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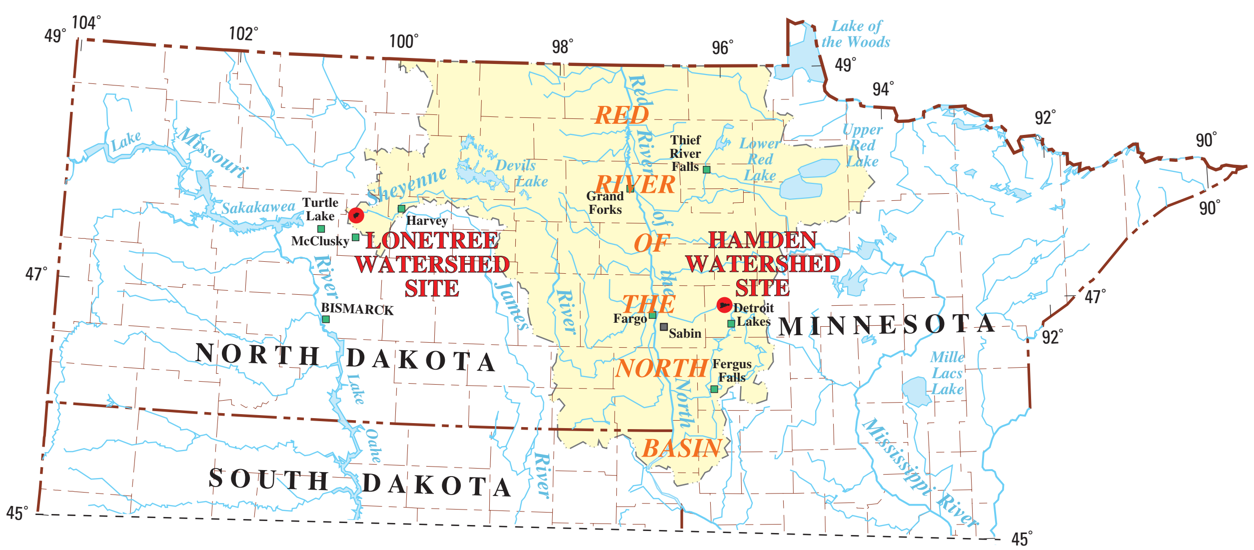
Simulation of Runoff and Wetland Storage in the Hamden and Lonetree Watershed Sites Within the Red River of the North Basin, North Dakota and Minnesota



Scientific Investigations Report 2004–5168

U.S. Department of the Interior
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Vining—**Simulation of Runoff and Wetland Storage in the Hamden and Lonetree Watershed Sites Within the Red River of the North Basin, North Dakota and Minnesota**—Scientific Investigations Report 2004–5168

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Simulation of Runoff and Wetland Storage in the Hamden and Lonetree Watershed Sites Within the Red River of the North Basin, North Dakota and Minnesota

By Kevin C. Vining

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

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Conversion Factors and Datums

Multiply	By	To obtain
Length		
inch	25.4	millimeter
foot	0.3048	meter
mile	1.609	kilometer
Area		
acre	0.4047	hectare
square mile	2.590	square kilometer
Volume		
acre-foot	1,233	cubic meter
Flow rate		
cubic foot per second	0.02832	cubic meter per second

Temperature in degrees Fahrenheit (°F) may be converted to temperature in degrees Celsius (°C) as follows: °C = (°F - 32) / 1.8.

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

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

Simulation of Runoff and Wetland Storage in the Hamden and Lonetree Watershed Sites Within the Red River of the North Basin, North Dakota and Minnesota

By Kevin C. Vining

Abstract

Re-establishment of wetlands has been promoted by various groups to control future floods in the Red River of the North Basin in North Dakota and Minnesota. Therefore, a study was conducted to simulate runoff and wetland storage in the Hamden and Lonetree watershed sites in the Red River of the North Basin. Data from geographic information system analyses, collected weather data, additional historic weather data, and geomorphology were used in a wetlands hydrologic model to simulate precipitation accumulation, snowmelt, evapotranspiration, soil infiltration, seepage to ground water, surface runoff, and streamflow. Simulated daily mean water volumes for the soil and wetlands in the Hamden and Lonetree watershed sites showed that the soils of the two sites stored as much water as the wetlands throughout most of the simulation period. Total simulated runoff for the Hamden watershed site for the period of record was reduced about 38 percent by increasing the Bisson Lake spillage threshold from 0.009 to 0.60. The additional simulated storage at the larger spillage threshold led to reductions in simulated runoff. Simulated daily mean streamflows for the Hamden watershed site at a Bisson Lake spillage threshold of 0.60 were less than those simulated for the same day at a Bisson Lake spillage threshold of 0.009. However, the peak streamflows simulated for June 2000 and April 2001 at a spillage threshold of 0.60 were about the same as those simulated at a spillage threshold of 0.009. Simulated runoff during flood conditions in April and June 2000 and March and April 2001 was reduced 1 to 6 percent for an increased spillage threshold. Total runoff for the period of record was reduced about 31 percent for the increased spillage threshold. Simulation results indicate total streamflow from a flood event may be reduced by wetland storage, but peak streamflows during a flood event may not be affected substantially.

Introduction

Changes in agricultural and other land-use practices can have substantial effects on the hydrologic processes of small watersheds (Woolhiser and Brakensiek, 1982). For example, variations in tillage techniques, alterations in wetlands and drainage channels, and urbanization can affect the amounts of evaporation, soil moisture, and runoff for a watershed. Brown (1988) noted that differences in land use appeared to have a major effect on the amount of runoff from a small watershed during a given year and that differences in precipitation appeared to have a major effect on the amount of runoff from a given watershed from year to year. Brown (1988) also noted that small watersheds that have considerable surface-water storage in wetlands and lakes had small amounts of runoff. However, if the surface-water storage in the wetlands and lakes was exceeded, the amount of runoff could be as large as the amount for watersheds that have little surface-water storage.

Miller and Frink (1984) noted little indication of significant changes in flood response on the Red River of the North (hereinafter called the Red River) main stem since the late 1800s as a result of the regionwide variability in runoff and the complexity of the runoff problem. Winter (1989) stated that the effects of wetland drainage on downstream flooding in the northern prairie region were difficult to evaluate because of the lack of understanding of runoff processes within the topography and geology of the region. Miller and Nudds (1996), in an investigation on the relations between historical runoff into regional rivers and wetland losses in the north-central United States and south-central Canada, noted a significant upward trend in runoff in the United States, where many wetlands have been altered. However, the precipitation trend in the United States had not increased significantly. In Canada, where fewer wetlands have been altered, most of the runoff and precipitation trends had not increased significantly. Simonovic and Juliano (2001) indicated that, given a low-frequency flood event such as the 1997 flood, an increase in wetlands area would provide minimal reduction in flood water volumes and flood peak water levels.

In North Dakota and Minnesota, the effect of wetland storage on runoff has been a significant issue, especially since the 1997 spring flood in the Red River Basin. Although a record snowpack existed in the basin prior to snowmelt, the severity of the flood also may have been a result of underpredicted peak river levels, inadequate dikes, drained fields, and destroyed wetlands in the basin. Because re-establishment of wetlands has been promoted by various groups to control future floods, information was needed on the effects of wetland storage, drainage, and antecedent soil conditions on runoff in the Red River Basin. To obtain this information, the U.S. Geological Survey (USGS), in cooperation with the Minnesota Department of Natural Resources, the North Dakota State Water Commission, the Red River Joint Water Resource Board, the Red River Watershed Management Board, and the U.S. Fish and Wildlife Service, conducted a study to simulate runoff and wetland storage for two small watersheds in the basin. This report describes the wetlands hydrologic model used to simulate the runoff and wetland storage and presents results of the simulation. Hydrologic data for May 1999 through September 2002 were used in the construction and calibration of the model. The calibrated model was modified with January through May 1997 data to simulate flood conditions. Information from the study may be useful to water-resource managers and researchers associated with watershed-runoff and wetland-storage issues.

Description of Study Sites

For this study, a small watershed site, called the Hamden watershed site, was established in west-central Minnesota (fig. 1), and another small watershed site, called the Lonetree watershed site, was established in central North Dakota (fig. 2). These sites were selected because they contained a variety of wetland types and because they represented extremes of physiographic and climatic regions in the Red River Basin (Winter, 1992). The soil-type and soil-moisture data for the sites were obtained from a county soil survey publication (Aziz and Lisante, 1994) and from the Soil Survey Geographic (SSURGO) database (U.S. Department of Agriculture, 2001). Climate normals for the sites for 1971-2000 were obtained from the National Climatic Data Center (2001).

The Hamden watershed site is located at the eastern edge of the Red River Basin in slightly rolling terrain near the upper reaches of the Buffalo River. The site had many marshes and wetlands that were destroyed for agriculture. Drainage channels, many of which were designed, are well defined at the site. Prominent features within the site include Bisson Lake, a wetland that is located in the northwest part of the site, and Ditch 15, a designed drainage ditch about 2 miles long that drains Bisson Lake and the western side of the site (fig. 3). A steel sheet-pile weir with removable stoplogs was installed in Ditch 15 downstream from Bisson Lake in 2000. The weir was operational beginning in April 2001 and was designed to retain about 110 acre-feet of water at full service level. The Hamden watershed site encompasses an area of about 9.9 square miles. Surface elevations range from about 1,420 feet above the North American Vertical Datum of 1988 in the east to about 1,230 feet above the North American Vertical Datum of 1988 in the southwest. The soils of the site consist of mostly silty clay loams in the wetlands and loams in the uplands. Annual precipitation at the site is about 26.4 inches. Mean monthly temperatures range from about 6 degrees Fahrenheit in January to about 69 degrees Fahrenheit in July.

The Lonetree watershed site is located at the western edge of the Red River Basin in mostly rolling terrain near the upper reaches of the Sheyenne River. The site has numerous wetlands. Drainage channels are not well defined in most areas of the site. Prominent features within the site include wetland 1, a 10-acre wetland that is located in the northeast corner of the site (fig. 4). The wetland is bisected by the Sheyenne River Tributary. A beaver dam was constructed in the Sheyenne River Tributary downstream from wetland 1 during 2001, but the dam was removed in June 2002. The Lonetree watershed site encompasses an area of about 7.2 square miles. Surface elevations range from about 2,090 feet above the North American Vertical Datum of 1988 in the southwest to about 1,800 feet above the North American Vertical Datum of 1988 in the northeast. The soils of the site consist of clay loams to silty clay loams in the wetlands and loams to sandy loams in the uplands. Annual precipitation at the site is about 17.7 inches. Mean monthly temperatures range from about 9 degrees Fahrenheit in January to about 71 degrees Fahrenheit in July.

Data Acquisition

Permanent and temporary water-level gaging stations were established at the Hamden watershed site during 1999 and at the Lonetree watershed site during 2000. The permanent stations were designed to be in place throughout the year, and the temporary stations were designed to be removed for the winter. Weather stations that measured precipitation, air temperature, humidity, and solar radiation also were installed at or near each site. At the Hamden watershed site, the permanent stations were located in the ditch upstream from Bisson Lake, in Bisson Lake, and in Ditch 15 at the outlet from the site (fig. 3). Each permanent station contained a pressure-transducer device to measure water levels. The temporary station at the site was located in wetland A and contained a float-counterweight-potentiometer device with a stilling well to measure water levels. The permanent station in Bisson Lake was a temporary station until 2001. At the Lonetree watershed site, the permanent station was located in the Sheyenne River Tributary (fig. 4). The station contained a float-counterweight-potentiometer device with a stilling well to measure water levels. The temporary stations were located in wetland 1 and in a wetland northwest of wetland 1 and also contained float-counterweight-potentiometer devices to measure water levels. Rainfall amounts at selected stations at both sites were measured using tipping-bucket rain gages. Data for all stations were recorded using electronic data recorders. Additional climate data for stations located at Detroit Lakes and Sabin, Minn., and Harvey, McClusky, and Turtle Lake, N. Dak., were used to supplement

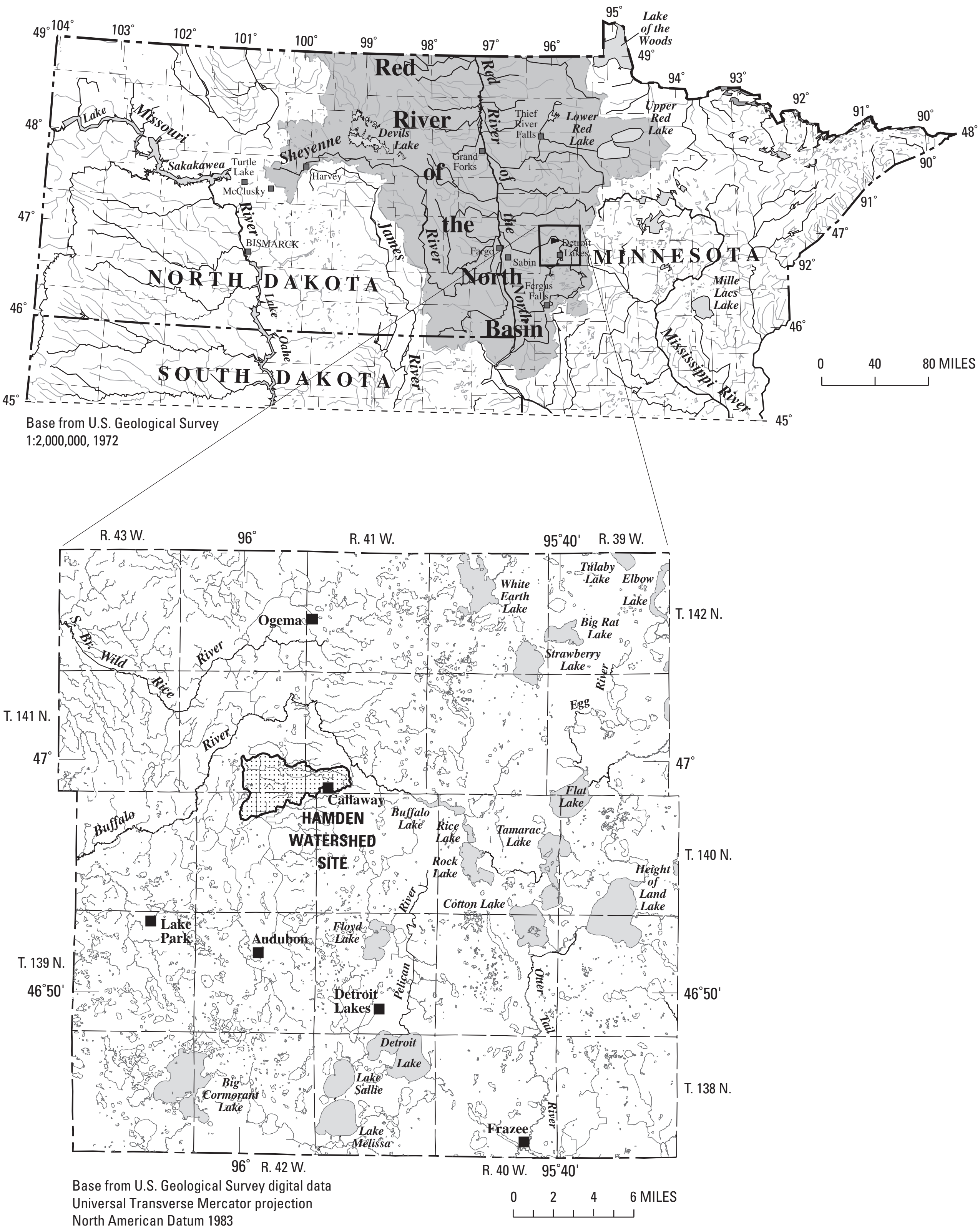

Figure 1. Location of the Hamden watershed site in western Becker County, west-central Minnesota.

