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Flood Hydrology and Dam-Breach Hydraulic Analyses of Four Reservoirs in the Black Hills, South Dakota

Scientific Investigations Report 2011–5011

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

Front cover. Horsethief Lake view from the outlet channel; dam is shown to the left.
Back cover. Iron Creek just below outlet from Lakota Lake.

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Conversion Factors

Multiply	**By**	**To obtain**
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Elevation, as used in this report, refers to distance above the vertical datum.

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Abbreviated units used in this report:

acre-ft	acre-feet
ft	feet
ft^3/s	cubic feet per second
hr	hour
mi	miles
mi^2	square miles
xh:1v	horizontal distance to 1 vertical distance unit
yr	year

Acronyms used in this report:

BHNF	Black Hills National Forest
BOR	Bureau of Reclamation
DEM	digital elevation model
GIS	geographical information system
HEC-HMS	Hydrologic Engineering Center Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center River Analysis System
IDF	inflow design flood
NID	National Inventory of Dams
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
PMP	probable maximum precipitation
SCS CN	Soil Conservation Service curve number
SSURGO	Soil Survey Geographic
UHG	unit hydrograph
USFS	U.S. Forest Service

Flood Hydrology and Dam-Breach Hydraulic Analyses of Four Reservoirs in the Black Hills, South Dakota

By Galen K. Hoogestraat

Abstract

Extensive information about the construction of dams or potential downstream hazards in the event of a dam breach is not available for many small reservoirs within the Black Hills National Forest. In 2009, the U.S. Forest Service identified the need for reconnaissance-level dam-breach assessments for four of these reservoirs within the Black Hills National Forest (Iron Creek, Horsethief, Lakota, and Mitchell Lakes) with the potential to flood downstream structures. Flood hydrology and dam-breach hydraulic analyses for the four selected reservoirs were conducted by the U.S. Geological Survey in cooperation with the U.S. Forest service to estimate the areal extent of downstream inundation. Three high-flow breach scenarios were considered for cases when the dam is in place (overtopped) and when a dam break (failure) occurs: the 100-year recurrence 24-hour precipitation, 500-year recurrence peak flow, and the probable maximum precipitation. Inundation maps were developed that show the estimated extent of downstream floodwaters from simulated scenarios. Simulation results were used to determine the hazard classification of a dam break (high, significant, or low), based primarily on the potential for loss of life or property damage resulting from downstream inundation because of the flood surge.

The inflow design floods resulting from the two simulated storm events (100-year 24-hour and probable maximum precipitation) were determined using the U.S. Army Corps of Engineers Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS). The inflow design flood for the 500-year recurrence peak flow was determined by using regional regression equations developed for streamflow-gaging stations with similar watershed characteristics. The step-backwater hydraulic analysis model, Hydrologic Engineering Center's River Analysis System (HEC-RAS), was used to determine water-surface profiles of in-place and dam-break scenarios for the three inflow design floods that were simulated. Inundation maps for in-place and dam-break scenarios were developed for the area downstream from the dam to the mouth of each stream.

Dam-break scenarios for three of the four reservoirs assessed in this study were rated as low hazards owing to absence of permanent structures downstream from the dams. Iron Creek Lake's downstream channel to its mouth does not include any permanent structures within the inundation flood plains. For the two reservoirs with the largest watershed areas, Lakota and Mitchell Lake, the additional floodwater surge resulting from a dam break would be minor relative to the magnitude of the large flood streamflow into the reservoirs, based on the similar areal extent of inundation for the in-place and dam-break scenarios as indicated by the developed maps. A dam-break scenario at Horsethief Lake is rated as a significant hazard because of potential lives-in-jeopardy in downstream dwellings and appreciable economic loss.

Introduction

Dams provide many societal benefits, but floods resulting from failures of constructed dams also have produced some of the most devastating disasters of the last two centuries. When dams fail, property damage is common, but loss of life can vary dramatically with the extent of the inundation area, the size of the population at risk, and the amount of warning time available (Bureau of Reclamation, 1998). In order to reduce the potential damages owing to dam breaches, several hydraulic modeling programs have been developed that can simulate downstream water levels in response to a dam breach.

In the Black Hills National Forest (BHNF), several dams have been created to form reservoirs used for recreation, fishing, water supply, and flood management. Water storage in these reservoirs ranges from less than 100 acre-feet (acre-ft) to more than 50,000 acre-ft at Pactola Reservoir (South Dakota Department of Game, Fish, and Parks, 2010). Although most of these reservoirs are located in relatively remote areas, permanent structures are scattered along many of the downstream channels. Crucial road bridges also cross the downstream channels, adding additional structures at risk of destruction during a dam breach (overtopping flow or a dam break). Two of the three largest reservoirs within BHNF boundaries, Pactola Reservoir and Deerfield Lake, currently (2010) are managed by the Bureau of Reclamation (BOR). Sheridan Lake, which is managed by the U.S. Forest Service (USFS), is the second largest reservoir inside BHNF with a storage of about 11,500 acre-ft (Driscoll and Norton, 2009).

Extensive information about the construction or potential downstream hazards in the event of a dam breach is not available for many of the smaller reservoirs in the BHNF. In 2009, the USFS identified the need for reconnaissance-level dam-breach assessments for four of these reservoirs within the BHNF (Iron Creek, Horsethief, Lakota, and Mitchell Lakes) with the potential to flood downstream structures. Flood hydrology and dam-breach hydraulic analyses for the four selected reservoirs were conducted by the U.S. Geological Survey in cooperation with the USFS to estimate the areal extent of downstream inundation.

Purpose and Scope

This report presents results of flood hydrology and dam-breach hydraulic analyses of four USFS dams within the BHNF (Iron Creek, Horsethief, Lakota, and Mitchell Lake). Three high-flow breach scenarios were considered for cases when the dam is in place (overtopped) and when a dam break (failure) occurs. Two storm events and one peak-flow event were simulated: the 1-percent exceedance (100-year (yr) recurrence) 24-hour (hr) precipitation, the 0.2-percent exceedance (500-yr recurrence) peak flow, and the probable maximum precipitation (PMP). The PMP hydrologic event was chosen for consistency with downstream hazard classification guidelines discussed in Bureau of Reclamation (1988), and the remaining two hydrologic events were chosen to represent smaller fractions of the PMP. Inundation maps were developed that show the extent of downstream floodwaters during simulated dam-breach scenarios. Simulation results of the dam-break scenarios were used to determine the hazard classification of the dam structure (high, significant, or low), based primarily on the potential for loss of life resulting from downstream inundation because of a flood surge.

Description of Study Areas

All four reservoirs described in this report are located in the Black Hills National Forest of western South Dakota (fig. 1). The Black Hills uplift formed as an elongated dome that trends north-northwest and is about 120 miles (mi) long and 60 mi wide (DeWitt and others, 1986). Land-surface elevations range from approximately 4,000 to 7,000 feet (ft), with the highest elevation (7,242 ft) at Harney Peak (2 mi southwest of Horsethief Lake). Streams generally flow from the highest elevations of the early Proterozoic- and late Archean-age rocks in the central core of the Black Hills radially outward to the Paleozoic- and Mesozoic-age formations that flank the Black Hills.

The Black Hills area 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 (Carter and others, 2002). Physiographic and climatological factors affect flooding in the Black Hills region, as summarized by (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 (Driscoll and others, 2010).

Iron Creek Lake

Iron Creek Lake is a 517 acre-ft reservoir on Iron Creek in central Lawrence County. The earthen dam was completed in 1937, and the lake is used primarily for fishing and recreational purposes (U.S. Army Corps of Engineers, 2009). Several seasonal homes and cabins are scattered along the shoreline, along with camping sites, and a small beach area. The contributing watershed to Iron Creek Lake is about 1.4 square miles (mi^2) of evergreen forest land on steep topography (fig. 2). The contributing watershed to Iron Creek Lake is primarily within Cenozoic-age rocks, which primarily consist of igneous quartz latitic intrusive rocks of Tertiary age (Redden and DeWitt, 2008). The sedimentary Deadwood Formation (Paleozoic age) also crops out in some parts of the contributing watershed. Downstream from the dam on Iron Creek Lake, Iron Creek flows through a steep narrow canyon (with vertical walls as high as 500 ft) into Spearfish Creek about 3.7 mi downstream from the dam and about 11 mi upstream from the city of Spearfish.

Horsethief Lake

Horsethief Lake is a 590 acre-ft reservoir on Pine Creek in southern Pennington County. Highway 244 runs across the top of the earthen dam, which was completed in 1940 (U.S. Army Corps of Engineers, 2009), and provides access to a popular summer campground. Tributaries to the lake drain about 2.8 mi^2 of dense evergreen forest land on steep topography (fig. 3). Rugged, undeveloped terrain dominates the contributing watershed to Horsethief Lake, with an average land slope of about 35 percent. Land slope was estimated from a 10-meter spatial resolution digital elevation model (DEM) derived from the National Elevation Dataset (Gesch, 2007) with geographical information system (GIS) software. The watershed is located in the central core of the Black Hills on the early Proterozoic- and late Archean-age rocks, with geologic formations primarily consisting of Harney Peak granite and metamorphosed black shale (fig. 1; Redden and DeWitt, 2008). Soil cover generally is thin and covered with forest litter. Pine Creek flows into Battle Creek about 1.7 mi downstream from the dam on Horsethief Lake and about 2.6 mi upstream from Keystone.

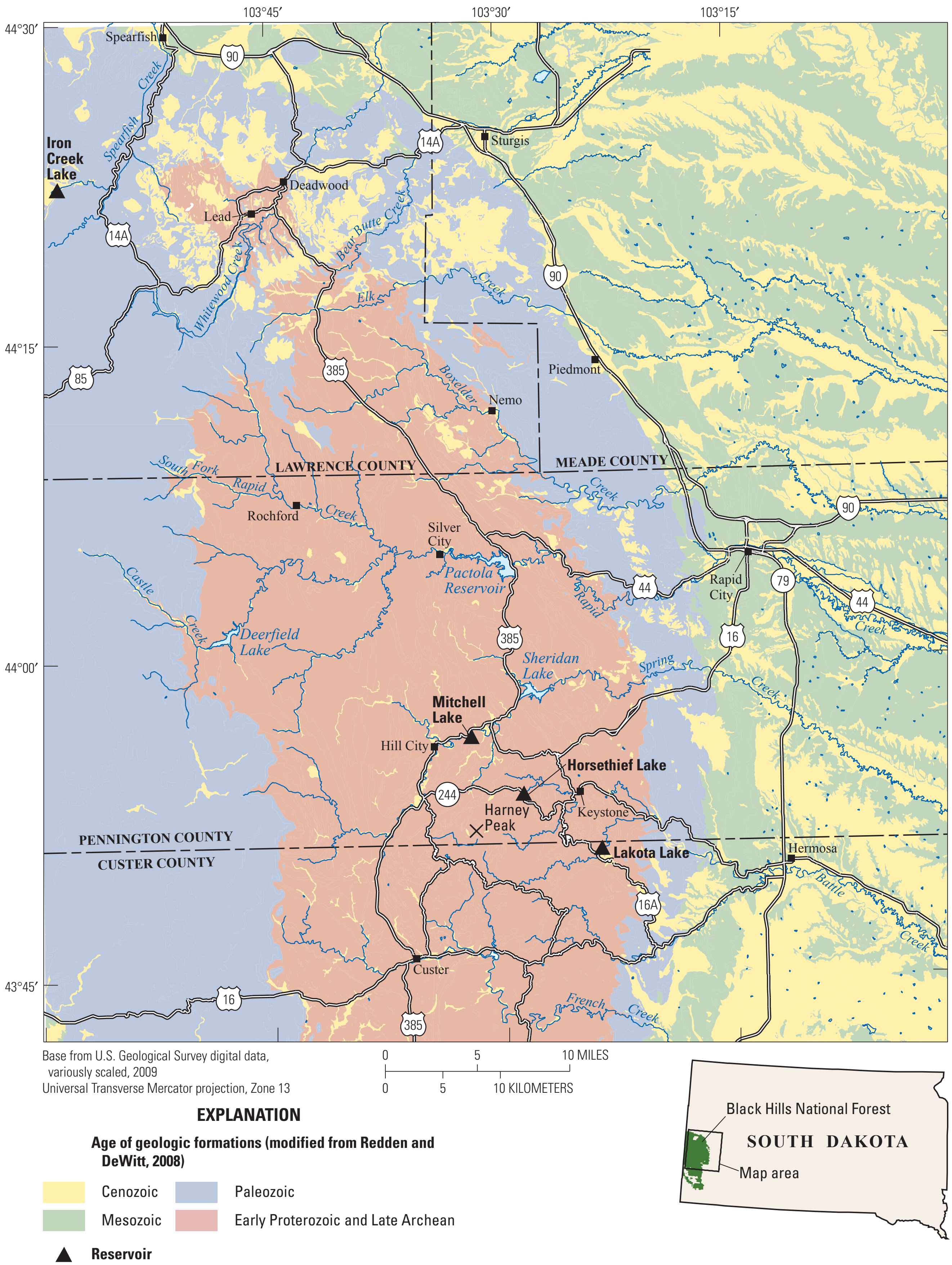


Figure 1. Locations of reservoirs in the Black Hills National Forest for which flood hydrology and dam-breach hydraulic analyses were performed.

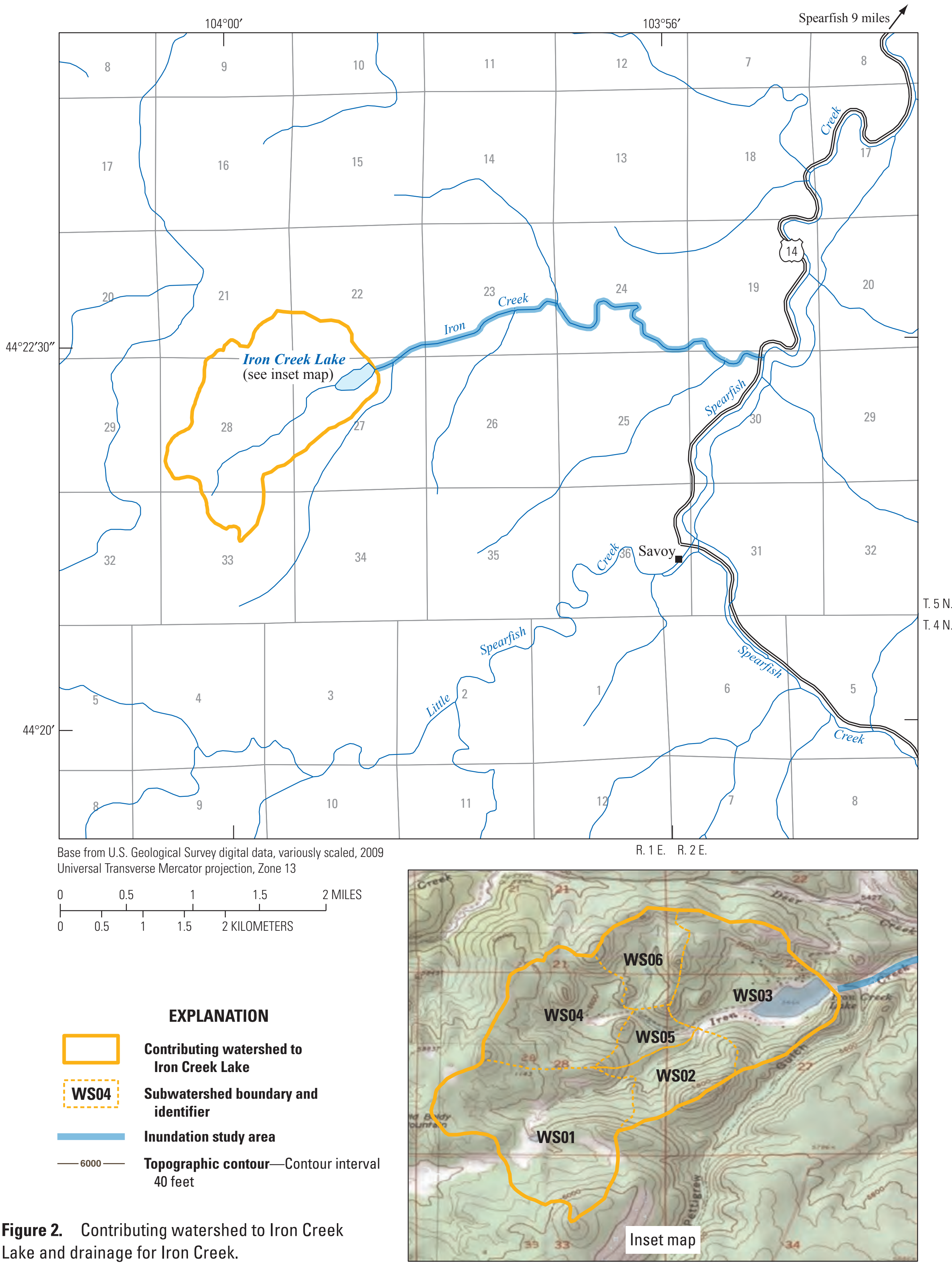
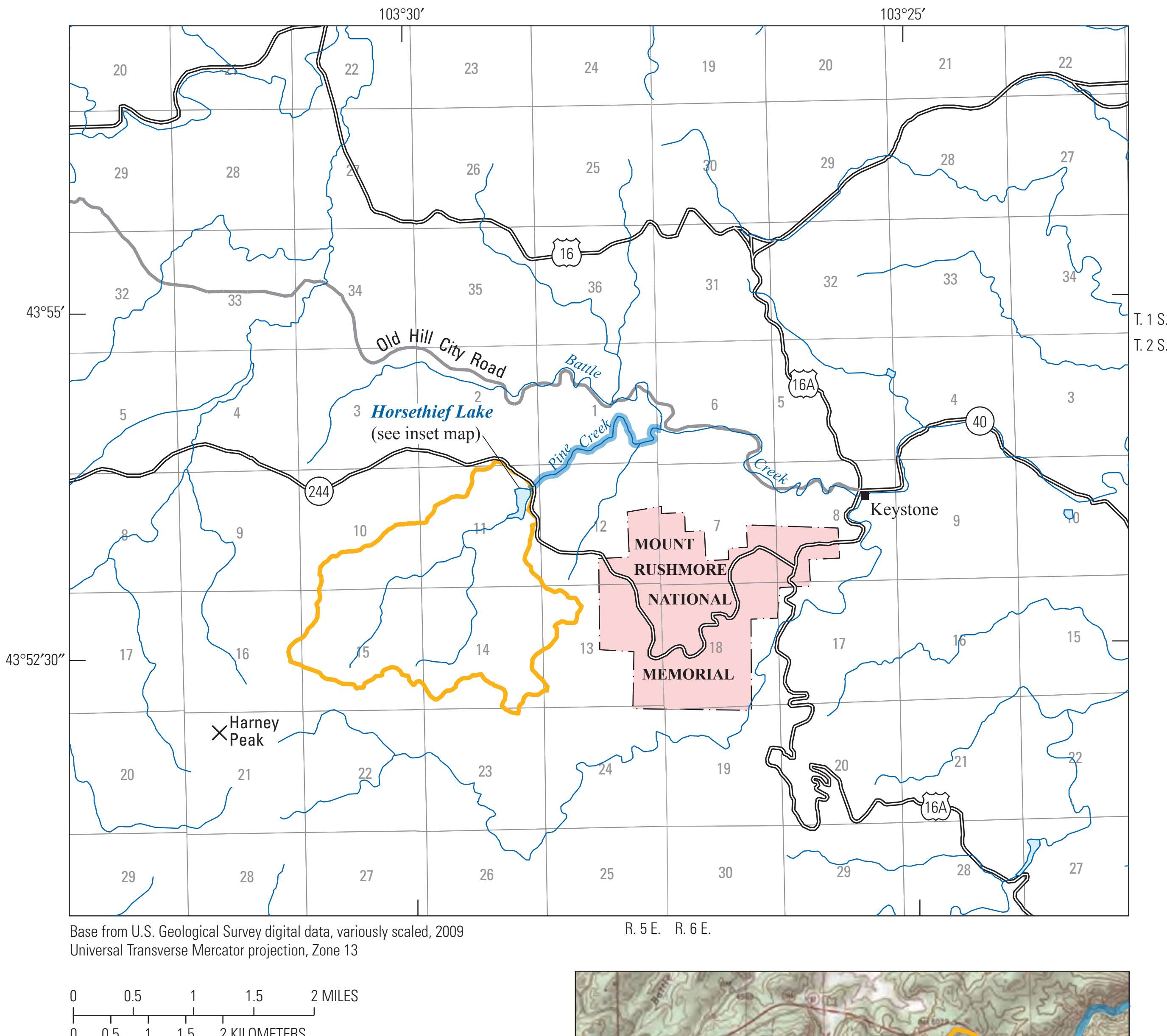


Figure 2. Contributing watershed to Iron Creek Lake and drainage for Iron Creek.



