Rapid Creek and Victoria Creek

Calculations of losses for Rapid Creek and one major tributary, Victoria Creek, are presented in the following sections. Three continuous-record and two miscellaneous-record stations (fig. 16, table 3) are used in the analysis of Rapid and Victoria Creeks.

Rapid Creek

Examination of streamflow records for sites 29 and 33 for WY56-96 provides initial insights regarding long-term loss characteristics for Rapid Creek. Annual streamflow loss rates between sites 29 and 33 are plotted in figure 20 as a function of weighted annual precipitation, within the intervening 51-mi^2 drainage area. Annual precipitation is estimated by weighting precipitation data (U.S. Department of Commerce, 1996), using the Thiessen polygon method, for gages at Pactola Dam (78.3 percent) and Rapid City (21.7 percent) (Driscoll, 1987). Examination of figure 20 indicates that the maximum annual loss rates are about 8 to 9 ft^3/s and generally occur during years of lower precipitation, when minimal tributary inflows would be expected.

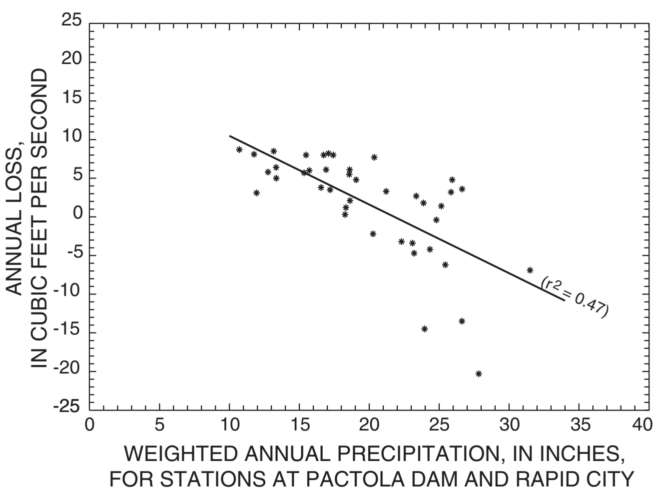


Figure 20. Annual loss rate for Rapid Creek (sites 29-33), as a function of weighted annual precipitation, water years 1956-96.

Daily streamflow records are available for WY89-96 for site 30, which is located downstream from site 29, but immediately upstream from the loss zone areas on Rapid Creek (fig. 16). The drainage area between sites 30 and 33 increases by only 16 mi^2 (table 3); thus, calculated losses are less susceptible to effects of tributary inflows than calculated losses between sites 29 and 33. Therefore, even though site 29 has a longer period of record, site 30 is used for subsequent comparisons with site 33.

Subsequent loss calculations between sites 30 and 33 exclude springflow from Tittle Springs, which is located within the intermediate reach (fig. 16). Numerous measurements for WY89-96 for station 06412300, Tittle Springs at Rapid City, (not included in this report) indicate that flow generally ranges from 1 to 3 ft^3/s. Hines (1991) concluded that water from Tittle Springs probably is derived from Rapid Creek. Hines also noted other areas of ground-water inflow, or streamflow gains, within the Rapid Creek loss zone. Because springflow is excluded, subsequent loss calculations represent net losses to the Madison Limestone, as well as possible losses to the Deadwood and Minnelusa Formations.

Annual losses between sites 30 and 33 are presented in table 18. A regression plot of monthly losses between sites 30 and 33, as a function of monthly flow at site 30, is shown in figure 21. These monthly losses exhibit considerably more variability than the annual losses (table 18). The median value of 8.2 ft^3/s for these monthly losses also is shown, which corresponds fairly closely with the Y-intercept of about 10.2 ft^3/s for the regression line. The Y-intercept may be more representative of the loss threshold than the median, because the regression line accounts for some of the variability in losses, while the median represents only the central tendencies. The mean monthly loss of 7.0 ft^3/s also is shown. The mean is smaller than the median because of effects of occasional tributary inflows, which result in smaller calculated losses, or occasional gains. Thus, the mean is a poorer representation of the loss threshold.

Table 18. Annual streamflow losses for Rapid Creek, between sites 30 and 33, water years 1989-96

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

Water year	Annual mean flow, in ft^3/s: Upstream station site 30	Annual mean flow, in ft^3/s: Downstream station site 33	Annual loss, in ft^3/s
1989	34.3	26.5	7.8
1990	28.8	19.0	9.8
1991	26.4	17.5	8.9
1992	33.7	20.7	13.0
1993	54.5	48.3	6.2
1994	62.5	55.5	7.0
1995	94.7	89.8	4.9
1996	103	105	-2

[1]Annual loss calculated as annual mean flow at upstream station minus downstream station.

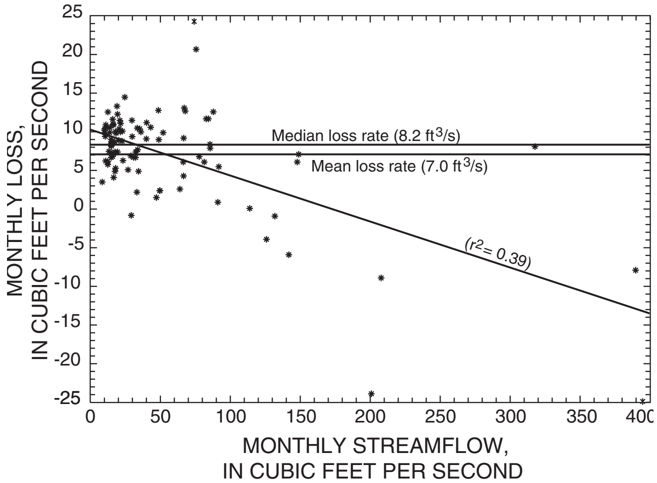


Figure 21. Monthly loss rate for Rapid Creek (sites 30-33), as a function of monthly streamflow at site 30, water years 1989-96.

Loss calculations using individual measurements for sites 30, 32, and 33 are presented in table 19. Histograms of loss rates calculated from both individual measurements and monthly streamflow records are presented in figure 22. Both histograms indicate that the loss rate most frequently is in the range of 7 to 11 ft^3/s.

Additional insights can be obtained by examination of figure 23, which shows plots of monthly weighted precipitation, monthly flow at site 30, and monthly losses between sites 30 and 33. The smallest monthly losses, including months of net gains, generally correspond with periods of high precipitation and associated tributary inflows. A line representing an approximate loss threshold of 10 ft^3/s also is shown in figure 23. Monthly losses during WY89-92 generally are about 10 ft^3/s; however, losses during WY93-96 generally are less than 10 ft^3/s. This decrease probably results primarily from increased springflow (groundwater discharge) within the loss zone, resulting from a general increase in precipitation during this period.

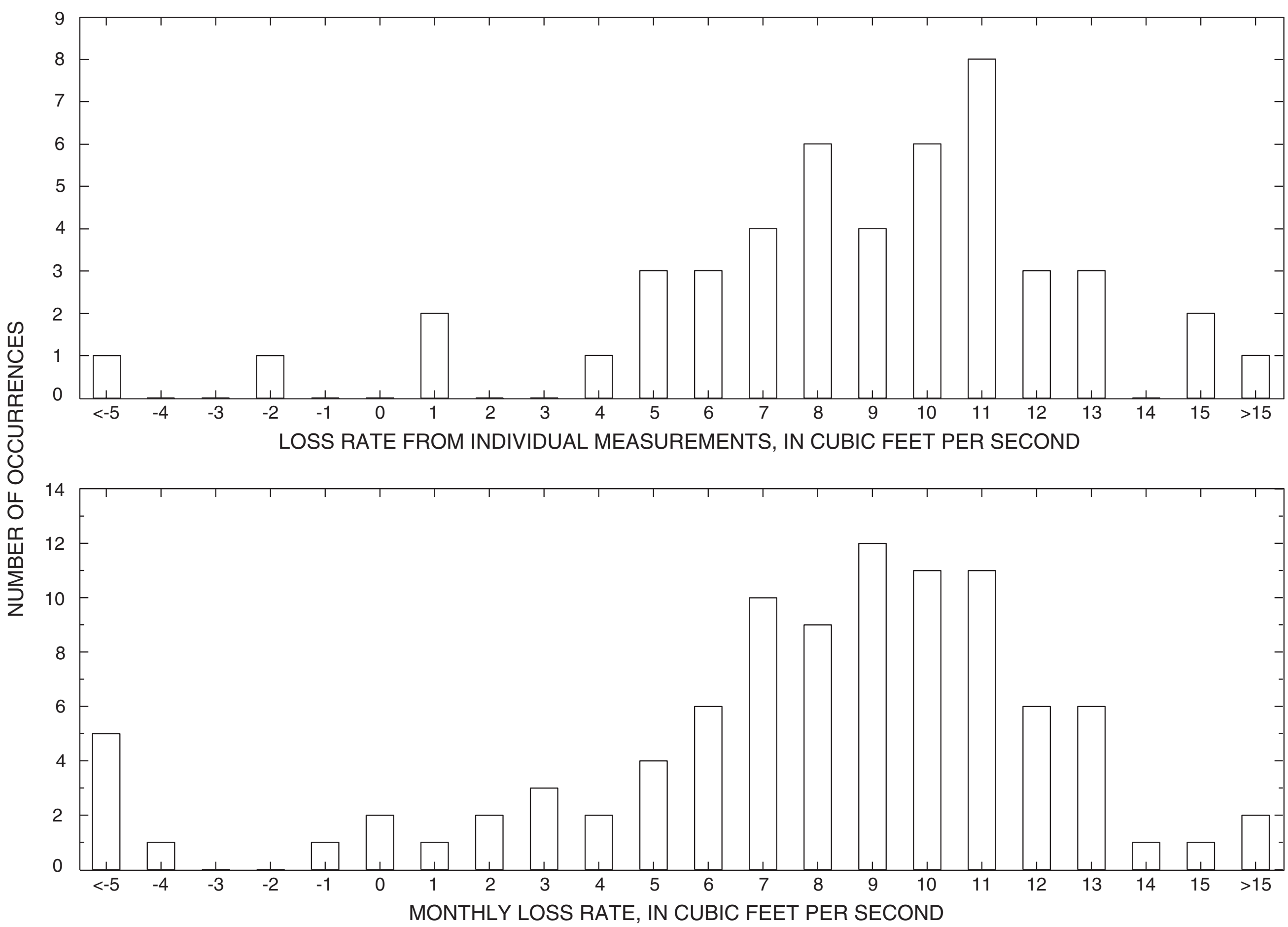


Figure 22. Histograms of calculated loss rate for Rapid Creek (between sites 30 and 33) from individual measurements and monthly flows, water years 1989-96.

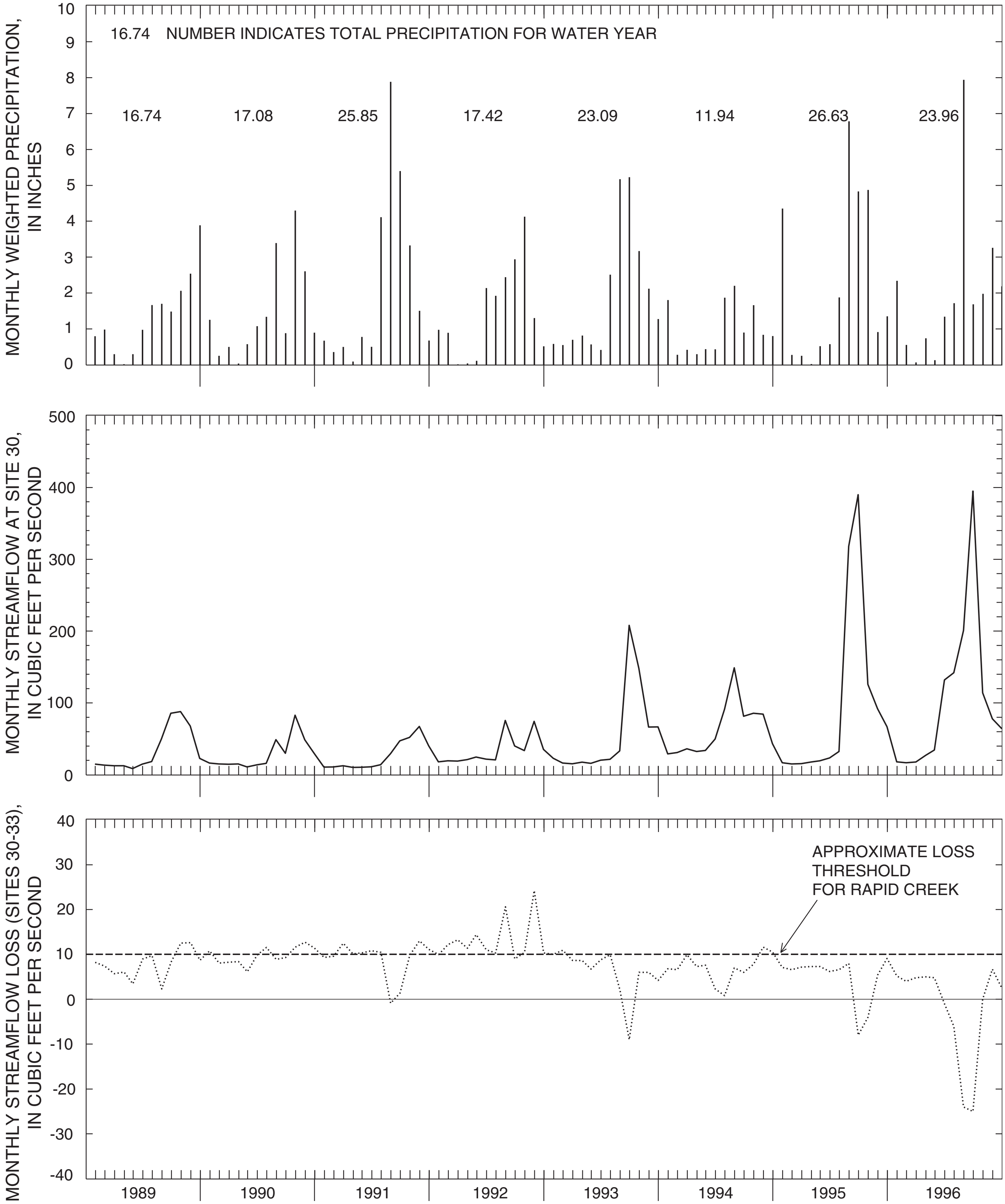


Figure 23. Monthly weighted precipitation, monthly streamflow at site 30, and monthly streamflow losses (sites 30-33), for Rapid Creek, water years 1989-96.