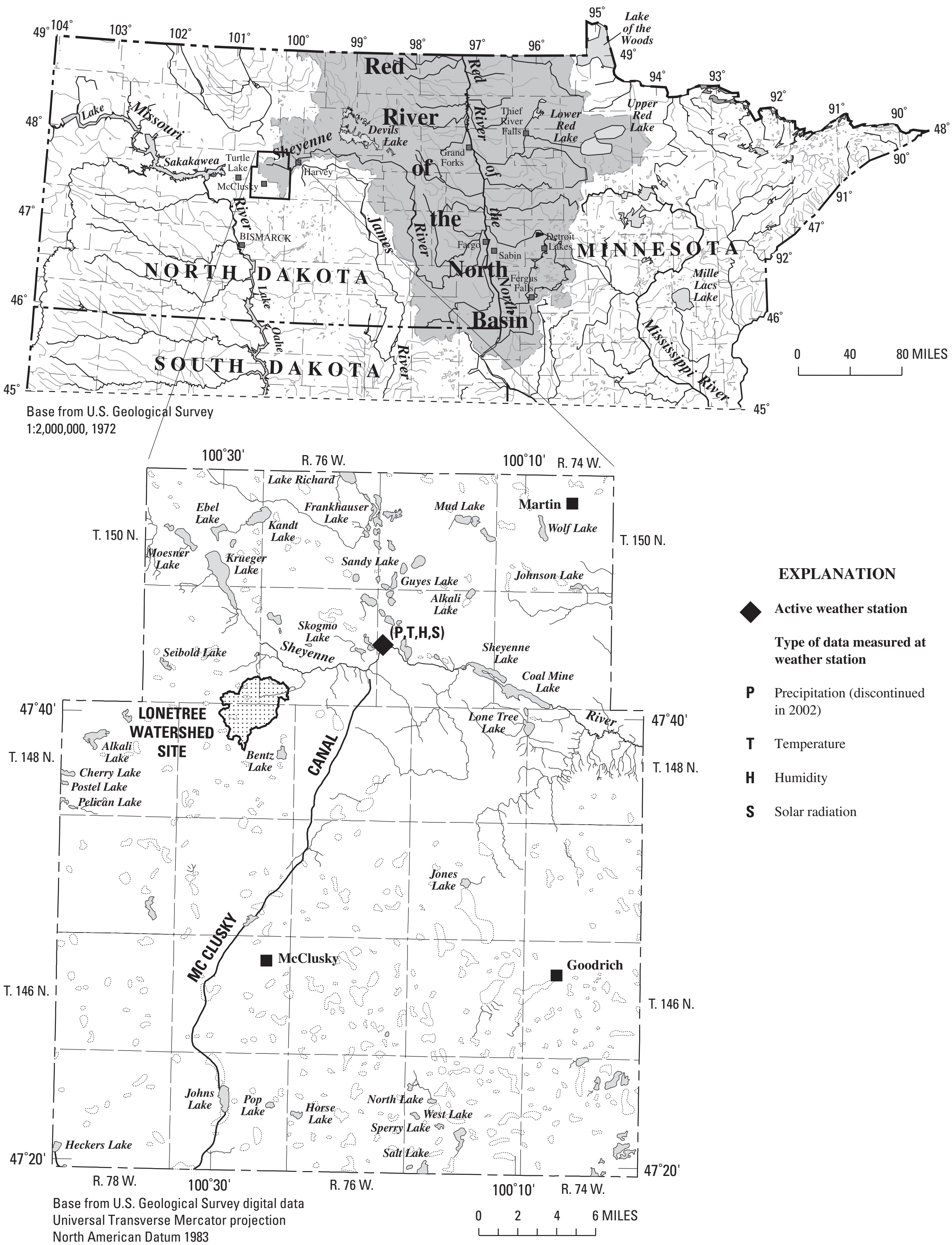

Figure 2. Location of the Lonetree watershed site in Sheridan County, central North Dakota.

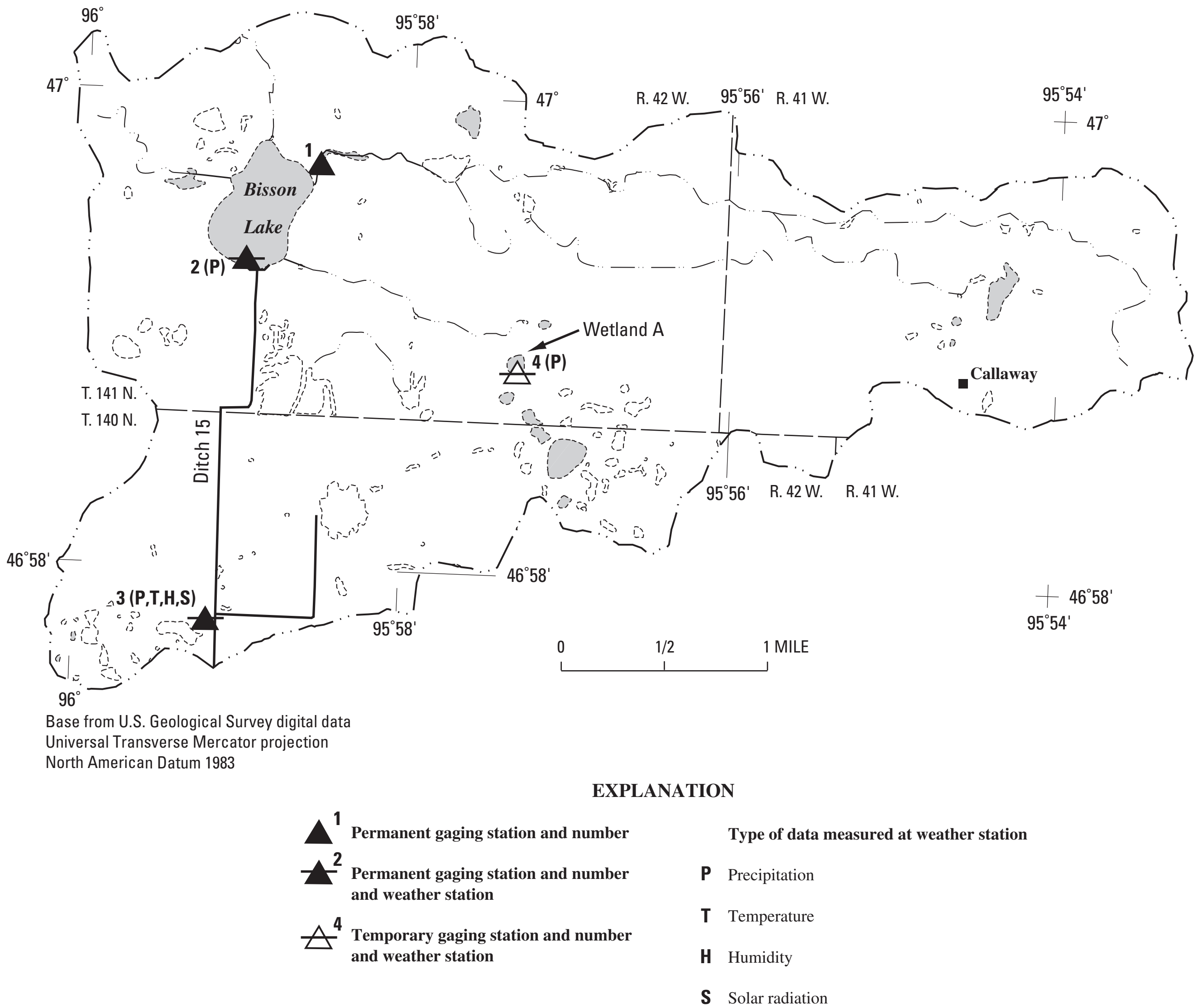

Figure 3. Location of data-collection stations in the Hamden watershed site, west-central Minnesota.

records where data were missing. Daily mean precipitation for the Hamden watershed site is shown in figure 5, and daily mean precipitation for the Lonetree watershed site is shown in figure 6.

Streamflow for the major drainages was measured periodically near the permanent gaging stations at both sites using established USGS techniques (Rantz and others, 1982). The streamflow data constituted a streamflow record for comparison with model results for the permanent stations. Landscape surveys were conducted at both sites during the autumn, when water levels generally are lowest, to provide detailed elevation information about surface features and wetlands at the sites and to establish hydrologic response parameters that were used to develop the hydrologic model used in the study. Changes in wetlands water volumes and wetlands areas also were determined from the surveys. Snow surveys were conducted prior to spring melt to provide information on the snowpack water equivalent at each site. Other information derived from topographic maps, digital-elevation models, and the geographic information system (GIS) were used to determine topographic and hydrologic parameters for each site.

Wetlands Hydrologic Model

A wetlands hydrologic model, which is a modified version of the USGS Precipitation-Runoff Modeling System (PRMS) (Leavesley and others, 1983; Leavesley and Stannard, 1995), was developed to simulate runoff and wetland storage for the Hamden and Lonetree watershed sites. The model was similar to the Devils Lake Basin wetlands model described in Vining

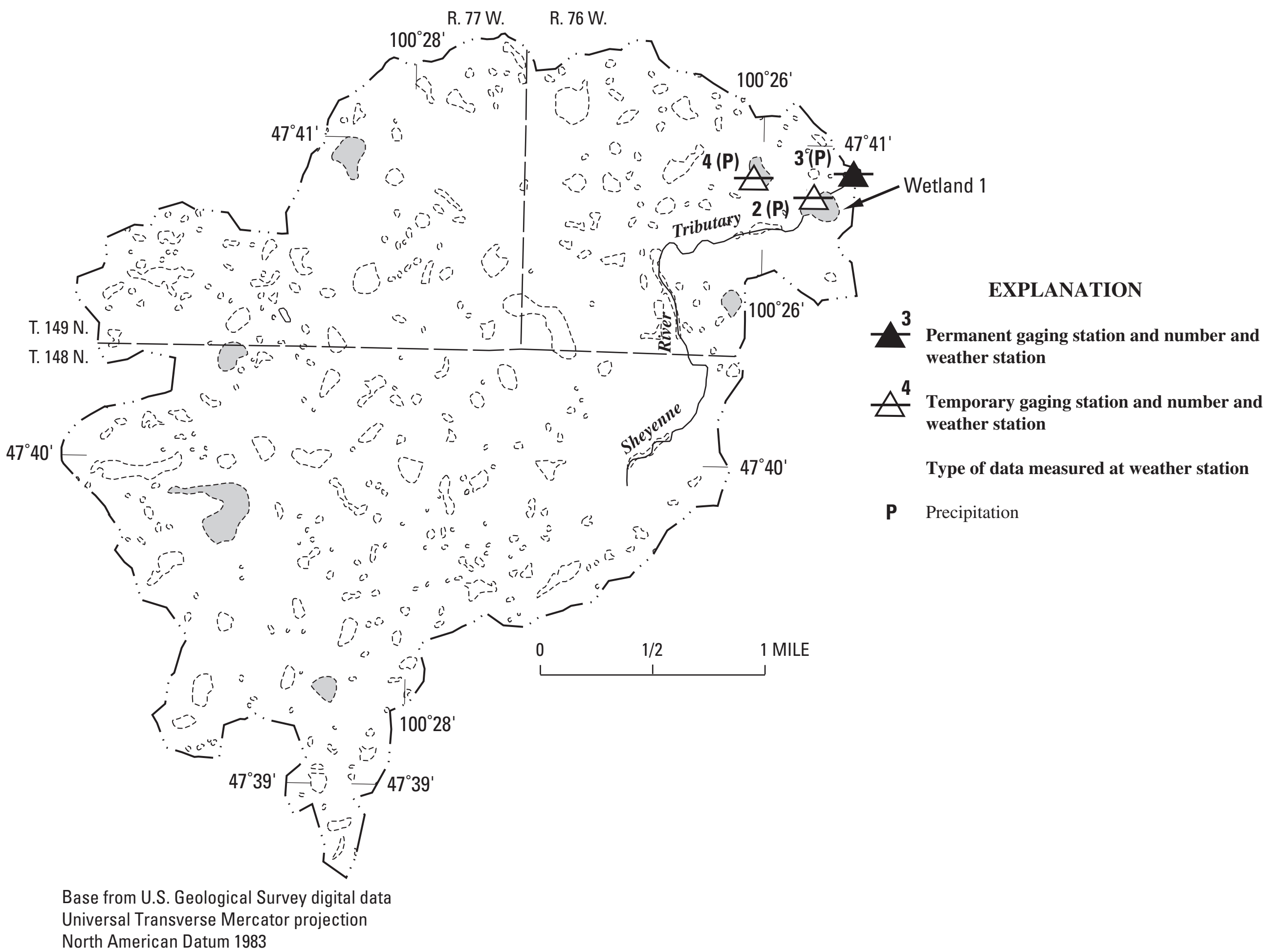

Figure 4. Location of data-collection stations in the Lonetree watershed site, central North Dakota.

(2002). A wetlands hydrologic model is a distributed-parameter model that uses physics-based mathematical relations to represent the hydrology of an area. In the model, computations are performed on a daily time step, and streamflow generated by the model during the daily time step leaves the modeled area by the next time step. Frozen-soil conditions that occur during spring snowmelt events are modeled by use of a parameter that limits soil infiltration when snow exists on the surface. For this study, data from the GIS analyses, collected weather data, additional historic weather data, and geomorphology were used in the model to simulate precipitation accumulation, snowmelt, evapotranspiration, soil infiltration, seepage to ground water, surface runoff, and streamflow.

Before runoff and wetland storage were simulated, the Hamden and Lonetree watershed sites were partitioned into hydrologic response units (HRUs) on the basis of characteristics such as slope, aspect, elevation, soil type, and vegetation type so that each unit had a homogeneous response to weather and hydrologic inputs. Information obtained from topographic maps, digital-elevation models, and field observations was used to delineate the HRUs for each site. The Hamden watershed site was partitioned into three HRUs (fig. 7), and the Lonetree watershed site was partitioned into six HRUs (fig. 8). Water balances and energy balances were produced in the wetlands hydrologic model for each HRU and then were quantified to represent the combined effect for each site.