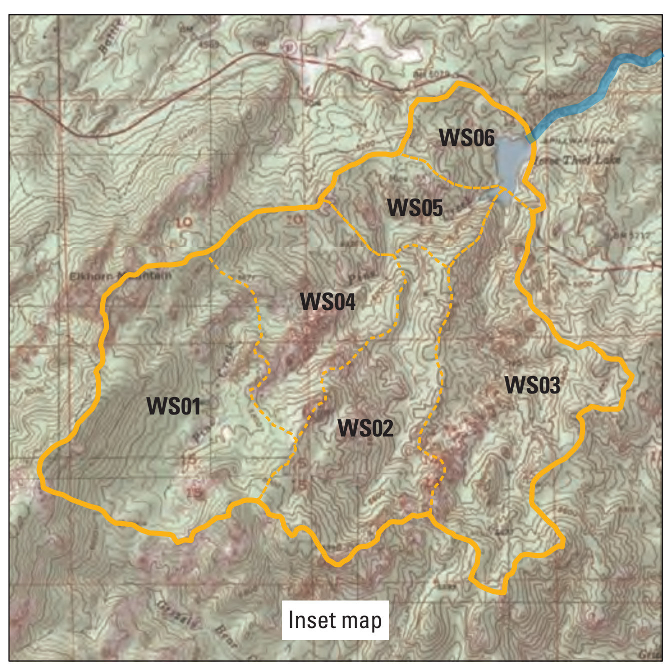


Figure 3. Contributing watershed to Horsethief Lake and drainage for Pine Creek.

Lakota Lake

Lakota Lake stores about 240 acre-ft of water on Iron Creek in northern Custer County near the Pennington County line. The earthen dam for Lakota Lake was completed on Iron Creek in 1962 (U.S. Army Corps of Engineers, 2009). The lake provides a day-use only fishing and recreation area along Highway 16A. Lakota Lake's watershed originates just south of Harney Peak and drains 12.5 mi^2 of the highest and steepest (37 percent average land slope (Gesch, 2007)) forested terrain in the Black Hills (fig. 4). The contributing watershed to Lakota Lake consists of Harney Peak granite in the upper part and metamorphosed quartzite, debris flow conglomerate, pelite, and greywacke (Redden and DeWitt, 2008) in the lower part near the reservoir. Iron Creek flows northeast into Battle Creek about 5.2 mi downstream from the dam, less than a mile upstream from Hayward.

Mitchell Lake

Mitchell Lake on Spring Creek has the largest contributing watershed (102.4 mi^2) but the smallest storage (181 acre-ft) of the four reservoirs described in this report. The dam was completed in 1936 (U.S. Army Corps of Engineers, 2009), and Mitchell Lake is used as a small day-use fishing area and as streamflow control for the downstream channel. Several permanent residences are scattered along the banks of Spring Creek downstream from the dam, and the stream passes under Highway 16 at three locations before it enters Sheridan Lake 5 mi downstream from the dam. In addition, several small driveway bridges pass over Spring Creek downstream from the dam on Mitchell Lake. The large contributing watershed to Mitchell Lake includes a wide variety of geology (fig. 1) and terrain (fig. 5). Spring Creek originates in the western part of the Black Hills near the boundary of the eastern edge of the Paleozoic-age formations and the western edge of the early Proterozoic- and late Archean-age formations (fig. 1). The surface geology of the contributing watershed to Mitchell Lake primarily consists of metamorphosed shale, tuff, and greywacke (Redden and DeWitt, 2008). Spring Creek flows through Hill City about 2 mi upstream from Lake Mitchell.

Flood Hydrology Analyses

The inflow design floods (IDFs) used as input for the three high-flow breach scenarios were estimated using two different approaches. The IDFs resulting from the two simulated storm events (100-yr 24-hr and PMP) were determined using the U.S. Army Corps of Engineers Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS; U.S. Army Corps of Engineers, 2008a). Available as a public-domain software, HEC-HMS is a computer model that simulates the rainfall-routing-runoff processes for a watershed. The model provides options for precipitation based on specified observations, design storms, or frequency events. Runoff losses (precipitation that does not contribute to streamflow) can be simulated using 10 different methods. Unit hydrograph transformations account for overland flow, storage, and energy losses as excess rainfall travels through the watershed. A channel routing component within the HEC-HMS model accounts for storage and energy flux as water moves through the main channels. The IDF for the 500-yr recurrence peak flow for the streams draining each of the four reservoirs was determined by using regression equations for streamflow-gaging stations with similar watershed characteristics (Sando, 1998; Sando and others, 2008).

Model Input Parameters

Development of the HEC-HMS models to determine the IDFs for the 100-yr 24-hr and PMP storms for each of the four reservoirs began with delineation of the contributing watershed to the reservoir, which was then divided into smaller subwatersheds with similar topographic and presumed runoff characteristics. The HEC-HMS model requires estimation of four primary components: design storms, runoff losses, unit hydrograph transformations, and channel routing. Additional options are available to simulate base flow, channel infiltration, and hydraulic control structures.

Watershed Delineation

Each reservoir's watershed was delineated using a 10-meter spatial resolution DEM derived from the National Elevation Dataset (Gesch, 2007) with GIS software. A single elevation value was assigned to each 10- by 10-meter cell in the grid. This level of detail caused minor discrepancies in the exact stream and watershed boundary locations within the model but was considered suitable for a reconnaissance-level assessment. The watersheds were divided into smaller subwatersheds to increase the accuracy of the hydrology model. Figures 2–5 show the watersheds and subwatershed boundaries for each reservoir.

Design Storms

The cumulative precipitation amounts for the 100-yr 24-hr storm were determined using National Oceanic and Atmospheric Administration (NOAA) hydrologic references and computations (U.S. Department of Commerce, 1961). The cumulative precipitation amounts for the PMP storm were determined from the Hydrometeorological Report 55A guidelines (U.S. Department of Commerce, 1988). Table 1 shows the cumulative precipitation amounts for both storms in the Black Hills region. Precipitation amounts shown in table 1 reflect the equivalent uniform amount that would fall on the entire watershed. These uniform amounts were estimated based on watershed size and location according to NOAA

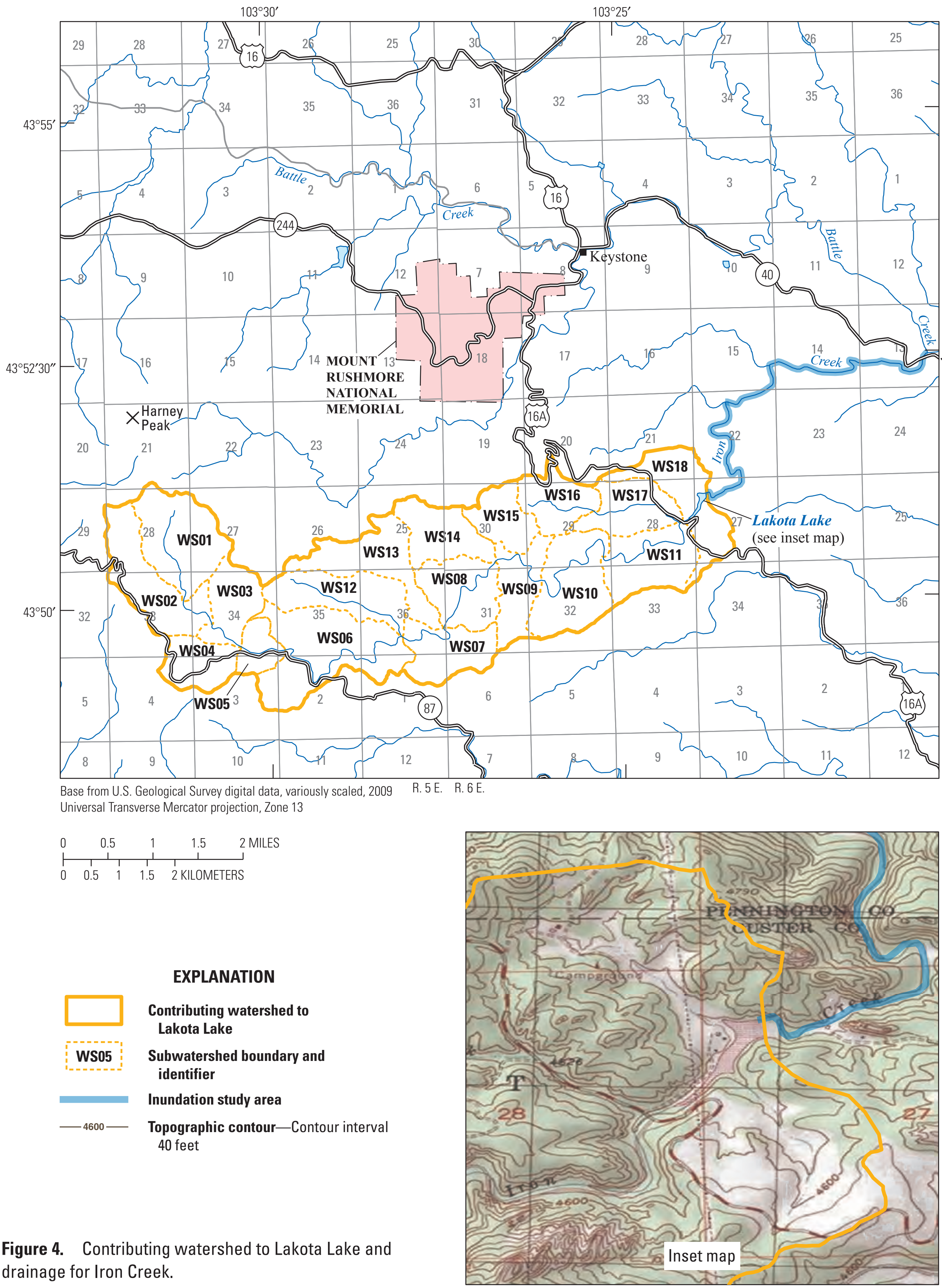
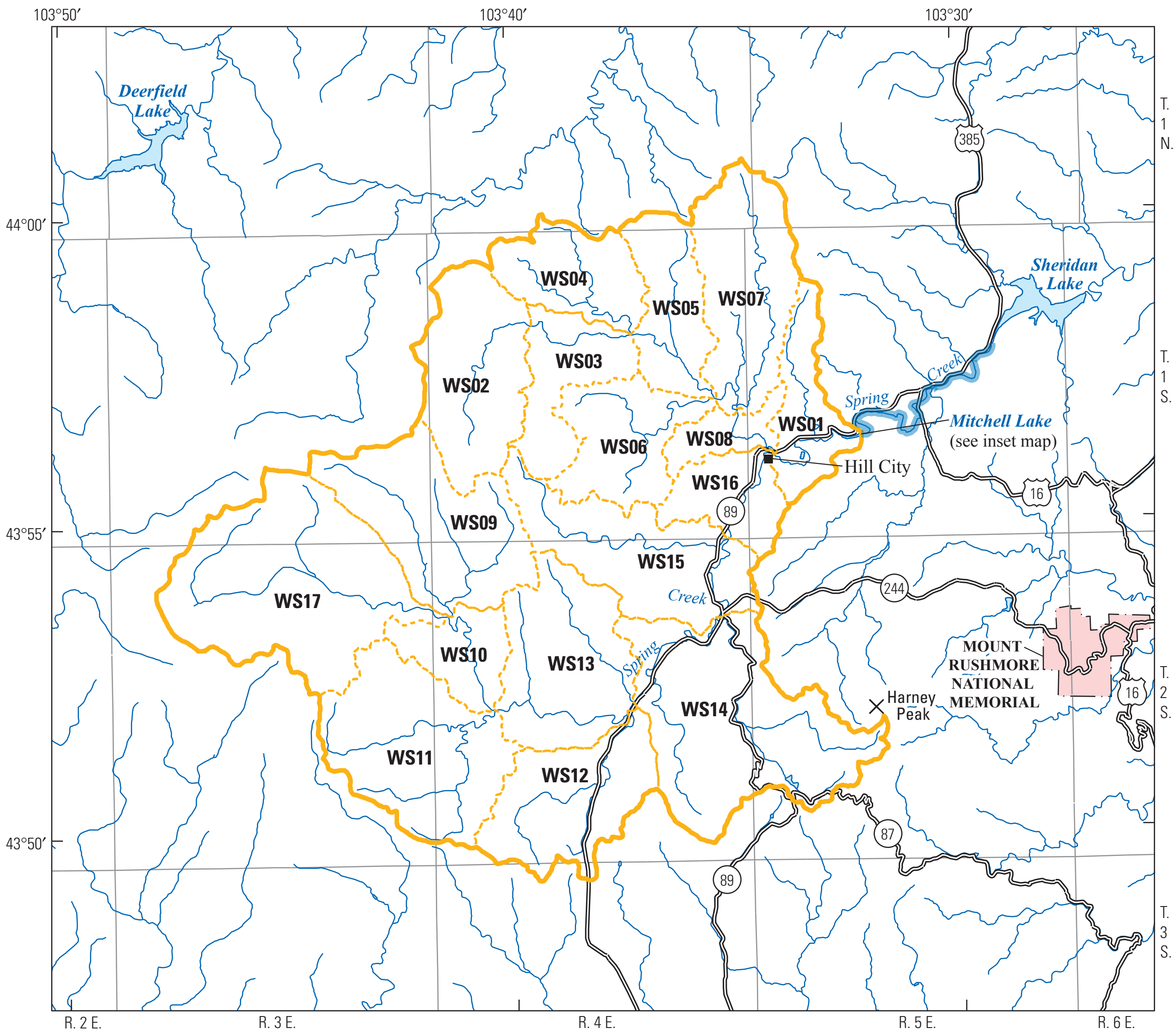


Figure 4. Contributing watershed to Lakota Lake and drainage for Iron Creek.



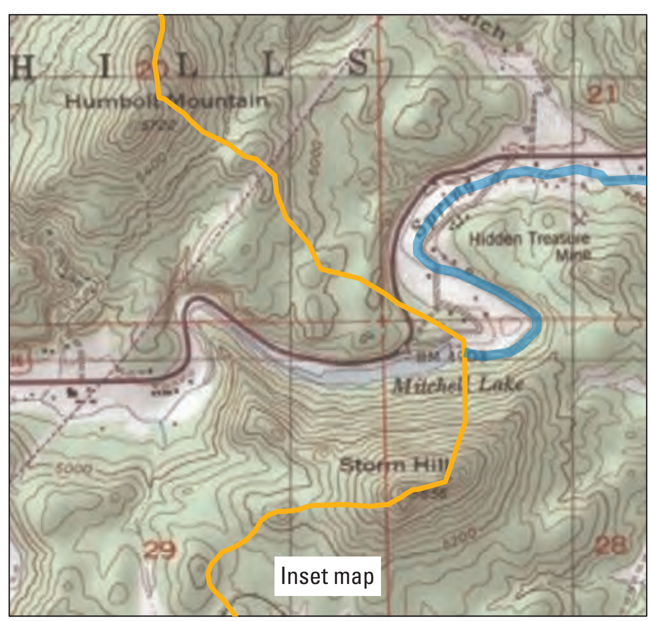


Figure 5. Contributing watershed to Mitchell Lake and drainage for Spring Creek upstream from Sheridan Lake.

guidance documents (U.S. Department of Commerce, 1961). Storms were assumed to follow a first-quartile distribution, where the peak rainfall occurs just after the end of the first quartile (at 6 hrs for a 24-hr storm).

Runoff Losses

Precipitation that does not result in surface-water flow is defined as losses. Losses primarily control the total runoff volume of a watershed and also affect the magnitude of peak streamflow. The primary components of losses are soil infiltration and initial abstraction. Initial abstraction refers to the total depression storage and vegetation interception that do not contribute to overland flow. Initial abstraction amounts were selected from guidance given in the city of Rapid City's drainage criteria manual (City of Rapid City, 1989). The infiltration losses were estimated using the Natural Resources Conservation Service (NRCS, formerly Soil Conservation Service) curve number method (SCS CN). The SCS CN method estimates precipitation excess as a function of cumulative precipitation, soil group, and land use.