Table 19. Calculations of streamflow losses for Rapid Creek

[ft^3/s, cubic feet per second; ( ), losses between specified sites calculated by performing indicated arithmetic operations; --, no data available]

Date	Upstream station site 30		Upstream tributary site 32		Downstream station site 33		Total loss, in ft^3/s (30 + 32 - 33)	Hydrograph changes[1]
	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s		
10-14-88	1040	14.3	--	--	1840	5.00	9.3	0%
11-21-88	0855	11.0	--	--	1050	3.89	7.1	0%
12-21-88	1200	12.9	--	--	1415	5.78	7.1	0%
6-06-89	0755	107	--	--	1005	95.6	11	+9%
7-06-89	1145	91.9	--	--	0920	77.4	14.5	-2%
10-02-89	1320	14.8	--	--	1520	3.88	10.9	0%
10-17-89	1130	16.9	--	--	1330	5.31	11.6	0%
11-06-89	1215	17.8	--	--	1635	7.59	10.2	+6%
2-01-90	0940	8.84	--	--	1210	2.80	6.04	-18%
4-19-90	1530	10.5	--	--	1320	2.10	8.4	-14%
5-16-90	1225	60.2	--	--	1410	48.8	11.4	-2%
6-12-90	0935	14.8	--	--	1315	5.24	9.6	0%
8-17-90	0945	43.9	--	--	1240	30.9	13.0	+5%
9-27-90	0915	22.2	--	--	1240	9.96	12.2	0%
3-27-91	1230	11.4	--	--	1435	.73	10.7	-9%
10-22-91	1358	16.7	--	--	1545	6.43	10.3	0%
7-09-92	1210	37.6	--	--	1025	26.8	10.8	-3%
8-28-92	1335	48.6	--	--	1105	35.9	12.7	0%
10-02-92	1315	48.6	--	--	1045	37.9	10.7	-19%
11-05-92	1355	16.3	--	--	1155	4.56	11.7	0%
1-05-93	1115	16.3	--	--	1345	9.07	7.2	0%
3-17-93	1150	23.7	--	--	0945	6.08	17.6	-5%
4-15-93	1140	22.5	--	--	1010	12.8	9.5	0%
5-27-93	1035	28.4	0800	3.05	1210	21.9	9.6	-3%
8-10-93	0915	50.0	0745	0.26	1045	46.0	4.3	-2%
9-03-93	1050	62.3	--	--	0930	61.5	.8	+2%
10-06-93	1200	22.5	--	--	1030	15.2	7.3	-11%
11-09-93	1155	30.4	--	--	1025	24.9	5.5	0%
1-12-94	1120	36.1	--	--	0905	28.9	7.2	+3%
3-29-94	1515	87.4	--	--	1355	96.3	-8.9	0%
5-02-94	0950	163	0850	0	0815	162	1	+1%
6-21-94	1510	64.7	1405	0	1345	59.3	5.4	-4%
10-07-94	1200	19.4	--	--	1045	10.8	8.6	+12%
11-29-94	1015	13.8	--	--	0825	7.49	6.3	0%
12-29-94	1110	17.5	1000	0	0845	8.71	8.8	0%
2-02-95	1035	23.2	0915	0	0840	14.1	9.1	+15%

Table 19. Calculations of streamflow losses for Rapid Creek —Continued

[ft^3/s, cubic feet per second; ( ), losses between specified sites calculated by performing indicated arithmetic operations; --, no data available]

Date	Upstream station site 30		Upstream tributary site 32		Downstream station site 33		Total loss, in ft^3/s (30 + 32 - 33)	Hydrograph changes[1]
	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s		
3-09-95	1055	26.7	0900	0	0835	12.6	14.1	+42%
4-07-95	1055	33.2	0900	0	0735	26.8	6.4	0%
5-05-95	1015	33.0	0910	0	0830	26.6	6.4	0%
8-21-95	1550	93.3	1445	0	1430	85.0	8.3	0%
11-03-95	1400	12.8	--	--	1210	5.35	7.4	-7%
12-01-95	1125	16.8	--	--	1310	12.4	4.4	0%
1-03-96	1030	28.5	--	--	0835	17.5	11.0	-4%
2-06-96	1040	31.9	--	--	0810	27.8	4.1	+13%
3-05-96	0920	37.4	--	--	0800	28.0	9.4	-3%
5-07-96	0820	144	--	--	0950	146	-2	-17%
6-04-96	0755	561	--	--	0910	555	6	-2%
7-09-96	0840	129	--	--	1000	125	4	0%

[1]Hydrograph changes calculated using daily mean streamflow at site 30: [(current day - previous day) / previous day] x 100%.

The general decrease in monthly loss rates corresponds to general decreases in individual losses (table 19) and annual losses (table 18), with the exception of WY92. Large monthly losses for May and August of 20.6 and 24.2 ft^3/s, respectively (fig. 23), are reflected in the annual losses for WY92 (table 18). Small calculated losses and calculated gains can result from inflows within the measurement reach; however, no physical explanation is available for the anomalously large calculated losses. Using site 29 instead of site 30 as the upstream site, calculated losses for May and August are 9.8 and 12.4 ft^3/s, respectively (U.S. Geological Survey, 1993), which are more representative of typical loss rates. Using these values, the annual loss rate for WY92 would be about 11.2 ft^3/s, which corresponds better with generally decreasing losses over the period (table 18).

Considering all of the data collectively, the loss threshold for Rapid Creek is estimated to be 10 ft^3/s. The generally lower loss rates during WY93-96 probably result from a decrease in the net loss rate, which is caused by an increase in springflow within the loss zone. Thus, it is hypothesized that the net loss rate to the bedrock outcrops along Rapid Creek is approximately constant. The "gross" loss rate is not determined, however, because of springflow within the reach.

Victoria Creek

Loss calculations for Victoria Creek, a tributary to Rapid Creek, are presented in table 20, which includes measurements for sites 31 and 32 (fig. 16). Calculated losses include combined losses to the Deadwood Formation and Madison Limestone (table 3).

Calculated losses for May 27 and August 10, 1993, are both about 1.0 ft^3/s; however, measurements for May 19, 1995 and June 10, 1996 indicate a gain between the two stations. The small calculated loss rate for July 11, 1996, probably is affected by continuing tributary inflow or springflow, resulting from wet conditions during preceding months. Thus, the loss threshold for Victoria Creek, using measurements from 1993, is estimated to be 1.0 ft^3/s.

Boxelder Creek

Two continuous-record and three miscellaneous-record stations are used to calculate losses on Boxelder Creek (fig. 16, table 3). Daily streamflow records also are available for WY78-80 for station 06422600, Boxelder Creek at Camp Columbus, which was located approximately 2 mi downstream from current site 34; however, these records are not used in subsequent analyses because site 34 has a longer period of record with very similar streamflow.

Table 20. Calculations of streamflow losses for Victoria Creek

[ft^3/s, cubic feet per second; ( ), losses between specified sites calculated by performing indicated arithmetic operation]

Date	Upstream station site 31		Downstream station site 32		Total loss, in ft^3/s (31 - 32)
	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s	
5-27-93	0910	3.95	0800	3.05	0.90
8-10-93	0805	1.44	0745	.26	1.18
5-19-95	0930	11.7	1250	13.0	-1.3
6-10-96	0745	7.89	0730	11.5	-3.6
7-11-96	0950	1.46	0900	1.19	.27

Determination of losses for Boxelder Creek is especially difficult because all of the factors that can affect loss calculations have potential for maximum effects. The stream length between sites 34 and 38 is approximately 10 mi (fig. 16) and the drainage area increases by 32 mi^2 (table 3); thus, effects of channel storage and tributary inflow can be large. The largest alluvial deposits within a loss zone for any of the stream reaches considered in this report occur between sites 36 and 38. Three springs (Gravel Spring, Doty Spring, and Dome Spring) are located within the Madison Limestone between sites 35 and 36 (fig. 16). Rahn and Gries (1973) reported that individual flows from each of these springs ranged from zero to about 10 ft^3/s during 1966-69. They also documented through dye testing that these springs are directly connected to sinkholes located just upstream, with travel times ranging from 1 to 6 hours. Another spring, Lang Spring, is located between sites 36 and 37 (fig. 16). The effects of these springs on loss calculations are discussed later in this section.

Individual measurements made at sites 34 and 35 during WY93-96 are used to analyze potential losses to the Deadwood Formation along Boxelder Creek (table 21). High-flow measurements for two dates indicate relatively large losses; however, high-flow measurements for two other dates indicate relatively large gains. Measuring conditions generally are poor at site 35 because of an extremely rocky channel, which probably affects measurement accuracy, especially during high flows. Measurements for other dates indicate either gains, or very small losses that could result from evapotranspiration. Therefore, it is concluded that losses to the Deadwood Formation along Boxelder Creek are negligible, relative to losses to other units.

Losses calculated using individual measurements from sites 35, 36, 37, and 38 during WY93-96 are presented in table 22. Losses to individual outcrops are identified for several dates. It should be noted that an unmapped outcrop of Madison Limestone is located within the Minnelusa reach of Boxelder Creek between sites 36 and 37 (fig. 16). Thus, losses denoted as "Minnelusa" in table 22 also may include losses to the Madison Limestone, which may be as large or larger than losses to the Minnelusa. In addition, losses denoted as "Minnekahta" may include losses to alluvial deposits between sites 37 and 38. The calculated losses in table 22 are extremely variable and individual loss calculations generally are considered only when analyzing hydrographs that are presented later in this section.

Individual measurements for sites 34 and 38 during WY88-94 are presented in table 40 of the Supplemental Information section. Zero flow was recorded at site 38 on all but two of the measuring dates. Calculated losses for these dates are subject to many complicating factors; thus, little insight is gained from analysis of these measurements.

The most useful insights on loss characteristics are obtained by analyzing hydrographs of daily streamflow for sites 34 and 38 for WY83-84, 91, and 93-96 (fig. 24). Flow during these years was sufficient to make it entirely through the loss zone for extended periods of time. An approximate bedrock loss threshold of 50 ft^3/s, which is estimated during subsequent discussions, is included on all graphs in figure 24.

The effects of streamflow losses to extensive alluvial deposits are evident in the hydrograph for WY83 (fig. 24A). Flow at the upstream station (site 34) exceeded the approximate loss threshold on

Table 21. Calculations of streamflow losses to the Deadwood Formation along Boxelder Creek

[ft^3/s, cubic feet per second; ( ), losses between specified sites calculated by performing indicated arithmetic operation]

Date	Upstream station site 34		Intermediate station site 35		Loss to Deadwood, in ft^3/s (34 - 35)
	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s	
5-17-93	0910	58.7	1040	62.0	-3.3
5-03-94	0820	111	0930	102	9
6-22-94	0900	28.6	1005	28.6	.0
7-26-94	1300	10.1	1405	8.56	1.5
8-30-94	0830	5.14	0935	4.65	.49
5-23-95	1055	127	1229	122	5
7-07-95	1040	65.1	1027	65.5	-.4
8-17-95	1340	21.7	1135	22.1	-.4
3-15-96	0845	67.2	0950	79.5	-12.3
5-13-96	1230	59.7	1255	62.1	-2.4
6-12-96	0925	137	1030	145	-8
7-02-96	0745	51.0	0920	51.1	-.1
8-28-96	0730	17.2	1100	17.0	.2

April 18, 1983; however, flow did not occur at the downstream station (site 38) until April 24. With the exception of a 5-day period in May of 1982, flow had not occurred at site 38 since WY78 (Miller and Driscoll, 1998). Therefore, total loss values that continued to exceed the threshold through the end of April probably resulted from filling initial storage in extensive alluvial deposits to a level equal to that of the stream stage. Alluvial storage volume in the area between sites 36 and 38 is estimated to exceed 600 acre-ft.

The existence of springflow upstream from site 38 also is evident in the hydrograph for WY83. Small and steadily decreasing flow was maintained at site 38 during most of June and July, although flow at site 34 decreased below the approximate threshold in late May. The calculated loss rate during June and July converges with flow at site 34, as measured springflow at site 38 approaches zero. Because springflow upstream from site 38 is not accounted for, the loss rates shown in figure 24 represent net losses. Actual losses would be larger than net losses during periods when springflow is occurring upstream from site 38.

