924	--	X	X	X	--	Belle Fourche River	--
--	Apr. 9, 1924	--	X	X	X	--	Belle Fourche River	--
--	Apr. 1924	--	X	X	X	--	Belle Fourche River	Sundance and Sand Creeks
--	Apr. 1924	--	X	X	X	--	Belle Fourche River	--
--	Apr. 1924	--	X	X	X	--	Belle Fourche River	Various streams in Wyoming
--	Apr. 1924	--	--	X	X	--	Belle Fourche River	--
--	Apr. 1924	--	X	X	X	--	Belle Fourche River	--
May 27, 1926	May 27, 1926	--	--	--	--	--	Rapid City	--
June 22, 1926	June 22, 1926	--	--	--	X	X	Beaver Creek	--
May 5 to unknown date, 1927	May 1927	--	--	X	X	X	Cheyenne and Bad Rivers	White and Missouri Rivers
May 1927	May 1927	--	--	--	--	--	--	--
May 1927	May 8–9, 1927	--	--	--	X	X	Belle Fourche River	Cheyenne River
May 1927	May 1927	--	--	--	X	X	Boxelder and Elk Creeks	--
May 1927	May 1927	--	--	--	--	X	--	Cheyenne River
May 1927	May 1927	--	--	--	--	X	--	--

Primary town or area	Secondary town or area	Description of event	Source of information[1]
Belle Fourche	--	Primarily provides same information and damage reports as previous articles.	Deadwood Daily Pioneer Times (Apr. 10, 1924).
Belle Fourche	--	New high water mark for Belle Fourche River was set 3 feet higher than previously registered. Back water from Belle Fourche River pushed bridge 100 feet upstream in Redwater River.	Belle Fourche Bee (Apr. 10, 1924).
Belle Fourche	--	More information provided on same flood (April 1924). Water was very high in Hulett, Wyo.	Northwest Post - Belle Fourche (Apr. 10, 1924).
Belle Fourche	--	Flooding reported in Belle Fourche from rain on 5 feet of snow, with 55 families displaced.	National Oceanic and Atmospheric Administration (2008).
Belle Fourche	--	Peak flow of 22,400 ft^3/s occurred on April 9, 1924, at station 06435500 (Belle Fourche River near Belle Fourche).	U.S. Geological Survey (2009).
Hulett and Beulah, Wyo.	--	Additional information provided on the April 1924 flood. Reported as highest known water level in Hulett, Wyo. Flooding reported in Sundance Creek and near Beulah, Wyo., as of date of article (1924).	Queen City Mail (Apr. 16, 1924).
Belle Fourche	--	Not as much damage reported in areas downstream from Belle Fourche.	New Underwood Times (Apr. 17, 1924).
Belle Fourche	--	Article provided a brief account of flooding along Belle Fourche River and other streams in Wyoming.	Sundance Times (Apr. 17, 1924).
Belle Fourche	--	Reported that Minturn bridge on Sturgis road can not be crossed.	White Owl Oracle (Apr. 18, 1924).
Belle Fourche	--	Article provided a brief account of flooding along Belle Fourche River.	Deadwood Telegram (May 10, 1924).
Sturgis, Deadwood	--	Rainfall of 3 inches in 3 hours reported in Rapid City, Sturgis, and Deadwood.	National Oceanic and Atmospheric Administration (2008).
Buffalo Gap	--	Heavy storm occurred west of Buffalo Gap, with lowland flooding and crop damage reported.	Buffalo Gap Gazette (June 26, 1926).
--	--	Heavy flooding occurred from prolonged precipitation through much of western South Dakota.	National Oceanic and Atmospheric Administration (2008).
--	--	Reported as worst May storm in 22 years. Heavy stock losses reported from snow that followed 4 days of rain.	Black Hills Press (May 12, 1927).
--	--	Article provided brief account of flood damage along the Belle Fourche and Cheyenne Rivers.	Wasta Gazette (May 12, 1927).
--	--	Widespread high water and flooding from prolonged precipitation reported.	New Underwood Times (May 12, 1927).
--	--	Heavy snow, high water, and rail damage reported. Old timers say they have never seen more moisture.	Wasta Gazette (May 12, 1927).
--	--	Prolonged precipitation and lowland flooding reported.	Oelrichs Advocate (May 12, 1927).

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

[All locations in South Dakota unless otherwise specified. Peak of record flow is the maximum instantaneous peak flow that has been recorded for the period of record for the streamflow-gaging station. Relative magnitude of event: 1, extreme; 2, severe; 3, moderate; 4, minor; 5, very minor; ft^3/s, cubic feet per second; USGS, U.S. Geological Survey; X, indicates applicable magnitude; --, not applicable or unknown]

Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
May 1927	May 9, 1927	--	X	X	X	X	Sulphur Creek	Red Owl Creek
--	May 13, 1927	--	--	--	X	X	Belle Fourche River	--
May 1927	May 1927	--	X	X	X	X	Many	--
May 1927	May 1927	--	--	--	X	X	Boxelder Creek	--
May 1927	May 1927	--	--	--	X	X	Belle Fourche River	--
--	May 1927	--	X	--	--	--	Belle Fourche River	--
--	--	--	--	--	--	--	Beaver Creek	--
June 19, 1927	June 19-20, 1927	--	--	X	X	--	Cold Brook, Fall River	--
--	June 30, 1927	--	--	--	--	X	Fall River	--
--	Mar. 12, 1928	--	--	--	--	--	Belle Fourche River	--
--	Apr. 8, 1929	--	--	--	--	--	Belle Fourche River	--
--	May 6, 1932	--	X	X	X	--	Rapid Creek	--
May 22, 1933	May 23, 1933	--	--	--	X	X	Rapid Creek	Various
May 22–23, 1933	May 23, 1933	--	--	--	X	X	Whitewood Creek	Spearfish Creek
May 22–23, 1933	May 23, 1933	--	--	--	X	X	Rapid Creek	Bear Butte and Battle Creeks