Soils are categorized into four hydrologic soil groups: A, B, C, and D. Group A soils have the highest infiltration capacity (0.4–1.0 inch per hour) and group D soils have the lowest infiltration capacity (0.01–0.05 inch per hour). A digital map of soil groups in the Black Hills is available from the Soil Survey Geographic (SSURGO) database provided by NRCS (U.S. Department of Agriculture, 2009). A dimensionless curve number is selected according to the unique combination of hydrologic soil group and land use available from various references (U.S. Department of Agriculture, 1986; U.S. Army Corps of Engineers, 2000). Curve numbers range from 0–100, with a value of 0 representing no runoff and 100 representing no infiltration. For a forested area with some forest litter covering the soil (the predominant land use in most Black Hills watersheds), the SCS CN for the A, B, C, and D soil groups are 36, 60, 73, and 79, respectively. For each subwatershed with more than one soil group within its boundary, an area-weighted SCS CN was calculated.

Unit Hydrographs

A hydrograph is a plot of discharge as a function of time. A unit hydrograph (UHG) is the resulting direct runoff hydrograph from one unit of rainfall for one unit of time and is used to define the theoretical shape of a hydrograph during a rainfall event (U.S. Army Corps of Engineers, 2000). Using parameterization of this empirical method, the timing and magnitude of the peak streamflow generated within a basin can be estimated. This component of the HEC-HMS model does not affect the total runoff volume from a watershed.

The SCS UHG method (U.S. Department of Agriculture, 1986) was applied to the four simulated watersheds. For this method, the lone input to the HEC-HMS model is the basin time lag. This parameter is a coefficient-adjusted estimate of the time of concentration, which is the time it takes for direct runoff to travel from the farthest point in a watershed to the outlet. The time of concentration typically is separated into three components described by the type of runoff flow: sheet, shallow concentrated, and channel. Sheet flow typically occurs for a maximum distance of 300 ft, after which the flow accumulates into shallow gullies or rills (shallow concentrated flow) and is conveyed into the main channel drainages. Methods for estimating each of these three flow components

Table 1. Cumulative precipitation amounts (in inches over watershed area) for 100-year 24-hour and probable maximum precipitation (PMP) storms in the Black Hills region, South Dakota (U.S. Department of Commerce, 1961, 1978, 1988).

Duration, hours	Iron Creek Lake		Horsethief Lake		Lakota Lake		Mitchell Lake	
	100-year 24-hour	PMP 24-hour	100-year 24-hour	PMP 24-hour	100-year 24-hour	PMP 24-hour	100-year 24-hour	PMP 24-hour
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
.25	1.57	4.84	1.54	4.45	1.52	3.43	1.46	1.64
.50	2.25	7.53	2.21	7.07	2.18	5.72	2.09	3.01
.75	2.60	9.14	2.55	8.68	2.52	7.13	2.42	4.11
1	2.95	10.75	2.89	10.32	2.86	8.60	2.74	5.16
2	3.06	14.51	3.00	14.00	2.97	11.90	2.85	7.69
3	3.20	17.20	3.14	16.68	3.10	14.45	2.98	10.00
4	3.30	19.35	3.23	18.77	3.20	16.45	3.07	13.00
5	3.40	21.50	3.33	20.96	3.30	18.49	3.16	16.00
6	3.50	22.58	3.43	22.01	3.40	22.50	3.26	21.00
12	4.05	26.86	3.97	26.86	3.93	26.86	3.77	24.44
24	4.50	29.50	4.41	29.50	4.37	29.50	4.19	26.85

are presented in U.S. Army Corps of Engineers (2000). Topographical features (channel length and slope) were estimated from the DEM using GIS software. Other pertinent parameters for estimating flow in channels (roughness coefficients and channel geometry) were selected from field observations in the study area.

Channel Routing

For subwatersheds that receive inflow from an upstream watershed, a channel routing routine is used to convey the discharge through the main channel to the basin outlet. Subwatersheds that do not receive inflow from an upstream subwatershed will not contain a routing element. The routing component of HEC-HMS controls the attenuation of streamflow because of energy resistance and thus can control the magnitude and timing of peak flows. It does not affect the total runoff volume generated within a watershed. The Muskingham-Cunge method was chosen as an appropriate routing method because the continuity and momentum equations are solved using parameters that are physically based with assumptions that are not violated in natural channels (U.S. Army Corps of Engineers, 2000). Using a specified channel geometry (length and slope derived from the DEM using GIS software) and roughness coefficient (Manning's n values estimated from field inspection), continuity and momentum equations were solved to estimate streamflow in the main channels. Routing parameters were identical to those used to determine the channel flow component of the SCS UHG portion of the model (described in the "Unit Hydrograph" section).

Summary of Input Parameters

Tables 2–5 summarize input parameters to the HEC-HMS model for all of the subwatersheds within each of the simulated reservoir watersheds. The HEC-HMS model was used to determine the IDFs for the 100-yr 24-hr and PMP storms.

Inflow Design Floods

The IDFs for each lake were estimated with the HEC-HMS model for the 100-yr 24-hr and PMP storms; the IDFs for the 500-yr recurrence peak flows were estimated using a regional "mixed-population analysis" that was developed for application to streams in the Black Hills (Sando and others, 2008). The mixed-population analysis uses joint probability theory to estimate peak-flow return periods based on two separate frequency curves. The first frequency curve, termed the "ordinary peaks," is derived from a standard log-Pearson III frequency distribution fit (U.S. Interagency Advisory Council on Water Data, 1982) to the main body of recorded peak flows for the streamflow-gaging station. In the absence of peak-flow data at the four reservoir sites, regional regression equations developed for streamflow-gaging stations (Sando, 1998) in the same regions as the reservoirs were used as the ordinary peaks component of the mixed-population analysis. The second frequency curve, termed the "high-outlier peaks," is based on the streamflow-gaging stations in the Black Hills region that have very large individual peak flows that plot substantially higher than the standard log-Pearson III frequency distribution fit. The net result of combining these two frequency curves into a regional mixed-population curve

Table 2. Summary of model input parameters for the Iron Creek Lake watershed.

[SCS CN, Soil Conservation Service curve number; ft, feet; --, not applicable]

Subwatershed identifier (figure 2)	Watershed area (square miles)	Runoff losses		Unit hydrograph	Channel routing					
		Initial abstraction (inches)[1]	SCS CN	SCS time lag (minutes)	Length (ft)	Slope (ft/ft)	Manning's n	Geometry shape	Bottom width (ft)	Side slope[2]
WS01	0.44	0.4	60.0	25.4	--	--	--	--	--	--
WS02	.14	.4	60.1	19.3	2,205	0.037	0.065	Trapezoid	1	1
WS03	.37	.4	64.3	34.0	3,066	.011	.065	Trapezoid	1	1
WS04	.29	.4	60.5	18.0	--	--	--	--	--	--
WS05	.07	.4	62.9	18.2	2,554	.098	.065	Trapezoid	1	1
WS06	.14	.4	60.0	19.3	--	--	--	--	--	--

[1]From table 2–4 in City of Rapid City (1989).

[2]Side slope is given in units of horizontal distance per 1 vertical distance unit on a right triangle.

Table 3. Summary of model input parameters for the Horsethief Lake watershed.

[SCS CN, Soil Conservation Service curve number; ft, feet; --, not applicable]

Subwatershed identifier (figure 3)	Watershed area (square miles)	Runoff losses		Unit hydrograph	Channel routing					
		Initial abstraction (inches)[1]	SCS CN	SCS time lag (minutes)	Length (ft)	Slope (ft/ft)	Manning's n	Geometry shape	Bottom width (ft)	Side slope[2]
WS01	0.76	0.4	69.7	23.8	--	--	--	--	--	--
WS02	.51	.4	74.9	28.6	--	--	--	--	--	--
WS03	.69	.4	74.2	37.4	--	--	--	--	--	--
WS04	.42	.4	74.9	19.3	3,548	0.117	0.07	Trapezoid	1	0.5
WS05	.20	.4	75.3	20.2	3,234	.059	.07	Trapezoid	1	.5
WS06	.17	.4	70.3	32.5	1,283	.003	.07	Trapezoid	1	.5

[1]From table 2–4 in City of Rapid City (1989).

[2]Side slope is given in units of horizontal distance per 1 vertical distance unit on a right triangle.

Table 4. Summary of model input parameters for the Lakota Lake watershed.

[SCS CN, Soil Conservation Service curve number; ft, feet; --, not applicable]

Subwatershed identifier (figure 4)	Watershed area (square miles)	Runoff losses		Unit hydrograph	Channel routing					
		Initial abstraction (inches)[1]	SCS CN	SCS time lag (minutes)	Length (ft)	Slope (ft/ft)	Manning's n	Geometry shape	Bottom width (ft)	Side slope[2]
WS01	0.97	0.4	74.3	26.5	--	--	--	--	--	--
WS02	.88	.4	70.7	39.7	2,649	0.030	0.065	Trapezoid	1	0.5
WS03	.52	.4	68.7	29.1	2,641	.030	.065	Trapezoid	1	.5
WS04	.46	.4	66.6	28.4	--	--	--	--	--	--
WS05	.27	.4	67.9	20.6	2,893	.037	.065	Trapezoid	1	.5
WS06	1.38	.4	66.8	71.4	12,490	.023	.065	Trapezoid	1	.5
WS07	.62	.4	65.1	34.8	4,635	.019	.065	Trapezoid	1	.5
WS08	.68	.4	73.2	62.3	6,538	.008	.065	Trapezoid	1	.5
WS09	.55	.4	61.3	32.0	4,462	.024	.065	Trapezoid	1	.5
WS10	.92	.4	64.5	63.0	8,951	.015	.065	Trapezoid	1	.5
WS11	.76	.4	66.3	50.3	8,324	.023	.065	Trapezoid	1	.5
WS12	.78	.4	66.3	37.0	--	--	--	--	--	--
WS13	.80	.4	66.4	53.8	--	--	--	--	--	--
WS14	.60	.4	65.7	31.9	--	--	--	--	--	--
WS15	.45	.4	68.9	19.7	--	--	--	--	--	--
WS16	.52	.4	65.8	20.2	--	--	--	--	--	--
WS17	.59	.4	60.0	33.6	6,130	.032	.065	Trapezoid	1	.5
WS18	.78	.4	62.9	32.1	2,613	.008	.065	Trapezoid	1	.5

[1]From table 2–4 in City of Rapid City (1989).

[2]Side slope is given in units of horizontal distance per 1 vertical distance unit on a right triangle.

Table 5. Summary of model input parameters for Mitchell Lake watershed.

[SCS CN, Soil Conservation Service curve number; ft, feet; --, not applicable]

Subwatershed identifier (figure 5)	Watershed area (square miles)	Runoff losses		Unit hydrograph	Channel routing					
		Initial abstraction (inches)[1]	SCS CN	SCS time lag (minutes)	Length (ft)	Slope (ft/ft)	Manning's n	Geometry shape	Bottom width (ft)	Side slope[2]
WS01	3.38	0.4	69.3	108	15,435	0.0068	0.08	Trapezoid	6	0.5
WS02	6.60	.4	67.0	85	--	--	--	--	--	--
WS03	3.88	.4	65.6	77	12,663	.0205	.08	Trapezoid	1	.5
WS04	4.07	.4	63.9	120	--	--	--	--	--	--
WS05	4.01	.4	64.1	97	12,672	.0362	.08	Trapezoid	2	.5
WS06	4.69	.4	63.9	109	--	--	--	--	--	--
WS07	6.78	.4	63.9	166	6,422	.0092	.08	Trapezoid	3	.5
WS08	1.70	.4	66.1	76	8,708	.0102	.08	Trapezoid	4	.5
WS09	7.96	.4	63.0	107	--	--	--	--	--	--
WS10	2.83	.4	68.8	66	15,647	.0107	.08	Trapezoid	1	.5
WS11	8.75	.4	61.9	103	--	--	--	--	--	--
WS12	6.11	.4	65.2	98	--	--	--	--	--	--
WS13	7.17	.4	67.8	109	18,503	.0165	.08	Trapezoid	2	.5
WS14	11.7	.4	68.9	133	17,834	.0116	.08	Trapezoid	3	.5
WS15	7.37	.4	67.8	126	11,964	.008	.08	Trapezoid	4	.5
WS16	3.05	.4	67.8	96	11,554	.0099	.08	Trapezoid	5	.5
WS17	12.4	.4	67.6	189	--	--	--	--	--	--

[1] From table 2–4 in City of Rapid City (1989).

[2] Side slope is given in units of horizontal distance per 1 vertical distance unit on a right triangle.

is an increase in the magnitude of the 500-yr recurrence peak flow into each of the four reservoirs, relative to the peak flows derived from regional regression equations alone (fig. 6).

The 100-yr 24-hr hydrograph was rescaled to formulate the 500-yr IDF using the ratio of peak flows. The three IDFs for each lake are shown in figures 7–10, and peak flows are shown in table 6. Peak-flow estimates for the PMP IDF are about an order of magnitude greater than the estimates for the 100-yr recurrence interval, and 500-yr peak flows are between the 100-yr and PMP peak flows for the three smallest watersheds (Iron Creek Lake, Horsethief Lake, and Lakota Lake).

Mitchell Lake has an estimated 500-yr peak flow of 18,700 cubic feet per second (ft^3/s), which is slightly less than the peak flow estimated for the 100-yr 24-hr IDF simulated by using the HEC-HMS model (20,600 ft^3/s, table 6). The IDFs for Mitchell Lake for the 100-yr 24-hr and PMP storms probably are overestimated owing to the application of equal precipitation over a relatively large watershed area (102.4 mi^2). The 100-yr peak flow downstream from Mitchell Lake at USGS streamflow-gaging station 06406920 (Spring Creek above Sheridan Lake near Keystone, S. Dak.; 127 mi^2 watershed area) using the Black Hills regional mixed-population analysis is 4,040 ft^3/s (Sando and others, 2008). Previous regressions show that peak flows for two sites on the same stream are proportional to the ratio of watershed areas raised to the 0.6 power (Sando and others, 2008). The equivalent 100-yr peak flow for Spring Creek at Mitchell Lake is about 3,550 ft^3/s, 83 percent less than the peak flow estimated by using the HEC-HMS model.

The total precipitation amount is the probable cause of the exceptionally high estimated 100-yr peak flow at Mitchell Lake rather than other HEC-HMS model input parameters. A 66-percent decrease in SCS CN values or a 600-percent increase in SCS lag times would be needed to simulate a peak flow of about 4,000 ft^3/s by using the HEC-HMS model to be consistent with the 3,550 ft^3/s value from the regional mixed-population analysis. Neither of these adjustments was considered a realistic characterization of the Mitchell Lake

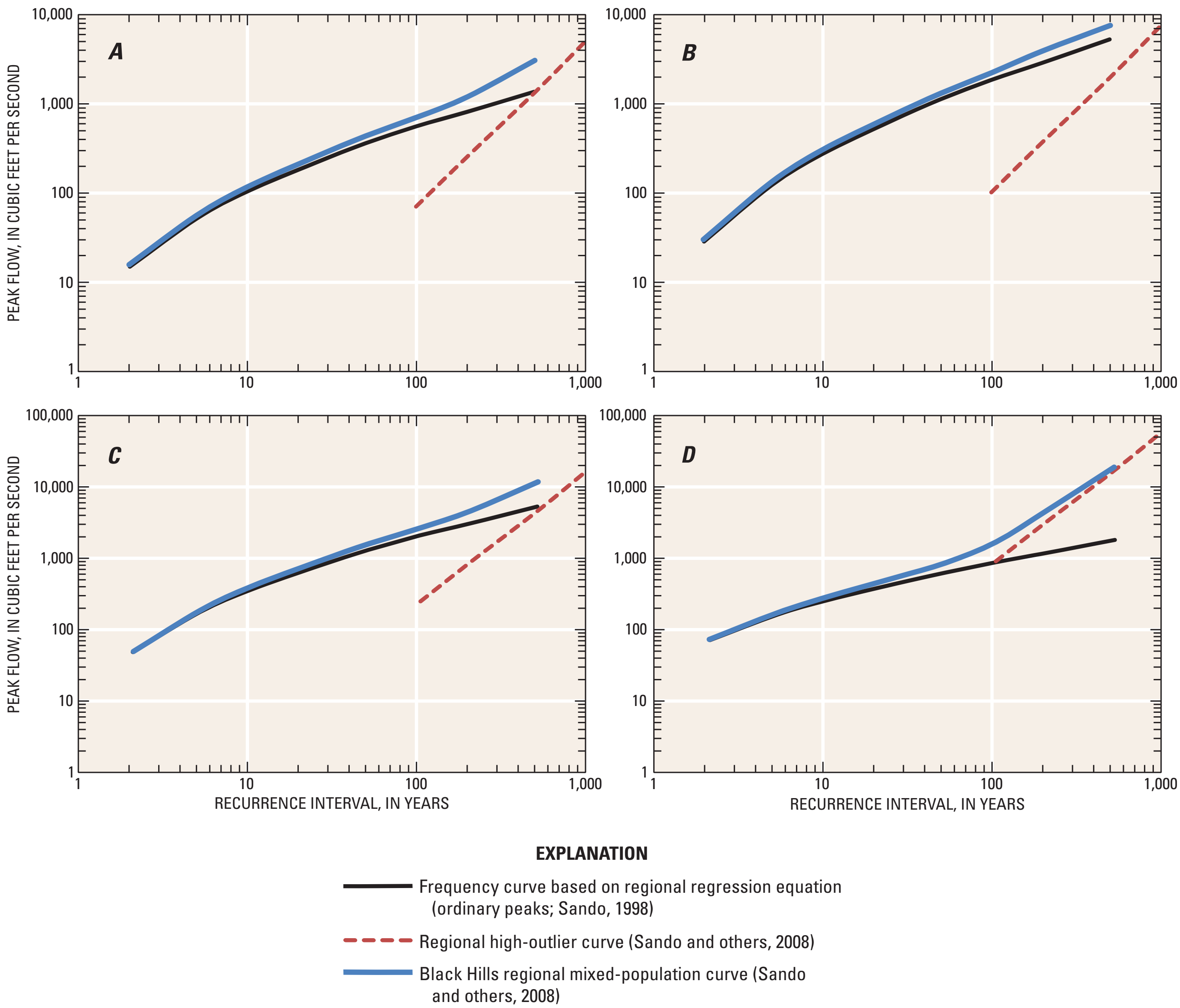


Figure 6. Frequency information for peak flows into (*A*) Iron Creek Lake, (*B*) Horsethief Lake, (*C*) Lakota Lake, and (*D*) Mitchell Lake.

watershed. Precipitation amounts listed for Mitchell Lake in table 1 represent 93 percent of the design storm amounts for a small area (point rainfall) in 24 hours (U.S. Department of Commerce, 1961), but would require additional suppression to simulate a lower peak flow by using the HEC-HMS model. A simulation of a redistribution of the storm in which the three greatest 15-minute incremental precipitation amounts were reduced by 50 percent resulted in a minimal (3 percent) reduction of peak flow. Despite the probable overestimation of flows, the IDFs for the 100-yr 24-hr and PMP storms simulated for Mitchell Lake by using the HEC-HMS model were used in the dam-breach hydraulic analyses without additional adjustment.