The water depth and the maximum possible area for each individual wetland at a site were determined from surveys and from topographic and planimetric analyses. However, because of constraints and the complexities of including each individual wetland in the model, each HRU was considered to include only one wetland, which was defined as having the average depth and total area of all individual wetlands in the HRU. Thus, three wetlands were modeled for the Hamden watershed site, and six wetlands were modeled for the Lonetree watershed site. The maximum water volume for each modeled wetland was calculated by multiplying the average water depth at maximum area

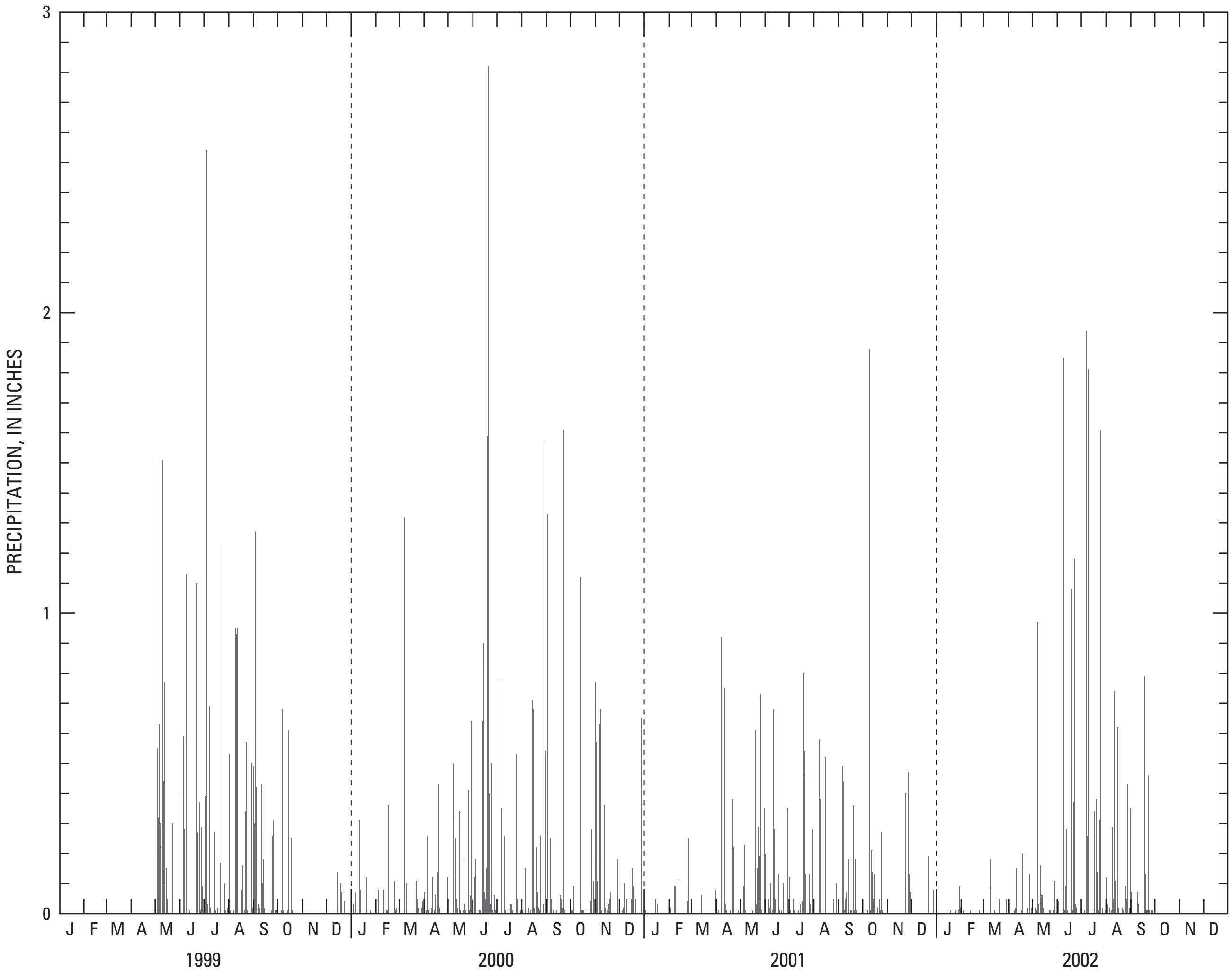

Figure 5. Daily mean precipitation for the Hamden watershed site, west-central Minnesota, May 1999 through September 2002.

by the maximum wetland area. The area-to-volume equation for each wetland was defined as shown in equation 1:

$$A_{\mathrm{frac}} = \exp^{c(\ln V_{\mathrm{frac}})} \tag{1}$$

where

A_{frac} is the decimal fraction of the maximum wetland area,

c is the area-to-volume coefficient, and

V_{frac} is the decimal fraction of the maximum wetland water volume.

The area-to-volume coefficients for the Hamden and Lonetree watershed sites were estimated to equal 0.5 on the basis of survey information obtained by the USGS in 1996 at several wetlands in North Dakota (unpublished data on file at the USGS office, Bismarck, N. Dak.). The large-scale simplification of the average water depth at maximum area and the maximum wetland area was deemed satisfactory for incorporating the concept of wetlands into the model but could lead to inaccuracies about how multiple wetland-catchment areas and storage volumes interact with hydrologic processes.

The average water depth at maximum area and the maximum area of the individual wetlands in each HRU were used for the modeled wetland regardless of whether the individual wetlands were wetlands that had spillways or were wetlands that would never spill. Each modeled wetland was partitioned, by use of a parameter, into an open wetland that had a spillway and a closed wetland that did not spill. The open wetland was defined as having an outlet and a fractional-volume spillage threshold that was equal to a fraction of the maximum water volume of the open wetland. For example, if an open wetland had a spillage threshold of 0.50, water would flow from the wetland when the water volume for that wetland reached 50 percent of the maximum water volume. The closed wetland was defined as not having an outlet; therefore, the closed wetland did not spill. Daily fractional spillage volumes for each open wetland were calculated using a user-defined fraction of

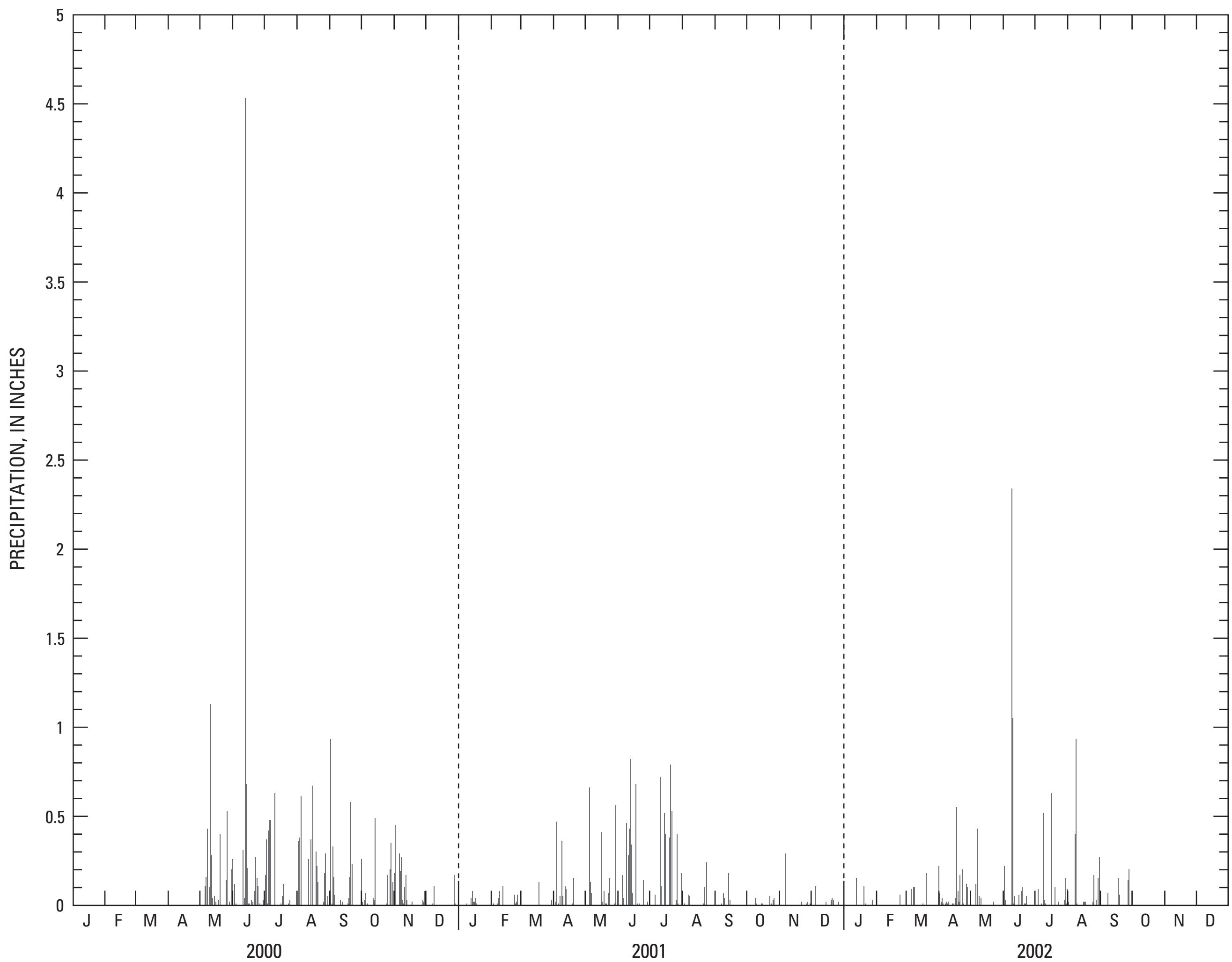

Figure 6. Daily mean precipitation for the Lonetree watershed site, central North Dakota, May 2000 through September 2002.

the difference between the wetland water volume and the wetland water volume at the spillage threshold. Spillage volumes were routed into the streamflow network. Precipitation and evaporation volumes for both the open and closed wetlands were dependent on calculated open-water areas, and seepage volumes were dependent on wetland water depths. Surface runoff for each HRU flowed into both the open and closed wetlands using a user-defined fraction of generated runoff. The remaining runoff entered the streamflow network.

Daily precipitation and snowmelt were partitioned among the soil, wetlands, and stream channels in each HRU. After soil-moisture conditions were met, the remaining water flowed to ground water or to wetlands and stream channels as runoff. The fraction of generated runoff that flowed directly into a wetland was estimated from calibration to be between 60 and 95 percent for the Hamden watershed site and between 90 and 99 percent for the Lonetree watershed site (table 1). The remaining generated runoff for each site flowed directly to stream channels. Evapotranspiration from the soil and the wetlands area was modeled using the Jensen-Haise formulation (Jensen and Haise, 1963).

Model Parameterization

Parameter values for the wetlands hydrologic model were chosen to closely approximate actual conditions in the Hamden and Lonetree watershed sites. Most values associated with surface features and weather conditions were determined from information derived from weather data, field observations, and soil-survey publications. Values associated with physics-based processes, such as snowmelt, infiltration, and radiation transfer, were obtained from the default parameter lists of previous versions of the PRMS. Each HRU was parameterized to reflect the occurrence of the wetland to be modeled for that HRU. At the Hamden watershed site, HRU 1 was parameterized to include Bisson Lake, and at the Lonetree watershed site, HRU 6 was parameterized to include wetland 1. Selected parameter values

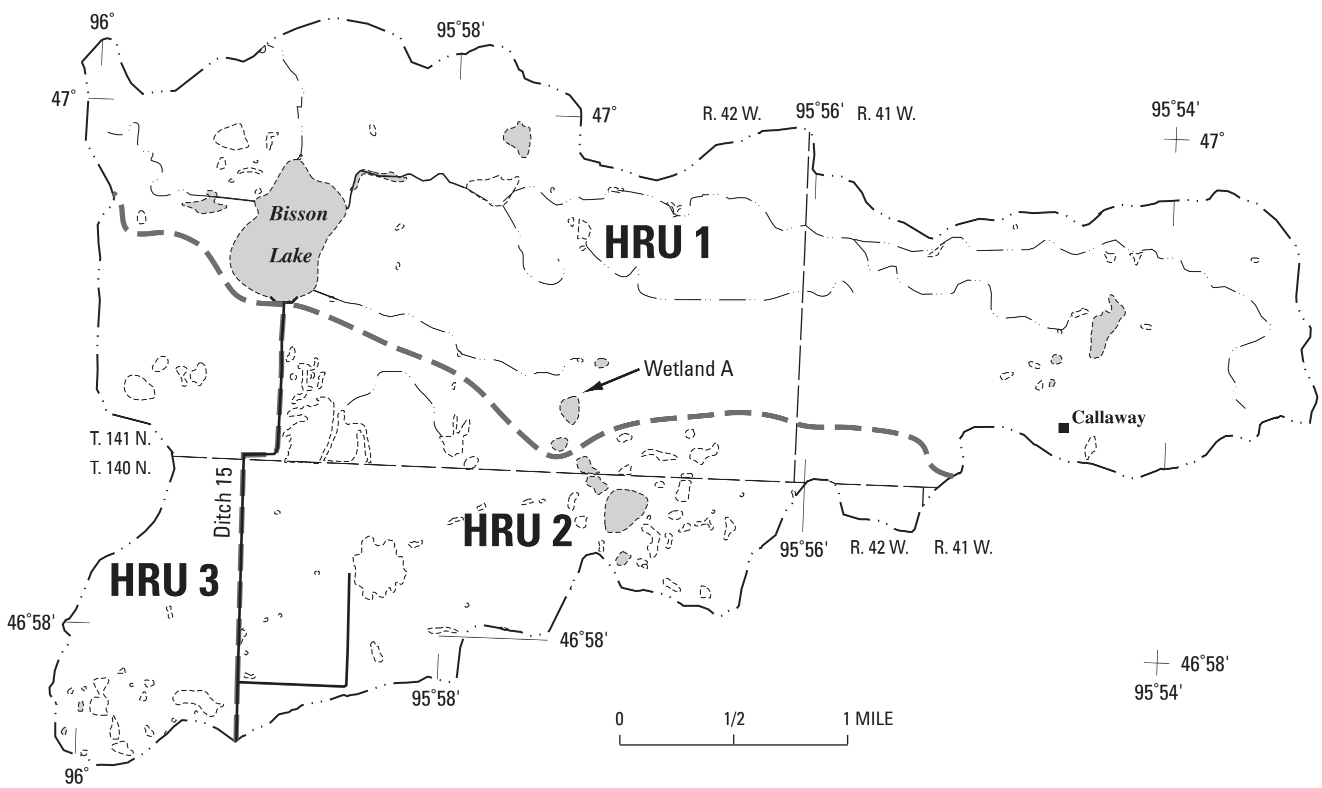

Figure 7. Hydrologic response units (HRUs) in the Hamden watershed site, west-central Minnesota. (The hydrologic response units were derived from topographic analysis.)

for the Hamden and Lonetree watershed sites are given in table 1.

Several assumptions about watershed and wetland processes were made from field observations, field measurements, and topographic information before the HRUs were parameterized. The percentage of open wetlands was estimated to be from 90 to 99 percent for the Hamden watershed site and from 15 to 99 percent for the Lonetree watershed site. The estimated average wetland water depths at maximum wetland area ranged from about 3 to 4.5 feet. Daily wetland seepage rates were assumed to equal 1 percent of the current wetland water depth (Winter and Rosenberry, 1995). Assumptions were made that the open wetlands in the Hamden watershed site had spillage thresholds of about 1 to 25 percent of the maximum wetland water volumes and that the open wetlands in the Lonetree watershed site had spillage thresholds of about 47 to 90 percent of the maximum wetland water volumes. The initial wetland water volume was assumed to be about 5 percent of the maximum wetland water volume for the Hamden watershed site and 55 percent of the maximum wetland water volume for the Lonetree watershed site. The initial wetland areas, wetland water volumes, and soil water volumes calculated on the basis of these assumptions are given in table 2.