The effects of alluvial storage and springflow also are evident in figure 24B-24F. These effects are quite variable, however, because of the transient nature of the springflow that occurs in the reach (Rahn and Gries, 1973) and complexities associated with alluvial storage. The alluvial deposits within the loss zone may be subject to rapid drainage into the underlying bedrock units; however, if springflow within the loss zone becomes sufficiently large, much of the alluvial area may remain saturated. As an example, large losses that occur in filling alluvial storage are evident for WY91 (fig. 24C) and WY93 (fig. 24D), indicating that alluvial storage was largely diminished during WY92 (not shown). Losses in filling alluvial storage are small during WY94 (fig. 24E), which indicates that alluvial storage was nearly satisfied when upstream flow first exceeded the loss threshold. Initial alluvial losses were again large during WY95 (fig. 24F) but almost nonexistent during WY96 (fig. 24G).

Considering all of the factors involved, 50 ft^3/s is selected as an approximate total loss threshold, based primarily on hydrographs for water years shown in figure 24. During these water years, total (net) losses that are consistently smaller than the approximate threshold of 50 ft^3/s generally are associated with springflow upstream from site 38. During many water years, the total (net) loss rate varies considerably, because of a wide variety of factors, as previously discussed.

Table 22. Calculations of streamflow losses for Boxelder Creek, water years 1993-96

[ft^3/s, cubic feet per second; Mdsn, Madison; Mnls, Minnelusa; Mnkt, Minnekahta; ( ), losses between specified sites calculated by performing indicated arithmetic operation; --, no data available; >, potential loss greater than indicated because of zero flow at downstream site]

Date	Upstream station site 35		Intermediate station site 36		Intermediate station site 37		Downstream station site 38		Loss to Mdsn, in ft^3/s (35 - 36)	Loss to Mnls, in ft^3/s (36 - 37)	Loss to Mnkt, in ft^3/s (37 - 38)	Total loss, in ft^3/s (35 - 38)	Hydrograph changes[1]/ remarks
	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s					
5-17-93	1040	62.0	0910	35.0	--	--	--	[2]0	27.0	--	--	>62.0	-8%
5-03-94	0930	102	1030	84.5	--	--	1215	47.6	18	--	--	54	+13%/day 3 of flow through
6-22-94	1005	28.6	1020	0	--	--	1215	0.16	>28.6	--	--	28.4	+39%
7-26-94	1405	8.56	1425	0	--	--	--	[2]0	>8.56	--	--	--	0%
8-30-94	0935	4.65	0700	0	--	--	--	[2]0	>4.65	--	--	--	+2%
5-23-95	1229	122	1342	117	--	--	--	[2]102	5	--	--	20	-8%
7-07-95	1027	65.5	1135	40.4	--	--	--	[2]22	25.1	--	--	44	+14%
8-17-95	1135	22.1	1015	3.29	--	--	1150	1.82	18.8	--	--	20.3	0%
3-15-96	0950	79.5	1100	67.1	--	--	1230	52.0	12.4	--	--	27.5	-14%
5-13-96	1255	62.1	1510	37.7	1240	19.5	1520	20.0	24.4	18.2	-0.5	42.1	+2%
6-12-96	1030	145	1200	138	1150	118	1340	114	7	20	4	31	-1%
7-02-96	0920	51.1	1025	31.2	1400	20.0	1215	20.8	19.9	11.2	-.8	30.3	-4%
8-28-96	1100	17.0	1220	0	1210	4.70	1250	1.71	>17.0	-4.7	2.99	15.3	-6%

[1]Hydrograph changes calculated using daily mean streamflow at site 34: [(current day - previous day) / previous day] x 100%.
[2]Indicated value for this date is the daily mean.

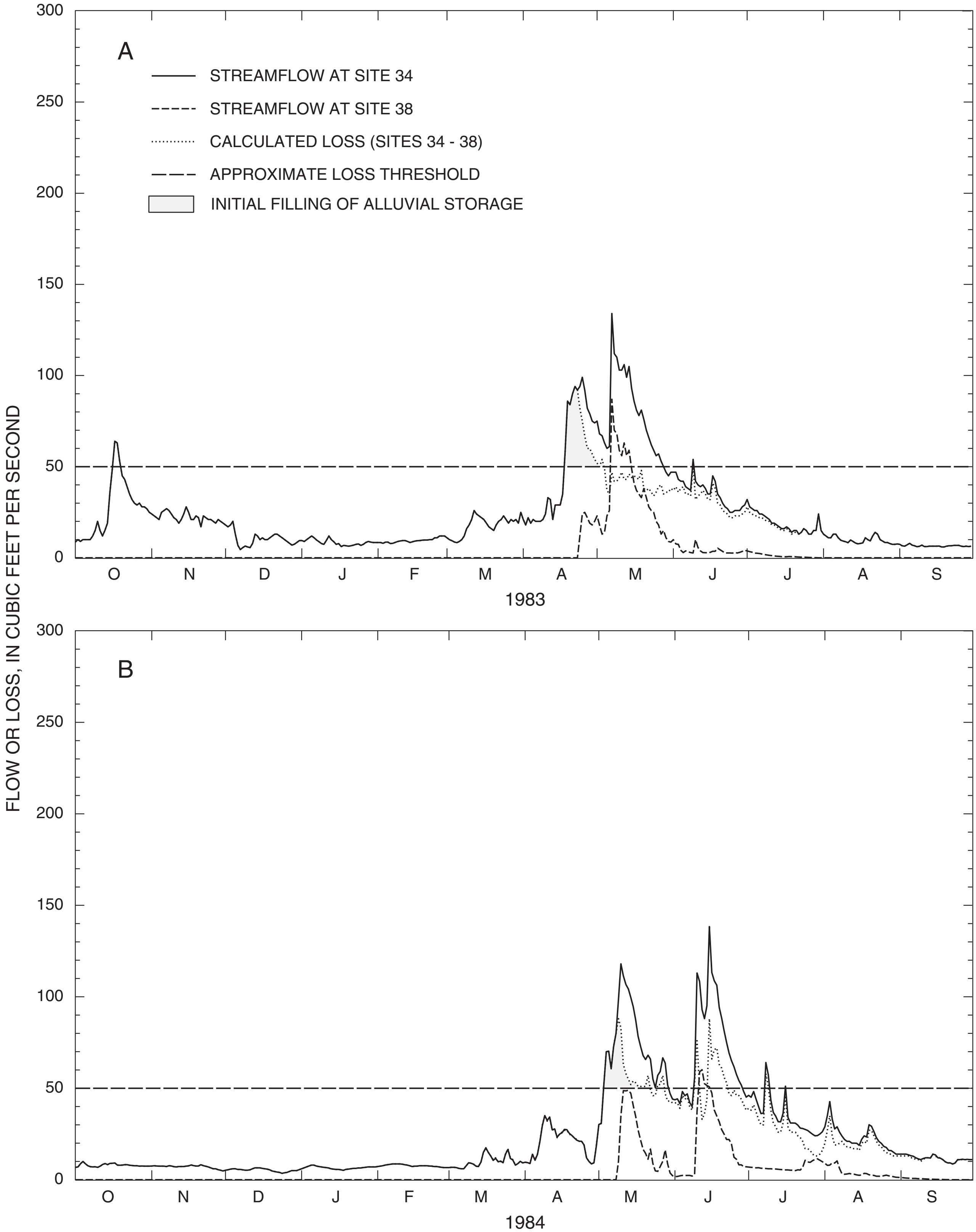


Figure 24. Daily hydrographs and calculated losses for site 34 (Boxelder Creek near Nemo) and site 38 (Boxelder Creek near Rapid City) for selected water years.

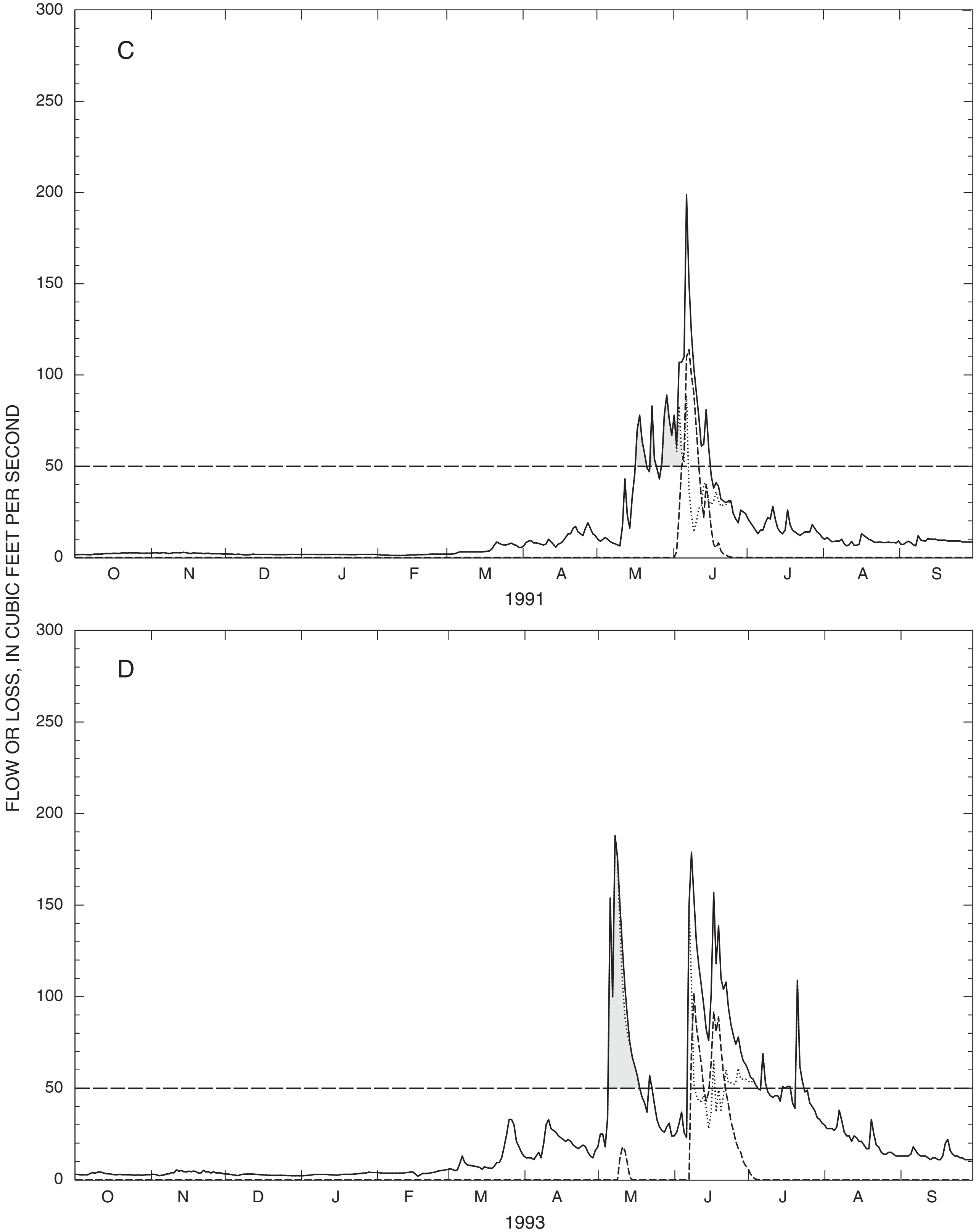


Figure 24. Daily hydrographs and calculated losses for site 34 (Boxelder Creek near Nemo) and site 38 (Boxelder Creek near Rapid City) for selected water years.--Continued