Primary town or area	Secondary town or area	Description of event	Source of information[1]
--	--	Sulphur Creek reported as higher by almost 8 feet than during any other high water.	White Owl Oracle (May 13, 1927).
Belle Fourche	--	Peak flow of 8,250 ft^3/s occurred on May 13, 1927, at station 06435500 (Belle Fourche River near Belle Fourche).	U.S. Geological Survey (2009).
Many	--	Widespread heavy flooding reported over large parts of western South Dakota.	Custer Chronicle (May 14, 1927).
Owanka	--	Flood took out both bridges across Boxelder Creek near Owanka.	Wasta Gazette (May 19, 1927).
--	--	Bridge across Belle Fourche River reported as impassable.	White Owl Oracle (May 20, 1927).
--	--	USGS records indicate a stage of 21.8 feet during May 1927 at station 06438000 (Belle Fourche River near Elm Springs). The discharge is unknown, but this is the highest known stage by about 2 feet (followed by 20.00 feet in 1933 and 19.73 feet in 2008).	U.S. Geological Survey (2009).
--	--	USGS records (Annual Data reports) indicate a 1927 flood stage of 18.0 feet for station 06402500 (Beaver Creek near Buffalo Gap).	U.S. Geological Survey (2009).
Hot Springs	--	Two people drowned when the crest of flood waters on Cold Brook struck the car in which they were crossing the bridge at the northern end of Hot Springs.	Hot Springs Weekly Star (June 21, 1927)
Hot Springs	--	Photographs show minor flooding occurred in Hot Springs.	Photographs by Fall River County Historical Society.
--	--	Peak flow of 9,660 ft^3/s occurred on March 12, 1928, at station 06435500 (Belle Fourche River near Belle Fourche).	U.S. Geological Survey (2009).
--	--	Peak flow of 15,000 ft^3/s occurred on April 8, 1929, at station 06435500 (Belle Fourche River near Belle Fourche).	U.S. Geological Survey (2009).
--	--	Peak flow of 16,000 ft^3/s occurred on May 6, 1932, at station 06422000 (Rapid Creek at Creston).	U.S. Geological Survey (2009).
Various	--	Widespread storm reported. Rapid Creek was high at Mystic. Bear Butte Creek was over the highway near Ft. Meade for the first time in history. Flooding reported in Spearfish.	Rapid City Journal (May 23, 1933).
Lead	Spearfish and others	Widespread storm reported; Lead received about 4.8 inches of rain in 12 hours. Worst flooding since 1910 reported in Spearfish. A later May 31, 1946, article refers to substantial rail damage in Spearfish Canyon from 1933 flooding.	Lead Call (May 23, 1933).
Various	Various	Article provided similar information as other articles for May 23, 1933. High water reported in Custer State Park.	Hot Springs Star (May 23, 1933).

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

[All locations in South Dakota unless otherwise specified. Peak of record flow is the maximum instantaneous peak flow that has been recorded for the period of record for the streamflow-gaging station. Relative magnitude of event: 1, extreme; 2, severe; 3, moderate; 4, minor; 5, very minor; ft^3/s, cubic feet per second; USGS, U.S. Geological Survey; X, indicates applicable magnitude; --, not applicable or unknown]

Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
May 22–23, 1933	May 23, 1933	--	--	--	X	X	Rapid Creek	Bear Butte Creek
May 22–23, 1933	May 23, 1933	--	--	--	X	X	Whitewood Creek	Various
--	May 24, 1933	--	X	X	X	--	Cheyenne River	--
June 22, 1933	June 22, 1933	--	--	--	--	X	Beaver Creek	--
Aug. 26–28, 1933	Aug.–Sept. 1933	--	--	X	X	X	Cheyenne River	White River
July 26, 1934	July 26, 1934	--	--	--	X	X	Beaver Creek	Elm Creek
May 31, 1935	May 31, 1935	--	--	--	--	X	Rapid Creek	--
May 31, 1935	May 31, 1935	--	--	--	--	X	Rapid Creek	Various
June 1935	June 1935	--	--	--	X	X	Various	Various
June 1935	June 1935	--	--	--	X	X	Old Woman Creek	Hat Creek
May 31, 1935	May 31, 1935	--	--	--	X	X	Boxelder Creek	--
June 17, 1937	June 17, 1937	--	--	--	--	X	Beaver Creek	--
June 17, 1937	June 17–18, 1937	--	X	X	--	--	Fall River	--
June 17, 1937	June 17–18, 1937	--	--	--	--	X	Fall River	--
June 17, 1937	June 17–18, 1937	--	X	X	--	--	Fall River	--
June 17, 1937	June 17–18, 1937	--	X	X	--	--	Fall River	--
June 1937	June 1937	--	--	--	--	X	Ash Creek	--
June 17, 1937	June 17–18, 1937	--	X	X	--	--	Fall River	--
June 17, 1937	June 17, 1937	--	X	X	X	--	Fall River	--
July 10, 1937	July 10, 1937	--	--	X	X	--	Hay Creek	--