The initial wetland area for each HRU (table 2) was calculated by multiplying the maximum wetland area for the HRU (table 1) by the decimal fraction of the maximum wetland area (A_{frac} in eq. 1). The decimal fraction of the maximum wetland area was obtained by setting the decimal fraction of the maximum wetland water volume (V_{frac} in eq. 1) equal to 0.05 (5 percent of the maximum wetland water volume) and the area-to-volume coefficient (c in eq. 1) equal to 0.5. For example, to calculate the initial wetland area for HRU 1 in the Hamden watershed site, the maximum wetland area (298 acres) was multiplied by the decimal fraction of the maximum wetland area (0.224). Thus, the initial wetland area for HRU 1 was 67 acres (298 acres times 0.224). The maximum wetland water volume (1,192 acre-feet) was determined by multiplying the maximum wetland area (298 acres) by the average wetland water depth at maximum wetland area (4 feet; table 1). The initial wetland water volume for each HRU (table 2) was calculated by multiplying the maximum wetland water volume for the HRU by the decimal fraction of the maximum wetland water

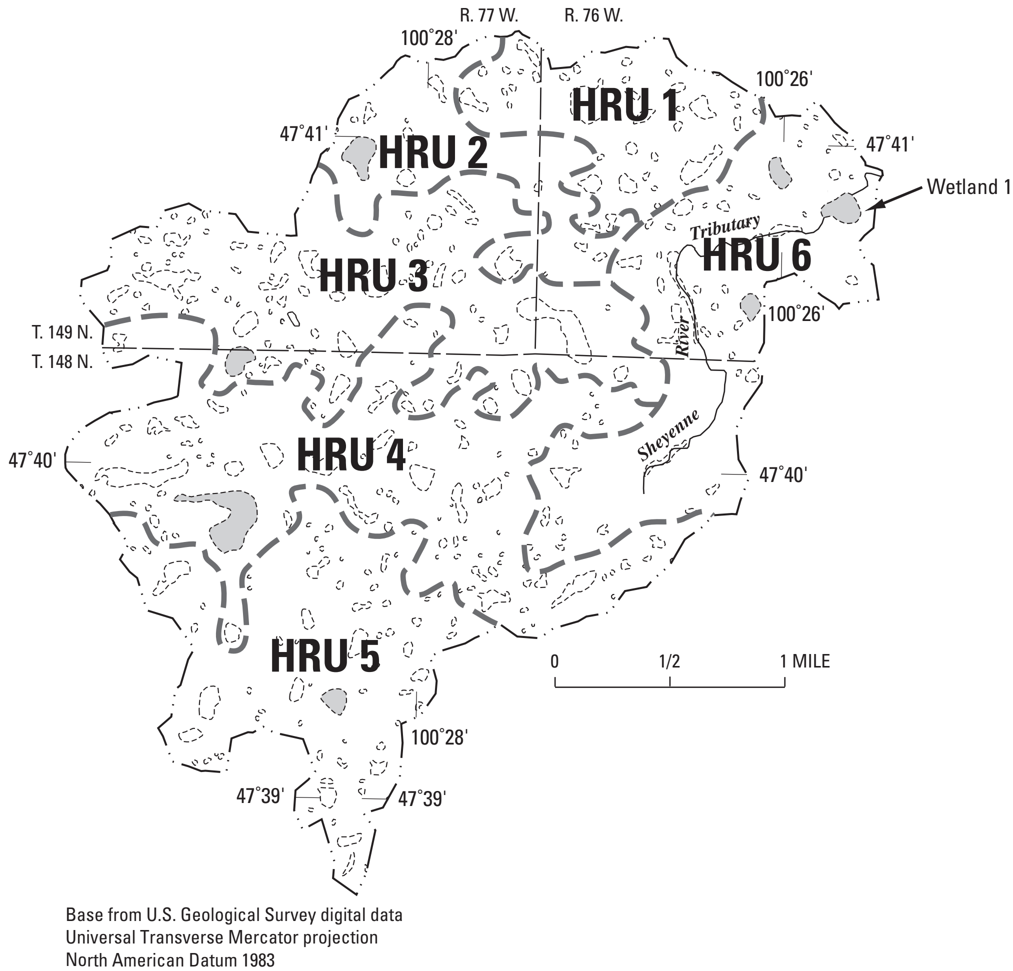

Figure 8. Hydrologic response units (HRUs) in the Lonetree watershed site, central North Dakota. (The hydrologic response units were derived from topographic analysis.)

volume (V_{frac} in eq. 1). Thus, because the decimal fraction of the maximum wetland water volume was set equal to 0.05, the initial wetland water volume was 60 acre-feet (table 2). The initial soil water volume for each HRU was determined by multiplying the initial soil area, in acres, by the initial soil moisture, in inches, and then dividing by 12 to obtain the appropriate units.

Model Calibration

Model runs were made on a daily time step for the period of record for each site. The periods of record were May 1999 through September 2002 for the Hamden watershed site and May 2000 through September 2002 for the Lonetree watershed site. The wetlands hydrologic model was calibrated to measured streamflows for the Hamden and Lonetree watershed sites and to measured water volumes for Bisson Lake in the Hamden watershed site and wetland 1 in the Lonetree watershed site.

The model was calibrated for streamflow by adjusting the values and coefficients for the soil water-holding capacity, the open wetland fractional-volume spillage threshold, the open wetland daily fractional spillage volume, and the area contributing to streamflow until the total simulated runoff for the period of record for the site nearly equaled the total measured runoff. Precipitation from snowfall was multiplied by an adjustment factor of 1.3 because actual snowfall on a basin can be as much as 20 to 90 percent greater than snow catch by precipitation gages (Yang and others, 1995). The amount of recalibration needed for the wetland water volumes generally was minimal and usually involved slight adjustments to the open wetland fractional-volume spillage thresholds and the open wetland daily fractional spillage volumes. After the model was calibrated for streamflow and wetland water volumes, another run was made to compare the total simulated runoff and the total measured runoff. Additional adjustments were made to the model until the simulated values showed no further improvement. The measured and simulated monthly runoff values for

Table 1. Selected parameter values for the wetlands hydrologic model.

[HRU, hydrologic response unit]

HRU number (see figures 7 and 8)	HRU area (acres)	Maximum wetland area (acres)	Percent of open wetlands	Average wetland water depth at maximum wetland area (feet)	Open wetland fractional-volume spillage threshold	Open wetland daily fractional spillage volume	Fraction of generated runoff that enters wetland	Maximum available soil water (inches)
Hamden watershed site								
1	3,725	298	99	4	0.009	0.20	0.95	7.5
2	1,740	191	90	3	.250	.05	.60	7.5
3	865	95	90	3	.250	.05	.60	7.5
Lonetree watershed site								
1	409	123	15	3	0.900	0.01	0.90	6.8
2	371	19	15	3	.900	.01	.90	6.8
3	930	93	15	3	.900	.01	.90	6.8
4	1,170	117	15	3	.900	.01	.90	6.8
5	848	85	15	3	.900	.01	.90	6.8
6	905	18	99	4.5	.470	.38	.99	7.0

the Hamden and Lonetree watershed sites and the monthly mean absolute differences between the measured and simulated values are given in table 3. The monthly mean absolute differences were calculated using equation 2,

$$\frac{\Sigma|s-m|}{n}, \qquad (2)$$

where

s is the simulated daily runoff, in inches;
m is the measured daily runoff, in inches; and
n is the number of days in the month.

The measured and simulated daily mean streamflows for the Hamden watershed site are shown in figure 9. Although the two traces are similar, differences in the timing of spring runoff from snowmelt occurred in March 2000 and March 2001 when the slow melt of ice in Ditch 15 delayed runoff from the site. Another difference occurred for a 32-day period from mid-June 2000 to mid-July 2000 following a large rainfall event. The measured peak streamflow for the 32-day period was about 54 cubic feet per second, but the simulated peak streamflow was about 105 cubic feet per second. The slower responses for the measured streamflows were caused partly by backwater conditions that occurred near the outlet gage. In many rivers within the Red River Basin, annual peak streamflows are caused by snowmelt events rather than rainfall events. Snowmelt events usually are widespread, and runoff from many small watersheds often accumulates and causes flooding at downstream locations. However, large rainfall events often are localized, and runoff may occur simultaneously from a few small watersheds; thus, the chance of major flooding at downstream locations may be reduced. The runoff values for the 32-day period from mid-June 2000 to mid-July 2000 were similar. The total measured runoff value was 2.69 inches, and the total simulated runoff value was 2.08 inches.

The measured and simulated daily mean water volumes for Bisson Lake during periods when data were collected are shown in figure 10. The simulated water volumes closely follow the measured water volumes for 1999 and 2000 but are substantially underestimated for 2001 and 2002. The parameter value for the Bisson Lake spillage threshold initially was set to 0.009, and nearly all water that entered Bisson Lake was allowed to discharge downstream. However, beginning in April 2001, the weir on Bisson Lake was operated to impound about 110 acre-feet of water, and the lake was drawn down during the winter. Therefore, to simulate the weir impoundment of about 110 acre-feet of water during 2001 and 2002, the parameter value for the Bisson Lake spillage threshold was set to 0.09 and the model was recalibrated. The measured and simulated water volumes obtained with the adjusted spillage threshold are in good agreement (fig. 11).

Table 2. Initial wetland and soil water volumes for the wetlands hydrologic model.

[Because values were rounded, calculations may not be exact; HRU, hydrologic response unit]

HRU number (see figures 7 and 8)	Initial wetland area (acres)	Initial wetland water volume (acre-feet)	Initial soil area (acres)	Initial soil moisture (inches)	Initial soil water volume (acre-feet)
Hamden watershed site (initial wetland water volume was assumed to be 5 percent of maximum)					
1	67	60	3,658	5.5	1,677
2	42	29	1,698	5.0	708
3	21	14	844	5.0	352
Total water volume		103			2,737
Lonetree watershed site (initial wetland water volume was assumed to be 55 percent of maximum)					
1	91	203	318	4.85	129
2	14	31	357	4.85	144
3	69	153	861	4.85	348
4	87	193	1,083	4.85	438
5	63	140	785	4.85	317
6	13	45	892	6.5	483
Total water volume		765			1,859

The measured and simulated daily mean streamflows for the Lonetree watershed site are shown in figure 12. The two traces are similar, especially during 2000 when several substantial rainfalls produced runoff. The measured and simulated peak streamflows for June 2000 were about 15 and 17 cubic feet per second, respectively. During most of 2001 and 2002, little runoff was produced because of small amounts of rainfall and overall dry conditions during that time. However, a peak streamflow of about 5 cubic feet per second occurred in June 2002 as a result of a substantial rainfall event (fig. 6) and partial removal of the beaver dam in the Sheyenne River Tributary downstream from wetland 1. The presence of the beaver dam may have caused some reduction in measured streamflow at the outlet gage. The effect of the beaver dam on wetland water volumes is shown in figure 13. The two traces correspond well during 2000 but differ during 2001 and 2002 when the dam was present. The two traces again correspond well in late June 2002 after the dam was removed.

Simulated daily mean water volumes for the soil, wetlands, and Bisson Lake in the Hamden watershed site are shown in figure 14. The simulations show that the soil stored more than 50 percent of the water at the site throughout the period of record. If all wetlands in the Hamden watershed site are restored to their total water volume, as calculated from table 1, wetland storage for the site would be about 2,050 acre-feet, a total that is less than the simulated maximum soil water volume (about 3,600 acre-feet) that occurred in March 2001 (fig. 14). Simulated daily mean water volumes for the soil, wetlands, and wetland 1 in the Lonetree watershed site show that the soil in the upland areas often stored more water than the wetlands throughout the period of record (fig. 15). The total water volume for the Lonetree watershed site, as calculated from table 1, is about 1,390 acre-feet, a total that is less than the simulated maximum soil water volume (about 2,350 acre-feet) that occurred in June 2000. During 2000 and 2001, the soils in the Lonetree watershed site stored less water than the wetlands. The soils in the Lonetree watershed site contain more sand than the soils in the Hamden watershed site and, therefore, store less water than the soils in the Hamden watershed site. Soil-management practices that improve soil structure possibly could increase the soil-water storage capacity at both sites. These practices, along with surface-water storage techniques, may result in reduced water flows from small watersheds during large precipitation and snowmelt events.

Table 3. Measured and simulated runoff, in inches, for the Hamden and Lonetree watershed sites.

Year	Month	Runoff		Monthly mean absolute difference
		Measured	Simulated	
		Hamden watershed site		
1999	May	0.151	1.101	0.0305
1999	June	.636	.304	.0138
1999	July	.608	.477	.0098
1999	August	.211	.350	.0062
1999	September	.556	.458	.0093
1999	October	.107	.182	.0024
1999	November	.012	.017	.0004
1999	December	0	.011	.0004
2000	January	0	.011	.0004
2000	February	0	.062	.0019
2000	March	.422	.244	.0177
2000	April	.108	.108	.0021
2000	May	.030	.149	.0038
2000	June	2.128	1.779	.0385
2000	July	.590	.481	.0159
2000	August	0	.194	.0062
2000	September	.099	.551	.0152
2000	October	.174	.242	.0034
2000	November	.975	.586	.0185
2000	December	.003	.053	.0016
2001	January	0	.013	.0003
2001	February	0	.009	.0003
2001	March	0	.640	.0205
2001	April	3.514	1.418	.0761
2001	May	.534	.306	.0086
2001	June	.249	.196	.0036
2001	July	.070	.141	.0036
2001	August	.014	.093	.0024
2001	September	0	.084	.0028
2001	October	0	.198	.0064
2001	November	0	.029	.0008
2001	December	.002	.014	.0003
2002	January	0	.015	.0003
2002	February	0	.047	.0015
2002	March	0	.017	.0003
2002	April	.061	.031	.0023
2002	May	.088	.096	.0018
2002	June	.928	.382	.0208
2002	July	.151	.557	.0136
2002	August	.001	.190	.0061
2002	September	.007	.143	.0046
Total		12.429	11.979	.0091

Table 3. Measured and simulated runoff, in inches, for the Hamden and Lonetree watershed sites.—Continued

Year	Month	Runoff		Monthly mean absolute difference
		Measured	Simulated	
Lonetree watershed site				
2000	May	0.068	0.093	0.0035
2000	June	.354	.418	.0049
2000	July	.153	.144	.0030
2000	August	0	.081	.0026
2000	September	.065	.051	.0015
2000	October	.003	.034	.0010
2000	November	0	.036	.0012
2000	December	0	.024	.0008
2001	January	0	.024	.0008
2001	February	0	.021	.0007
2001	March	.017	.027	.0013
2001	April	.153	.044	.0043
2001	May	.021	.023	.0012
2001	June	.015	.046	.0016
2001	July	.027	.037	.0010
2001	August	.008	.021	.0007
2001	September	0	.017	.0006
2001	October	0	.016	.0005
2001	November	0	.014	.0005
2001	December	0	.014	.0004
2002	January	0	.013	.0004
2002	February	0	.011	.0004
2002	March	.029	.012	.0012
2002	April	.061	.013	.0020
2002	May	.022	.013	.0007
2002	June	.070	.035	.0020
2002	July	.005	.014	.0005
2002	August	.021	.014	.0010
2002	September	0	.012	.0004
Total		1.092	1.322	.0014

Simulation of Runoff and Wetland Storage

Runoff and wetland storage were simulated for the Hamden watershed site by using different Bisson Lake spillage thresholds for the model. Changes in the spillage threshold corresponded to changes in the weir configuration at Bisson Lake. Bisson Lake spillage thresholds were set at 0.20, 0.40, and 0.60 and corresponded to the impoundment of about 240, 480, and 720 acre-feet of water, respectively, in Bisson Lake. Runoff and wetland storage were not simulated for the Lonetree watershed site because of the small area contributing to streamflow and the small capacity of wetland 1.