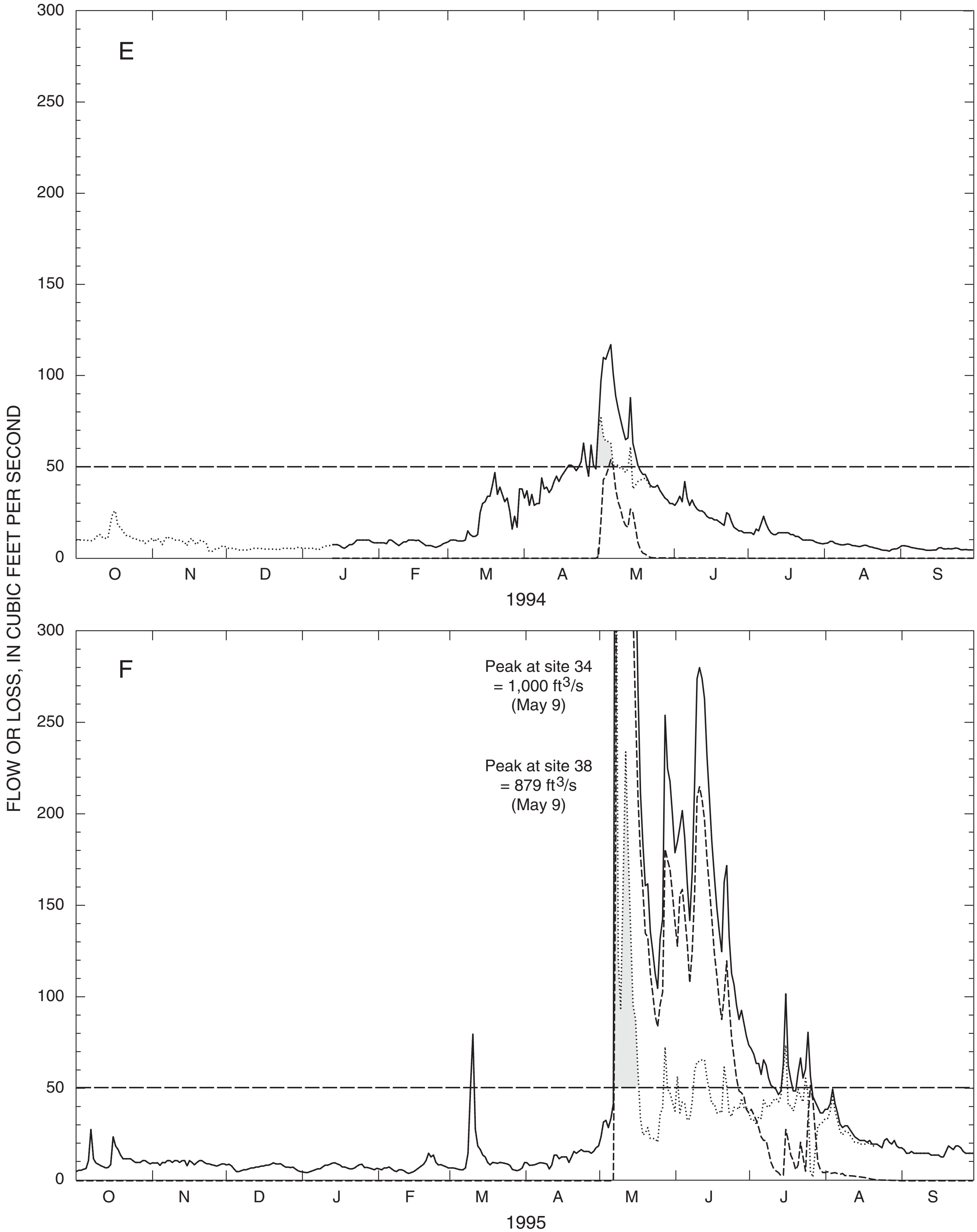


Figure 24. Daily hydrographs and calculated losses for site 34 (Boxelder Creek near Nemo) and site 38 (Boxelder Creek near Rapid City) for selected water years.--Continued

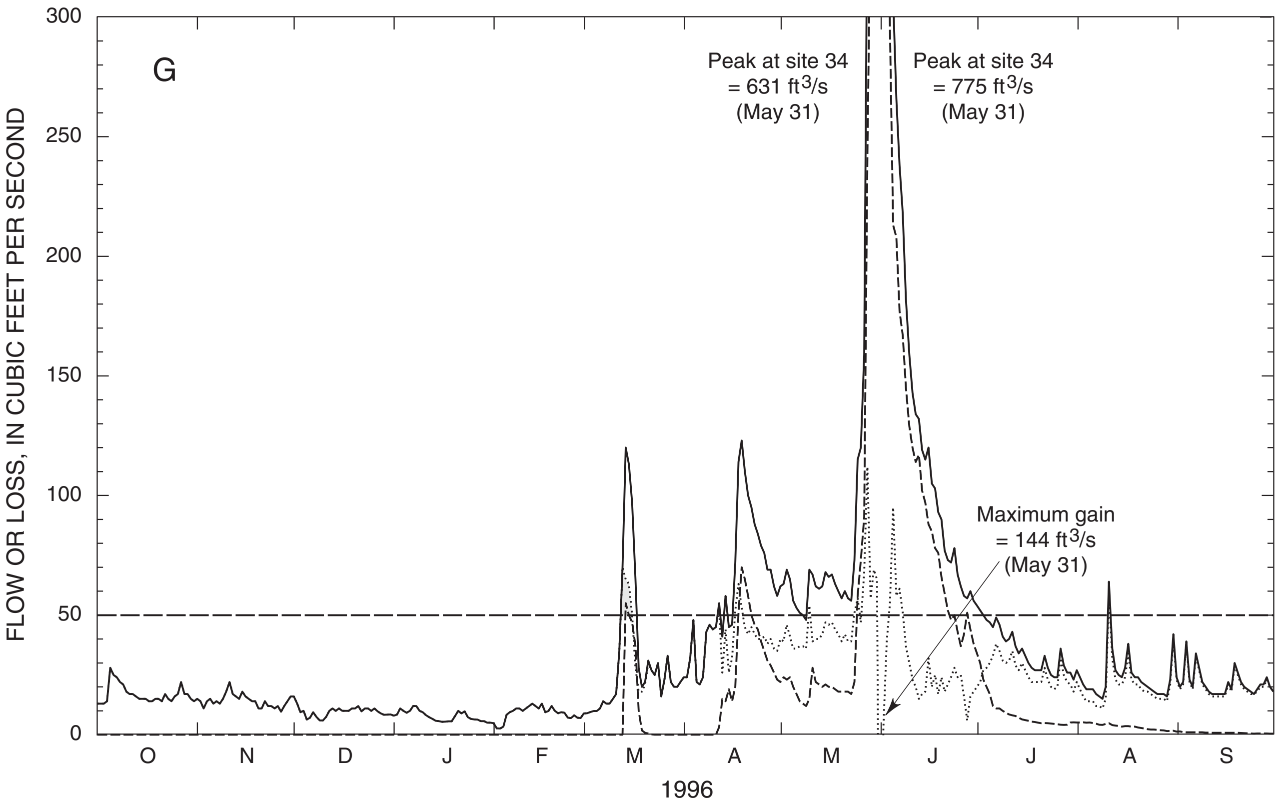


Figure 24. Daily hydrographs and calculated losses for site 34 (Boxelder Creek near Nemo) and site 38 (Boxelder Creek near Rapid City) for selected water years.--Continued

Hydrographs of daily streamflow for sites 34, 36, and 38 for WY78 (fig. 25) and WY96 (fig. 26) provide additional insights on the complicated interactions that occur within the loss zone of Boxelder Creek. The hydrograph for site 36 for WY96 is derived from daily staff gage readings by an observer (table 3).

Figures 25 and 26 both show total (net) losses between sites 34 and 38, as well as losses to an upstream reach (between sites 34 and 36) and a downstream reach (between sites 36 and 38). Losses in the upstream reach occur primarily to the Madison Limestone (assuming losses to the Deadwood Formation are negligible). Losses in the downstream reach may occur to several outcrops. The predominant outcrop within the downstream reach is the Minnelusa Formation; however, losses also occur to the previously mentioned outcrop of Madison Limestone located within this reach. In addition, an outcrop of the Minnekahta Limestone and extensive alluvial deposits are located within the downstream reach.

Losses appear to be divided about evenly between the upstream and downstream reaches. During late May and early June of WY78 (fig. 25), losses to both the upstream and downstream reaches were relatively steady and averaged about 20 ft^3/s, with total (net) losses averaging about 40 ft^3/s. During late June and early July of WY96 (fig. 26), losses to the upstream reach also were about 20 ft^3/s; however, losses in the downstream reach during this period were inconsistent, primarily because of a small peak in the flow at site 38 during late June.

Gradually declining springflow upstream from site 38 is evident during the latter months of both WY78 and WY96 (figs. 25A and 26A), which indicates that zero-flow must occur somewhere between sites 34 and 38. Furthermore, it can be deduced that the zero-flow zone can encompass site 36 and extends into the downstream reach, because flow was maintained at site 38, after flow ceased at site 36, during both years (figs. 25C and 26C). The location of the zero-flow zone can also be confirmed by measurements made on August 28, 1996 (table 22), when zero flow was recorded at site 36 and 4.70 ft^3/s was measured at site 37.

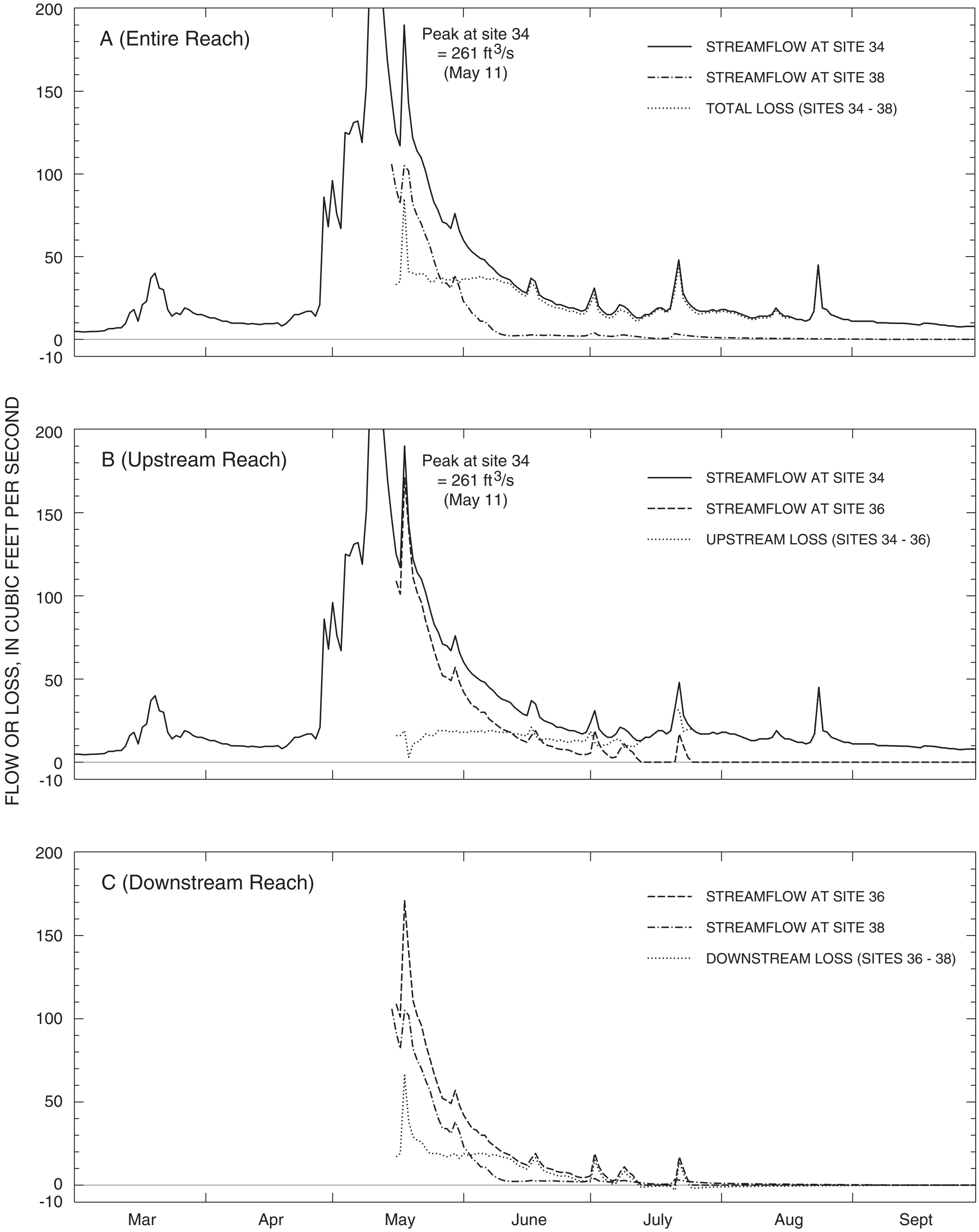


Figure 25. Daily hydrographs and calculated losses for site 34 (Boxelder Creek near Nemo), site 36 (Boxelder Creek at Doty School), and site 38 (Boxelder Creek near Rapid City), water year 1978.

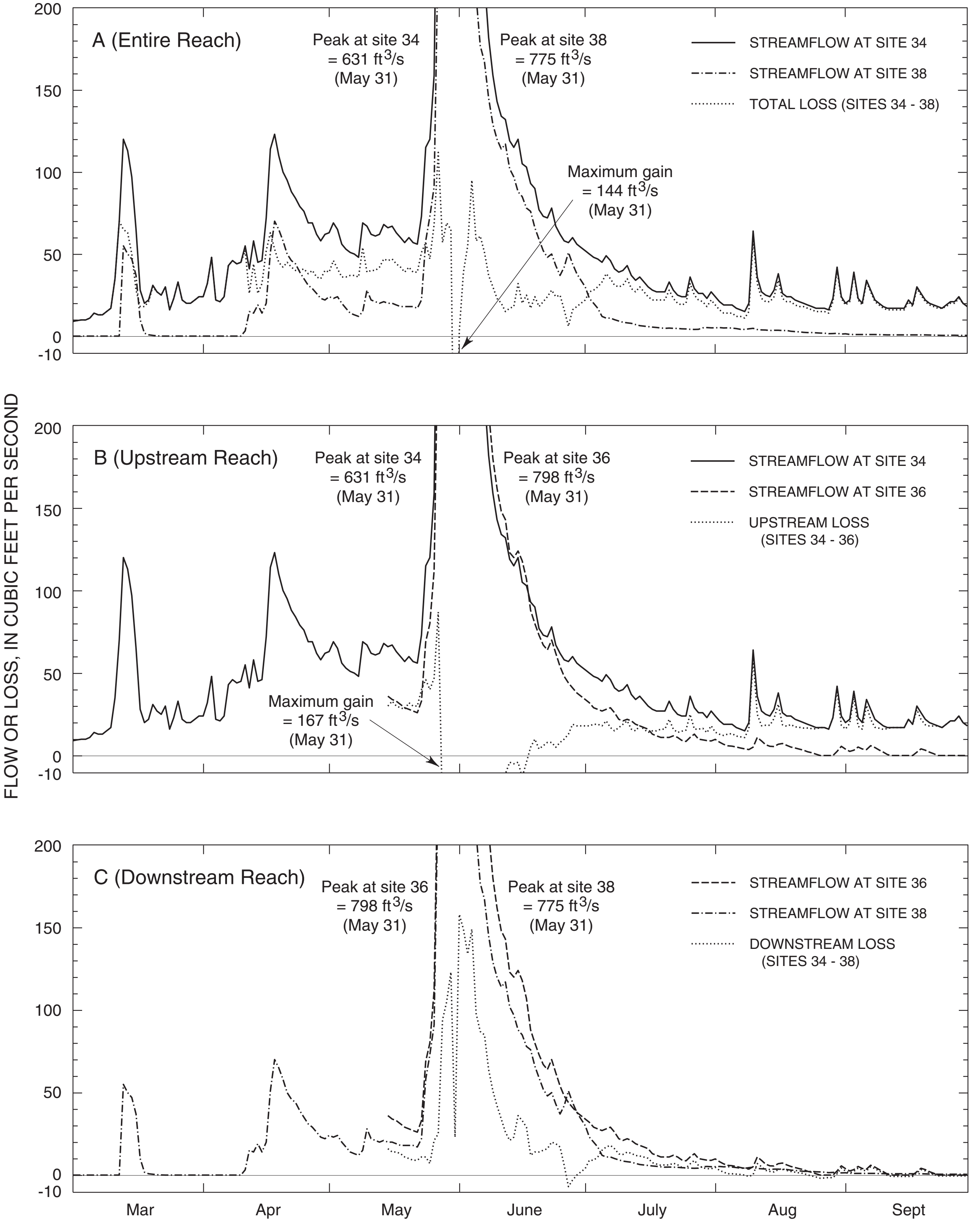


Figure 26. Daily hydrographs and calculated losses for site 34 (Boxelder Creek near Nemo), site 36 (Boxelder Creek at Doty School), and site 38 (Boxelder Creek near Rapid City), water year 1996.