Primary town or area	Secondary town or area	Description of event	Source of information[1]
--	--	Article provided similar information as other articles for May 23, 1933.	Lead Call (May 23, 1933).
Deadwood	Various	Article provided similar information as other articles for May 23, 1933. Extensive damage reported to area roads.	Deadwood Pioneer Times (May 24, 1933).
--	--	Peak of record flow of 114,000 ft^3/s occurred on May 24, 1933, at station 06439500 (Cheyenne River near Eagle Butte).	U.S. Geological Survey (2009).
--	--	Beaver Creek reported as highest in several years, with some damage reports provided.	Buffalo Gap Gazette (June 23, 1933).
--	--	Cheyenne River reported as highest since 1926.	Buffalo Gap Gazette (Sept. 1, 1933).
Buffalo Gap	--	Beaver Creek reached “highest stage in years.” Water was 1 foot deep in streets of Buffalo Gap.	Buffalo Gap Gazette (July 27, 1934).
Rapid City	Black Hawk	Rapid Creek reported as out of its banks in several places.	Rapid City Journal (May 31, 1935).
--	--	Minor flooding in Rapid City reported with good rains throughout much of the Black Hills area.	Rapid City Journal (May 31, 1935).
--	--	Moderate damage reported to highways and rail lines from recent flooding.	Rapid City Journal (June 3, 1935).
--	--	Heavy, widespread rains reported. Old Woman Creek reported as highest level ever seen as of date of article (1935).	Edgemont Tribune (June 5, 1935).
New Underwood	Box Elder	Lowland flooding reported in New Underwood.	New Underwood Times (June 6, 1935).
Buffalo Gap	--	Beaver Creek exceeded capacity of rail bridge.	Buffalo Gap Gazette (June 18, 1937).
Hot Springs	--	Severe flood occurred along Fall River, with 13 rail bridges and 8 city bridges destroyed. The 1937 flood is specifically mentioned in the article “prelude” as being larger than the “smaller floods” of 1938 and 1941.	Hot Springs Weekly Star (April 18, 1946 reprint of June 18, 1937 article).
Hot Springs	--	Substantial damage reported in Hot Springs from severe flood along Fall River.	Rapid City Journal (June 18, 1937).
Hot Springs	--	Flooding along Fall River caused substantial damage in Hot Springs.	National Oceanic and Atmospheric Administration (2008).
--	--	Photograph showing aftermath of 1937 flood in Hot Springs	Original photos courtesy of Hot Springs Public Library and Rapid City Journal.
--	--	Vehicle was swept downstream in flood.	Black Hills Press (June 20, 1937).
Hot Springs	--	Two scanned articles available; one relating flood damage and one relating an account by the late Joe Petty “that the Indians showed him water marks halfway up the cliff” in Hot Springs.	Rapid City Journal and Hot Springs Evening Star (June 21, 1937).
Hot Springs	--	Hydroelectric dam damaged.	Hot Springs Weekly Star (June 22, 1937).
Belle Fourche	--	About 50 residences along Hay Creek flooded.	Lead Call (July 10, 1937).

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

[All locations in South Dakota unless otherwise specified. Peak of record flow is the maximum instantaneous peak flow that has been recorded for the period of record for the streamflow-gaging station. Relative magnitude of event: 1, extreme; 2, severe; 3, moderate; 4, minor; 5, very minor; ft^3/s, cubic feet per second; USGS, U.S. Geological Survey; X, indicates applicable magnitude; --, not applicable or unknown]

Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
July 10 and 12, 1937	July 10 and 12, 1937	--	--	X	X	X	Hay Creek	--
July 10–12, 1937	July 10 and 12, 1937	--	--	--	X	X	Hay Creek	--
July 23, 1938	July 23–24, 1938	--	--	--	X	X	Rapid Creek	Cheyenne River
Sept. 4, 1938	Sept. 4, 1938	--	X	X	--	--	Fall River	--
Sept. 4, 1938	Sept. 4, 1938	--	X	X	--	--	Beaver Creek	--
--	Sept. 4, 1938	--	--	--	X	--	Cheyenne and Belle Fourche Rivers	Fall River
Sept. 4, 1938	Sept. 4, 1938	--	--	X	--	--	Fall River	--
July 1941	July 1941	--	--	--	X	X	Dry Creek	Various
July 1941	July 1941	--	--	--	--	X	--	Crow Creek
Aug.1941	Aug. 6, 1941	--	--	X	X	--	Fall River	--
1943	June 13, 1943	--	--	--	--	X	Rapid Creek	--
July 12, 1944	July 12, 1944	--	--	--	--	X	Fall River	--
Apr.–May 1946	May 1–2, 1946	--	--	--	X	X	Bear Butte Creek	--
Apr.–May 1946	May 1–2, 1946	--	--	--	X	X	Whitewood Creek	Bear Butte Creek
Apr.–May 1946	May 1–2, 1946	--	--	--	X	X	Bear Butte Creek	--

Primary town or area	Secondary town or area	Description of event	Source of information[1]
Belle Fourche, Vale	--	Second flood reported along Hay Creek in 3 days. Earlier flood (July 10, 1937) was largest along Hay Creek since 1923 and caused worst flooding in Belle Fourche since 1924 (as of date of article). Almost 6 inches of rain fell in deluge near Vale.	Belle Fourche Post (July 13, 1937).
--	--	Two floods along Hay Creek and heavy rain near Vale were mentioned. Reported that 7 inches of rain fell in upper Horse Creek. Large benefits from widespread rains reported.	Rapid City Journal (July 14, 1937).
Rapid City	--	Lowland flooding in Rapid City and some road damage east of Rapid City reported.	Rapid City Journal (June 24, 1938).
Hot Springs	--	Peak of record flow of 13,100 ft^3/s occurred on September 4, 1938, at station 06402000 (Fall River at Hot Springs).	U.S. Geological Survey (2009).
Buffalo Gap	--	Peak of record flow of 11,700 ft^3/s occurred on September 4, 1938, at station 06402500 (Beaver Creek near Buffalo Gap).	U.S. Geological Survey (2009).
Hot Springs	--	September 4, 1938, flood on Lame Johnny Creek reported as worst in 35 years. Flood on same date in Hot Springs was less severe than flood of June 17, 1937.	Rapid City Journal (Sept. 24, 1938).
Hot Springs	--	Article reported that the 1938 flood was higher in Hot Springs by about 1 foot than the 1937 flood, however, farther down the canyon the 1937 water level exceeded that of 1938 by about 3 feet.	Hot Springs Weekly Star (Sept. 6, 1938)
Sturgis	--	Some rail and highway damage from heavy rains and high water reported throughout widespread area.	Valley Irrigator (June 12, 1941).
--	--	Area streams were high from widespread, prolonged precipitation.	Valley Irrigator (June 19, 1941).
Hot Springs	--	Peak flow of 4,700 ft^3/s occurred on August 6, 1941, at station 06402000 (Fall River at Hot Springs).	U.S. Geological Survey (2009).
Rapid City	--	Peak flow of 936 ft^3/s reported for Rapid Creek for June 13, 1943.	Miller (1986).
Hot Springs	--	Article reported 2.34 inches of rain fell on July 12, 1944, in Hot Springs in an hour.	Hot Springs Weekly Star (July 20, 1944).
Sturgis	--	Nearly 7 inches of rain reported for past 2 days at Deadwood. Several homes along Bear Butte Creek were moved because of flood threat.	Rapid City Journal (May 2, 1946).
Deadwood	Sturgis	Street damage reported for Deadwood. Additional damage along Bear Butte Creek reported.	Rapid City Journal (May 3, 1946).
Sturgis	--	Congressional committee ordered review by army engineers of possible flood improvements along Bear Butte Creek; instigated by flooding of recent days.	Rapid City Journal (May 4, 1946).