Runoff simulated for the Hamden watershed site at Bisson Lake spillage thresholds of 0.009, 0.20, 0.40, and 0.60 is given in table 4. Increases in the spillage thresholds resulted in substantial reductions in simulated runoff during the nonwinter months. Total simulated runoff for the period of record was

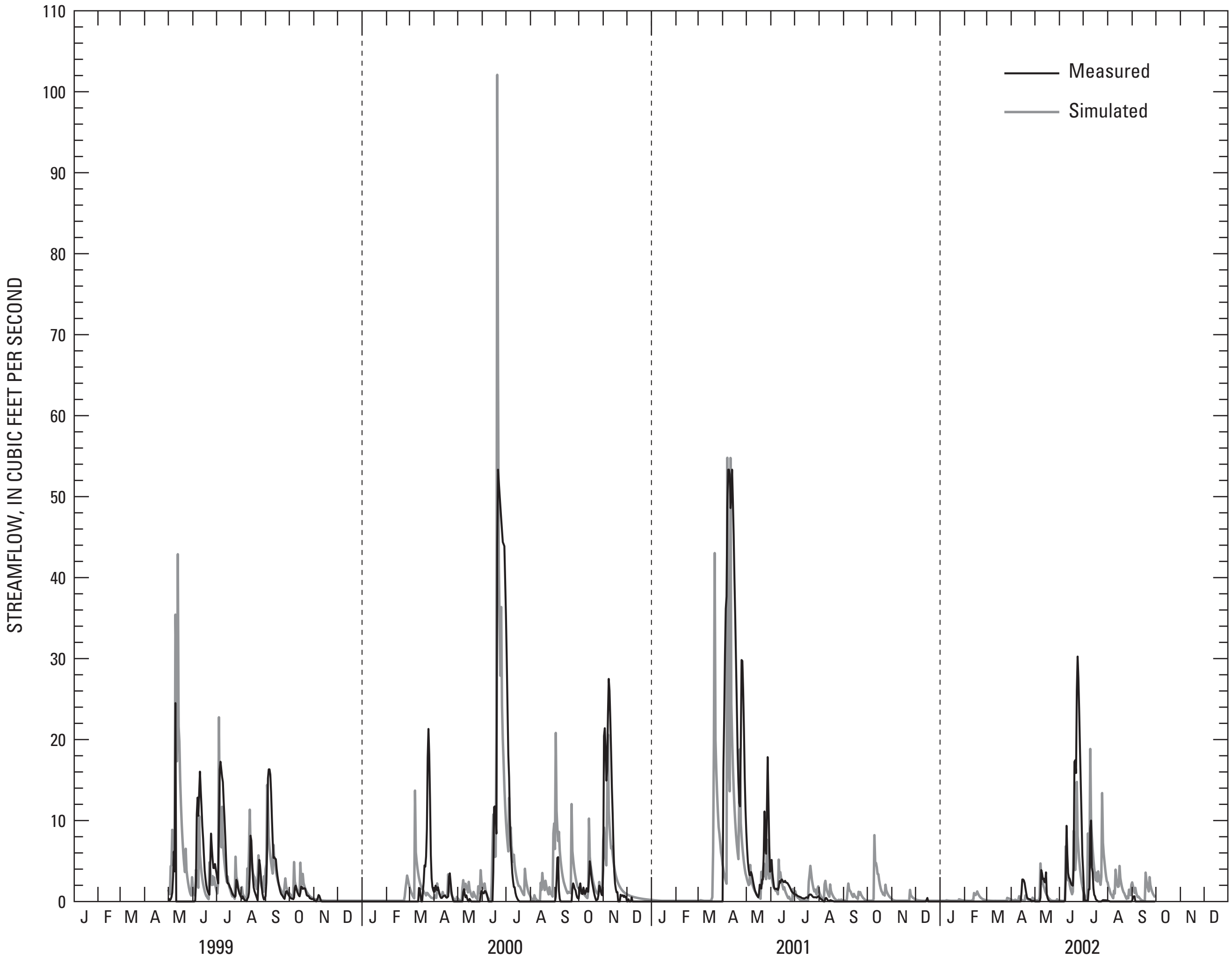

Figure 9. Measured and simulated daily mean streamflows for the Hamden watershed site, west-central Minnesota, May 1999 through September 2002.

reduced about 38 percent by increasing the spillage threshold from 0.009 to 0.60. Much less reduction occurred in June 2000 and April 2001. Rainfall input to the model of about 3 to 4 inches during 3 days in June 2000 caused a simulated rapid filling of Bisson Lake to about 1,070 acre-feet (fig. 16) and resulted in only slight reductions of about 6 percent in simulated runoff (from 1.779 inches at a spillage threshold of 0.009 to 1.670 inches at a spillage threshold of 0.60) (table 4). After June 2000, simulated daily mean water volumes for Bisson Lake decreased as evapotranspiration and seepage removed water from the lake (fig. 16). The additional simulated storage at the larger spillage thresholds led to reductions in simulated runoff for several months following June 2000 (table 4). A similar pattern occurred in April 2001 for a Bisson Lake spillage threshold of 0.60. Simulated daily mean water volumes increased to about 900 acre-feet during a rapid snowmelt that was followed by a rainfall of about 1 to 2 inches (fig. 16). After April 2001, simulated daily mean water volumes for the lake decreased as evapotranspiration and seepage removed water from the lake. The additional simulated storage at the larger spillage thresholds led to reductions in simulated runoff for several months following April 2001 (table 4). During the winter, simulated runoff tended to increase slightly at the larger spillage thresholds because of larger simulated base flows. The larger base flows may have occurred as a result of increased ground-water volumes and, thus, increased ground-water flow to streamflow because of seepage from the larger water volume of Bisson Lake.

Daily mean streamflows simulated for the Hamden watershed site at a Bisson Lake spillage threshold of 0.60 are shown in figure 17. Many of the streamflows that were less than 20 cubic feet per second were less than those simulated for the same day at a Bisson Lake spillage threshold of 0.009 (fig. 9). However, because Bisson Lake was nearly full before the June

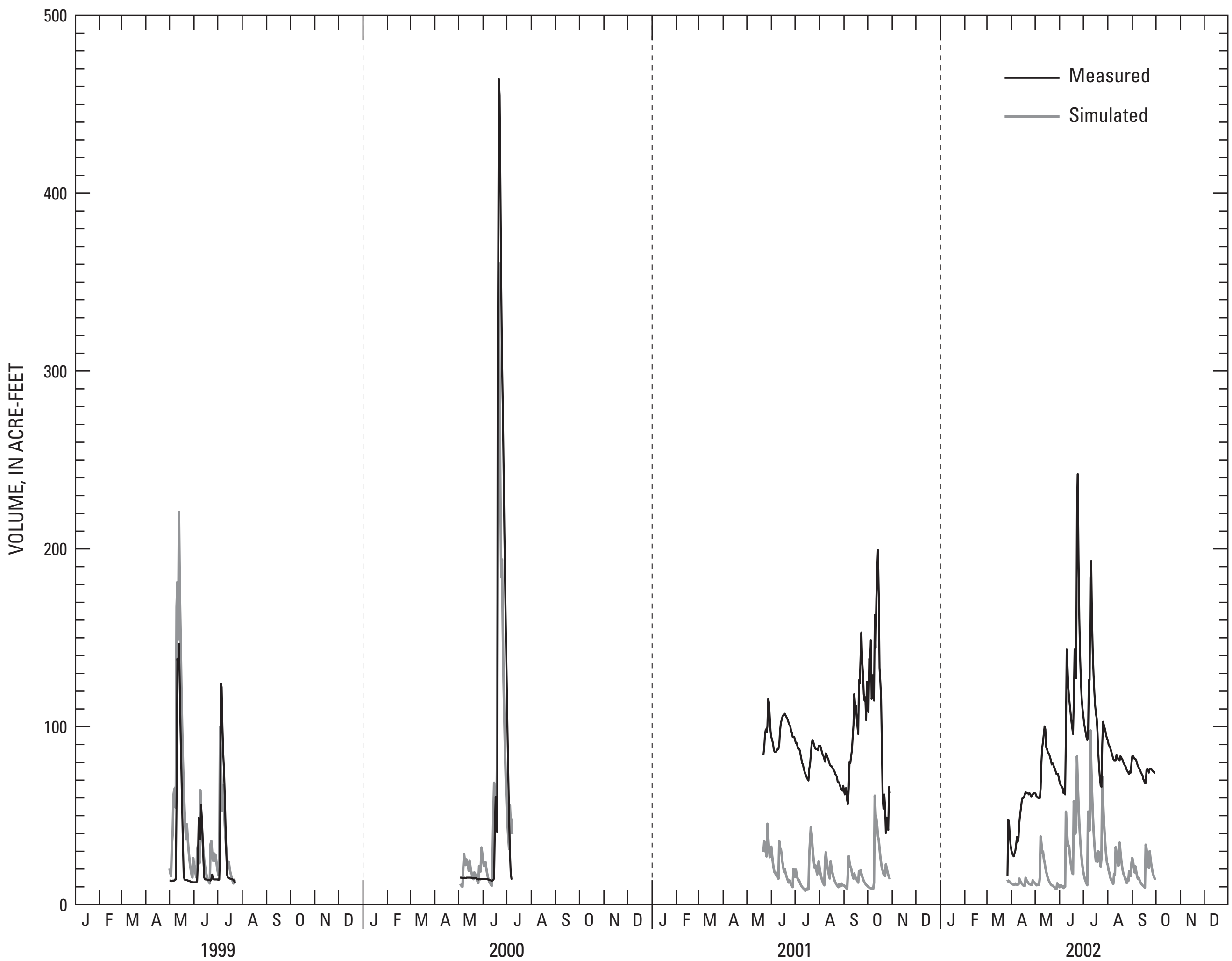

Figure 10. Measured and simulated daily mean water volumes for Bisson Lake in the Hamden watershed site, west-central Minnesota, May 1999 through September 2002.

2000 and April 2001 runoff events (fig. 16), peak streamflows simulated for those months at a spillage threshold of 0.60 (fig. 17) were about the same as those simulated at a spillage threshold of 0.009 (fig. 9). Because less water was released from Bisson Lake at a spillage threshold of 0.60 than at a spillage threshold of 0.009, simulated runoff for June 2000 and April 2001 also was less than at a spillage threshold of 0.009 (table 4). Thus, simulation results indicate total streamflow from a runoff event may be reduced by wetland storage, but peak streamflows during a runoff event may not be affected substantially.

Runoff from the Hamden watershed site during flood conditions and water volumes for Bisson Lake during flood conditions were simulated by substituting January through May 1997 daily temperature and precipitation data for Detroit Lakes, Minn., for the January through May 2000 data for the Hamden watershed site. The substituted data were used to simulate the occurrence of the 1997 flood in the Red River Basin followed by the occurrence of the June 2000 rainfall event at the Hamden watershed site. Flood conditions were not simulated for the Lonetree watershed site.

Simulated daily mean streamflows for the Hamden watershed site during flood conditions at a Bisson Lake spillage threshold of 0.009 are shown in figure 18. For 1999, daily streamflows during flood conditions were the same as those during nonflood conditions (fig. 9) because the data sets were identical. However, beginning in March 2000, peak streamflows were greater during flood conditions than during nonflood conditions (fig. 9) because the 1997 data set was used. The peak streamflows during flood conditions were about 163 cubic feet per second in April 2000 and about 117 cubic feet per second in June 2000 (fig. 18). The daily streamflows

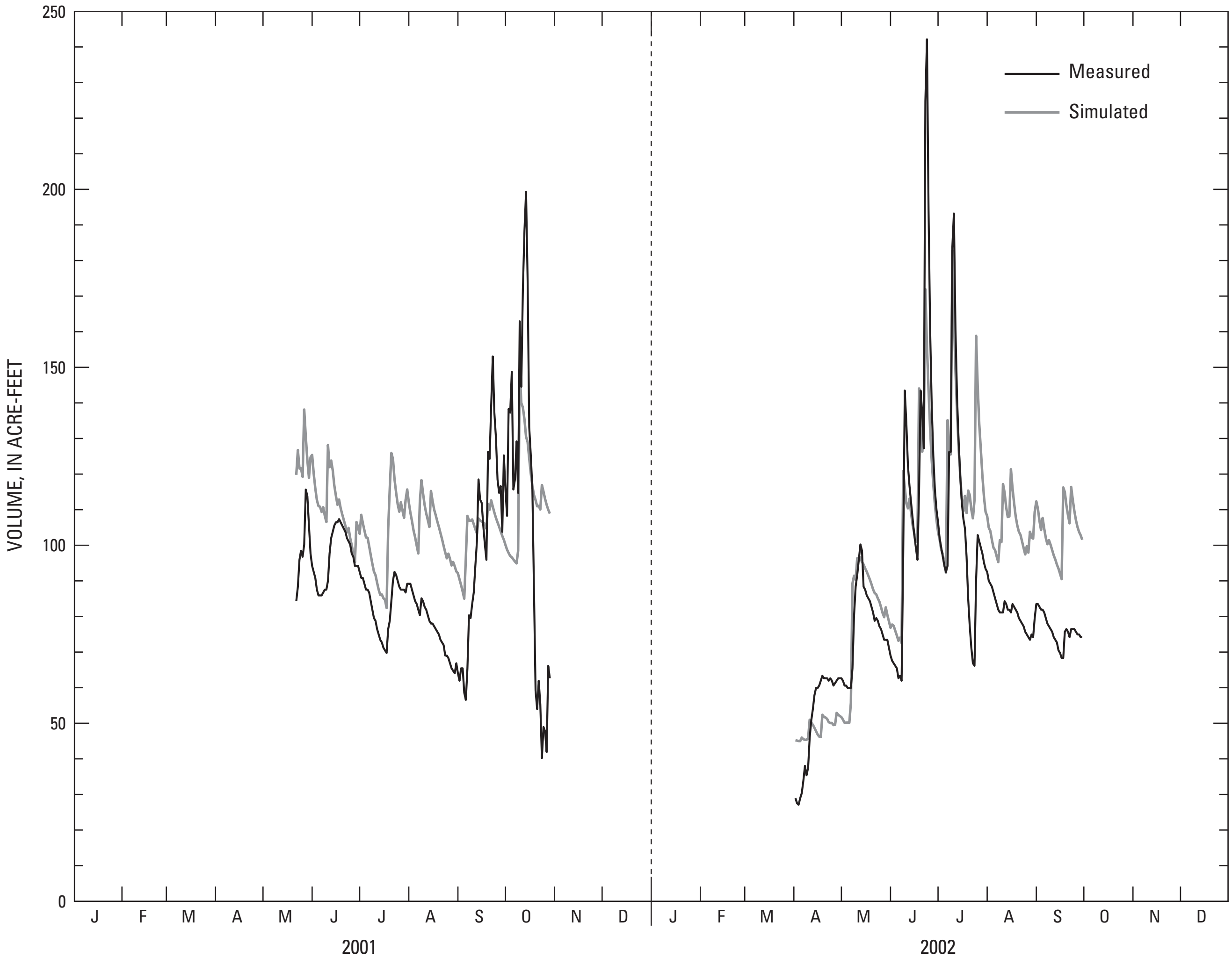

Figure 11. Measured and simulated daily mean water volumes for Bisson Lake in the Hamden watershed site, west-central Minnesota, at a spillage threshold of 0.09, May 2001 through September 2002.

during nonflood conditions were about 13 cubic feet per second in March 2000 and about 103 cubic feet per second in June 2000 (fig. 9). Increasing the Bisson Lake spillage threshold to 0.60 during flood conditions did little to reduce the peak streamflows that occurred during the 2000 and 2001 runoff events. However, streamflows throughout the period of record were smaller at a spillage threshold of 0.60 (fig. 19) than at a spillage threshold of 0.009 (fig. 18).