Rahn and Gries (1973) documented large, transient springflow from Gravel, Doty, and Dome Springs upstream from site 36, as previously discussed. It can be deduced that large flows from these springs are intermixed within the loss zones upstream from site 36 because the hydrograph for site 36 is dampened, relative to site 34, similar to the dampening seen between sites 36 and 38 (figs. 25 and 26). In addition, the calculated net loss rate in the upstream reach consistently decreased to less than 20 ft^3/s as flow at site 34 decreased.

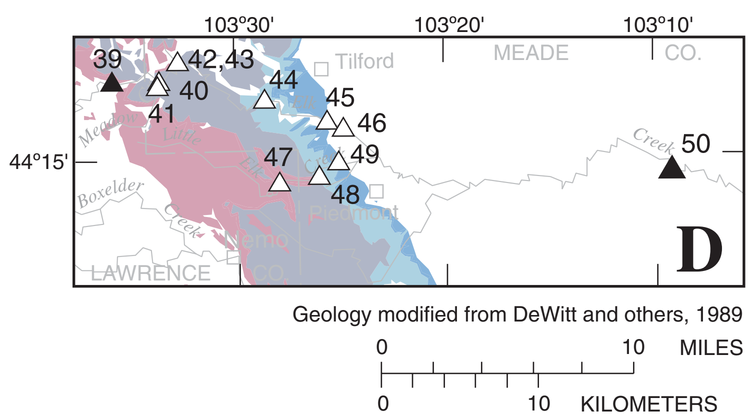
After analyzing calculated losses in figures 24, 25, and 26 and considering the effects of variable springflow within both the upstream and downstream reaches, it is estimated that the loss rate is about 25 ft^3/s in each reach during years of relatively small recharge and coinciding small springflow. The net loss rate probably decreases to about 20 ft^3/s or less in each reach, when recharge is sufficient to increase springflow within the loss zone. Losses to the Madison Limestone probably are larger than to the Minnelusa Formation, because subsequent field observations have confirmed large losses to the Madison outcrop located within the Minnelusa reach, between sites 36 and 37. Losses to the Minnekahta Limestone between sites 37 and 38 probably are relatively small (less than 5 ft^3/s) and may include alluvial losses. Losses within this reach apparently are affected by transient springflow, which probably varies considerably with recharge conditions, based on individual measurements presented in table 22. Thus, the total loss threshold for Boxelder Creek is estimated as 50 ft^3/s, with losses to the various individual outcrops estimated as follows: Madison, >25 ft^3/s; Minnelusa, <20 ft^3/s; and Minnekahta, <5 ft^3/s.

Elk Creek and Little Elk Creek

Losses are calculated for the main stem of Elk Creek and one major tributary, Little Elk Creek. Two continuous-record and ten miscellaneous-record stations are located along Elk Creek and Little Elk Creek (fig. 27, table 3).

Elk Creek

Loss calculations for Elk Creek for WY96 are presented in table 23, which includes measurements for sites 39-45. Site 39 is the only continuous-record station of this group; the other sites are miscellaneous-record stations that were established during WY96 to determine losses in various reaches of Elk Creek.



Site Number	Station Name
39	Elk Creek near Roubaix
40	Elk Creek above Meadow Creek
41	Meadow Creek above Elk Creek
42	Elk Creek trib (from North)
43	Elk Creek below trib from North
44	Elk Creek below Madison outcrop
45	Elk Creek at Minnekahta outcrop
46	Elk Creek at I-90
47	Little Elk Creek below Dalton Lake
48	Little Elk Creek below Madison outcrop
49	Little Elk Creek at Minnekahta outcrop
50	Elk Creek near Rapid City

EXPLANATION

DEADWOOD FORMATION

MADISON LIMESTONE

MINNELUSA FORMATION

MINNEKAHTA LIMESTONE

▲39 CONTINUOUS-RECORD STREAM-FLOW-GAGING STATION--Number indicates site number

△40 MISCELLANEOUS-RECORD STREAM-FLOW-GAGING STATION--Number indicates site number

Figure 27. Insert D from figure 6, showing location of measurement sites and generalized outcrops for Elk Creek and Little Elk Creek. Outcrops shown may include other formations.

Table 23. Calculations of streamflow losses for Elk Creek, water year 1996

[ft^3/s, cubic feet per second; ( ), losses between specified sites calculated by performing indicated arithmetic operations; >, potential loss greater than indicated because of zero flow at downstream site]

Date	Upstream station site 39		Intermediate station site 40		Upstream tributary site 41		Upstream tributary site 42		Intermediate station site 43	
	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s
4-24-96	0715	31.9	0900	31.0	1000	1.56	1320	2.81	1228	29.5
5-07-96	1050	26.6	0720	22.8	0805	1.66	0920	1.81	0950	23.6
7-01-96	0910	12.1	1040	11.2	1115	3.13	1210	1.20	1245	8.80
7-12-96	0930	9.85	0750	6.91	0830	2.84	0915	.91	0940	5.50
7-22-96	0930	7.35	1105	6.11	1140	2.56	1250	.65	1320	2.36
8-20-96	0830	4.65	1010	2.96	1045	1.80	1200	.55	1220	0

Date	Intermediate station site 44		Downstream station site 45		Loss to Madison, in ft^3/s				Loss to Minnelusa, in ft^3/s (44 - 45)	Total loss, in ft^3/s (39 + 41 + 42 - 45)
	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s	Upstream (39 - 40)	Intermediate (40 + 41 + 42 - 43)	Downstream (43 - 44)	Total (39 + 41 + 42 - 44)		
4-24-96	1435	26.2	1538	18.3	0.9	5.9	3.3	10.1	7.9	18.0
5-07-96	1125	18.8	1210	10.7	3.8	2.7	4.8	11.3	8.1	19.4
7-01-96	1350	16.3	1440	9.90	.9	6.7	-7.5	.1	6.4	6.5
7-12-96	1040	10.9	1130	5.56	2.94	5.16	-5.4	2.7	5.3	8.0
7-22-96	1240	7.49	1340	2.72	1.24	6.96	-5.13	3.07	4.77	7.84
8-20-96	1310	5.17	1405	.68	1.69	>5.31	-5.17	1.83	4.49	6.32
				Mean loss[1]	1.9	5.5	[2]4.0	[2]10.7	[2]8.0	[2]18.7
				Median loss[1]	1.5	5.9	[2]4.0	[2]10.7	[2]8.0	[2]18.7

[1]Calculated using finite values only.
[2]Calculated using only measurements for April 24 and May 7, 1996.

Individual measurements for April 24 and May 7, 1996, produced similar results (table 23). Total bedrock losses through the entire reach, which include losses to the Madison Limestone and Minnelusa Formation, as well as possible losses to the Deadwood Formation, were very similar. Losses in individual reaches also were quite similar. On July 1, however, a streamflow gain of 7.5 ft^3/s was measured in the downstream portion of the Madison loss zone, between sites 43 and 44. Streamflow gains within this same reach were slightly larger than 5.0 ft^3/s for subsequent measurements during the remainder of WY96 (table 23).

Streamflow gains across a specific stream reach generally result from tributary inflows or springflow. Increased tributary inflows were not observed within the reach after May 7, 1996; however, extremely wet climatic conditions during the spring and early summer of 1996 provided an opportunity for significant recharge to the large outcrops of the Madison Limestone along Elk Creek. Thus, it is likely that springflow (ground-water discharge) from the Madison is the cause of streamflow gains within the reach. Rahn and Gries (1973) noted springflow within this same reach that averaged about 5 ft^3/s during WY67-70, which also was a very wet period. They also stated that, except for periods of high flow, the channel generally was dry upstream from the spring area. The calculated loss rates to the Minnelusa Formation also decreased slightly subsequent to the measurements made on May 7, 1996 (table 23). Springflow within this reach also is a likely explanation for decreased calculated losses to the Minnelusa.

Because springflow probably had an effect on loss calculations subsequent to May 7, 1996, the individual measurements for April 24 and May 7, 1996, are used to estimate the loss threshold for Elk Creek. Total bedrock losses are estimated to be at least 19 ft^3/s, with individual losses of 11 ft^3/s to the Madison and 8 ft^3/s to the Minnelusa. In each case, the loss threshold may be even larger because of possible springflow within the loss zones.

Additional insights regarding streamflow losses and springflow along Elk Creek can be obtained from examination of streamflow data for sites 46 and 50. Individual measurements during WY94-96 for site 46 are presented in table 24, along with individual measurements or daily mean values for site 39 and daily mean values for site 50, which is a continuous-record station located downstream from the confluence with Little Elk Creek and other smaller tributaries (fig. 27). Direct calculation of streamflow losses using data from the two continuous-record stations (sites 39 and 50) fails to produce meaningful results because of unmeasured tributary inflows within the large intervening drainage area and because of complicated interactions with extensive alluvial deposits, between sites 46 and 50 (table 3). Intermittent springflow upstream from site 50 (Miller and Driscoll, 1998) further complicates loss calculations. Following is a discussion of how streamflow between sites 39 and 50 is affected by tributary inflows, springflow, and alluvial interactions.

Table 24. Calculations of streamflow losses for Elk Creek, water years 1994-96

[ft^3/s, cubic feet per second; ( ), losses between specified sites calculated by performing indicated arithmetic operation; >, potential loss greater than indicated because of zero flow at downstream site]

Date	Upstream station site 39		Intermediate station site 46		Upstream loss[1], in ft^3/s (39 - 46)	Downstream station site 50		Downstream loss[1], in ft^3/s (46 - 50)
	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s		Time, in hours	Flow, in ft^3/s	
5-11-94	1155	37.6	1315	8.37	29.2	--	[2]5.9	2.5
5-18-95	1225	70.2	1103	77.8	-7.6	--	[2]141	-63
7-10-95	--	[2]10	1700	5.21	5	--	[2]32	-27
7-14-95	--	[2]9.8	1200	2.00	7.0	--	[2]34	-32
7-28-95	--	[2]5.8	1200	0	>5.8	--	[2]31	-31
7-22-96	0930	7.35	1400	0	>7.35	--	[2]27	-27

[1]Calculated loss does not account for tributary inflows within reach.
[2]Indicated value for this date is the daily mean.

Streamflow hydrographs for WY93-96 are presented in figure 28 for sites 39 and 50. Individual measurements obtained during WY94-96 for site 46 also are shown in figure 28. Springflow at site 50 was nonexistent during the beginning and ending months of WY93-94 (figs. 28A and 28B). Zero-flow conditions at this site are common during dry years (Miller and Driscoll, 1998).

Flow at the upstream station (site 39) exceeded the approximate bedrock loss threshold of about 20 ft^3/s for several extended periods during May and June of WY93 (fig. 28A); however, most of the flow that may have passed through the Madison and Minnelusa loss zones probably was subsequently lost to alluvial deposits upstream from site 50. Periods when downstream peak flows exceeded upstream peak flows probably resulted primarily from tributary inflow between sites 39 and 50.

Flow at the upstream station (site 39) also exceeded the approximate bedrock loss threshold for an extended period during March through May of WY94 (fig. 28B). Again, most of the flow that may have passed through the bedrock loss zone probably was lost to alluvial storage, considering that various peaks in excess of 20 ft^3/s at the upstream site were not transmitted to the downstream site. An upstream loss of 29.2 ft^3/s is calculated for May 11, 1994 (table 24); however, the validity of this calculation is questionable because of unmeasured tributary inflows, rapidly changing streamflow, and the possibility of losses to the alluvium.