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

[All locations in South Dakota unless otherwise specified. Peak of record flow is the maximum instantaneous peak flow that has been recorded for the period of record for the streamflow-gaging station. Relative magnitude of event: 1, extreme; 2, severe; 3, moderate; 4, minor; 5, very minor; ft³/s, cubic feet per second; USGS, U.S. Geological Survey; X, indicates applicable magnitude; --, not applicable or unknown]

Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
--	May 24, 1946	--	--	X	X	X	Bear Butte Creek	--
May 1946	May 1946	--	--	X	--	--	Spearfish Creek	--
May 1946	May 1946	--	--	--	X	X	Spearfish Creek	--
May 1946	--	--	--	--	--	--	--	--
--	July 18, 1946	--	--	--	--	X	Rapid Creek	--
--	1946	--	--	--	--	--	Redwater River and Hay Creek	--
June 20, 1947	June 20, 1947	--	X	X	--	--	Fall River	--
June 20, 1947	June 20, 1947	--	X	X	--	--	Fall River	--
June 17, 1947	June 17–18, 1947	--	X	X	--	--	Fall River	--
June 20, 1947	June 20, 1947	--	X	X	--	--	Fall River	--
--	June 24, 1947	--	--	--	--	X	Rapid Creek	--
Aug. 15, 1949	Aug. 15, 1949	--	--	--	--	X	Rapid Creek	--
--	Aug. 15, 1949	--	--	--	--	X	--	--
May 21–22, 1952	May 21–22, 1952	--	--	--	X	X	Rapid Creek	Various
May 22, 1952	May 22–23, 1952	--	--	--	X	X	Rapid Creek	--
--	May 23, 1952	--	--	--	X	X	Rapid Creek	--
--	May 23,24, 1952	--	--	--	X	X	Rapid Creek	--

Primary town or area	Secondary town or area	Description of event	Source of information[1]
--	--	Peak flow of 9,800 ft^3/s occurred on May 24, 1946, at station 06437500 (Bear Butte Creek near Sturgis).	U.S. Geological Survey (2009).
Spearfish	--	May rainfall at Lead (?) broke 41-year record. Spearfish Creek reported to be as high as during flood of 1933, when rail bed in Spearfish Canyon was washed out.	Lead Call (May 31, 1946).
Spearfish	--	Damage in Spearfish area reported to be most severe since early 1930s. Army engineers arrived to investigate flood damages.	Queen City Mail (May 4, 1946).
Lead, Deadwood	--	Precipitation totals for May 1946 of 18.61 inches for Deadwood and 15.31 inches for Lead provided. Indicates that very wet conditions existed in May 1946 for this area.	Driscoll and others (2000).
Rapid City	--	Peak flow of 1,000 ft^3/s reported for Rapid Creek for July 18, 1946.	Miller (1986).
--	--	Article listed major flood years for Redwater River as 1906, 1922, 1935, 1941, and 1946; and for Hay Creek as 1923, 1926, 1930, 1937, and 1940.	Rapid City Journal (Oct. 22, 1946).
Hot Springs	--	Fall River reported as highest since 1938.	Edgemont Tribune (June 25, 1947).
--	--	Peak flow of 8,300 ft^3/s occurred on June 20, 1947, at station 06402000 (Fall River at Hot Springs). This was the last large peak flow prior to the construction of two flood-control reservoirs within Fall River Basin.	U.S. Geological Survey (2009).
Hot Springs	--	Flooding along Fall River caused substantial damage in Hot Springs.	National Oceanic and Atmospheric Administration (2008).
Spearfish	Deadwood, Spearfish	Flash flood occurred in Hot Springs. Wet conditions existed near Deadwood and Spearfish.	Queen City Mail (June 26, 1947).
Rapid City	--	Peak flow of 1,170 ft^3/s reported for Rapid Creek for June 24, 1947.	Miller (1986).
Rapid City	--	Flash flooding occurred along Rapid Creek.	National Oceanic and Atmospheric Administration (2008).
Rapid City	--	Heavy rain reported in western part of Rapid City.	Miller (1986).
Rapid City	--	Flooding occurred in many streams from widespread rains throughout Black Hills area.	Rapid City Journal (May 22, 1952).
Rapid City	Deadwood, Sturgis	Damage reported for Canyon Lake area of western Rapid City. Heavy rains reported for other areas.	National Oceanic and Atmospheric Administration (2008).
Rapid City	--	Peak flow of 2,540 ft^3/s reported for Rapid Creek for May 23, 1952.	Miller (1986).
Rapid City	--	Peak flows of 2,540 ft^3/s on May 23, 1952, at station 06414000 (Rapid Creek at Rapid City) and 1,770 ft^3/s on May 24, 1952, at station 06421500 (Rapid Creek near Farmingdale) occurred on Rapid Creek.	U.S. Geological Survey (2009).