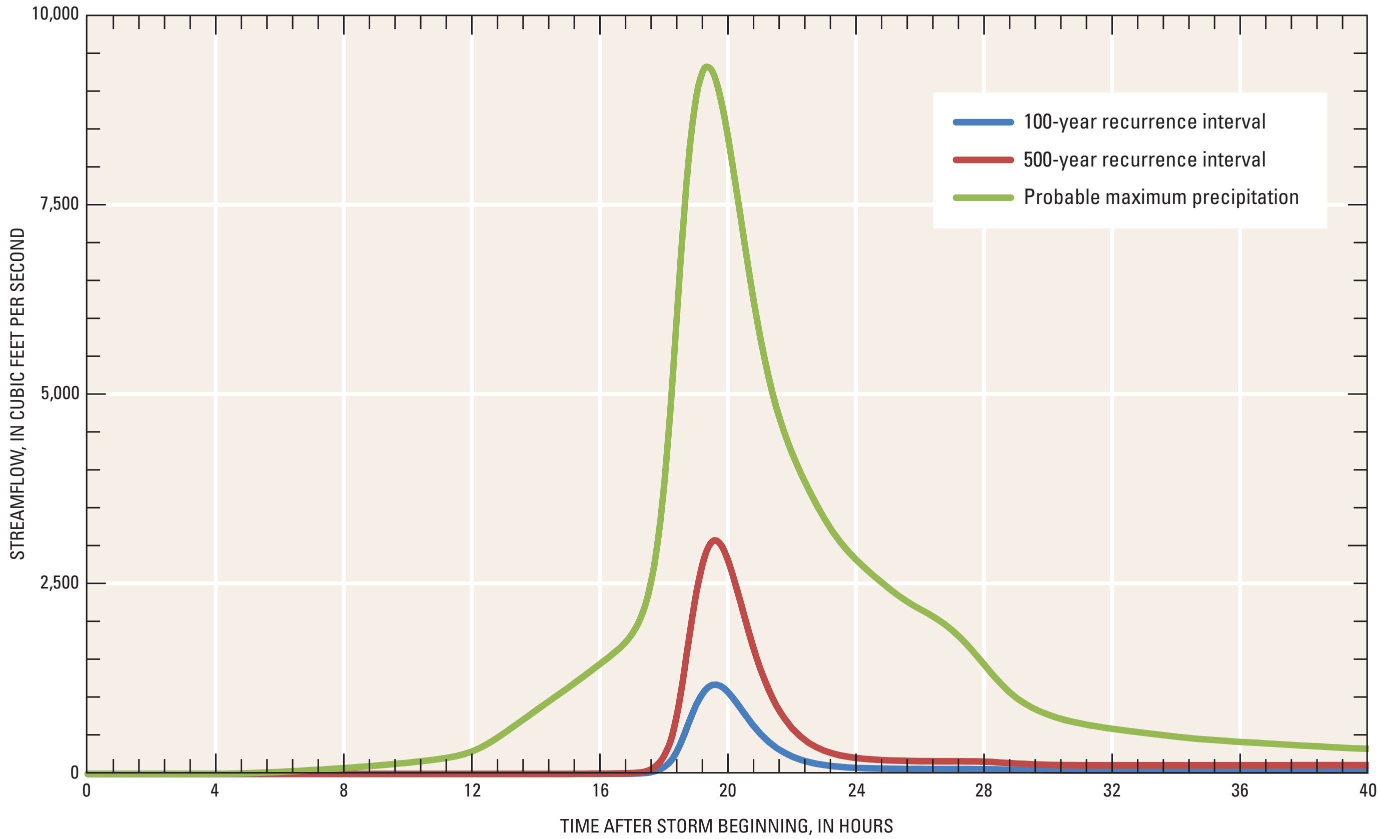


Figure 7. Inflow design floods for the Iron Creek Lake watershed.

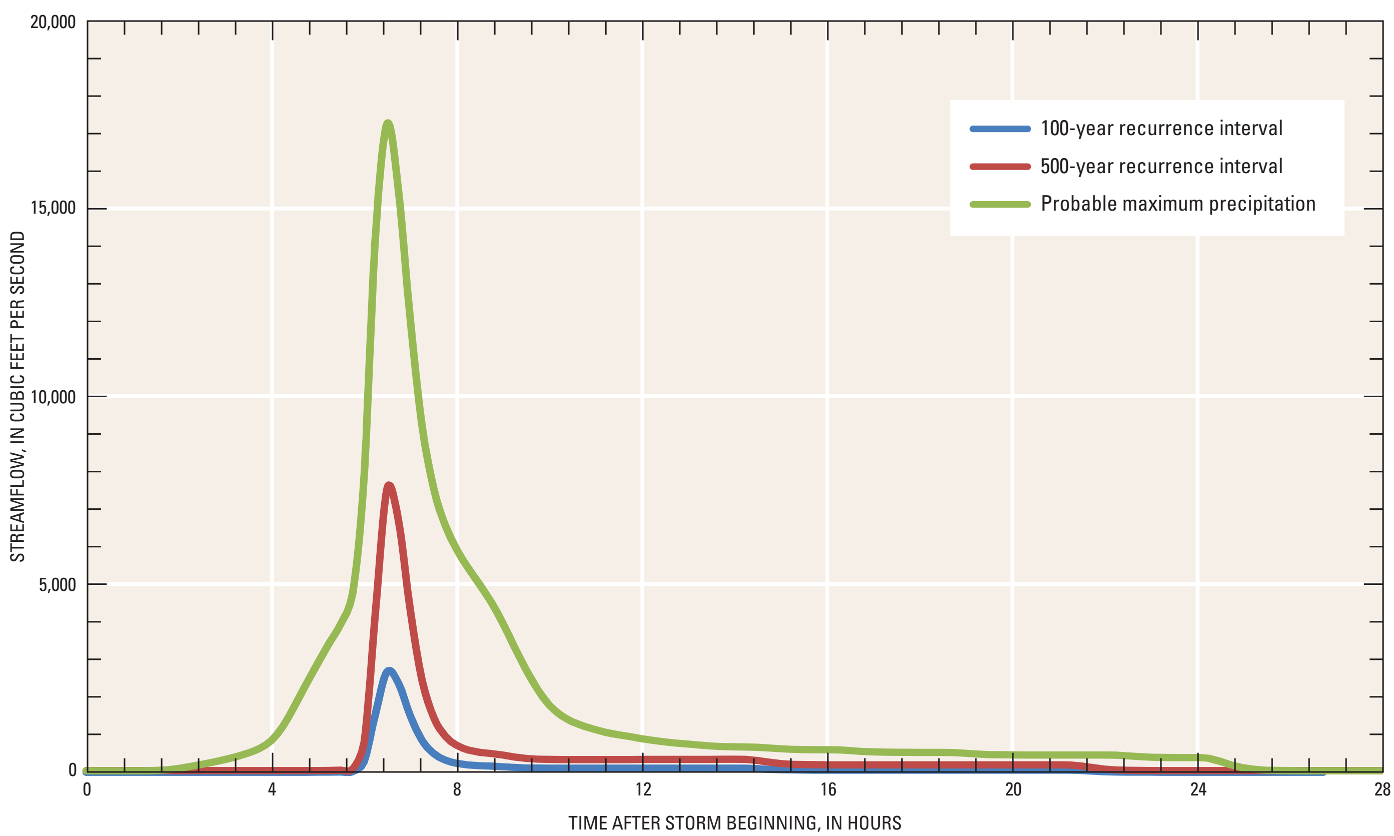


Figure 8. Inflow design floods for the Horsethief Lake watershed.

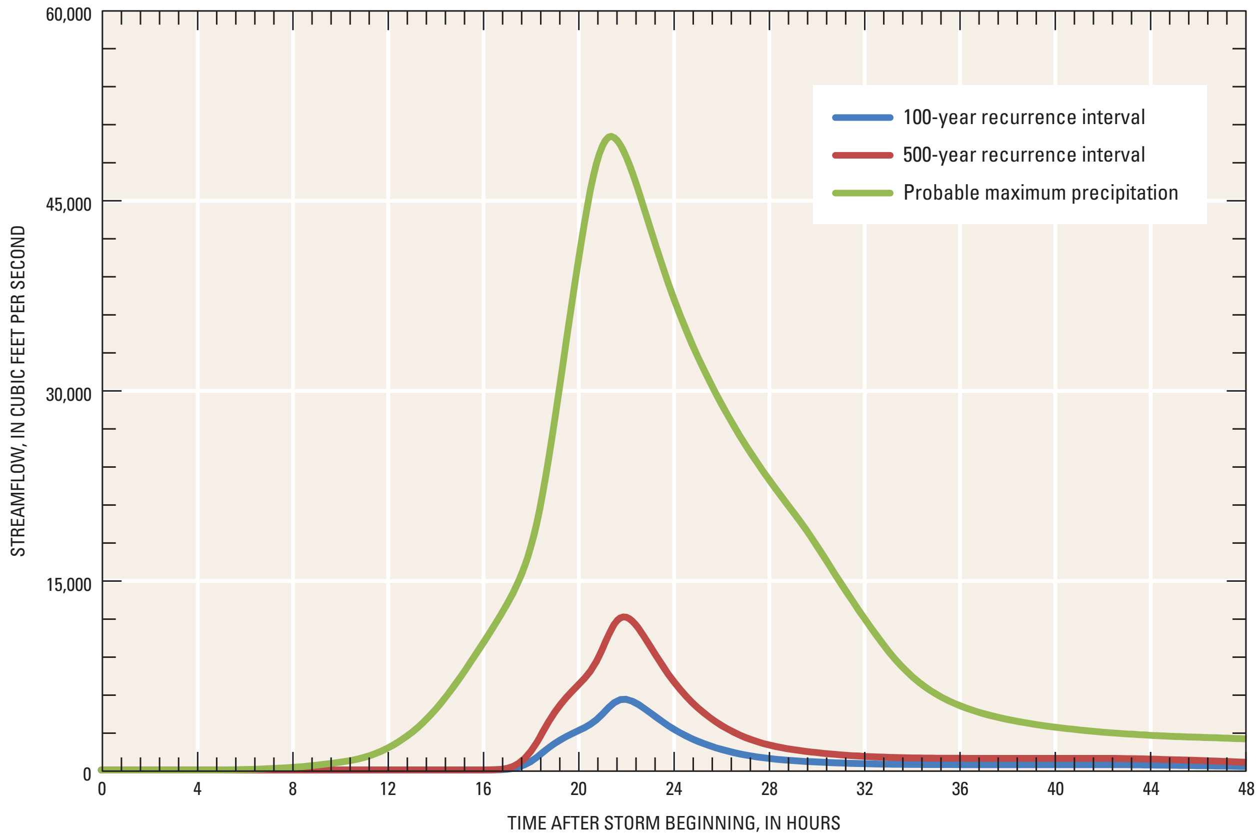


Figure 9. Inflow design floods for the Lakota Lake watershed.

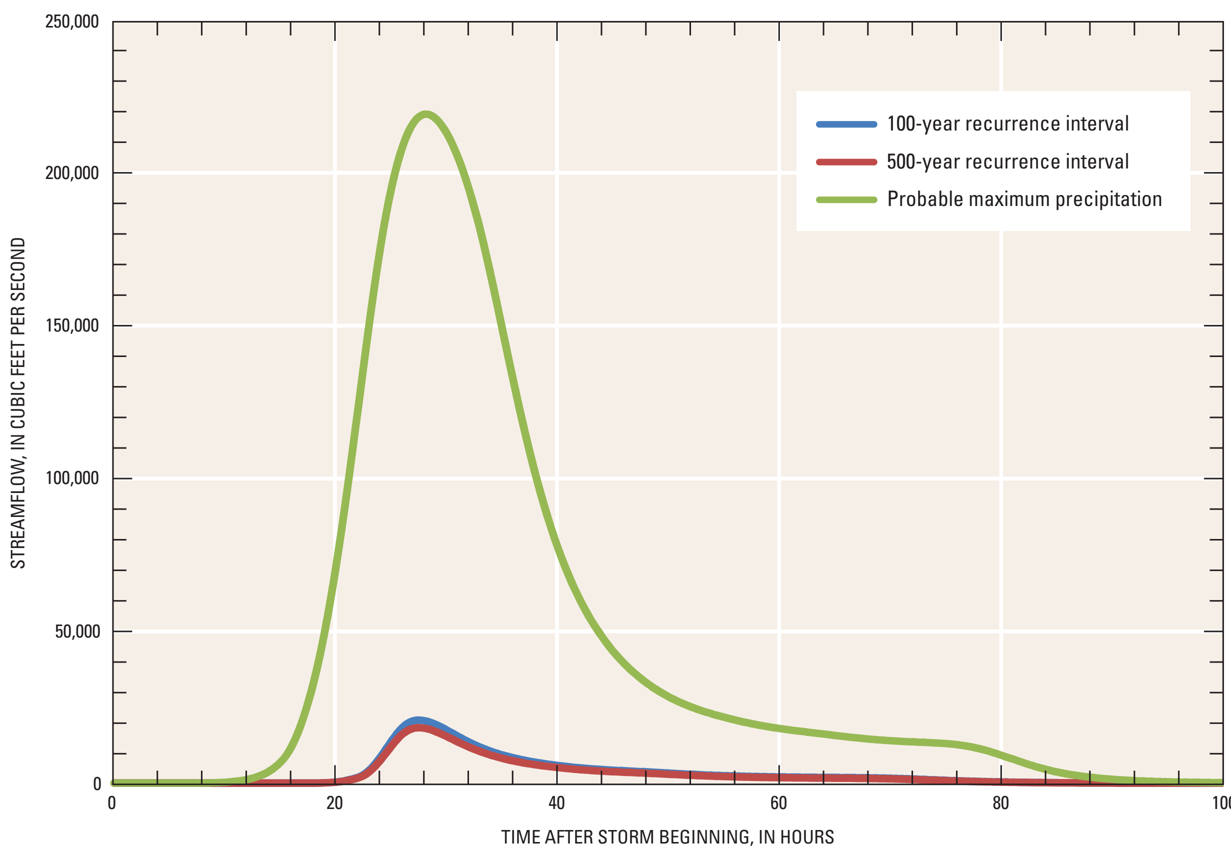


Figure 10. Inflow design floods for the Mitchell Lake watershed.

Table 6. Estimated peak flows into each reservoir for the three inflow design floods.

[ft^3/s, cubic feet per second]

Reservoir	Peak flow for inflow design flood (ft^3/s)		
	100-year[1]	500-year[2]	PMP[1]
Iron Creek Lake	1,180	3,070	9,290
Horsethief Lake	2,660	7,570	17,300
Lakota Lake	5,610	12,000	50,100
Mitchell Lake	20,600	18,700	220,000

[1]Estimated from HEC-HMS simulation results.

[2]Estimated from Black Hills regional mixed-population frequency analyses (Sando and others, 2008).

Dam-Breach Hydraulic Analyses

The step-backwater hydraulic analysis model, Hydrologic Engineering Center's River Analysis System (HEC-RAS) 4.0 (U.S. Army Corps of Engineers, 2008b, 2008c), was used to determine water-surface profiles of in-place and dam-break scenarios for the three simulated IDFs. The in-place scenario refers to a dam breach with an IDF being routed through the dam structure without a failure. The dam-break scenario refers to a dam breach with an IDF being routed through the dam structure during and after a failure. Input data for the hydraulic models included stream cross section, hydraulic structure, and dam geometries; IDF hydrographs; and roughness coefficients (Manning's n values).

General parameters such as storage, height, design outflow, and other information were available from the National Inventory of Dams (NID) database (U.S. Army Corps of Engineers, 2009) for all four dams. Storage estimates from the NID database are used in this report, which reflect the original capacity prior to sedimentation. Current (2010) storage values are probably less than reported, but use of the larger storage values results in a more conservative model ("worst-case scenario"). All information from the NID database was field-verified where possible. Topography (elevation contours) was available from the National Elevation Dataset (Gesch, 2007), but contours immediately upstream from the dams represent the normal pool elevations of the reservoirs rather than the preconstruction elevation. A bathymetric map of Iron Creek Lake was available from the South Dakota Department of Game, Fish, and Parks (South Dakota Department of Game, Fish, and Parks, 2010). Approximate bathymetric maps were created for the remaining three reservoirs using the known storage, normal pool water shoreline location, and elevations upstream and downstream from the reservoir.

Dam Geometry

Pertinent characteristics of the dam structure for input to the HEC-RAS model include storage; elevations of the normal pool, toe of dam, and top of dam; valley length; crest width; and embankment side slopes were determined from field surveys or available information in the NID database.

Iron Creek Lake

Iron Creek Lake has a maximum storage of about 517 acre-ft behind a 40-ft high earthen dam (U.S. Army Corps of Engineers, 2009). The dam has a length of about 275 ft and a top width of about 30 ft between upstream and downstream dam faces. Normal pool elevation (5,444 ft above NAVD 88) is about 5 ft below the top of dam, and storage capacity (517 acre-ft) is referenced to the top of dam elevation. The normal outlet structure consists of 16-ft railroad ties that span an opening between two rock outcrop walls, capable of a maximum discharge of about 332 ft^3/s prior to overtopping (U.S. Army Corps of Engineers, 2009). The outflow structure currently (2010) is in poor condition because the wooden railroads ties have deteriorated and allow flow to pass through several large cracks. Upstream and downstream dam faces slope at angles of about 1.8 horizontal distance to 1 vertical distance unit (1.8h:1v). Figure 11 shows the relation between stage and discharge for flow through the outlet structure at Iron Creek Lake, as determined from a series of steady-flow HEC-RAS simulations.

Horsethief Lake

Horsethief Lake has a maximum storage of about 590 acre-ft behind an earthen dam that extends 65 ft above the natural channel bottom (U.S. Army Corps of Engineers, 2009). The dam spans a length of about 325 ft and has a top width of about 40 ft. The upstream face slopes to the normal pool water surface at a ratio of 2.1h:1v, with a slightly steeper downstream face at a ratio of about 1.9h:1v. The roadway (top of dam) slopes toward the center of the dam, with the lowest top of dam elevation about 5–10 ft lower than the outer edges. The primary outlet structure consists of a curved concrete box culvert under the road that measures 16 ft wide by 8 ft high is capable of a maximum discharge of 990 ft^3/s (U.S. Army Corps of Engineers, 2009). Figure 12 shows the relation between stage and discharge for flow through the outlet structure. Normal pool elevation is held at about 4,920 ft, and weir flow over the roadway occurs at a stage of about 4,931 ft.