Springflow upstream from site 50 apparently started during November or December of WY95 (fig. 28C). Flow at site 39 generally was less than the approximate bedrock loss threshold through most of April; however, the threshold was exceeded for most of May and June. Alluvial storage probably was satisfied during early May of 1995, concurrent with large peaks at sites 39 and 50. Flow at site 50 generally exceeded flow at site 39 for the remainder of the year. Calculated upstream losses for July 10 and July 14, 1995, were 5 and 7 ft^3/s (table 24), respectively, which is considerably less than the approximate bedrock loss threshold. The occurrence of flow at site 46 for these dates, even when flow at site 39 was well below the estimated threshold, indicates a strong likelihood that springflow probably was occurring in the downstream portion of the Madison loss zone. In addition, zero flow was recorded at site 46 on July 28, 1995, which indicates that all flow at site 50 resulted from springflow or tributary inflow between sites 46 and 50.

Flow at site 50 approached or exceeded 10 ft^3/s for all of WY96 (fig. 28D). Much of this flow occurred during baseflow conditions, when flow at site 39 was less than the approximate bedrock loss threshold of 20 ft^3/s. Peaks in excess of this threshold generally were transmitted to the downstream station, indicating that the alluvial storage capacity remained satisfied during this period. Zero flow was again recorded at site 46 on July 22, 1996. Therefore, flow occurring at site 50 after July 22 probably resulted from springflow between sites 46 and 50.

As previously mentioned, streamflow data for sites 46 and 50 are not useful for improving the estimated threshold for Elk Creek; however, several conclusions can be derived from these data sets. First, the available storage in the alluvial deposits upstream from site 50 is apparently quite large, consistent with alluvial deposits downstream from loss zones in other area streams. Second, springflow, or ground-water discharge, within the Madison loss zone along Elk Creek apparently occurred during WY95, prior to the extensive measurements collected during WY96 (table 24). This springflow seems to decline relatively quickly when dryer conditions occur. Springflow within the loss zone apparently began prior to July 10, 1995 (table 24), and declined between July 10 and July 14, 1995. It cannot be determined if springflow ceased after July 14, because losses to the Minnelusa can approach or exceed 5 ft^3/s (table 23). Thus, there may have been measurable springflow between sites 43 and 44 on July 28, 1995, when zero flow was observed at site 46 (table 24). Furthermore, it is possible that springflow also was occurring within the Madison loss zone on April 24 and May 7, 1996, when losses to the downstream portion of the Madison loss zone were measured (table 23). Thus, total losses to the Madison may be larger than the estimated threshold of 11 ft^3/s (table 23). Finally, springflow between sites 46 and 50 is quite variable (ranging from less than 1.0 to in excess of 10 ft^3/s) and most likely is related to recent recharge conditions. It cannot be determined from this analysis, however, whether springflow between sites 46 and 50 is derived from alluvial sources, bedrock sources, or a combination of both.

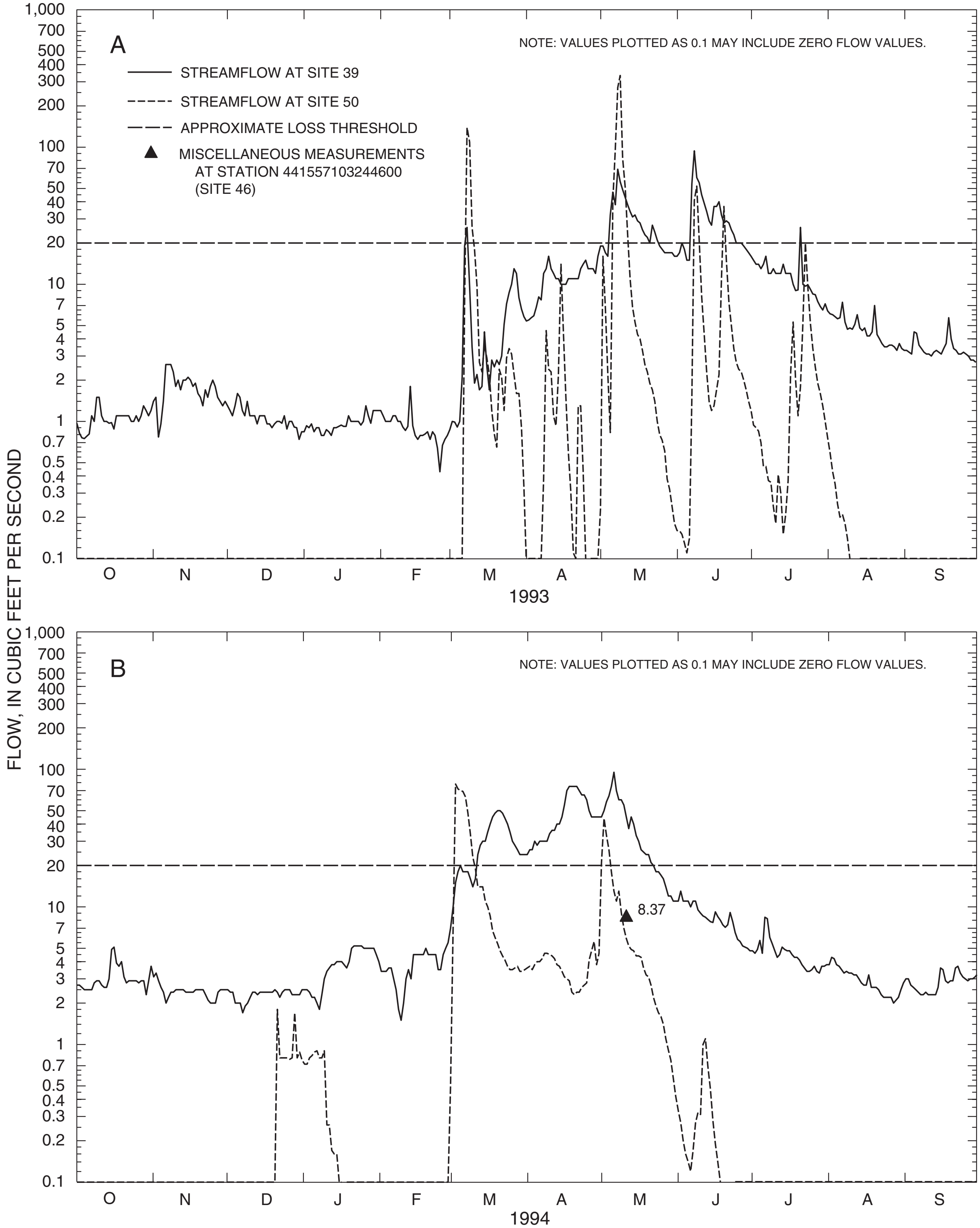


Figure 28. Daily hydrographs and miscellaneous measurements for site 39 (Elk Creek near Roubaix) and site 50 (Elk Creek near Rapid City), water years 1993-96.

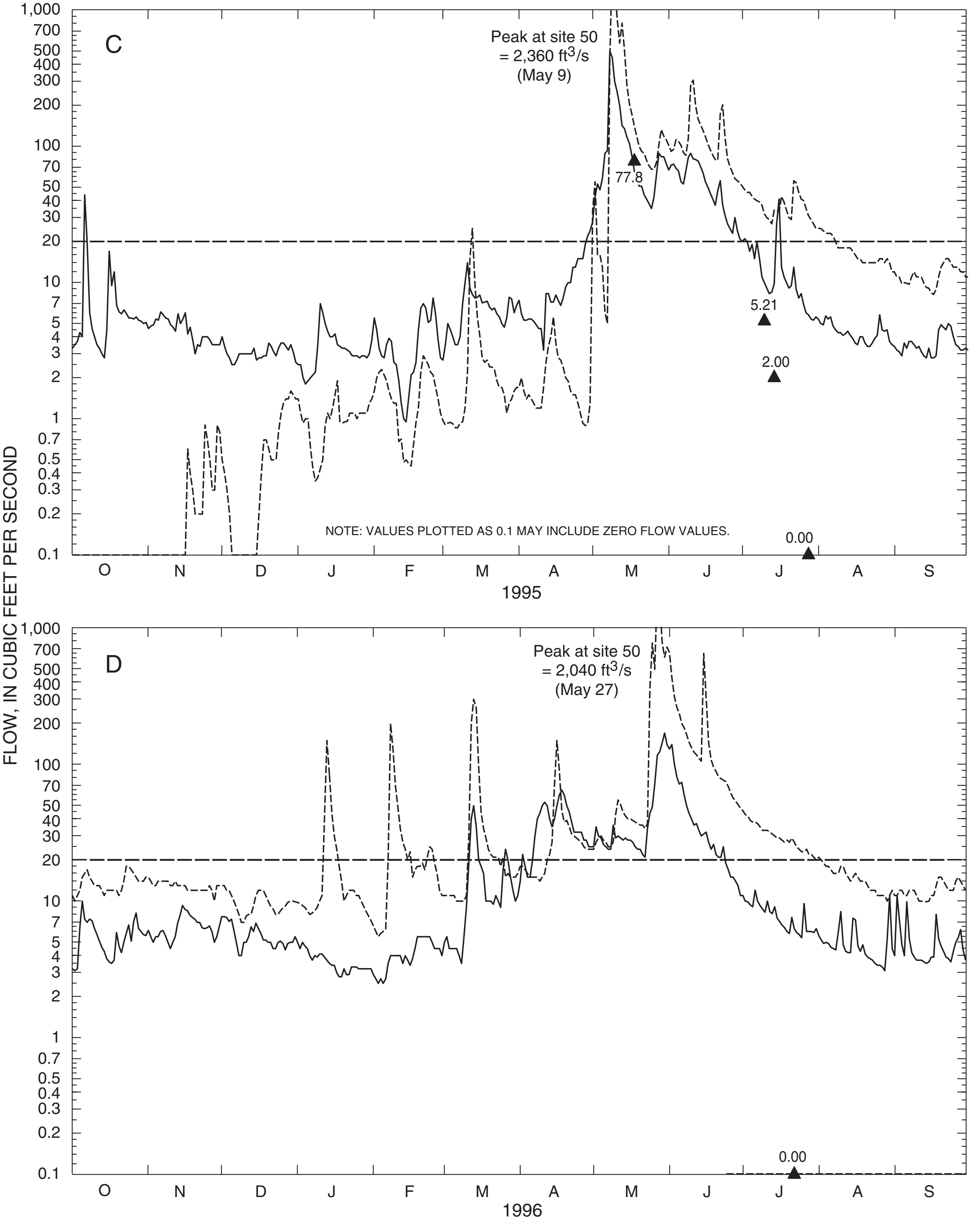


Figure 28. Daily hydrographs and miscellaneous measurements for site 39 (Elk Creek near Roubaix) and site 50 (Elk Creek near Rapid City), water years 1993-96.--Continued

Little Elk Creek

Loss calculations for Little Elk Creek are presented in table 25, which includes measurements for sites 47, 48, and 49 (fig. 27). Losses to the Madison Limestone can be differentiated from losses to the Minnelusa Formation. Calculated losses to the Madison in the upstream reach also may include minor losses to the Deadwood Formation (table 3).

Calculated losses to the Madison for July 8, 1996, probably are not representative of actual losses because of apparent tributary inflows between sites 47 and 48. The calculated loss to the Minnelusa for this date is somewhat larger than losses for other dates, which indicates that tributary inflow probably was not significant within this reach. Using the median values, the following bedrock loss thresholds for Little Elk Creek are estimated: Madison Limestone, 0.7 ft^3/s; Minnelusa Formation, 2.6 ft^3/s; and combined losses to the Madison and Minnelusa, 3.3 ft^3/s.

Redwater River Tributaries

Losses are calculated for four tributaries to the Redwater River (Bear Gulch, Beaver Creek, Spearfish Creek, and False Bottom Creek), as well as two tributaries to Spearfish Creek (Iron Creek and Higgins Gulch). Two continuous-record stations, twenty-two miscellaneous-record stations, and one zero-flow station are located along these streams (fig. 29, table 3)

Bear Gulch

Loss calculations for Bear Gulch are presented in table 26, which includes measurements for sites 51 and 52. Calculated losses in table 26 are combined losses to the Madison Limestone, Minnelusa Formation, and Minnekahta Limestone. Zero flow was recorded at the downstream station (site 52) on three dates during WY95-96 (table 26). Mean and median loss rates of 4.4 ft^3/s and 4.0 ft^3/s are calculated using the remaining measurements. Thus, the bedrock loss threshold for Bear Gulch is estimated to be 4 ft^3/s.

Beaver Creek

Loss calculations for Beaver Creek are presented in table 27, which includes measurements for sites 53 and 55. Also included in table 27 is a single measurement for site 54, which is located approximately 1.0 mi downstream from site 53 and just upstream from the outcrop of Madison Limestone (fig. 29). The single measurement was made to account for tributary inflows that were occurring downstream from site 53 during high-flow conditions on June 2, 1995. Calculated losses in table 27 are combined losses to the Madison Limestone, Minnelusa Formation, and Minnekahta Limestone (table 3).

Zero flow was recorded at the downstream station (site 55) on three of the dates shown in table 27. Mean and median loss rates of 9.4 and 9.1 ft^3/s are calculated using the remaining measurements. Thus, the bedrock loss threshold for Beaver Creek is estimated to be 9 ft^3/s.