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

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Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
--	May 23, 1952	--	--	X	X	X	Rapid Creek	--
--	May 23, 1954	--	--	X	X	--	Hat Creek	--
July 28, 1955	July 28, 1955	--	--	X	X	--	Rapid Creek	--
July 28, 1955	July 28, 1955	--	--	X	X	--	Castle and Rapid Creeks	--
July 28, 1955	July 28, 1955	--	--	--	X	--	Rapid Creek	--
June 20, 1960	1960	--	--	--	--	X	--	--
May 15–22, 1962	May 22, 1962	--	--	--	--	X	Bear Butte Creek	--
May 1962	May–June 1962	--	--	--	--	X	Alkali Creek	--
June 15, 1962	June 15–16, 1962	--	X	X	--	--	Bear Butte Creek	Deadman and Spring Creeks
June 15, 1962	June 15–16, 1962	--	--	X	X	--	Rapid Creek	Bear Butte Creek
June 16, 1962	June 16–17, 1962	--	--	X	X	X	Rapid Creek	Others
--	June 15–16, 1962	--	X	X	--	--	Bear Butte Creek	--
July 13–14, 1962	July 13–14, 1962	--	--	--	--	X	Bear Butte Creek	Deadman Creek
July 13, 1962	July 13, 1962	--	--	X	X	--	Rapid Creek	--
July 13, 1962	July 13, 1962	--	--	X	X	--	Rapid Creek	--

Primary town or area	Secondary town or area	Description of event	Source of information[1]
--	--	Aerial photographs showed flooding for Rapid Creek east of Rapid City.	USGS aerial photos.
--	--	Peak flow of 9,430 ft^3/s occurred on May 23, 1954, at station 06400000 (Hat Creek near Edgemont); second only to peak flow of 13,300 ft^3/s on June 16, 1967.	U.S. Geological Survey (2009).
Rochford, Mystic	--	Heavy rain and minor flooding reported for Rochford and Mystic area.	National Oceanic and Atmospheric Administration (2008).
Rochford	--	Indirect measurements of peak flow reported for nine sites where large flows occurred.	Wells (1962).
--	--	Peak flow of 1,520 ft^3/s on July 28, 1955, at station 06410500 (Rapid Creek above Pactola Reservoir).	U.S. Geological Survey (2009).
Rapid City, New Underwood	--	Heavy storm reported for the Rapid City and New Underwood area.	National Oceanic and Atmospheric Administration (2008).
Sturgis	--	Article reported 7.93 inches of rain in Sturgis between May 15 and May 22, 1962. Bear Butte Creek was running high in Boulder Canyon.	Sturgis Tribune. (May 23, 1962).
Sturgis	--	Alkali Creek was running high following recent rains.	Sturgis Tribune. (June 6, 1962).
Sturgis	--	Almost 4.5 inches of rain reported for June 15 in Sturgis. Severe flooding reported with evacuations and destruction of homes, highways, and infrastructure.	Black Hills Press. (June 16, 1962).
Rapid City	Sturgis, Whitewood, St. Onge	Substantial storm damage and flooding reported from Rapid City to Sturgis to Whitewood. Reported an unofficial 2-day rainfall total of 8.15 inches near Piedmont.	Rapid City Journal. (June 16, 1962).
Rapid City	Sturgis, others	Second heavy storm in 2 days reported for Rapid City and other parts of the Black Hills. Flooding generally was less severe than for the storm of the previous day.	Rapid City Journal. (June 17, 1962).
Sturgis	--	Article reported that a 1957 U.S. Army Corps of Engineers flood plan was not implemented because of lack of local support. Also reported that 14 inches of rain fell between 5 and 11 p.m. on June 15, 1962, in Whitewood.	Black Hills Press. (June 23, 1962).
Sturgis	--	Reported that 1.46 inches of rain fell in 24 hours that ended July 14, 1962, but did not cause flood damage.	Black Hills Press. (July 14, 1962).
Rapid City	--	Substantial flooding reported along Rapid Creek. Reported that as much as 3 or 4 inches of rain fell west of town.	Rapid City Journal. (July 14, 1962).
Rapid City	--	Additional information provided about substantial damage from flooding along Rapid Creek.	Rapid City Journal. (July 15, 1962).

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

[All locations in South Dakota unless otherwise specified. Peak of record flow is the maximum instantaneous peak flow that has been recorded for the period of record for the streamflow-gaging station. Relative magnitude of event: 1, extreme; 2, severe; 3, moderate; 4, minor; 5, very minor; ft^3/s, cubic feet per second; USGS, U.S. Geological Survey; X, indicates applicable magnitude; --, not applicable or unknown]

Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
June 1962	June 15, 1962	--	--	--	--	X	Rapid Creek	--
July 13, 1962	July 13, 1962	--	--	X	X	--	Rapid Creek	--
July 13, 1962	July 13, 1962	--	--	X	X	--	Rapid Creek	--
July 13, 1962	July 13, 1962	--	X	--	--	--	Cleghorn Canyon	--
--	May–June1962	--	--	X	X	X	Elk Creek, Redwater River, Bear Butte Creek	--
--	June 9, 1964	--	--	X	X	--	Spearfish Creek	--
May 15, 1965	May 15, 1965	--	--	X	X	X	Spearfish and Rapid Creeks	Various
--	May 14–15, 1965	--	--	X	X	X	Various	--
--	June 11, 1965	--	--	--	--	X	Rapid Creek	--
--	June 16, 1967	--	X	X	X	--	Hat Creek	--
June 9–10, 1972	June 9–10, 1972	X	X	X	X	--	Rapid Creek	Various
June 9–10, 1972	June 9–10, 1972	X	--	--	--	--	Rapid Creek	--
June 9–10, 1972	June 9–10, 1972	X	X	X	X	--	Many	Many