At a spillage threshold of 0.60 during flood conditions, simulated daily mean water volumes in Bisson Lake generally were about 720 acre-feet (fig. 20). The water volumes were greater only during flood conditions in 2000 and during the large runoff event in 2001. After May 2001, the water volumes were less than 720 acre-feet, indicating additional wetland storage was available. Simulated runoff during flood conditions at spillage thresholds of 0.009 and 0.60 is given in table 5 along with the percentage of reduction in runoff from an increased spillage threshold. Reductions during flood conditions in April and June 2000 and March and April 2001 ranged from 1 to 6 percent for an increased spillage threshold. Reductions for most other spring, summer, and fall months ranged from 18 to 80 percent. During most of the winter, simulated runoff increased at a spillage threshold of 0.60, probably as a result of increased base flow from a full Bisson Lake. Less-than-10-percent reductions in simulated runoff from an increased spillage threshold occurred only for the spring and summer 2000 months that were modeled to simulate the occurrence of the 1997 flood in the Red River Basin and for the spring 2001 months that were modeled to simulate the occurrence of the snowmelt and rainfall event. Total runoff for the period of record was reduced about 31 percent for the increased spillage threshold. Thus, simulation results indicate total streamflow from a flood event may be

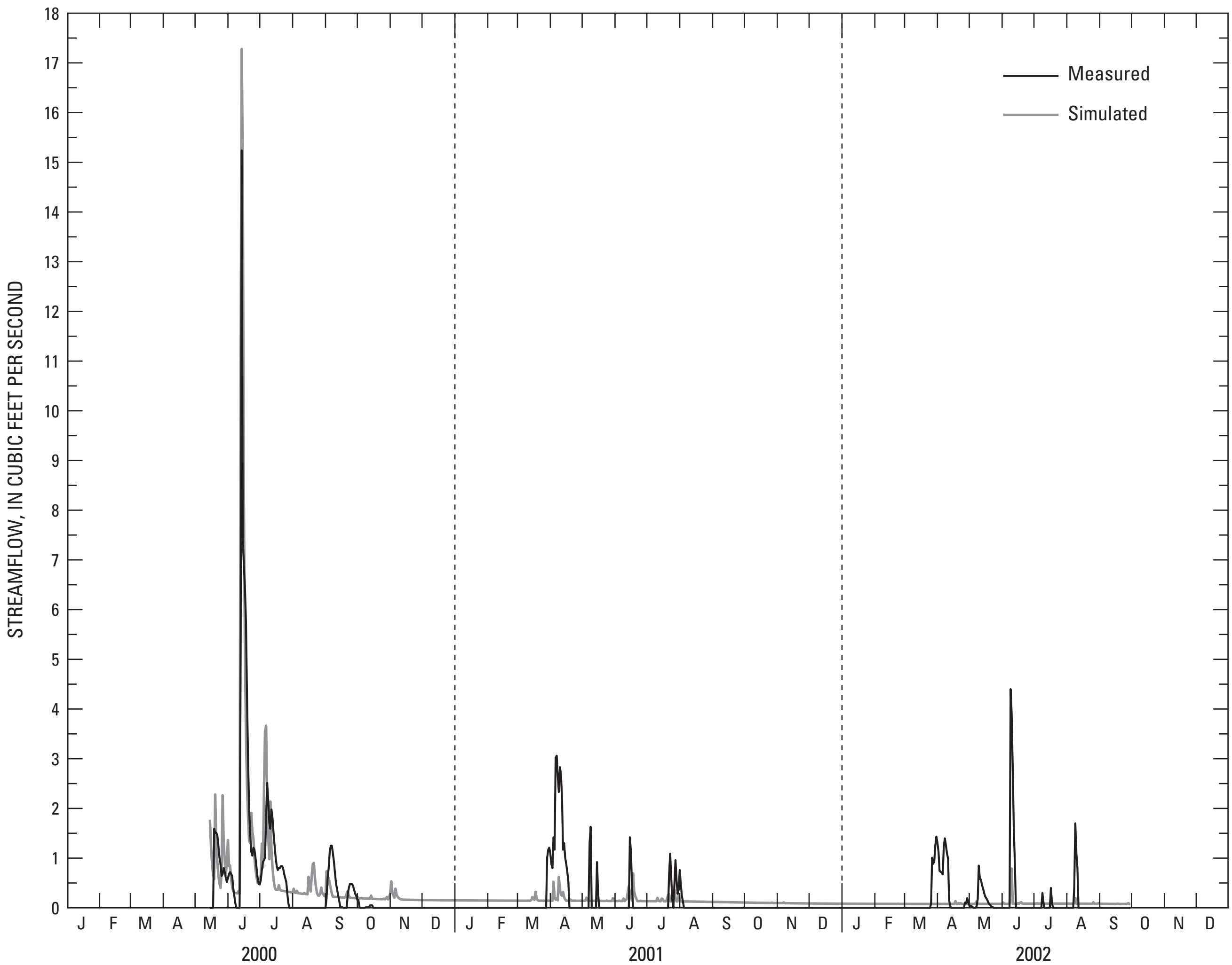

Figure 12. Measured and simulated daily mean streamflows for the Lonetree watershed site, central North Dakota, May 2000 through September 2002.

reduced by wetland storage, but peak streamflows during a flood event may not be affected substantially.

Model Limitations and Considerations

The wetlands hydrologic model used in this study provided reasonable simulations of the streamflows and water volumes for the period of record. Simulated runoff from the Hamden watershed site was affected by backwater conditions near the outlet station, and simulated runoff from both the Hamden and Lonetree watershed sites probably was affected by the large variations in precipitation within the watershed. Also, the lack of a frozen-soil subroutine in the model probably inhibited the accurate simulation of snowmelt runoff because of the model-building assumption that limited snowmelt infiltration occurs during the spring snowmelt season. However, many of the parameters related to wetlands hydrology were reasonable approximations of the physical features even without a quantitative representation of those features in the model.

More work is needed to improve the wetlands hydrologic model. The wetlands subroutines in the model could be modified to include more than one wetland per HRU and to include a variable spillage threshold to simulate weirs or dams. Incorporation of additional variables to address the complex physical features of wetlands hydrology, such as ground-water/surface-water interaction and wetland basin snow catch, and incorporation of a frozen-soil subroutine likely would improve the capabilities of the model. Additional precipitation and runoff data for the Hamden and Lonetree watershed sites, especially for flood or near-flood conditions, would improve the data sets used to run the model and improve the understanding of the effects of wetland storage on runoff from small watersheds.

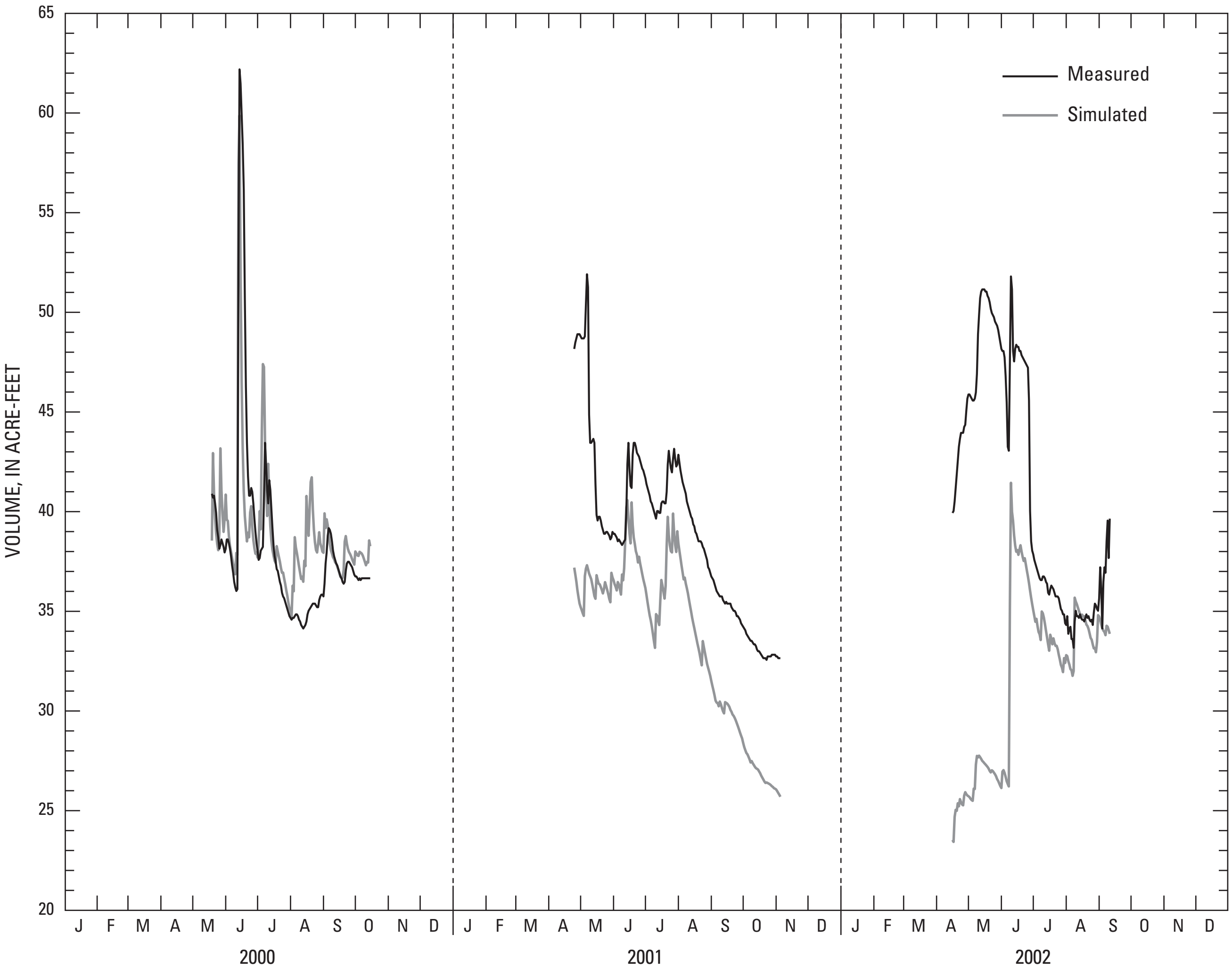

Figure 13. Measured and simulated daily mean water volumes for wetland 1 in the Lonetree watershed site, central North Dakota, May 2000 through September 2002.

Summary

Re-establishment of wetlands has been promoted by various groups to control future floods in the Red River of the North (Red River) Basin in North Dakota and Minnesota. Therefore, a study was conducted by the U.S. Geological Survey in cooperation with the Minnesota Department of Natural Resources, the North Dakota State Water Commission, the Red River Joint Water Resource Board, the Red River Watershed Management Board, and the U.S. Fish and Wildlife Service to simulate runoff and wetland storage for two small watersheds in the basin. Information from the study may be useful to water-resource managers and researchers associated with watershed-runoff and wetland-storage issues.

For this study, a small watershed site, called the Hamden watershed site, was established in west-central Minnesota, and another small watershed site, called the Lonetree watershed site, was established in central North Dakota. These sites were selected because they contained a variety of wetland types and because they represented extremes of physiographic and climatic regions in the Red River Basin. Water-level gaging stations were established at each site. Weather stations that measured precipitation, air temperature, humidity, and solar radiation also were installed at or near each site. Streamflow for the major drainages was measured periodically at both sites using established U.S. Geological Survey techniques. Landscape surveys were conducted at both sites to provide detailed elevation information about surface features and wetlands at the sites and to establish hydrologic response parameters that were used to develop the hydrologic model used in the study. Changes in wetlands water volumes and wetlands areas also were determined from the surveys. Other information derived from topographic maps, digital-elevation models, and the geo-

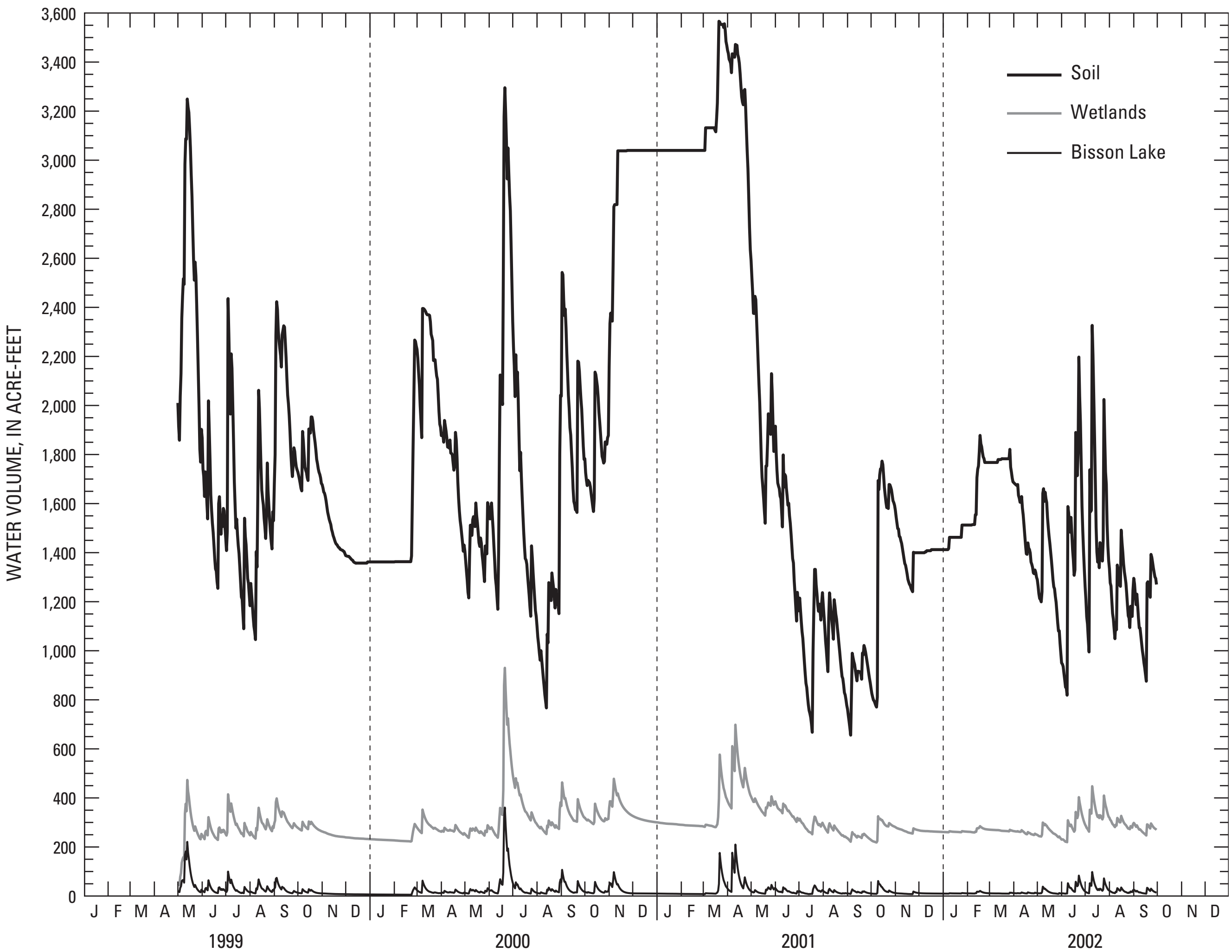

Figure 14. Simulated daily mean water volumes for the soil, wetlands, and Bisson Lake in the Hamden watershed site, west-central Minnesota, May 1999 through September 2002. (The Bisson Lake spillage threshold was 0.009.)

graphic information system (GIS) were used to determine topographic and hydrologic parameters for each site.

A wetlands hydrologic model, which is a modified version of the U.S. Geological Survey Precipitation-Runoff Modeling System, was developed to simulate runoff and wetland storage for the Hamden and Lonetree watershed sites. The wetlands hydrologic model is a distributed-parameter model that uses physics-based mathematical relations to represent the hydrology of an area. Streamflow generated by the model during the daily time step leaves the modeled area by the next time step. For this study, data from the GIS analyses, collected weather data, additional historic weather data, and geomorphology were used in the model to simulate precipitation accumulation, snowmelt, evapotranspiration, soil infiltration, seepage to ground water, surface runoff, and streamflow. The Hamden and Lonetree watershed sites were partitioned into hydrologic response units (HRUs) on the basis of characteristics such as slope, aspect, elevation, soil type, and vegetation type so that each unit had a homogeneous response to weather and hydrologic inputs. The Hamden watershed site was partitioned into three HRUs, and the Lonetree watershed site was partitioned into six HRUs. Because of the complexities of including each individual wetland in the model, all wetlands within each HRU were modeled as one wetland. Thus, three wetlands were modeled for the Hamden watershed site, and six wetlands were modeled for the Lonetree watershed site.