Spearfish Creek and Tributaries

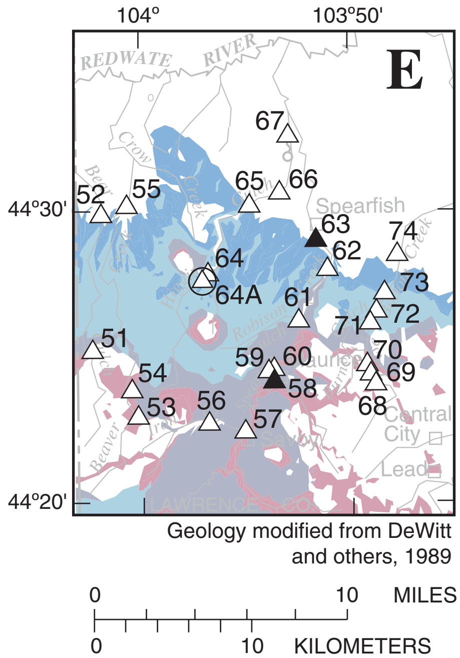
Losses are calculated for Spearfish Creek and two of its tributaries, Iron Creek and Higgins Gulch (fig. 29, table 3). The confluence with Iron Creek is upstream from the loss zone on Spearfish Creek and the confluence with Higgins Gulch is downstream from the loss zone.

Table 25. Calculations of streamflow losses for Little Elk Creek

[ft^3/s, cubic feet per second; ( ), losses between specified sites calculated by performing indicated arithmetic operation]

Date	Upstream station site 47		Intermediate station site 48		Downstream station site 49		Loss to Madison, in ft^3/s (47 - 48)	Loss to Minnelusa, in ft^3/s (48 - 49)	Total loss, in ft^3/s (47 - 49)
	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s			
4-26-96	1351	5.13	1523	4.61	1636	2.13	0.52	2.48	3.00
7-08-96	1110	7.64	1515	9.14	1620	4.68	[1]-1.50	4.46	[1]2.96
7-22-96	0810	6.19	0905	5.22	1015	2.60	.97	2.62	3.59
						Mean loss	.74	3.19	3.30
						Median loss	.74	2.62	3.30

[1]Excluded from calculations of mean and median values because of apparent tributary inflow.



Site Number	Station Name
51	Bear Gulch near Maurice
52	Bear Gulch below Minnekahta outcrop
53	Beaver Creek near Maurice
54	Beaver Creek below Beaver Crossing
55	Beaver Creek below Minnekahta outcrop
56	Iron Creek below Sawmill Gulch
57	Iron Creek near Lead
58	Spearfish Creek above Spearfish
59	Aqueduct Inlet below Maurice
60	Spearfish Creek below Homestake Diversion
61	Spearfish Creek below Robison Gulch
62	Spearfish Creek below Madison outcrop
63	Spearfish Creek at Spearfish
64A	Higgins Gulch above East Fork
64	Higgins Gulch below East Fork
65	Higgins Gulch above Spearfish
66	Higgins Gulch at Spearfish
67	Higgins Gulch below I-90
68	False Bottom Creek above Madison outcrop
69	False Bottom Creek trib (1st West trib)
70	False Bottom Creek trib (2nd West trib)
71	False Bottom Creek below Madison outcrop
72	Burno Gulch above False Bottom Creek
73	False Bottom Creek (below Minnelusa outcrop)
74	False Bottom Creek at I-90

EXPLANATION

DEADWOOD FORMATION

MADISON LIMESTONE

MINNELUSA FORMATION

MINNEKAHTA LIMESTONE

▲63 CONTINUOUS-RECORD STREAM-FLOW-GAGING STATION--Number indicates site number

△64 MISCELLANEOUS-RECORD STREAM-FLOW-GAGING STATION--Number indicates site number

64A ZERO-FLOW STATION--Number indicates site number

Figure 29. Insert E from figure 6, showing location of measurement sites and generalized outcrops for Redwater River tributaries. Outcrops shown may include other formations.

Table 26. Calculations of streamflow losses for Bear Gulch

[ft^3/s, cubic feet per second; ( ), losses between specified sites calculated by performing indicated arithmetic operation; >, potential loss greater than indicated because of zero flow at downstream site]

Date	Upstream station site 51		Downstream station site 52		Total loss, in ft^3/s (51 - 52)
	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s	
6-02-95	1510	24.8	1704	20.6	4.2
6-21-95	1340	7.43	1510	1.85	5.58
7-17-95	1315	2.28	1100	0	>2.28
5-01-96	1200	10.7	1330	6.78	3.9
6-12-96	1520	6.84	1650	3.12	3.72
7-10-96	1530	1.44	1415	0	>1.44
8-27-96	1545	.37	1720	0	>.37
				Mean loss[1]	4.4
				Median loss[1]	4.0

[1]Calculated using finite values only.

Table 27. Calculations of streamflow losses for Beaver Creek

[ft^3/s, cubic feet per second; ( ), losses between specified sites calculated by performing indicated arithmetic operation; --, no data available; >, potential loss greater than indicated because of zero flow at downstream site]

Date	Upstream station site 53		Intermediate station site 54		Downstream station site 55		Total loss, in ft^3/s (53 - 55)
	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s	
6-02-95	0915	18.7	1005	22.4	1251	13.4	[1]9.0
6-21-95	1030	8.32	--	--	1200	.07	8.25
7-17-95	1020	.37	--	--	1400	0	>.37
5-01-96	1520	17.5	--	--	1415	8.32	9.2
6-11-96	1330	11.2	--	--	1415	.15	11.0
7-11-96	1000	2.30	--	--	1410	0	>2.30
8-29-96	1200	1.18	--	--	1300	0	>1.18
						Mean loss[2]	9.4
						Median loss[2]	9.1

[1]Loss calculated as flow at site 54 minus site 55, because of tributary inflows upstream.
[2]Calculated using finite values only.

Iron Creek (tributary)

Loss calculations for Iron Creek (table 28) show a gain of about 1 to 2 ft^3/s between sites 56 and 57. A distinct decrease in streamflow was noted downstream from site 56 on both measurement dates, with zero flow observed on July 19, 1996; however, flow increased farther downstream on both dates. No tributary inflow was observed on either date; thus, it is hypothesized that streamflow gains were a result of springflow (ground-water discharge) within the downstream portion of the reach. It is concluded that Iron Creek is a net discharge zone for the Madison Limestone, rather than a recharge zone.

Spearfish Creek (main stem)

Most of the flow of Spearfish Creek is diverted around the bedrock loss zone, from a diversion dam located about 5 mi south of Spearfish to a power plant located in Spearfish, just upstream from site 63 (fig. 29). Flow in the stream channel upstream from the power plant occurs only when flow at site 58 exceeds both the capacity of the diversion aqueduct and the loss threshold of the creek. Measurements made at sites 58, 59, and 60 provide insights regarding the approximate maximum diversion rate from Spearfish Creek (table 29). On May 10, 1994, measurements were made at sites 58 and 60 (located upstream and downstream from the diversion dam, respectively) indicating a diversion rate of about 116 ft^3/s. On May 18, 1995, a flow of 136 ft^3/s was measured in the aqueduct inlet (site 59), with additional flow bypassing the diversion dam. Thus, the maximum diversion rate is estimated to be in the range of 115 to 135 ft^3/s.

Table 28. Calculations of streamflow losses for Iron Creek

[ft^3/s, cubic feet per second; mi, miles; ( ), losses between specified sites calculated by performing indicated arithmetic operation; u/s, upstream; d/s, downstream]

Date	Upstream station site 56		Downstream station site 57		Total loss, in ft^3/s (56 - 57)	Remarks
	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s		
6-28-96	1415	1.33	1550	2.71	-1.38	Flow estimated as 0.2 to 0.3 ft^3/s about 0.75 mi d/s from site 56
7-19-96	1303	.40	1410	2.20	-1.80	Zero flow observed 0.3 mi d/s from site 56

Table 29. Measurements of streamflow diverted from Spearfish Creek for power plant

[ft^3/s, cubic feet per second; --, no data available]

Date	Above diversion site 58		Diversion inlet site 59		Below diversion site 60		Estimated diversion, in ft^3/s
	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s	
5-10-94	1105	139	--	--	1145	23.1	116
5-18-95	--	--	0815	136	--	--	136

Loss calculations for the main stem of Spearfish Creek are presented in table 30, which includes measurements for sites 61 and 62. Calculated losses are combined losses to the Madison Limestone and Minnelusa Formation (fig. 29, table 3). The calculated loss for April 17, 1996, probably is affected by alluvial losses because flow was just beginning to pass completely through the loss zone. The other three finite loss values are quite consistent and are used to estimate the loss threshold for Spearfish Creek as 21 ft^3/s.

The entire flow of Spearfish Creek, up to the maximum diversion rate, generally is diverted through the aforementioned aqueduct to the power plant. During periods when the entire flow upstream from the diversion dam is diverted, flow at site 61 (located about 2 mi downstream from the diversion dam) results from possible seepage through the diversion dam, tributary inflow, and ground-water discharge within the reach. Numerous discharge measurements for WY89-91, when the upstream diversion threshold was not exceeded, are available for site 61. For these measurements, flow generally ranged from about 2 to 5 ft^3/s, and averaged about 3 ft^3/s (Driscoll and Hayes, 1995).

Bedrock losses also occur within the diversion aqueduct, as shown by an analysis of monthly flow data for sites 58 and 63 for WY89-96 (table 31). Mean and median values are not calculated for April through September because the flow of Spearfish Creek frequently exceeded the maximum diversion rate during these months. The mean and median loss values calculated for October through March are 2.1 and 1.8 ft^3/s, respectively. Thus, the loss threshold within the diversion aqueduct is estimated to be about 2 ft^3/s.

Table 30. Calculations of streamflow losses for the main stem of Spearfish Creek

[ft^3/s, cubic feet per second; ( ), losses between specified sites calculated by performing indicated arithmetic operation; >, potential loss greater than indicated because of zero flow at downstream site]

Date	Upstream station site 61		Downstream station site 62		Total loss, in ft^3/s (61 - 62)	Remarks
	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s		
5-10-94	1300	34.8	1425	15.4	19.4	
5-18-95	1150	107	1245	84.1	23	
4-17-96	1555	42.9	1650	3.39	39.5	Just starting to flow through loss zone
6-04-96	1000	53.8	1100	32.5	21.3	
6-13-96	1435	15.9	1530	0	>15.9	
				Mean loss[1]	21	
				Median loss[1]	21.3	

[1]Calculated using finite values only, excluding the value from April 17, 1996, because of probable alluvial losses.

Table 31. Monthly streamflow and loss values for Spearfish Creek, water years 1989-96

[--, not calculated]

Station	Monthly mean values, in cubic feet per second											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
WY89												
06430900 (site 58)	43.3	41.7	41.4	41.2	39.2	43.8	51.1	71.5	46.5	39.8	41.6	39.1
06431500 (site 63)	40.0	39.9	38.4	33.5	32.6	37.4	43.0	72.5	44.6	38.4	39.2	39.3
Calculated loss	3.3	1.8	3.0	7.7	6.6	6.4	8.1	-1.0	1.9	1.4	2.4	-0.2
WY90												
06430900 (site 58)	38.8	39.2	36.9	37.6	37.4	40.8	58.7	74.7	48.3	37.7	36.7	36.4
06431500 (site 63)	37.2	37.7	35.8	35.9	36.5	39.1	56.8	69.3	45.9	35.2	35.2	36.5
Calculated loss	1.6	1.5	1.1	1.7	0.9	1.7	1.9	5.4	2.4	2.5	1.5	-0.1
WY91												
06430900 (site 58)	36.4	37.2	36.0	38.0	37.9	39.8	47.0	81.7	63.9	43.6	37.8	34.9
06431500 (site 63)	34.6	36.5	30.0	30.8	34.3	35.8	43.6	70.8	63.3	41.0	33.0	34.3
Calculated loss	1.8	0.7	6.0	7.2	3.6	4.0	3.4	10.9	0.6	2.6	4.8	0.6
WY92												
06430900 (site 58)	36.7	41.7	41.4	41.2	37.9	40.8	44.8	45.3	41.4	39.4	35.9	36.0
06431500 (site 63)	39.1	40.8	39.6	38.5	39.2	39.0	45.5	48.7	37.8	35.2	32.9	31.2
Calculated loss	-2.4	0.9	1.8	2.7	-1.3	1.8	-0.7	-3.4	3.6	4.2	3.0	4.8
WY93												
06430900 (site 58)	35.5	37.3	38.3	37.2	37.0	39.5	60.4	81.8	103	53.5	43.9	42.7
06431500 (site 63)	32.1	31.2	32.7	31.4	31.4	36.5	52.1	71.0	74.7	50.1	42.9	43.8
Calculated loss	3.4	6.1	5.6	5.8	5.6	3.0	8.3	10.8	28	3.4	1.0	-1.1
WY94												
06430900 (site 58)	42.5	41.1	44.2	40.5	39.1	51.6	112	114	63.2	64.8	50.4	57.2
06431500 (site 63)	46.8	39.7	40.4	38.1	37.7	49.4	91.9	95.9	54.5	55.5	52.3	55.3
Calculated loss	-4.3	1.4	3.8	2.4	1.4	2.2	20	18	8.7	9.3	-1.9	1.9
WY95												
06430900 (site 58)	67.2	54.1	49.9	47.7	47.8	55.6	65.4	307	123	86.7	72.0	67.0
06431500 (site 63)	75.3	57.1	46.7	45.2	49.7	56.4	60.7	269	110	81.9	63.9	65.0
Calculated loss	-8.1	-3.0	3.2	2.5	-1.9	-0.8	4.7	38	13	4.8	8.1	2.0
WY96												
06430900 (site 58)	72.0	73.7	70.2	63.6	64.1	70.4	125	150	129	84.5	92.1	78.5
06431500 (site 63)	71.3	71.8	68.8	62.8	63.6	68.5	93.2	118	114	74.4	74.1	78.8
Calculated loss	0.7	1.9	1.4	0.8	0.5	1.9	32	32	15	10.1	18.0	-0.3
Mean loss	-0.5	1.4	3.2	3.9	1.9	2.5	--	--	--	--	--	--
Median loss	1.2	1.5	3.1	2.6	1.2	2.1	--	--	--	--	--	--
Mean loss (October through March)	2.1											
Median loss (October through March)	1.8											

In summary, bedrock losses along Spearfish Creek consist of two components. Losses within the diversion aqueduct average about 2 ft^3/s and the total loss threshold for the main stem of Spearfish Creek is estimated to be 21 ft^3/s. Bedrock losses within the main stem typically are much less than this, because most of the flow generally is diverted through the aqueduct. Bedrock losses along the main stem generally are less than 5 ft^3/s, except when upstream flow exceeds the maximum diversion rate (115 to 135 ft^3/s).