Primary town or area	Secondary town or area	Description of event	Source of information[1]
Rapid City	Various	Minor flooding reported for Rapid City on June 15, 1962, and subsequent dates. Heavy rains and flood damage reported throughout northern Black Hills during late June.	National Oceanic and Atmospheric Administration (2008).
Rapid City	--	Heavy rain and flooding reported for Rapid City.	National Oceanic and Atmospheric Administration (2008).
Rapid City	--	Peak flow of 3,300 ft^3/s occurred on July 13, 1962, for station 06414000 (Rapid Creek at Rapid City) after 3.4 inches of rain in Rapid City.	Miller (1986); U.S. Geological Survey (2009).
Rapid City	--	Peak flow of 2,920 ft^3/s occurred on July 13, 1962, at station 440325103182500 along Cleghorn Canyon.	U.S. Geological Survey (2009).
--	--	High flows reported for several streams along northeastern flank of Black Hills in 1962. Noteworthy peak flows include 7,040 ft^3/s on May 29 at station 06425500 (Elk Creek near Elm Springs); 16,400 ft^3/s on June 16 at station 06433000 (Redwater River above Belle Fourche); and 12,700 ft^3/s on June 16 at station 06437500 (Bear Butte Creek near Sturgis).	U.S. Geological Survey (2009).
Spearfish	--	Peak flow of 3,040 ft^3/s occurred on June 9, 1964, at station 06431500 (Spearfish Creek at Spearfish).	U.S. Geological Survey (2009).
Spearfish	Various	Heavy rain on snow caused flooding in Spearfish and many other areas.	National Oceanic and Atmospheric Administration (2008).
--	--	High flows in many streams in central and northern Black Hills in May 1965. Noteworthy peak flows include a peak of record flow of 2,060 ft^3/s on May 15 at station 06410500 (Rapid Creek above Pactola Reservoir); and peak flows of 4,240 ft^3/s on May 15 at station 06431500 (Spearfish Creek at Spearfish); 1,060 ft^3/s on May 14 at station 06432200 (Polo Creek near Whitewood); and 8,480 ft^3/s on May 15 at station 06433000 (Redwater River above Belle Fourche).	U.S. Geological Survey (2009).
Rapid City	--	Peak flow of 706 ft^3/s reported for Rapid Creek on June 11, 1965.	Miller (1986).
--	--	Peak of record flow of 13,300 ft^3/s occurred on June 16, 1967, at station 06400000 (Hat Creek near Edgemont).	U.S. Geological Survey (2009).
Rapid City	Various	Various details provided for worst known storm and flooding since European settlement of the Black Hills area.	National Oceanic and Atmospheric Administration (2008).
Rapid City	--	Peak flow of 50,000 ft^3/s reported for Rapid Creek on June 9, 1972.	Miller (1986).
--	--	Large peak flows occurred for many streams in Black Hills area, with peaks of record for many.	U.S. Geological Survey (2009).

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

[All locations in South Dakota unless otherwise specified. Peak of record flow is the maximum instantaneous peak flow that has been recorded for the period of record for the streamflow-gaging station. Relative magnitude of event: 1, extreme; 2, severe; 3, moderate; 4, minor; 5, very minor; ft^3/s, cubic feet per second; USGS, U.S. Geological Survey; X, indicates applicable magnitude; --, not applicable or unknown]

Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
June 9–10, 1972	June 9–10, 1972	X	X	X	X	--	Many	Many
June 9–10, 1972	June 9–10, 1972	X	X	X	X	--	Many	Many
June 9–10, 1972	June 9–10, 1972	X	X	--	--	--	Rapid Creek	Many
June 9–10, 1972	June 9–10, 1972	X	X	--	--	--	Rapid Creek	Many
June 9–10, 1972	June 9–10, 1972	--	--	--	--	--	--	--
June 8, 1975	June 8, 1975	--	--	--	--	X	--	--
June 13–16, 1976	June 1976	--	--	X	X	X	--	--
--	June 15–16, 1976	--	--	X	X	X	Various	--
July 23, 1981	July 23, 1981	--	--	--	--	X	--	--
--	June 9, 1982	--	--	X	X	--	Spearfish Creek, Horse Creek, Belle Fourche River	Redwater River, Whitewood Creek
1991	1991	--	--	--	--	X	--	--
May–Aug.1993	May–Aug.1993	--	--	--	--	X	Battle Creek	--
May 7–9, 1995	May 7–9, 1995	--	--	--	--	X	--	--

Primary town or area	Secondary town or area	Description of event	Source of information[1]
--	--	Documented the storm, flood, and damage from the 1972 event. Nearly 15 inches of rain fell in about 6 hours near Nemo and more than 10 inches of rain fell over a 60 square-mile area.	Schwarz and others (1975).
--	--	Fact sheet recounted the 1972 flood 25 years after the event that claimed the lives of 238 people.	Carter and others (2002).
Rapid City	Many	Web page describes 1972 flood event and provides photographs.	http://www.crh.noaa.gov/unr/?n=1972_Flood
Rapid City	Many	Web page describes 1972 flood event and provides photographs.	http://sd.water.usgs.gov/projects/1972flood/
--	--	The 1972 flood event was one of the most severe flash flood events in US history in terms of loss of life. Numerous documents proving more details are available; however, providing a comprehensive bibliography is beyond the intended scope of this product.	Numerous unlisted sources.
Rapid City	--	Almost 2.5 inches of rain fell in 30 minutes in the Rapid City area.	National Oceanic and Atmospheric Administration (2008).
Various	--	Substantial damage reported for the northern Black Hills from prolonged heavy rain and flooding.	National Oceanic and Atmospheric Administration (2008).
--	--	High flows in many streams in northern Black Hills in June 1976. Noteworthy peak flows include 1,460 ft^3/s on June 15 at station 06425500 (Elk Creek near Elm Springs); 3,870 ft^3/s on June 15 at station 06431500 (Spearfish Creek at Spearfish); 6,780 ft^3/s on June 15 at station 06433000 (Redwater River above Belle Fourche); and 16,700 ft^3/s on June 15 at station 06436700 (Indian Creek near Arpan).	U.S. Geological Survey (2009).
Rapid City	--	Minor flooding of Rapid City streets reported.	National Oceanic and Atmospheric Administration (2008).
--	--	Peaks of record flow were recorded for stations along Horse Creek (station 06436700) and the Belle Fourche River (station 06437000). Large peak flows also were recorded along Spearfish Creek, Redwater River, and Whitewood Creek.	U.S. Geological Survey (2009).
Keystone	--	Minor flooding of roads reported.	National Oceanic and Atmospheric Administration (2008).
Keystone	Rapid City	Minor flooding for three separate dates reported.	National Oceanic and Atmospheric Administration (2008). (3 entries).
Hill City , Rapid City	--	Flooding and damage of roads reported.	National Oceanic and Atmospheric Administration (2008). (2 entries).

Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

[All locations in South Dakota unless otherwise specified. Peak of record flow is the maximum instantaneous peak flow that has been recorded for the period of record for the streamflow-gaging station. Relative magnitude of event: 1, extreme; 2, severe; 3, moderate; 4, minor; 5, very minor; ft^3/s, cubic feet per second; USGS, U.S. Geological Survey; X, indicates applicable magnitude; --, not applicable or unknown]

Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
--	May 8–9, 1995	--	--	--	X	X	Various	--
May 30, 1996	May 30, 1996	--	--	X	X	--	Spring Creek	--
May 30, 1996	May 30, 1996	--	--	X	X	--	Spring Creek	--
June 14, 1996	June 14, 1996	--	--	X	X	--	Alkali Creek	--
June 14, 1996	June 14, 1996	--	--	X	X	--	Alkali Creek	--
May 24, 1997	May 24, 1997	--	--	--	--	X	Rapid Creek	--
June 2, 1997	June 2, 1997	--	--	--	X	X	Rapid Creek	--
June 14, 1997	--	--	--	--	X	X	--	--
June 23–24, 1998	--	--	--	--	X	X	--	--
June 18, 1999	June 18, 1999	--	--	--	X	X	Battle Creek	--
June 18, 1999	June 18, 1999	--	--	--	X	X	Battle Creek	--
Aug. 7, 1999	--	--	--	--	X	X	--	--
July 21, 2001	July 21, 2001	--	--	--	--	X	Battle Creek	--
July 5, 2003	--	--	--	--	X	X	--	--
May 6–7, 2005	--	--	--	--	X	X	--	--
May 19, 2007	--	--	--	--	X	X	--	--
May 28, 2007	--	--	--	--	X	X	--	--

Primary town or area	Secondary town or area	Description of event	Source of information[1]
--	--	Relatively small peak flows reported for several streams in southern Black Hills, including French, Battle, Grace Goolidge, and Spring Creeks. Larger peak flows reported for many streams in northern Black Hills, including Redwater River and Spearfish, Hay, Whitewood, and Bear Butte Creeks. Peaks of record were established on May 8, 1995, at four stations along Whitewood Creek.	U.S. Geological Survey (2009).
--	--	Severe storm documented along Spring Creek south of Rapid City.	National Oceanic and Atmospheric Administration (2008).
--	--	Peak flow of 6,910 ft^3/s occurred on May 30, 1996, at station 06408500 (Spring Creek near Hermosa); second only to 1972 peak flow of 13,400 ft^3/s.	U.S. Geological Survey (2009).
--	--	Various damage reported from severe storm along Alkali Creek of Sturgis.	National Oceanic and Atmospheric Administration (2008).
--	--	Peak flow of 16,900 ft^3/s occurred on June 14, 1996, at station 442205103073200 along Alkali Creek.	U.S. Geological Survey (2009).
--	--	Minor flooding reported along Rapid Creek and tributaries from 4 to 5 inches of rain.	National Oceanic and Atmospheric Administration (2008).
--	--	Flooding along Rapid Creek and tributaries from as much as 4.5 inches of rain in 30 minutes.	National Oceanic and Atmospheric Administration (2008).
East of Sturgis	--	No information is available regarding magnitudes of any associated peak flows.	Radar image from National Oceanic and Atmospheric Administration.
East of Sturgis	--	No information is available regarding magnitudes of any associated peak flows.	Radar image from National Oceanic and Atmospheric Administration.
Keystone	--	Damage from heavy rains along Battle Creek reported.	National Oceanic and Atmospheric Administration (2008). & radar image.
--	--	Peak flow of 2,000 ft^3/s occurred on June 18, 1999, at station 06404000 (Battle Creek near Keystone); second only to 1972 peak flow of 26,200 ft^3/s.	U.S. Geological Survey (2009).
Northwest of Custer	--	No information is available regarding magnitudes of any associated peak flows.	Radar image from National Oceanic and Atmospheric Administration.
Keystone	--	Some damage from localized flooding in Keystone reported.	National Oceanic and Atmospheric Administration (2008).
Nemo, Rockerville	--	No information is available regarding magnitudes of any associated peak flows.	Radar image from National Oceanic and Atmospheric Administration.
Hot Springs, Red Shirt	--	No information is available regarding magnitudes of any associated peak flows.	Radar image from National Oceanic and Atmospheric Administration.
Lead, Rochford	--	No information is available regarding magnitudes of any associated peak flows.	Radar image from National Oceanic and Atmospheric Administration.
Lead, Spearfish	--	No information is available regarding magnitudes of any associated peak flows.	Radar image from National Oceanic and Atmospheric Administration.