The average water depth at maximum area and the maximum area of the individual wetlands in each HRU were used for the modeled wetland regardless of whether the individual wetlands were wetlands that had spillways or were wetlands that would never spill. Open wetlands were defined as having an outlet and a fractional-volume spillage threshold that was equal

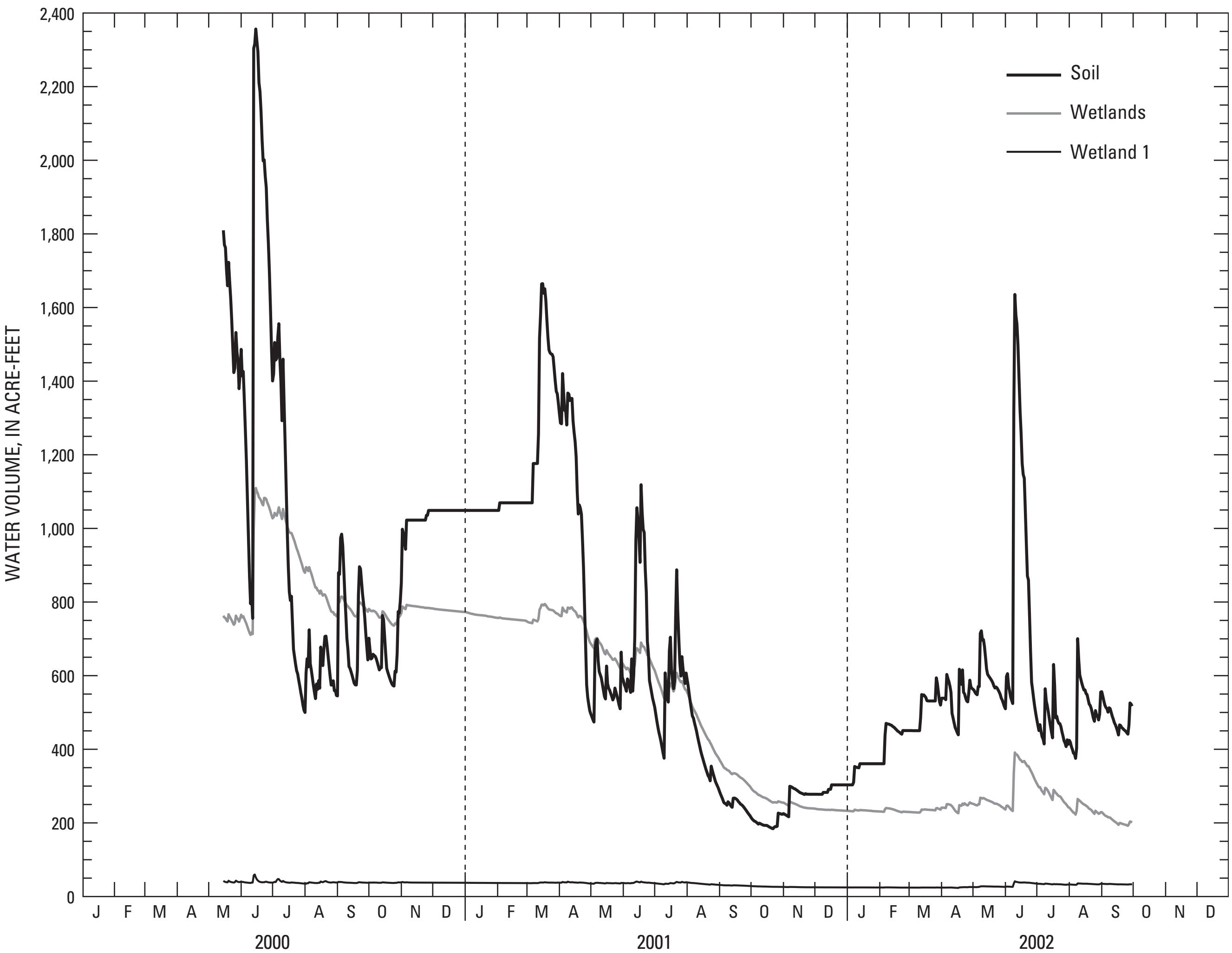

Figure 15. Simulated daily mean water volumes for the soil, wetlands, and wetland 1 in the Lonetree watershed site, central North Dakota, May 2000 through September 2002. (The wetland 1 spillage threshold was 0.47.)

to a fraction of the maximum water volume of the open wetland. Closed wetlands were defined as not having an outlet; therefore, the closed wetlands did not spill. Precipitation and evaporation volumes for both the open and closed wetlands were dependent on calculated open-water areas, and seepage volumes were dependent on wetland water depths. Surface runoff flowed into both the open and closed wetlands using a user-defined fraction of generated runoff. The remaining runoff entered the streamflow network.

Model runs were made on a daily time step for the period of record for each site. The periods of record were May 1999 through September 2002 for the Hamden watershed site and May 2000 through September 2002 for the Lonetree watershed site. The measured and simulated daily mean streamflows for the Hamden watershed site were similar although differences in the timing of spring runoff from snowmelt occurred in March 2000 and March 2001 when the slow melt of ice in a drainage ditch delayed runoff from the site. Another difference occurred from mid-June 2000 to mid-July 2000 following a large rainfall event. The total measured runoff value for mid-June 2000 to mid-July 2000 was 2.69 inches, and the total simulated runoff value for mid-June 2000 to mid-July 2000 was 2.08 inches.

The measured and simulated daily mean water volumes for Bisson Lake were similar for 1999 and 2000. However, the simulated water volumes were substantially underestimated for 2001 and 2002 when the weir on Bisson Lake was operated. Therefore, to simulate the weir impoundment, the parameter value for the Bisson Lake spillage threshold was adjusted and the model was recalibrated. The measured and simulated water volumes obtained with the adjusted spillage threshold were in good agreement.

Table 4. Simulated runoff, in inches, for the Hamden watershed site at varying Bisson Lake spillage thresholds.

Year	Month	Spillage threshold			
		0.009	**0.20**	**0.40**	**0.60**
1999	May	1.101	0.682	0.242	0.230
	June	.304	.208	.127	.076
	July	.477	.382	.343	.178
	August	.350	.251	.177	.123
	September	.458	.414	.394	.208
	October	.182	.156	.140	.101
	November	.017	.019	.021	.022
	December	.011	.014	.016	.017
2000	January	.011	.014	.016	.017
	February	.062	.029	.020	.021
	March	.244	.204	.176	.140
	April	.108	.077	.060	.050
	May	.149	.077	.043	.039
	June	1.779	1.753	1.719	1.670
	July	.481	.406	.385	.371
	August	.194	.091	.063	.056
	September	.551	.495	.418	.341
	October	.242	.209	.192	.177
	November	.586	.580	.585	.585
	December	.053	.057	.059	.061
2001	January	.013	.017	.020	.022
	February	.009	.013	.015	.017
	March	.640	.613	.621	.619
	April	1.418	1.400	1.390	1.381
	May	.306	.246	.210	.187
	June	.196	.136	.111	.096
	July	.141	.026	.029	.031
	August	.093	.023	.025	.027
	September	.084	.020	.022	.024
	October	.198	.119	.038	.040
	November	.029	.018	.020	.022
	December	.014	.016	.018	.020
2002	January	.015	.016	.018	.020
	February	.047	.016	.017	.018
	March	.017	.015	.017	.019
	April	.031	.016	.018	.019
	May	.096	.047	.024	.026
	June	.382	.266	.112	.092
	July	.557	.445	.352	.187
	August	.190	.103	.074	.071
	September	.143	.063	.032	.034
Total runoff		11.979	9.752	8.379	7.455

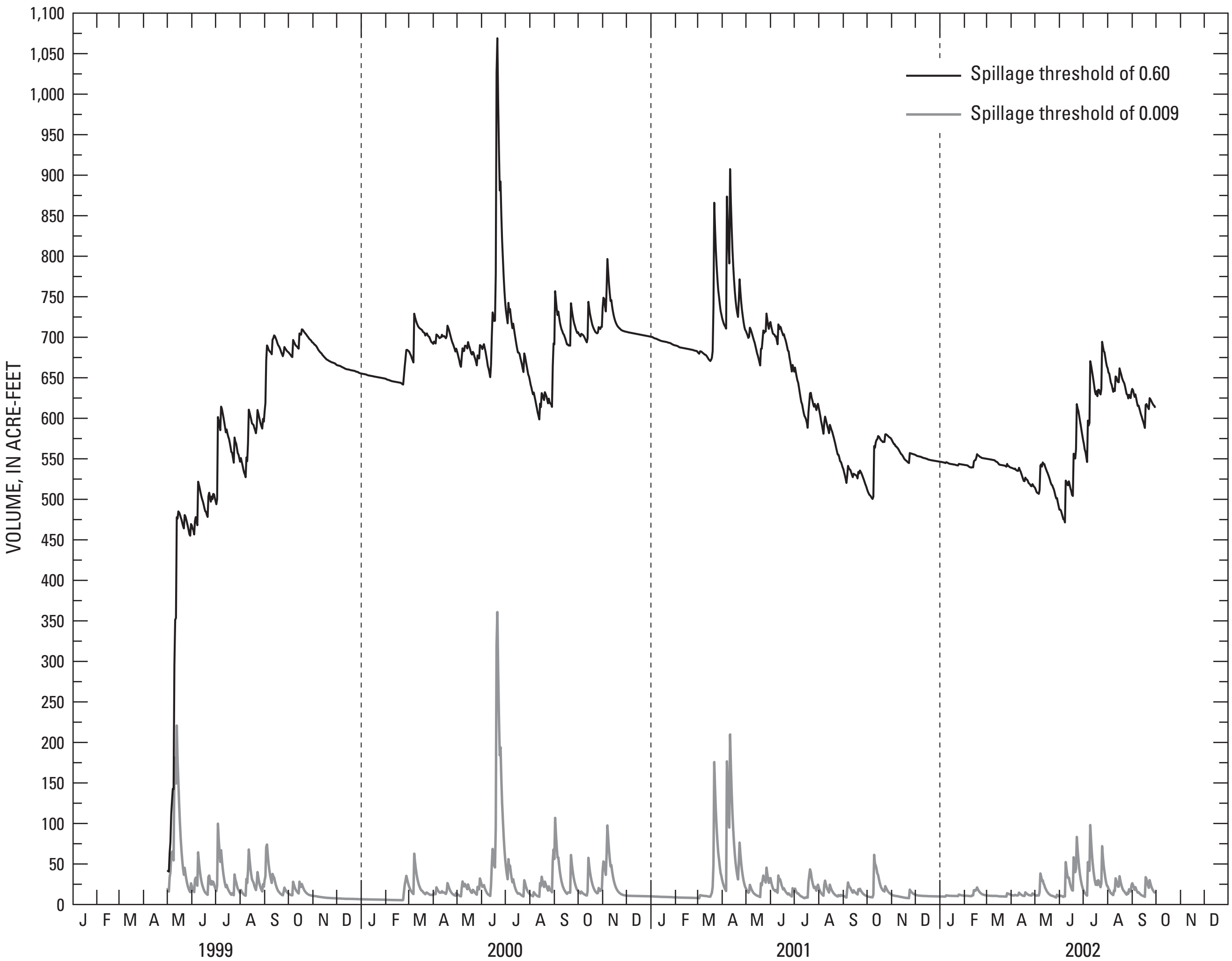

Figure 16. Simulated daily mean water volumes for Bisson Lake in the Hamden watershed site, west-central Minnesota, at spillage thresholds of 0.009 and 0.60, May 1999 through September 2002.

The measured and simulated daily mean streamflows for the Lonetree watershed site were similar, especially during 2000 when several substantial rainfalls produced runoff. The measured and simulated peak streamflows for June 2000 were about 15 and 17 cubic feet per second, respectively. A peak streamflow of about 5 cubic feet per second occurred in June 2002 as a result of a substantial rainfall event and partial removal of a beaver dam in the Sheyenne River Tributary downstream from wetland 1. The presence of the beaver dam may have caused some reduction in measured streamflow at the outlet gage. The measured and simulated water volumes corresponded well after removal of the dam in late June 2002.

Simulated daily mean water volumes for the soil and wetlands in the Hamden and Lonetree watershed sites showed that the soils of the two sites stored as much water as the wetlands throughout most of the simulation period. During 2000 and 2001, the soils in the Lonetree watershed site stored less water than the wetlands. Soil-management practices that improve soil structure possibly could increase the soil-water storage capacity at both sites. These practices, along with surface-water storage techniques, may result in reduced water flows from small watersheds during large precipitation and snowmelt events.

Total simulated runoff for the Hamden watershed site for the period of record was reduced about 38 percent by increasing the Bisson Lake spillage threshold from 0.009 to 0.60. The additional simulated storage at the larger spillage threshold led to reductions in simulated runoff. Simulated daily mean streamflows for the Hamden watershed site at a Bisson Lake spillage threshold of 0.60 were less than those simulated for the same day at a Bisson Lake spillage threshold of 0.009. However, the peak streamflows simulated for June 2000 and April 2001 at a spillage threshold of 0.60 were about the same as those simu-

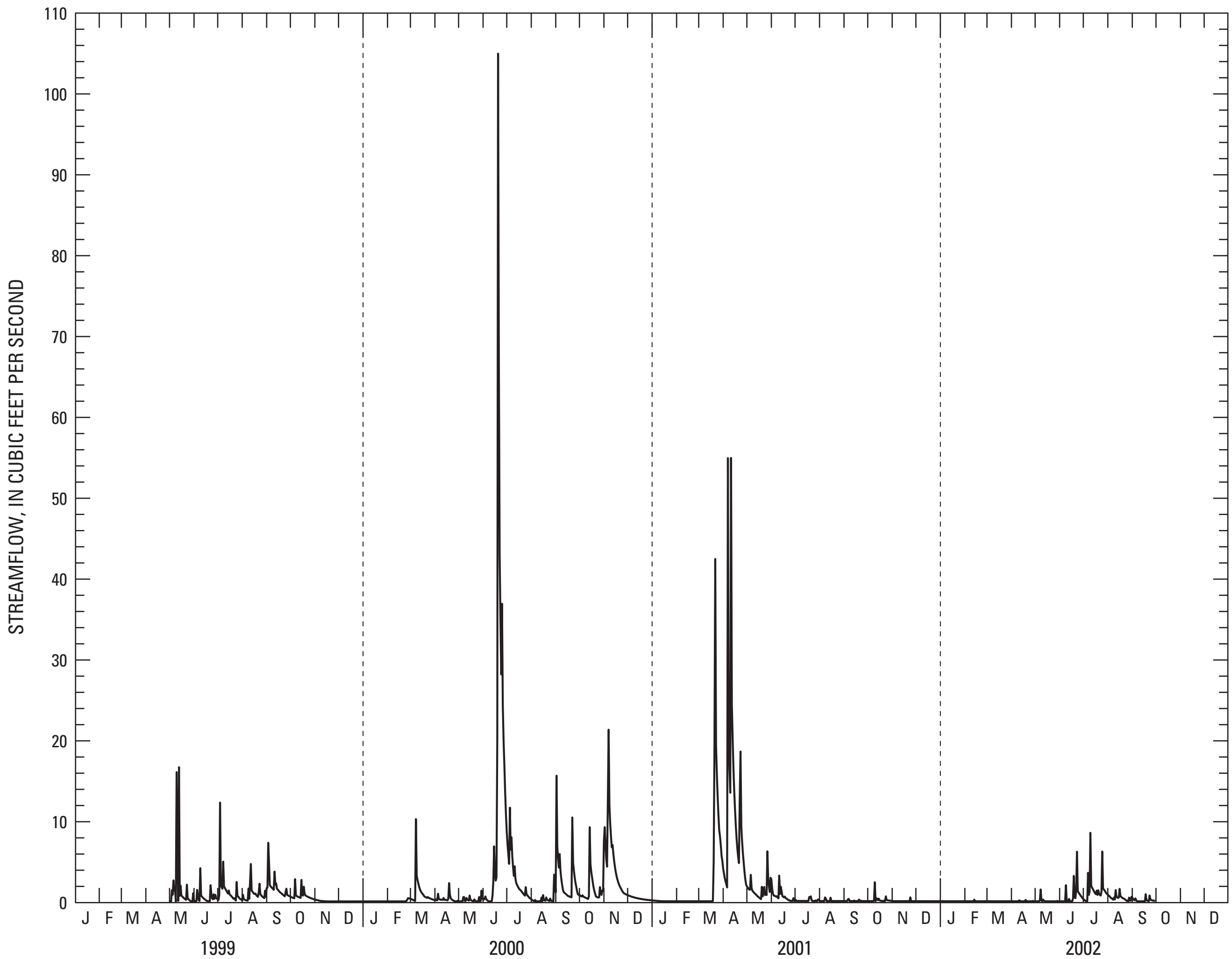

Figure 17. Simulated daily mean streamflows for the Hamden watershed site, west-central Minnesota, at a Bisson Lake spillage threshold of 0.60, May 1999 through September 2002.

lated at a spillage threshold of 0.009. Thus, simulation results indicate total streamflow from a runoff event may be reduced by wetland storage, but peak streamflows during a runoff event may not be affected substantially.