Lakota Lake

Lakota Lake has a maximum storage of about 240 acre-ft of water behind a 34-ft high earthen dam (U.S. Army Corps of Engineers, 2009). The dam spans a length of about 400 ft and has a top width of about 15 ft. The dam embankment

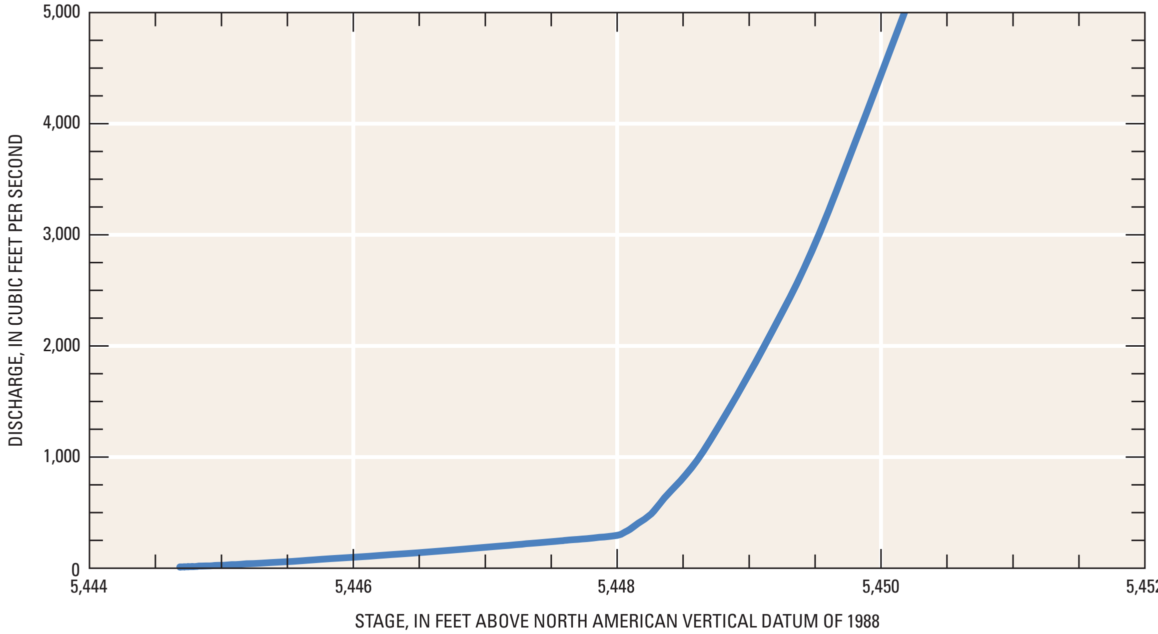


Figure 11. Relation between stage and discharge for the Iron Creek Lake outlet structure.

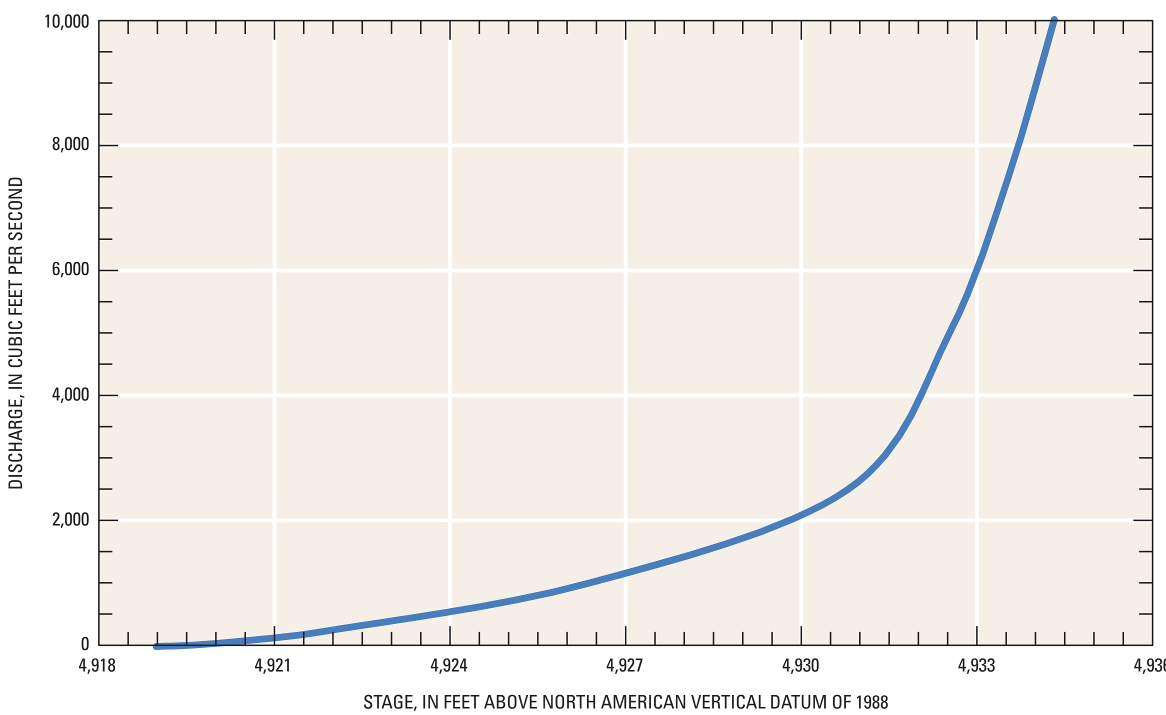


Figure 12. Relation between stage and discharge for the Horsethief Lake outlet structure.

slopes to the natural channel at a ratio of about 1.8h:1v for the upstream and downstream sides. The outlet structure consists of a natural rock-bottom weir spanning 33 ft between 100-ft-high rock outcrop walls and can pass a maximum discharge of 2,610 ft^3/s (U.S. Army Corps of Engineers, 2009). The dam has about 8 ft of freeboard above the normal pool elevation (4,472 ft). Figure 13 shows the relation between stage and discharge for flow through the outlet structure.

Mitchell Lake

Mitchell Lake has a maximum storage of about 181 acre-ft of water behind an earthen dam that extends about 26 ft above the natural channel bottom (U.S. Army Corps of Engineers, 2009). The dam spans a length of about 330 ft and has a top width of about 21 ft. The upstream face slopes to the normal pool water surface at a ratio of 2.8h:1v, with a slightly steeper downstream face at a ratio of about 2.1h:1v. The normal outlet structure consists of a 21-ft wide concrete weir and tapered-width channel that extends down to an elevation close to that of the natural streambed. The primary outlet structure can pass a maximum flow of about 2,300 ft^3/s (U.S. Army Corps of Engineers, 2009). The normal pool elevation is at 4,863 ft and has about 10 ft of freeboard to the top of the dam. Figure 14 shows the relation between stage and discharge for flow through the outlet structure.

Dam Break

A dam overtopping failure was used as the dam-break scenario for HEC-RAS simulations. The parameters of average break width and time of formation were estimated as a function of lake volume based on 63 previous case studies in a methodology described in Froehlich (1995). Model input parameters for the four simulated dam breaks are similar to parameters for four case studies of dam breaks with similar characteristics (Bureau of Reclamation, 1998; table 7).

Downstream Channel Geometry

Synthetic cross sections of the downstream channel geometry were determined from DEM elevations. Field survey data were used to check the accuracy of synthetic cross-sections at two or three locations downstream from each dam. The field survey data indicated that the synthetic cross sections accurately portrayed the channel geometry downstream from the dams. Synthetic cross sections were spaced approximately every 50–150 ft, with increasing resolution (closer spacing) through bends and changes in channel geometry. Constant Manning's n values were assumed throughout the entire down-stream reach and ranged from 0.15–0.20 for the HEC-RAS simulations. These values were greater than those estimated in

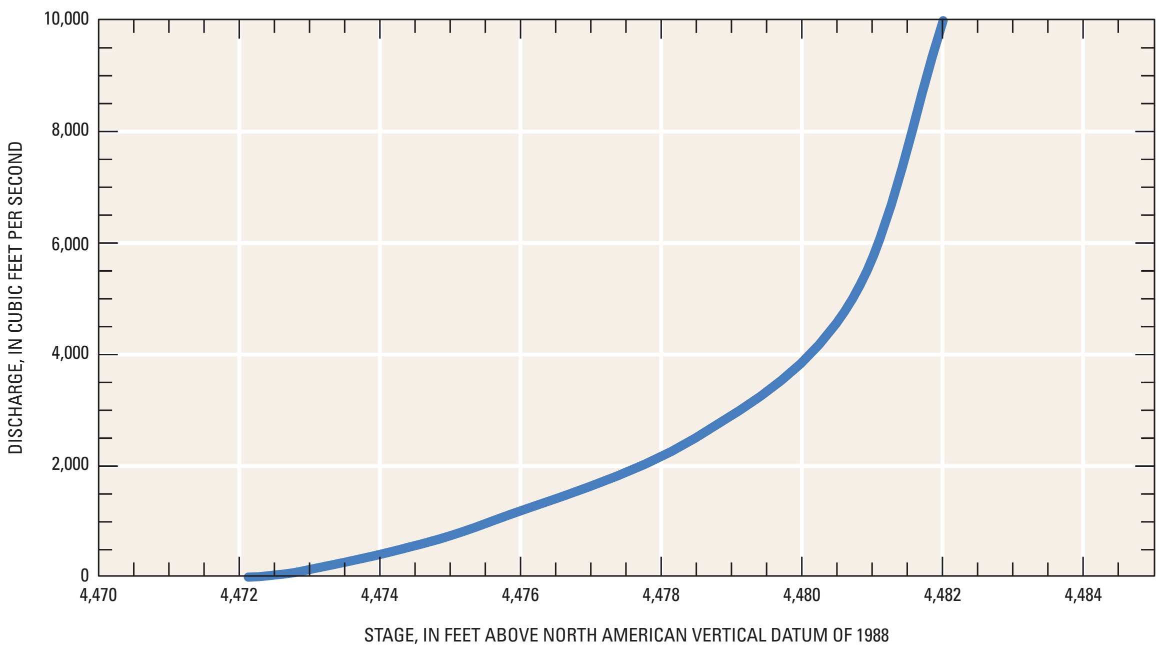


Figure 13. Relation between stage and discharge for the Lakota Lake outlet structure.

the field (tables 2–5) and used in the the HEC-HMS simulations, but give a more conservative estimate (higher simulated water surfaces). Figure 15 shows an example cross section of Pine Creek downstream from Horsethief Lake.

Inundation Maps

Inundation maps (11- by 17-inch size) are provided in the Appendix for in-place and dam-break scenarios (figs. 16–27) for the three simulated IDFs (100-yr 24-hr, 500-yr peak flow, and PMP). The downstream limit ("terminal point") of the inundation was chosen such that the hazard classification could be determined or where adequate floodwater disposal is reached. For example, if a small community is located immediately downstream from a dam, the inundation study would not need to extend beyond this point. In most BHNF reservoir cases, the terminal point is determined by adequate floodwater disposal or the point below which potential for loss of life and substantial property damage caused by floodwaters appear limited. This includes such situations as no human occupancy, anticipated future development, floodwaters contained in a large reservoir or main-stem channel, or floodwaters being contained within the channel banks (Bureau of Reclamation, 1988). For the dam-breach scenarios simulated for the four reservoirs in this report, the mouth of each stream (where the flooded channel enters a higher-order tributary) was used as the terminal point of the study.

Hazard Classification

This dam-breach inundation study was performed for the purpose of determining the effect of a dam-breach flood on possible downstream hazards. A downstream hazard is defined as the potential lives-in-jeopardy or property damage downstream from a dam or associated facility because of floodwaters released at the structure. The existing condition of the dam is not associated with the downstream hazard classification, and the cost of the dam itself, related facilities (such as pump stations or canals), and consequences of rapid reservoir drawdown are not considered property damage at risk (Bureau of Reclamation, 1988). Hazard classifications described in the following sections are based only on the additional flood surge resulting from a dam break and are not based on inundation from dam in-place (overtopping) scenarios. Table 8 provides additional information on downstream hazard classifications.

Iron Creek Lake

Iron Creek Lake's dam-break hazard classification was rated low owing to absence of permanent structures in the downstream inundation area (figs. 16–18). No permanent dwellings are along Iron Creek's channel until its confluence with Spearfish Creek at Highway 14. One road crossing (Tinton Road) would likely be washed out less than a mile

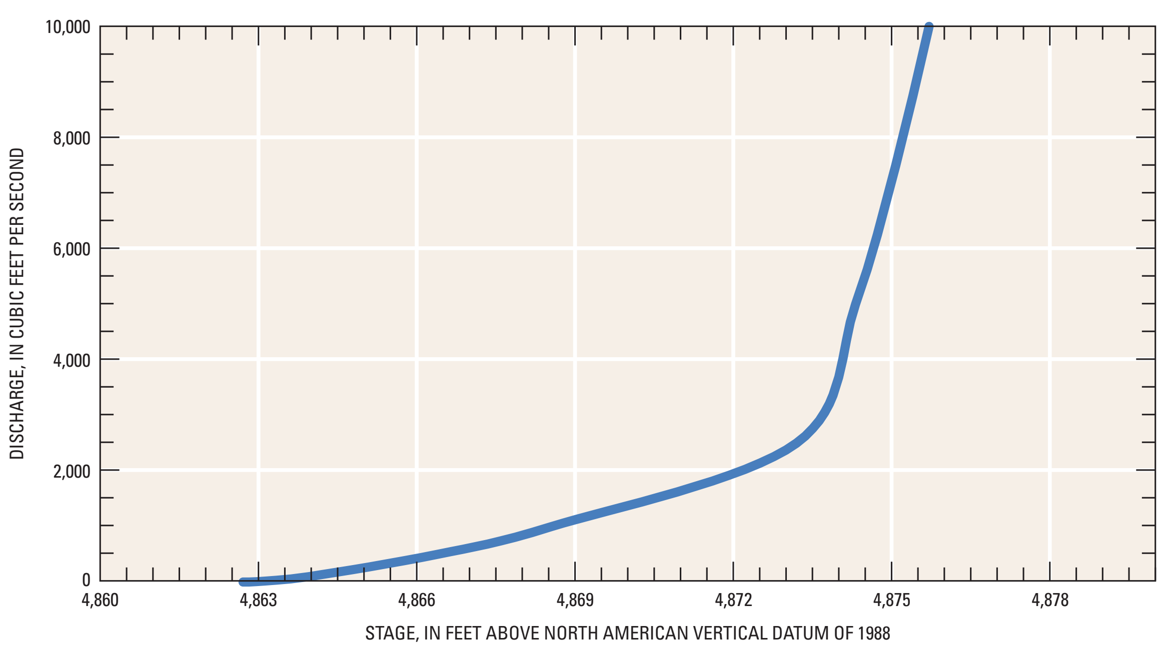


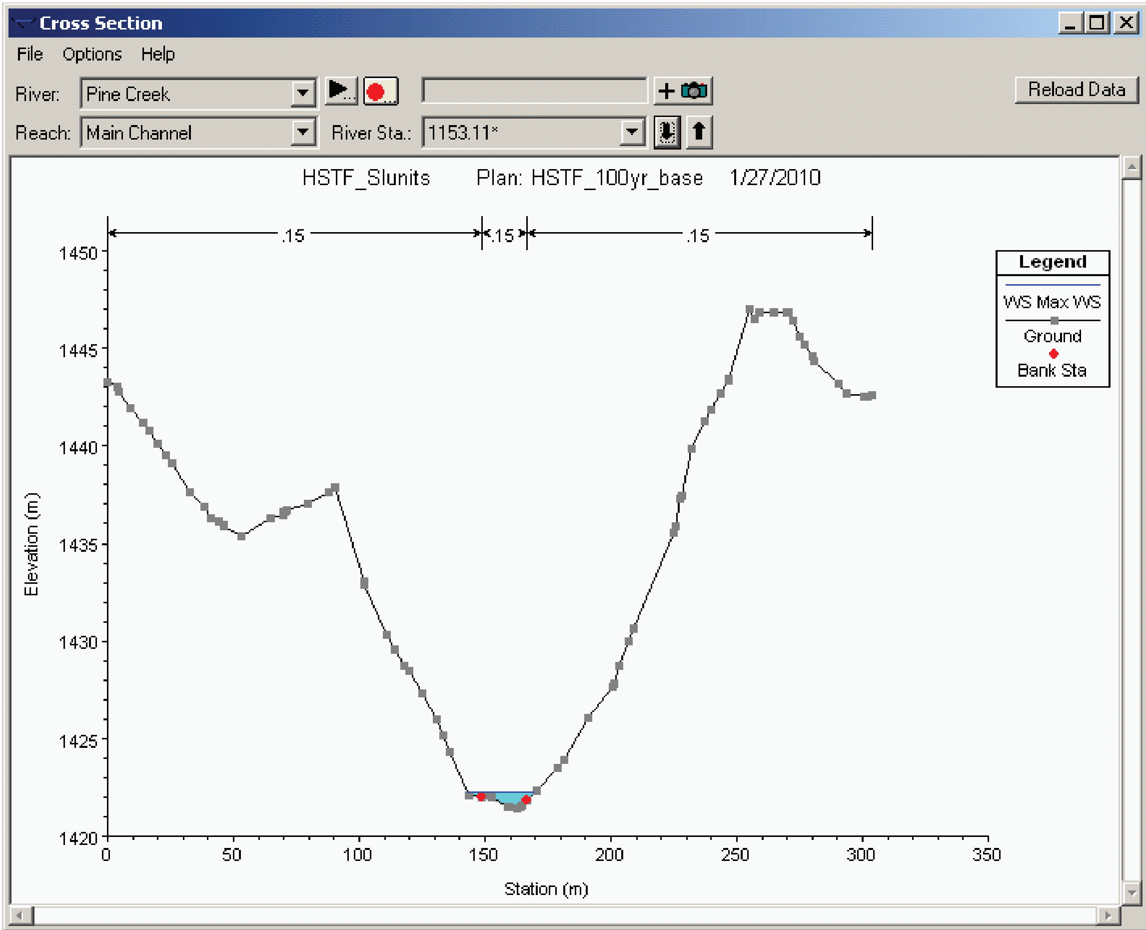
Figure 14. Relation between stage and discharge for the Mitchell Lake outlet structure.

Table 7. Model input parameters for simulated dam breaks and selected case studies.