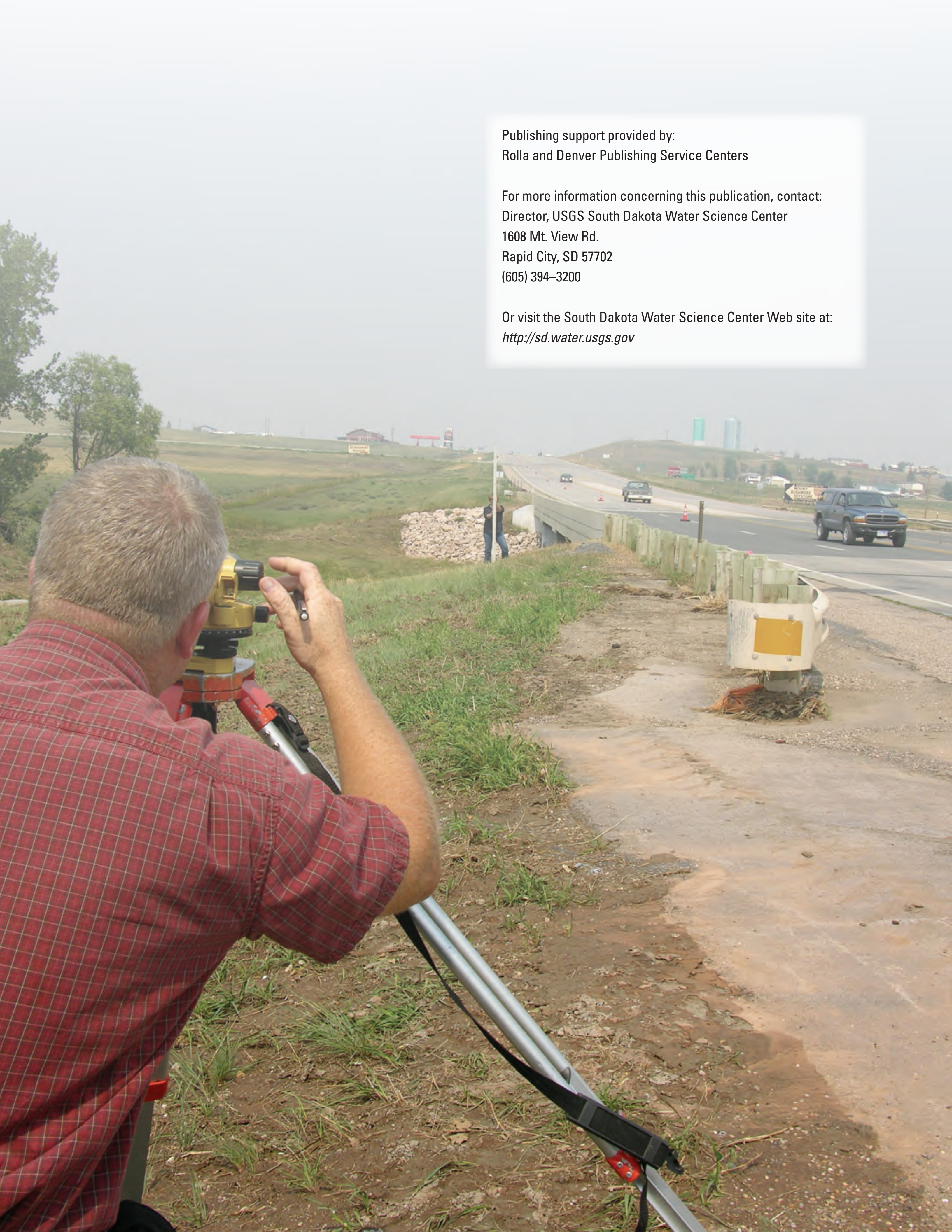
Table 10. Chronology of selected large storm and flood events for the Black Hills area, 1877–2009.—Continued

[All locations in South Dakota unless otherwise specified. Peak of record flow is the maximum instantaneous peak flow that has been recorded for the period of record for the streamflow-gaging station. Relative magnitude of event: 1, extreme; 2, severe; 3, moderate; 4, minor; 5, very minor; ft^3/s, cubic feet per second; USGS, U.S. Geological Survey; X, indicates applicable magnitude; --, not applicable or unknown]

Date of storm	Date of flood	Relative magnitude of event					Primary stream	Secondary stream(s)
		1	2	3	4	5		
June 21, 2007	--	--	--	--	X	X	--	--
Aug. 17, 2007	Aug. 17, 2007	--	X	X	X	X	--	--
--	Aug. 17, 2007	--	X	X	X	X	Battle Creek	--
July 6–7, 2008	July 6–7, 2008	--	--	X	X	X	Rapid Creek	--
July 6–7, 2008	July 6–7, 2008	--	X	X	X	X	Rapid Creek	--
--	April 14, 2009	--	--	--	--	X	Belle Fourche River	--

[1]All newspaper articles used as source documentation in this chronology are available from U.S. Geological Survey (2010a).

Primary town or area	Secondary town or area	Description of event	Source of information[1]
Newcastle	--	No information is available regarding magnitudes of any associated peak flows.	Radar image from National Oceanic and Atmospheric Administration.
Hermosa	Piedmont	Severe hail damage near Piedmont and substantial flooding along Battle Creek near Hermosa.	Radar image from National Oceanic and Atmospheric Administration.
Hermosa	Piedmont	Peak flow of 18,600 ft^3/s occurred on August 17, 2007, at station 06406000 (Battle Creek at Hermosa); second only to 1972 peak flow of 21,400 ft^3/s.	U.S. Geological Survey (2009).
Rochford	--	High flows in Rapid Creek extended from Pactola Reservoir to upstream from Rochford. Flood damage was limited primarily to relatively minor damage to various roads.	Radar image from National Oceanic and Atmospheric Administration (2008).
Rochford	--	Peak flow of 400 ft^3/s occurred on July 7, 2008, at station 06408850 (Silver Creek near Rochford); next largest peak flows were 14 ft^3/s (1976 and 1978). Peak flow of 1,640 ft^3/s occurred on July 7, 2008, at station 06410500 (Rapid Creek above Pactola Reservoir), which was second only to 1965 peak flow of 2,060 ft^3/s.	U.S. Geological Survey (2009).
Elm Springs	--	Peak flow of 29,500 ft^3/s occurred on April 14, 2009, at station 06438000 (Belle Fourche River near Elm Springs).	U.S. Geological Survey (2009).



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Back cover. Center: Reach of Rapid Creek downstream from Silver Creek. Photograph by Dan Driscoll.
Lower left: More than 10 inches of rain in 3 hours were reported during the August 17, 2007 storm. Photograph by Mark T. Anderson.
Lower right: Water standing in low-lying areas on the flood plain of Battle Creek on the day after the August 2007 flood event in the Hermosa area. Photograph by Mark T. Anderson.
Background: Aftermath of May 17, 1883, flood in Deadwood. Photographs courtesy of Adams Museum, Deadwood, SD (used with permission).

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