Runoff from the Hamden watershed site during flood conditions and water volumes for Bisson Lake during flood conditions were simulated by substituting January through May 1997 daily temperature and precipitation data for Detroit Lakes, Minn., for the January through May 2000 data for the Hamden watershed data set. The substituted data were used to simulate the occurrence of the 1997 flood in the Red River Basin followed by the occurrence of the June 2000 rainfall event at the Hamden watershed site.

Peak streamflows during flood conditions were about 163 cubic feet per second in April 2000 and about 117 cubic feet per second in June 2000. Daily streamflows during non-flood conditions were about 13 cubic feet per second in March 2000 and about 103 cubic feet per second in June 2000. Simulated runoff during flood conditions in April and June 2000 and March and April 2001 was reduced 1 to 6 percent for an increased spillage threshold. Reductions for most other spring, summer, and fall months ranged from 18 to 80 percent. Total runoff for the period of record was reduced about 31 percent for the increased spillage threshold. Thus, simulation results indicate total streamflow from a flood event may be reduced by wetland storage, but peak streamflows during a flood event may not be affected substantially.

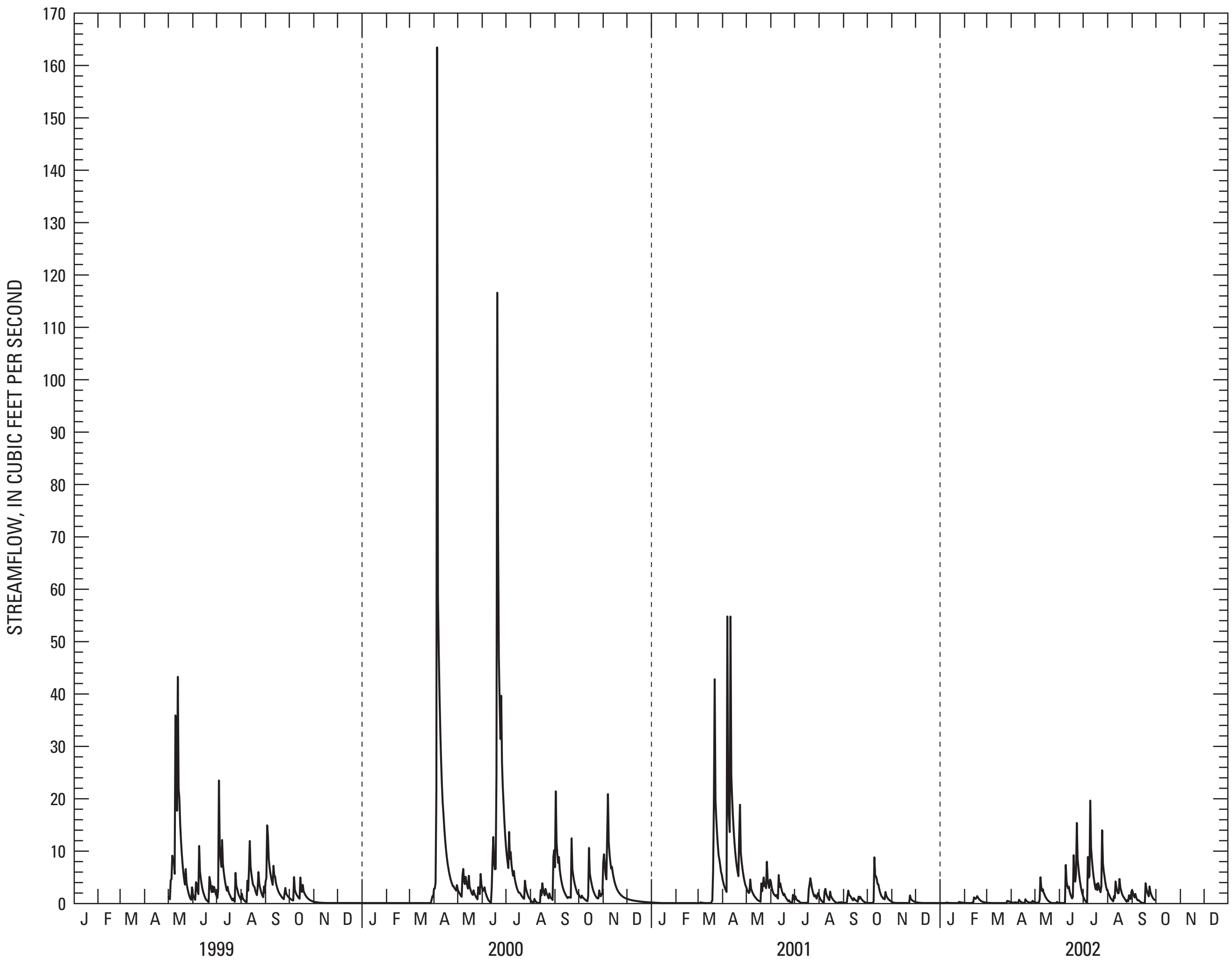

Figure 18. Simulated daily mean streamflows during flood conditions for the Hamden watershed site, west-central Minnesota, at a Bisson Lake spillage threshold of 0.009, May 1999 through September 2002.

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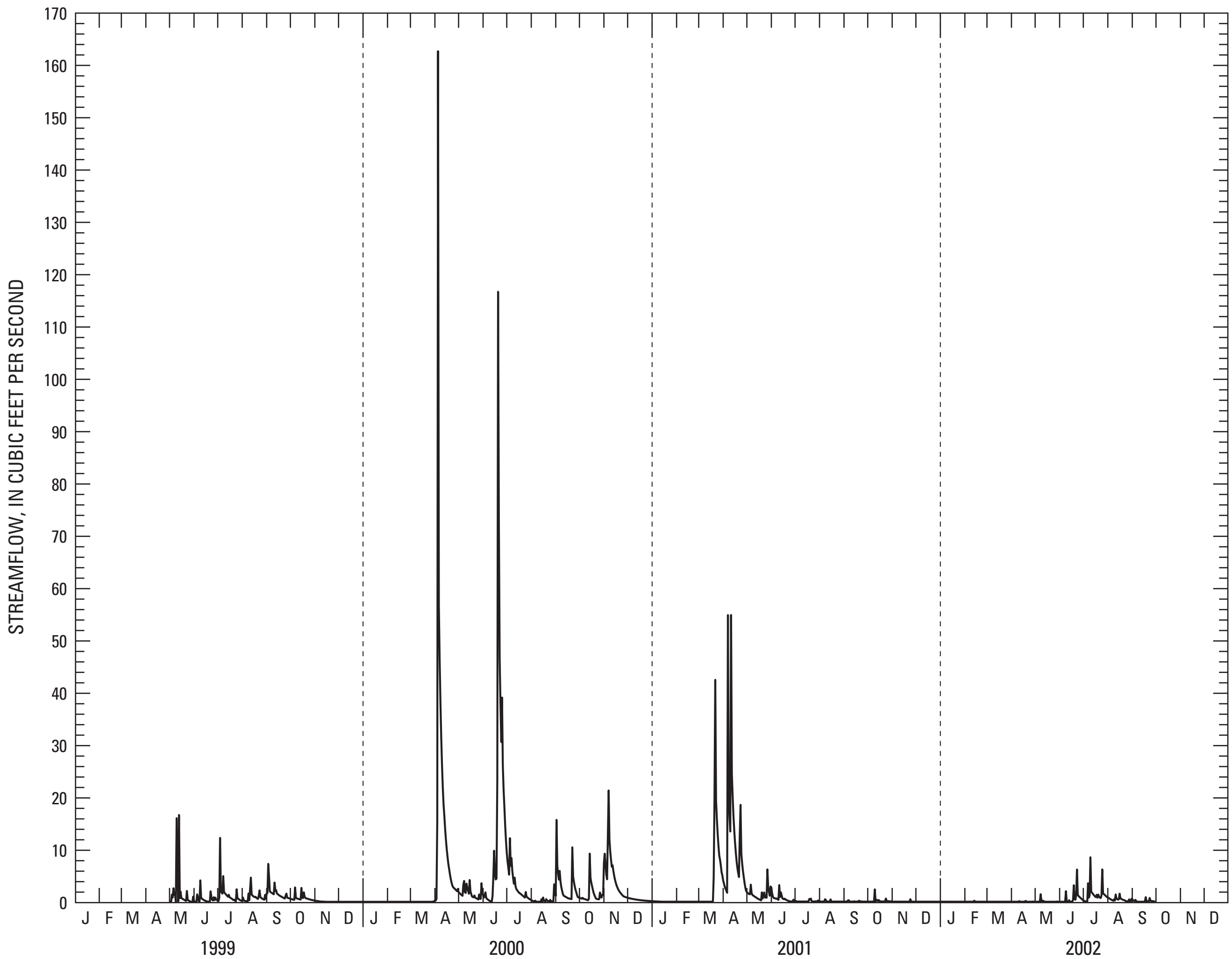

Figure 19. Simulated daily mean streamflows during flood conditions for the Hamden watershed site, west-central Minnesota, at a Bisson Lake spillage threshold of 0.60, May 1999 through September 2002.

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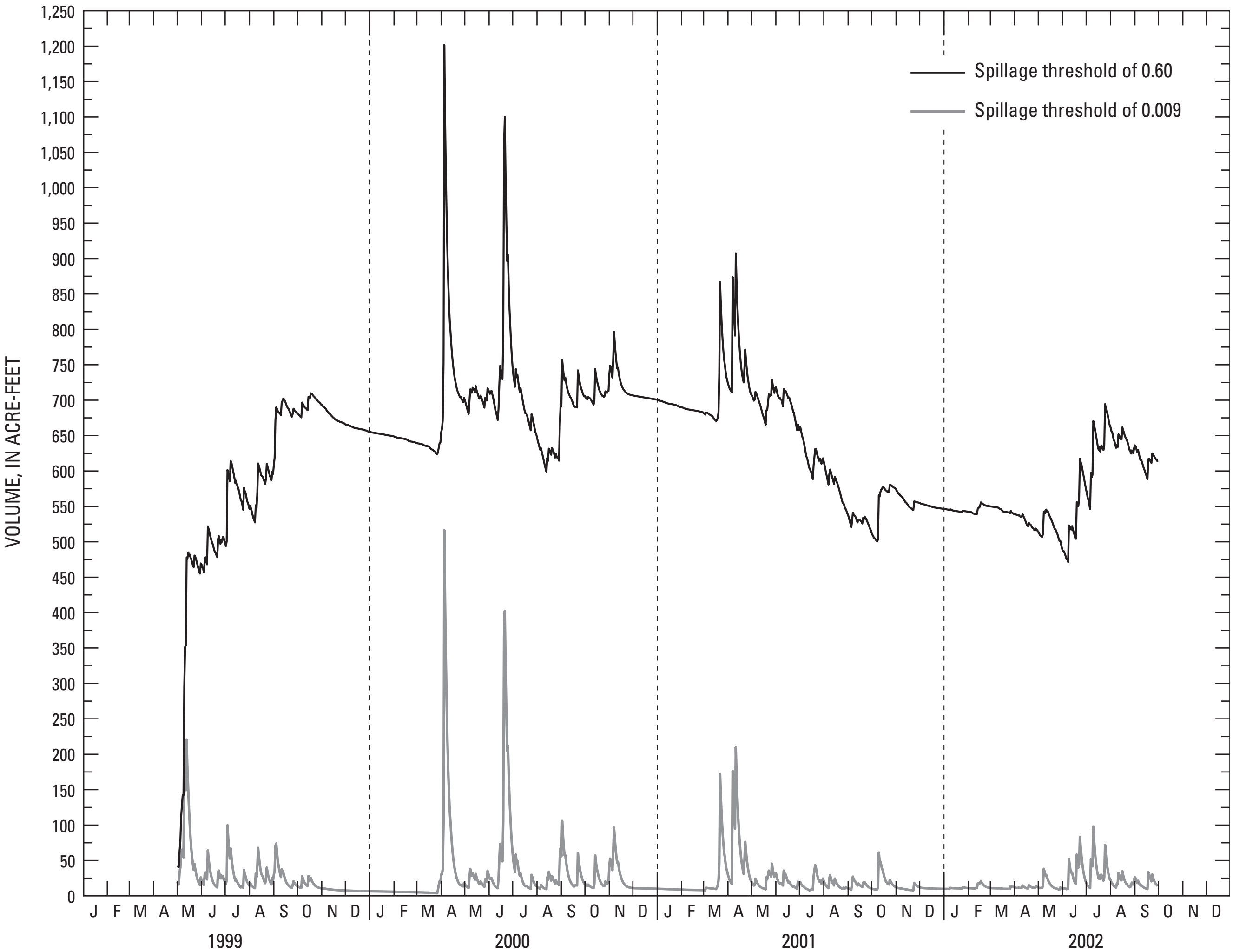

Figure 20. Simulated daily mean water volumes during flood conditions for Bisson Lake in the Hamden watershed site, west-central Minnesota, at spillage thresholds of 0.009 and 0.60, May 1999 through September 2002.

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Table 5. Simulated runoff, in inches, for the Hamden watershed site during flood conditions and percent reduction in runoff from an increased spillage threshold.

Year	Month	Spillage threshold		Percent reduction
		0.009	0.60	
1999	May	1.101	0.230	79
	June	.304	.076	75
	July	.477	.178	63
	August	.350	.123	65
	September	.458	.208	55
	October	.182	.101	45
	November	.017	.022	-29
	December	.011	.017	-55
2000	January	.011	.017	-55
	February	.010	.016	-60
	March	.022	.018	18
	April	2.115	1.991	6
	May	.335	.213	36
	June	1.993	1.875	6
	July	.516	.402	22
	August	.196	.059	70
	September	.549	.345	37
	October	.241	.178	26
	November	.583	.586	-1
	December	.054	.061	-13
2001	January	.013	.022	-69
	February	.009	.017	-89
	March	.630	.622	1
	April	1.417	1.381	3
	May	.306	.187	39
	June	.197	.096	51
	July	.141	.031	78
	August	.093	.027	71
	September	.085	.024	72
	October	.199	.040	80
	November	.029	.022	24
	December	.014	.020	-43
2002	January	.015	.020	-33
	February	.047	.018	62
	March	.017	.019	-12
	April	.031	.020	35
	May	.096	.026	73
	June	.382	.092	76
	July	.557	.187	66
	August	.190	.071	63
	September	.143	.034	76
Total runoff		14.136	9.692	31