[Shading denotes case study data for similar-sized dams from Bureau of Reclamation, 1998; --, not applicable]

Parameter	Iron Creek	Horsethief	Lakota	Mitchell	Elk City	Lake Frances	Grand Rapids	Coedty
Location	South Dakota	South Dakota	South Dakota	South Dakota	Oklahoma	California	Michigan	England.
Year built / failed	1937 / --	1940 / --	1962 / --	1936 / --	1925 / 1936	1899 / 1899	1874 / 1900	1924 / 1925
Construction	Earthfill	Earthfill	Earthfill	Earthfill	Sandy clay with concrete corewall	Earthfill	Earthfill with clay corewall	Earthfill with corewall.
Storage (acre-feet)	517	590	240	181	600	701	178	251
Dam height (feet)	40	65	34	31	30	50	25	36
Crest Width (feet)	30	36	13	21	16	16	12	10
Length (feet)	246	492	394	304	1,850	--	1,447	860
Upstream slope[1]	3.7	2.1	3.2	2.8	3	3	1.5	--
Downstream slope[1]	1.7	1.9	3.7	2.1	2	2	1.5	--
Failure mode	Overtopping	Overtopping	Overtopping	Overtopping	Overtopping	Piping	Overtopping	Overtopping.
Breach height (feet)	40	62	34	26	30	56	21	36
Breach top length (feet)	152	174	120	100	151	98	40	220
Breach bottom length (feet)	40	36	25	27	92	34	20	60
Breach side slopes[1]	1.4	1.4	1.4	1.4	1	.65	2.26	2.22
Breach formation time (hours)	.32	.28	.25	.27	--	1	.5	.25

[1]Side slope is given in units of horizontal distance per 1 vertical distance unit on a right triangle.



Note: HSTF_Slunits, project identifier; HSTF_100yr_base, scenario identifier; ws, water surface; max, maximum; sta, station; m, meter.

Figure 15. Synthetic cross section of Pine Creek downstream from Horsethief Lake used in the Hydrologic Engineering Center Hydrologic Modeling System (HEC-RAS) model.

Table 8. Downstream hazard classification system (Bureau of Reclamation, 1988).

Classification	Lives-in-jeopardy	Economic loss
Low	0 (none expected)	Minimal (undeveloped agriculture, occasional uninhabited structures, or minimal outstanding natural resources).
Significant	1–6 (few)	Appreciable (rural area with notable agriculture, industry, or worksites, or outstanding natural resources).
High	Greater than 6 (more than a few)	Excessive (urban area including extensive community, industry, agriculture, or outstanding natural resources.

downstream from the dam in all three dam-break scenarios (100-yr 24-hr storm, 500-yr peak flow, and PMP storm). The flood surge likely would be attenuated to an in-channel elevation by the time it reaches Spearfish Creek.

Horsethief Lake

The classification of a dam break for Horsethief Lake was rated as a significant hazard because of potential lives-in-jeopardy in downstream dwellings and appreciable economic loss. A flood resulting from a dam break likely would cause inundation or destruction of some permanent structures in addition to the loss of a span of Highway 244 near Mount Rushmore National Memorial. A summer campground that typically houses temporary residents from June through August is located about a mile downstream from the dam. The facility includes more than 20 cabins and buildings, which can provide housing for more than 200 campers. Inundation maps for the simulated 100-yr 24-hr storm, 500-yr peak flow, and PMP storm (figs. 19–21, respectively) illustrate that some of the campground could experience flooding (depth of about 1–6 ft) during the maximum surge of all three dam-break scenarios, but would not be at risk of flooding during the in-place scenarios for the 100-yr 24-hr storm and 500-yr peak flow. Most cabins are located on higher ground about 25 ft above the stream channel, but other structures are located on lower ground that would be flooded. A small impoundment that provides additional storage of floodwaters on Pine Creek is located near the campground. Inundation maps for all three storm simulations for in-place and dam-break scenarios indicate that an additional four single family dwellings also could be flooded near the confluence with Battle Creek. A railroad bridge and driveway crossing are located at the confluence point, both of which would be at risk of damage or complete destruction during a dam break.

Lakota Lake

A dam break at Lakota Lake was rated as a low hazard. The inundation maps for the simulated 100-yr 24-hr storm and the 500-yr peak flow (figs. 22 and 23, respectively) do not show any dwellings at risk, with little difference in inundation areas between the in-place and dam-break scenarios. Three dwellings potentially could be flooded during the PMP storm for the in-place and dam-break scenarios (fig. 24), but the dam break would have little additional effect relative to the in-place scenario. The floodwaters will probably attenuate to an in-channel elevation before reaching the confluence with Battle Creek near Hayward.

Mitchell Lake

Mitchell Lake was rated a low hazard classification because the dam-break surge is relatively inconsequential compared to magnitude of the IDFs. All three in-place scenarios for the simulated 100-yr 24-hr storm, 500-yr peak flow, and PMP storm (figs. 25–27, respectively) demonstrate potential inundation of several (more than 20) permanent dwellings or commercial structures. Two bridges on Highway 385 and one on Highway 16 are at high risk for damaging scour or complete washout during all in-place and dam-break scenarios. Several other driveways and bridges with less traffic would likely be washed out regardless of a dam failure. Detailed hydraulic analysis of bridge scour was not examined in this study. At some locations, simulation results show that the PMP dam-break scenario actually floods less area than the PMP in-place scenario, possibly because of higher conveyance (less resistance) at the dam location, changing the timing of the flood surge.

Summary and Conclusions

Extensive information about the construction or potential downstream hazards in the event of a dam breach is not available for many small reservoirs within the Black Hills National Forest. In 2009, the U.S. Forest Service (USFS) identified the need for reconnaissance-level dam-breach assessments for four of these reservoirs within the Black Hills National Forest (Iron Creek, Horsethief, Lakota, and Mitchell Lakes) with the potential to flood downstream structures. Flood hydrology and dam-breach hydraulic analyses for the four selected reservoirs were conducted by the U.S. Geological Survey in cooperation with the USFS to estimate the areal extent of downstream inundation. Three high-flow scenarios were considered for cases when the dam is in place (overtopped) and when a dam break (failure) occurs: the 100-year recurrence 24-hour precipitation, 500-year recurrence peak flow, and the probable maximum precipitation. Inundation maps were developed that show the extent of downstream floodwaters during simulated scenarios. Simulation results of a dam-break scenario were used to determine the hazard classification of the dam structure (high, significant, or low) based primarily on the potential for loss of life resulting from downstream inundation.

The inflow design floods (IDFs) resulting from the two simulated storm events (100-year 24-hour and probable maximum precipitation) were determined using the U.S. Army Corps of Engineers Hydrologic Engineering Center Hydrologic Modeling System, and the IDF for the 500-yr recurrence peak flow was determined by using regional regression equations developed for streamflow-gaging stations with similar watershed characteristics. Each reservoir's watershed was delineated using a 10-meter spatial resolution digital elevation model derived from the National Elevation Dataset. The 100-year 24-hour and PMP design storms were determined using National Oceanic and Atmospheric Administration hydrologic references and Hydrometeorological Report-55A guidelines, respectively. The infiltration losses were estimated using the Natural Resources Conservation Service curve number method, which estimates precipitation excess as a function of cumulative precipitation, soil group, and land use. A unit hydrograph method was applied to the modeled watersheds, described by a single parameter estimate of the time of concentration. Using a specified channel geometry and roughness coefficient, continuity and momentum equations were solved to estimate streamflow in the main channels.

The step-backwater hydraulic analysis model, Hydrologic Engineering Center's River Analysis System (HEC-RAS), was used to determine water-surface profiles for in-place and dam-break scenarios for the three simulated IDFs. Input data for the HEC-RAS models included stream cross section, hydraulic structure, dam geometries, IDF hydrographs, and roughness coefficients (Manning's n values). A dam overtopping scenario was used as the dam-break scenario for HEC-RAS simulations, with breach parameters based on relations from previous dam failures with similar characteristics. Inundation maps for in-place and dam-break scenarios were developed downstream from the dam to the mouth of each stream.

Dam-break scenarios for three of the four reservoirs assessed in this study were rated as a low hazard owing to absence of permanent structures downstream from the dams. Iron Creek Lake's downstream channel to its mouth does not include any permanent structures within the inundation flood plains. For the two reservoirs with the largest watershed areas, Lakota and Mitchell Lake, the additional floodwater surge resulting from a dam break would be minor relative to the magnitude of the large flood streamflow into the reservoirs, based on the similar areal extent of inundation for the in-place and dam-break scenarios as indicated by the developed maps. A dam-break scenario at Horsethief Lake was rated as a significant hazard because of potential lives-in-jeopardy in downstream dwellings and appreciable economic loss. The flood resulting from a dam break at Horsethief Lake would likely cause inundation or destruction of some permanent structures at a campground and houses near the mouth of the stream, in addition to the loss of a span of Highway 244 near Mount Rushmore National Memorial.

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Appendix. Inundation maps

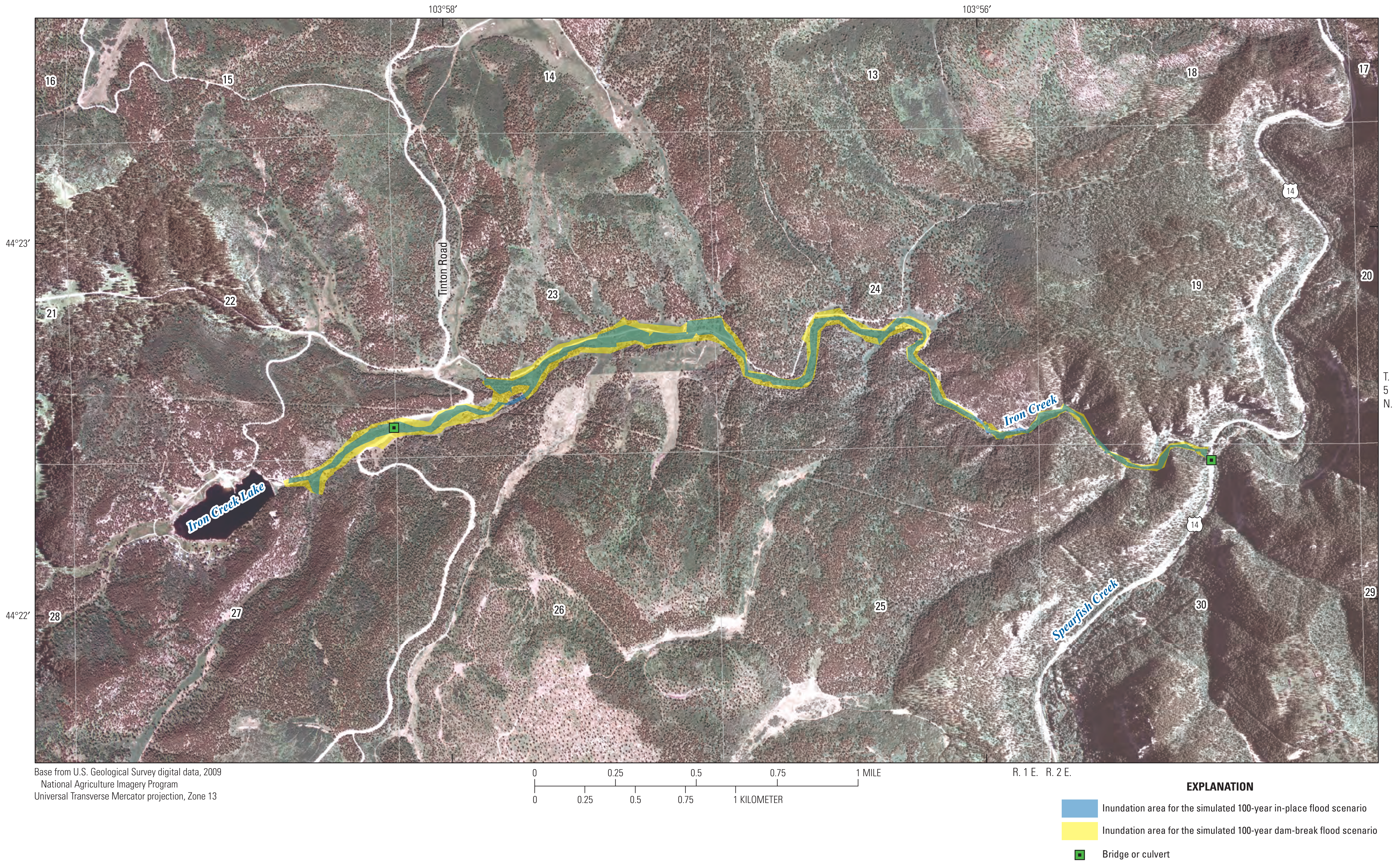


Figure 16. Flood inundation map for a simulated dam break from a 100-year 24-hour inflow design flood for Iron Creek Lake.

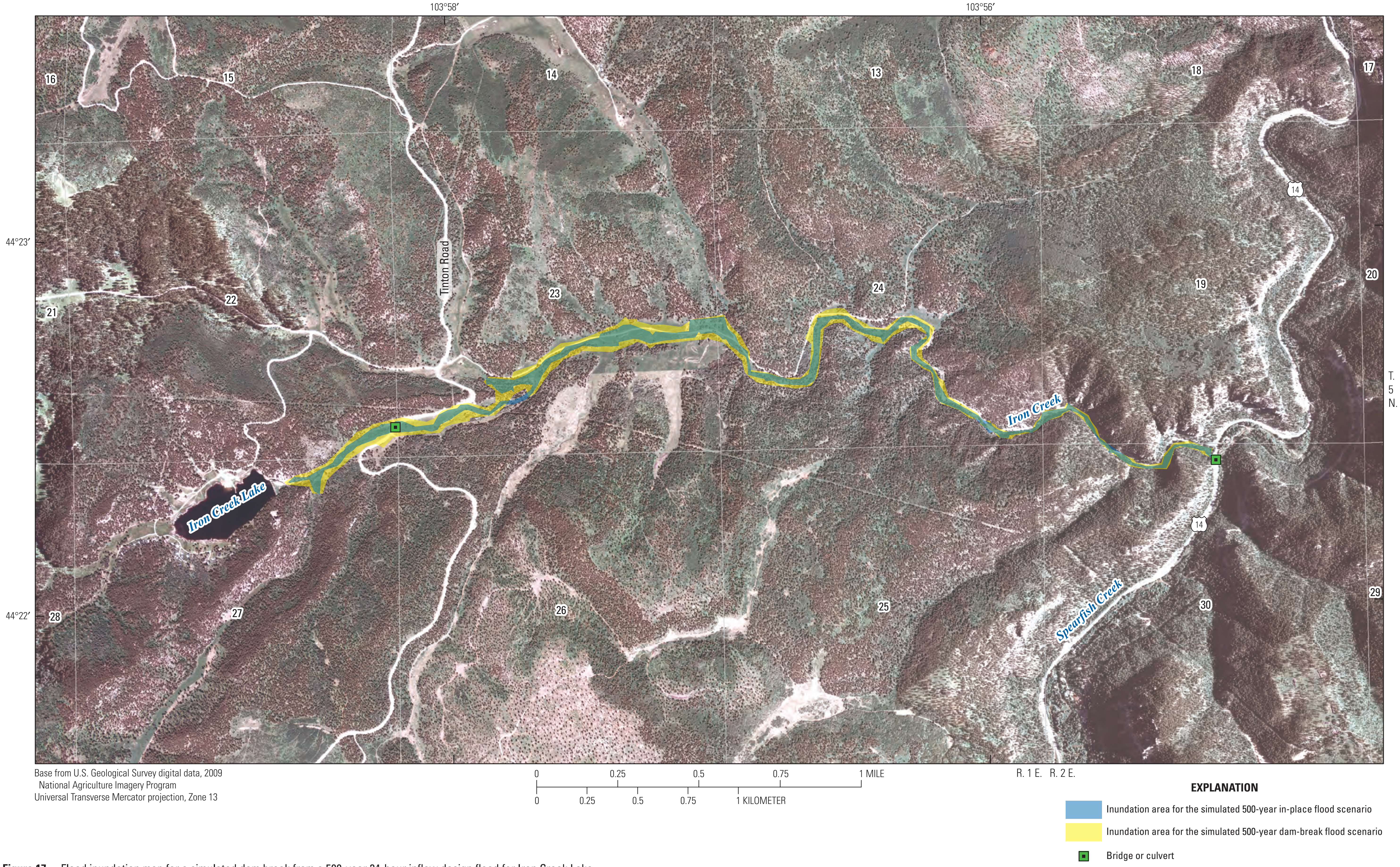


Figure 17. Flood inundation map for a simulated dam break from a 500-year 24-hour inflow design flood for Iron Creek Lake.

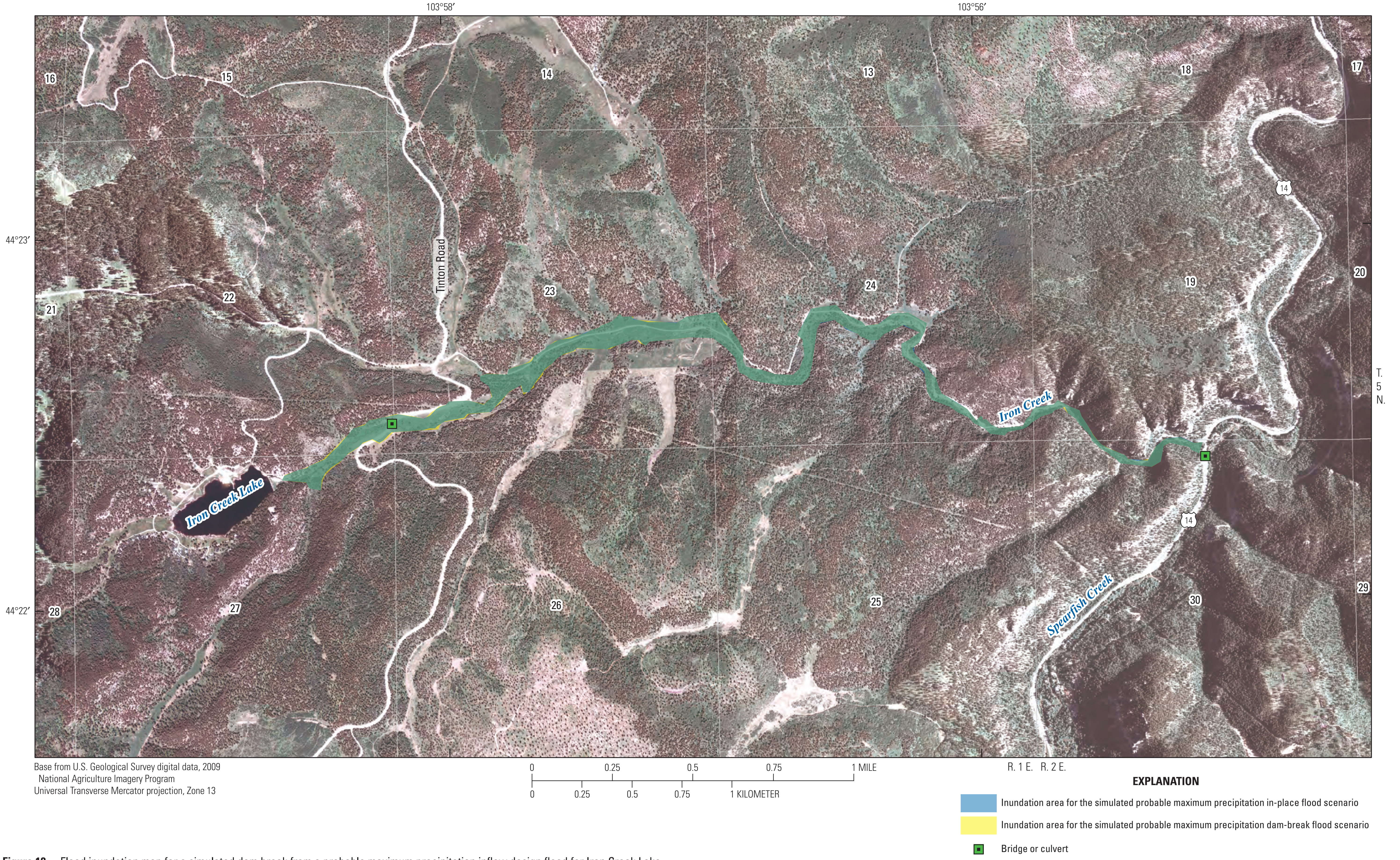


Figure 18. Flood inundation map for a simulated dam break from a probable maximum precipitation inflow design flood for Iron Creek Lake.

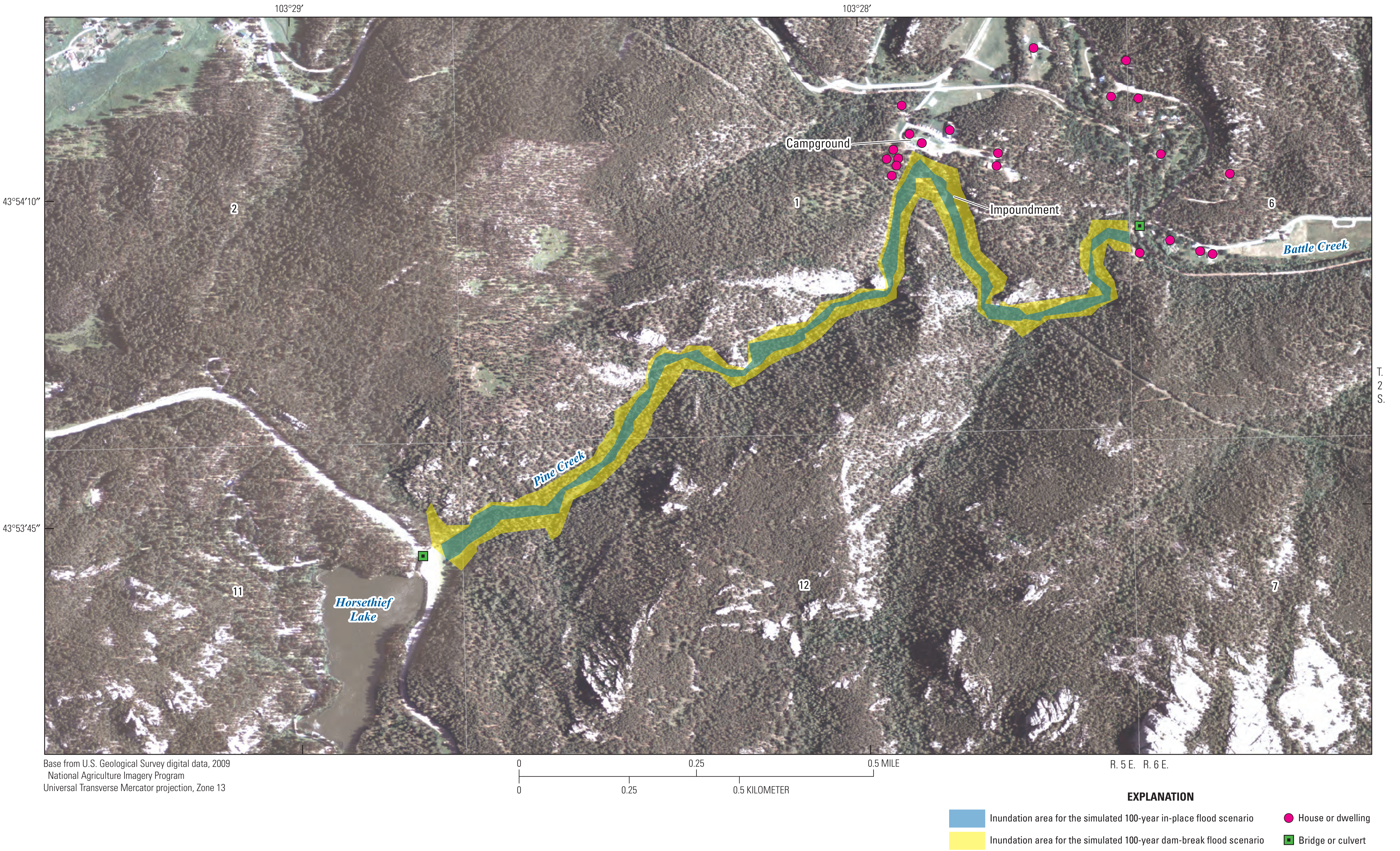


Figure 19. Flood inundation map for a simulated dam break from a 100-year 24-hour inflow design flood for Horsethief Lake.

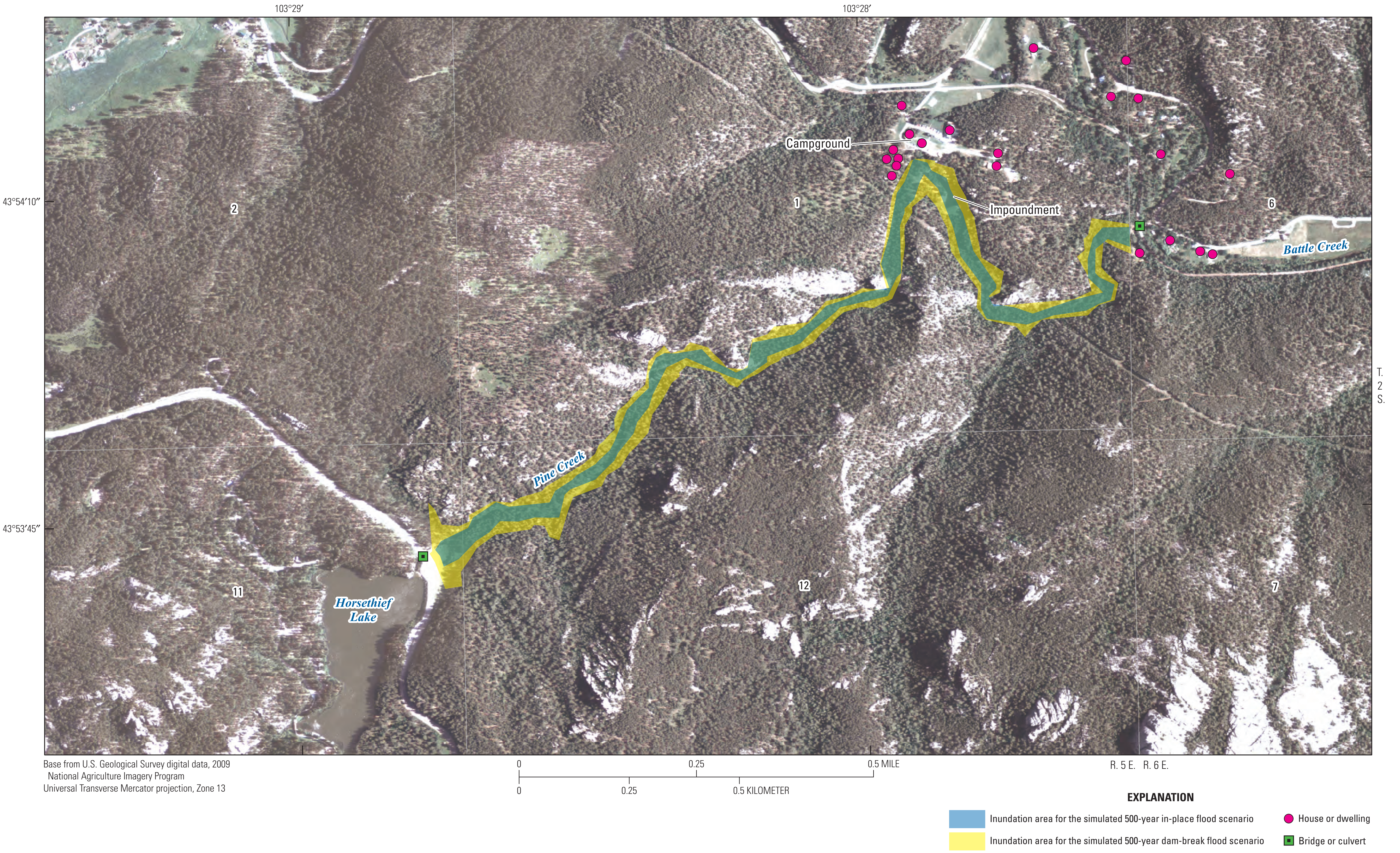


Figure 20. Flood inundation map for a simulated dam break from a 500-year 24-hour inflow design flood for Horsethief Lake.

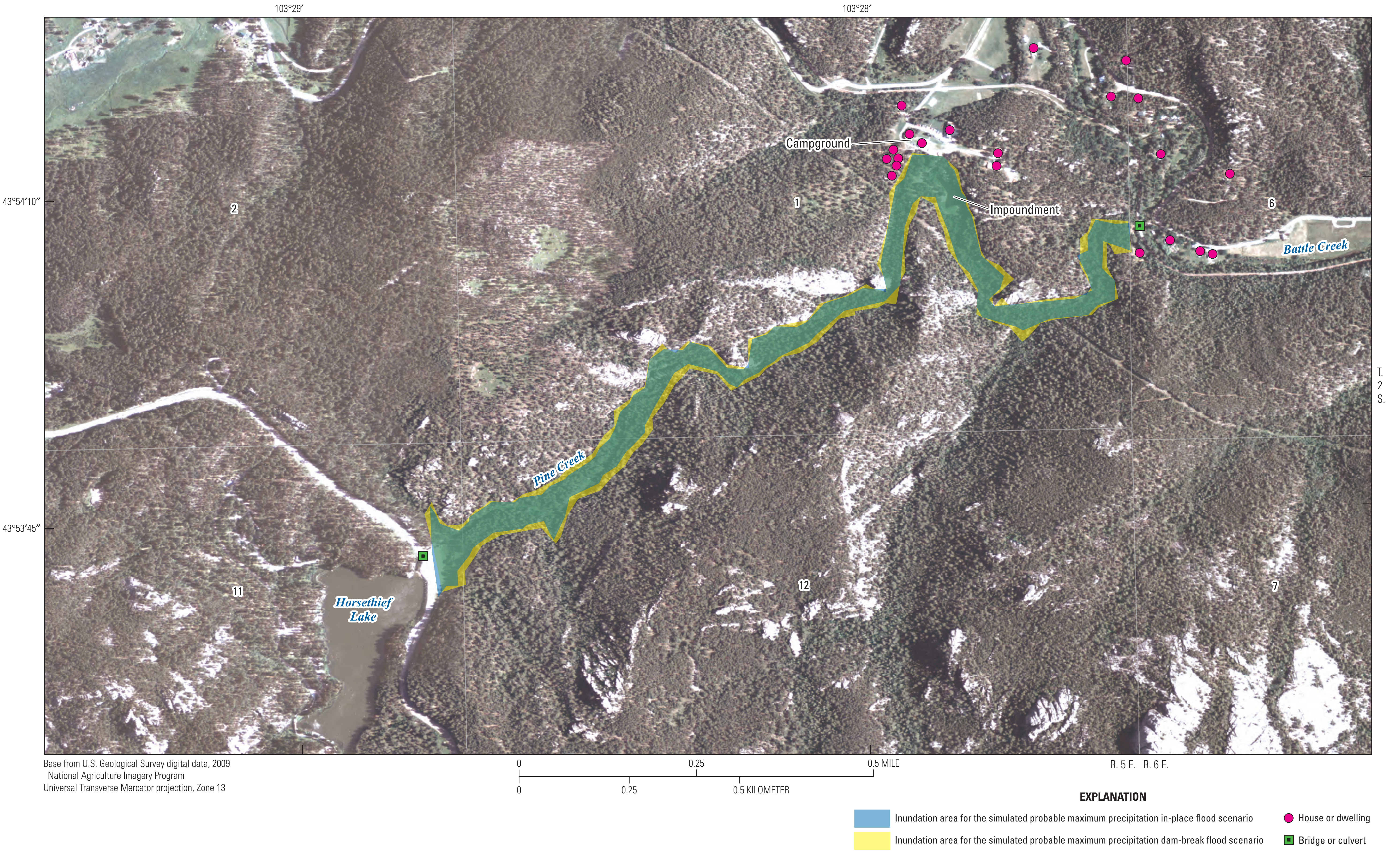


Figure 21. Flood inundation map for a simulated dam break from a probable maximum precipitation inflow design flood for Horsethief Lake.

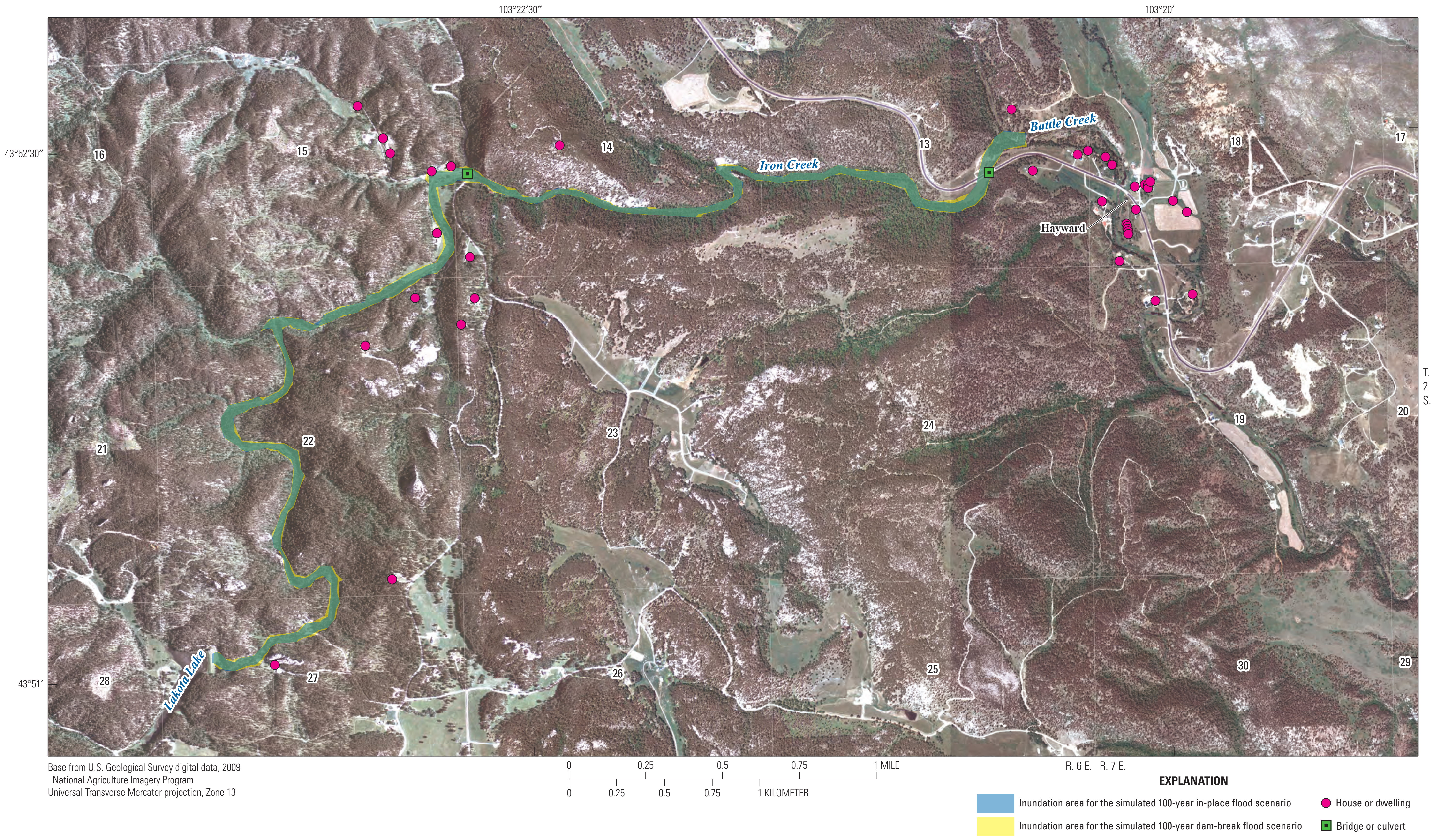
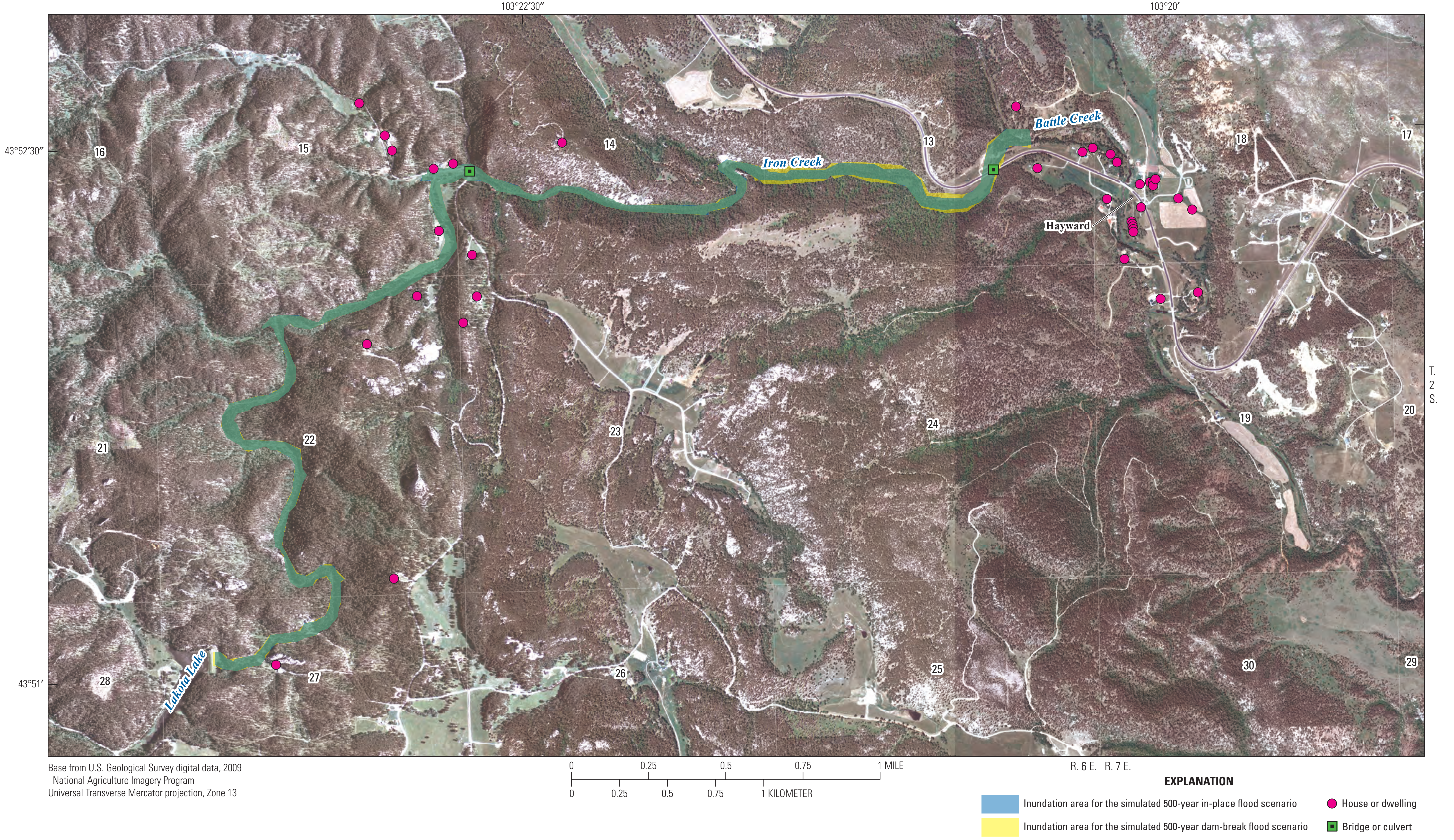


Figure 22. Flood inundation map for a simulated dam break from a 100-year 24-hour inflow design flood for Lakota Lake.



Base from U.S. Geological Survey digital data, 2009
National Agriculture Imagery Program
Universal Transverse Mercator projection, Zone 13

Figure 23. Flood inundation map for a simulated dam break from a 500-year 24-hour inflow design flood for Lakota Lake.

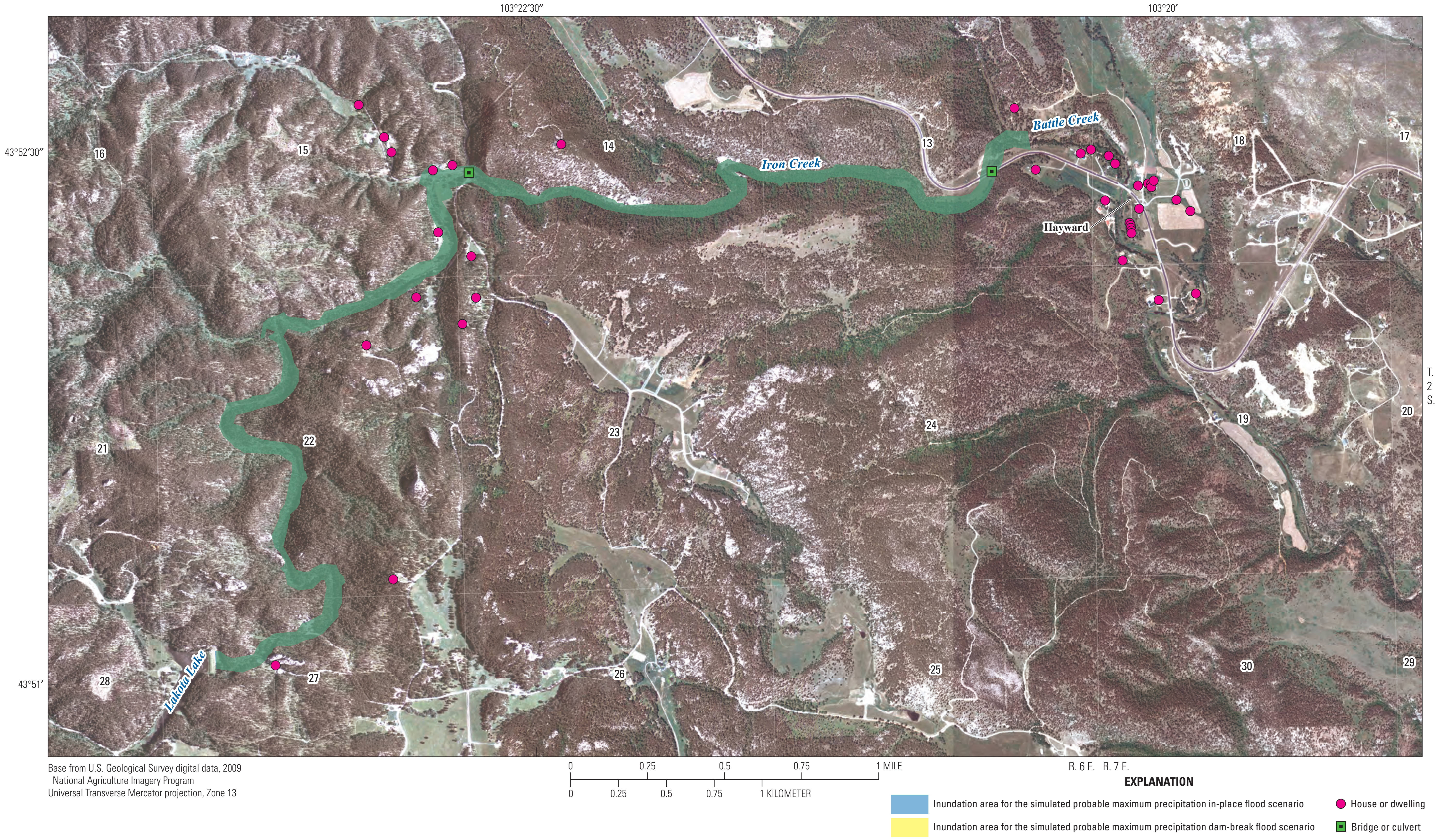


Figure 24. Flood inundation map for a simulated dam break from a probable maximum precipitation inflow design flood for Lakota Lake.

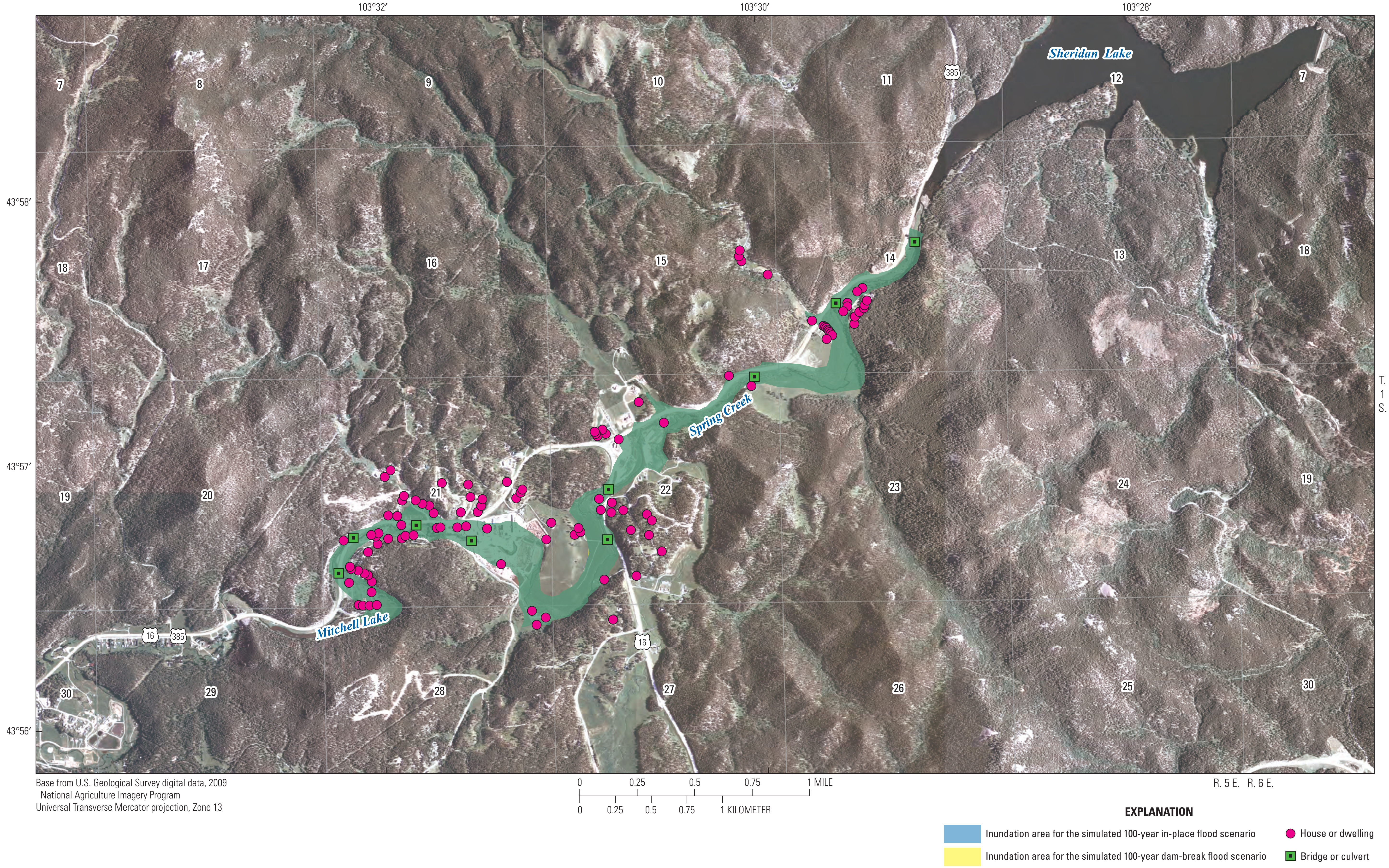


Figure 25. Flood inundation map for a simulated dam break from a 100-year 24-hour inflow design flood for Mitchell Lake.

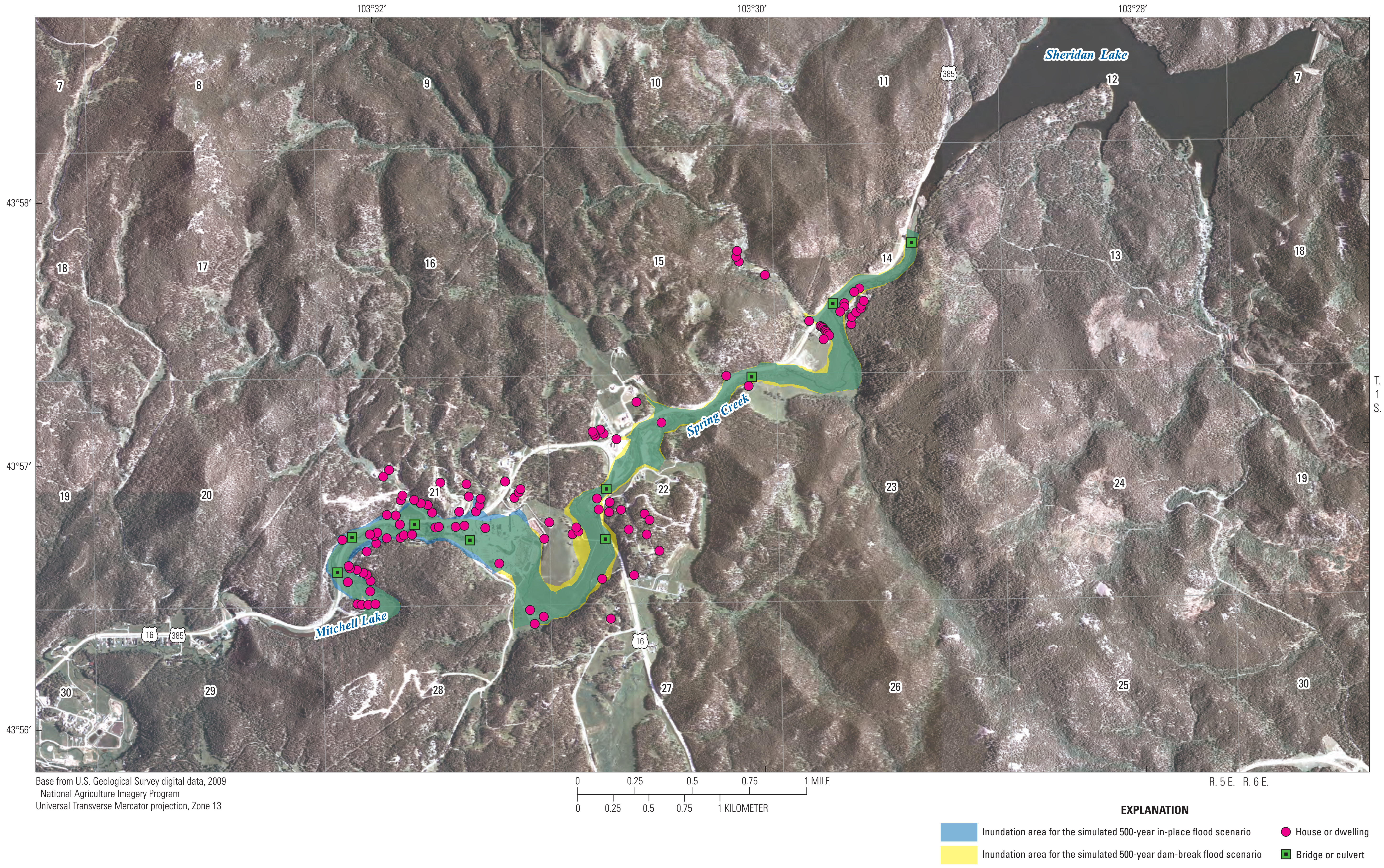
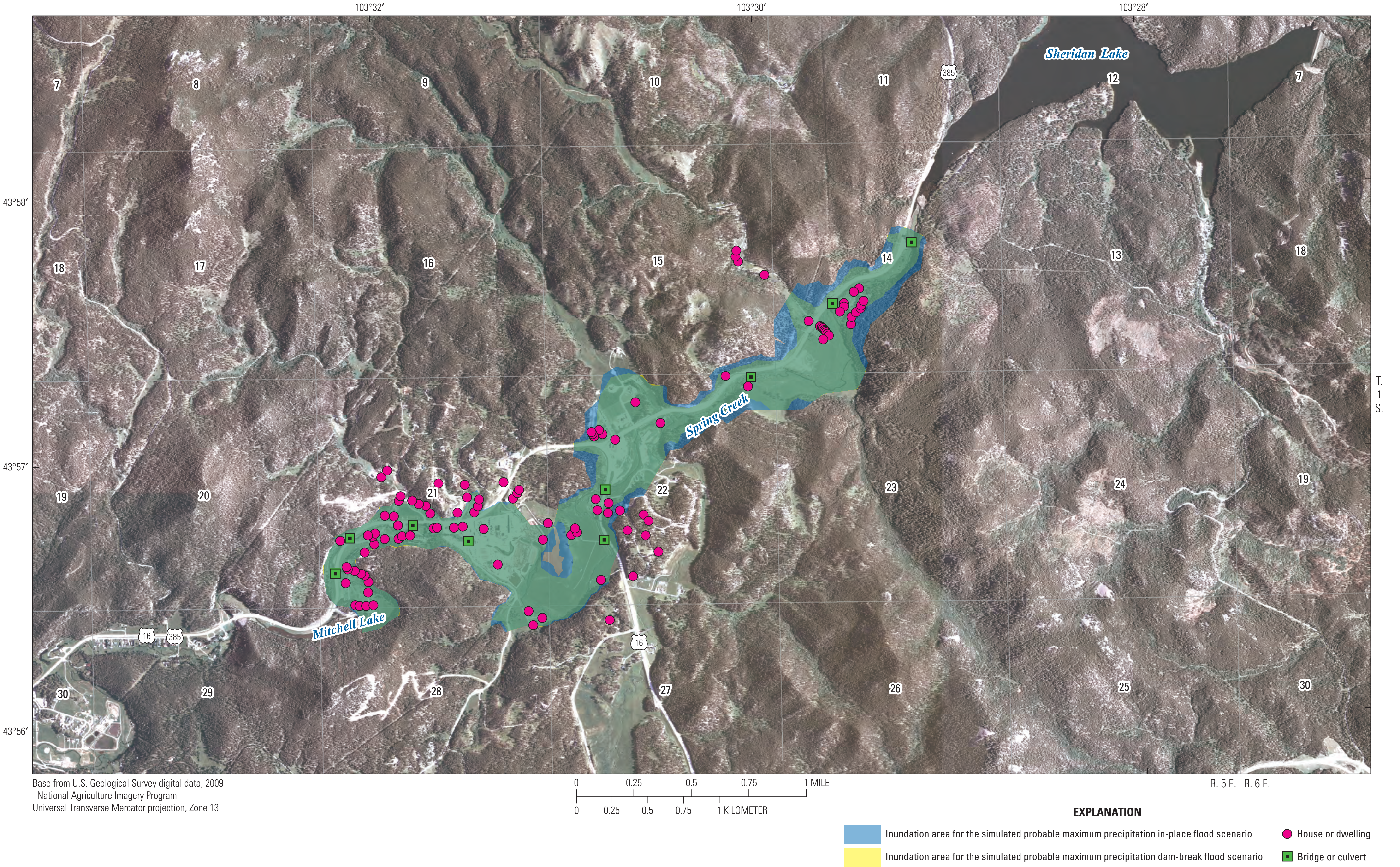


Figure 26. Flood inundation map for a simulated dam break from a 500-year 24-hour inflow design flood for Mitchell Lake.



Base from U.S. Geological Survey digital data, 2009
National Agriculture Imagery Program
Universal Transverse Mercator projection, Zone 13

Figure 27. Flood inundation map for a simulated dam break from a probable maximum precipitation inflow design flood for Mitchell Lake.

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