Higgins Gulch (tributary)

Streamflow information for Higgins Gulch is presented in table 32, which includes measurements on three dates for sites 64, 65, 66, and 67 (fig. 29). Also included in the table are notations of zero flow at site 64A, Higgins Gulch above East Fork, which is located just upstream from site 64. Individual measurement notes for all three dates also indicate that zero flow occurred at several locations within the reach between sites 64 and 65. Flow generally increased in a downstream direction between sites 64 and 67, with the exception of small decreases between sites 65 and 66 on July 19 and August 6, 1996. Much of the reach between sites 65 and 67 generally is dry; however, the reach immediately upstream from site 67 was previously identified as a perennial spring reach, with measured flows of 3.4 and 7.1 ft^3/s on July 12, 1991, and September 26, 1994, respectively (Driscoll and others, 1996).

It is concluded that no significant streamflow losses occur within Higgins Gulch. It is further concluded that Higgins Gulch is a discharge point for the Minnelusa Formation between sites 64A and 65. Klemp (1995) concluded from geochemical analysis, that springflow just upstream from site 67 probably originates primarily from the Madison Limestone.

Higgins Gulch heads within an outcrop of the Madison Limestone with no drainage area upstream from the Madison. Thus, there is no opportunity for the loss of streamflow that originates upstream from the Madison. Streamflow seldom occurs in the portion of Higgins Gulch located within the Madison outcrop due to lack of runoff, presumably because precipitation rates seldom exceed infiltration rates for the Madison. As an example, no flow was observed in the channel of Higgins Gulch, within the Madison outcrop area, on June 2, 1995, following an extended period of heavy rainfall. In comparison, large flows upstream from the Madison Limestone were measured on the same date in two nearby streams (Bear Gulch, table 26; and Beaver Creek, table 27).

False Bottom Creek

Seven miscellaneous-record stations (sites 68, 69, 70, 71, 72, 73, and 74) are used in the calculation of losses for False Bottom Creek (fig. 29, table 3). Losses to the Madison Limestone, Minnelusa Formation, and Minnekahta Limestone are presented in table 33. Calculated losses to the Madison may include minor losses to the Deadwood Formation and calculated losses to the Minnekahta may include losses to alluvial deposits.

Measurements for May 18, 1995, indicate a gain of about 1 ft^3/s across the Madison Limestone and a loss of about 5 ft^3/s across the Minnelusa Formation. The gain across the Madison on this date probably is a result of unmeasured tributary inflows, in addition to the estimated tributary inflows, resulting from large precipitation amounts during the preceding week. Similarly, it is likely that minor, unmeasured tributary inflows also were occurring within the Minnelusa reach. Thus, measurements for this date are excluded from subsequent calculations of means and medians. Measured flows on two subsequent dates were considerably smaller, with less likelihood of tributary inflows. Thus, combined losses to the Madison and Minnelusa are estimated to be 8.7 ft^3/s, with individual losses of 1.4 and 7.3 ft^3/s, respectively.

Table 32. Streamflow information for Higgins Gulch

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

Date	Zero-flow station[1] site 64A	Upstream station site 64		Intermediate station site 65		Intermediate station site 66		Downstream station site 67	
	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s
6-28-96	0	1245	1.16	0825	3.04	0945	3.11	1030	6.26
7-19-96	0	1200	.64	0840	2.32	0928	2.13	1007	6.88
8-06-96	0	1215	.54	0905	2.04	1245	1.50	1330	6.66

[1]On each measurement date, zero flow was observed at site 64A, which is located at a road crossing about 0.25 mi upstream from site 64.

Table 33. Calculations of streamflow losses for False Bottom Creek

[ft^3/s, cubic feet per second; ( ), losses between specified sites calculated by performing indicated arithmetic operations; est, estimated flow; --, no data available; >, potential loss greater than indicated because of zero flow at downstream site]

Date	Upstream station site 68		Upstream tributary site 69		Upstream tributary site 70		Intermediate station site 71		Upstream tributary site 72	
	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s
5-18-95	1410	26.7	est	1	est	1	1525	29.3	est	2
4-26-96	0845	14.5	1000	0.70	0932	0.21	1025	13.5	1115	2.96
5-14-96	1005	10.8	est	0.3	est	0.1	1200	10.3	est	0.2

Date	Intermediate station site 73		Downstream station site 74		Loss to Madison, in ft^3/s (68 + 69 + 70 -71)	Loss to Minnelusa, in ft^3/s (71 + 72 - 73)	Combined loss to Madison and Minnelusa, in ft^3/s (68 + 69 + 70 + 72 - 73)	Loss to Minnekahta, in ft^3/s (73 - 74)	Total loss, in ft^3/s (68 + 69 + 70 + 72 - 74)
	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s					
5-18-95	1625	26.6	--	--	[1]-1	[1]5	[1]4	--	>4
4-26-96	1200	9.80	est	3	1.9	6.7	8.6	7	15
5-14-96	1315	2.6	1400	0	0.9	7.9	8.8	>2.6	>11.4
				Mean loss[2]	1.4	7.3	8.7	--	--
				Median loss[2]	1.4	7.3	8.7	--	--

[1]Excluded from mean and median loss calculation because of unmeasured tributary inflows.
[2]Calculated excluding values from May 18, 1995.

One measurement is available for calculation of losses to the Minnekahta Limestone; however, the measurement reach between sites 73 and 74 includes extensive alluvial deposits. Thus, the calculated loss of 7 ft^3/s on April 26, 1996, also may include alluvial losses that may be large relative to losses to the Minnekahta. The total bedrock loss threshold for False Bottom Creek is estimated to be about 15 ft^3/s.

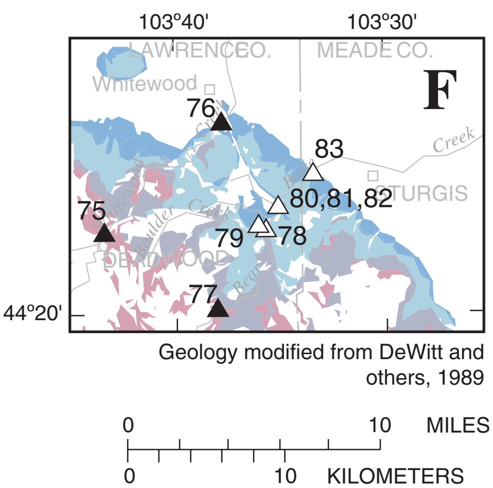
Whitewood Creek

Two continuous-record stations are used to calculate losses for Whitewood Creek (fig. 30, table 3). Monthly flows and calculated losses for both stations (sites 75 and 76) for WY83-95 are presented in table 41 of the Supplemental Information section. Calculated losses in table 41 indicate that Whitewood Creek generally is a gaining stream. The mean and median loss rates for the period of record are both -2 ft^3/s, which indicates a small net gain across the stratigraphic section from the Deadwood Formation through the Minnekahta Limestone. A histogram of calculated monthly loss rates for Whitewood Creek is presented in figure 31. Values used to generate this histogram (table 34) indicate that monthly gains occur about 78 percent of the time and losses occur only about 22 percent of the time.

Table 34. Distribution of monthly losses for Whitewood Creek, water years 1983-95

[ft^3/s, cubic feet per second; Š≥, greater than or equal to; >, greater than]

Calculated monthly loss rate (ft^3/s)	Number of occurrences	Cumulative frequency (percent)
Š≥-5.00	16	10.32
-4.99 to -4.00	5	13.55
-3.99 to -3.00	14	22.58
-2.99 to -2.00	31	42.58
-1.99 to -1.00	33	63.87
-0.99 to 0.00	22	78.06
0.01 to 1.00	11	85.16
1.01 to 2.00	10	91.61
2.01 to 3.00	6	95.48
3.01 to 4.00	1	96.13
4.01 to 5.00	3	98.06
>5.00	3	100.00



Site Number	Station Name
75	Whitewood Creek at Deadwood
76	Whitewood Creek above Whitewood
77	Bear Butte Creek near Deadwood
78	Bear Butte Creek above Boulder Creek
79	Boulder Creek above Bear Butte Creek
80	Bear Butte Creek at Boulder Park
81	Bear Butte Trib No. 1 at Boulder Park
82	Bear Butte Trib No. 2 at Boulder Park
83	Bear Butte Creek above Sturgis

EXPLANATION

DEADWOOD FORMATION

MADISON LIMESTONE

MINNELUSA FORMATION

MINNEKAHTA LIMESTONE

▲77 CONTINUOUS-RECORD STREAMFLOW-GAGING STATION--Number indicates site number

△78 MISCELLANEOUS-RECORD STREAMFLOW-GAGING STATION--Number indicates site number

Figure 30. Insert E from figure 6, showing location of measurement sites and generalized outcrops for Whitewood Creek and Bear Butte Creek. Outcrops shown may include other formations.

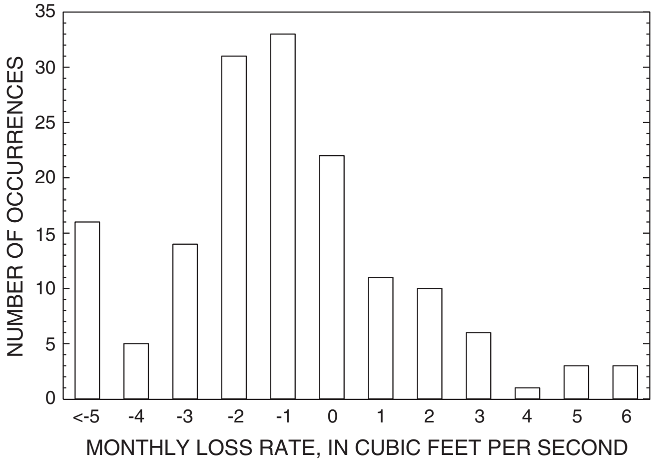


Figure 31. Histogram of monthly loss rates for Whitewood Creek (sites 75-76), water years 1983-95.

Monthly loss rates in table 41 indicate that most losses occur during January to February and July to August. The calculated losses for these months are minor and probably result from ice formation in the winter and evapotranspiration in the summer. Thus, it is concluded that significant losses do not occur to the bedrock units along Whitewood Creek.

There is evidence that Whitewood Creek was a "losing stream" in the late 1800's. Newton and Jenney (1880) observed flow in Whitewood Creek of about 300 miner's inches (approximately 7.5 ft^3/s), that was completely lost near the east edge of present-day Deadwood (fig. 30). Thus, Whitewood Creek apparently changed from a "losing" to a "non-losing" stream sometime between the 1880's and 1980's.

The apparent change in the loss characteristics of Whitewood Creek may have resulted from the extensive gold-mining activity in the area. Goddard (1989) reported that as much as 100 million tons of mill tailings were discharged into Whitewood Creek and its tributaries between 1876 and 1977. These fine-ground mill tailings may have effectively sealed the loss zones along Whitewood Creek.

Bear Butte Creek

One continuous-record and six miscellaneous-record stations are used in the calculation of losses for Bear Butte Creek (fig. 30, table 3). Loss calculations for Bear Butte Creek (table 35) include measurements for sites 77, 78, 79, 80, 81, 82, and 83. Sites 80-82 are located within an outcrop of Minnekahta Limestone that is perched within the Minnelusa section (DeWitt and others, 1989). This small Minnekahta outcrop probably is isolated from the main outcrop of the Minnekahta, which occurs several miles downgradient; thus, these stations are treated as being within the Minnelusa Formation.

Losses are not calculated for May 4, 1994, because tributary inflows were not measured. Calculated losses within each reach are similar for the two remaining dates. Thus, the estimated loss thresholds for Bear Butte Creek are as follows: Madison Limestone, 4 ft^3/s; upstream Minnelusa Formation, 4 ft^3/s; downstream Minnelusa Formation (including possible losses to Minnekahta Limestone), 4 ft^3/s; and total bedrock losses, 12 ft^3/s.

Summary of Losses

A summary of approximate loss thresholds is presented in table 36 for the 24 streams previously discussed. The first and second columns of table 36 list the stream names and bedrock aquifers that are exposed within the entire measurement reach for each stream. The third column lists the approximate threshold for total bedrock losses within the entire measurement reach. The last three columns list individual loss thresholds to the Madison Limestone, Minnelusa Formation, and Minnekahta Limestone.

Previous investigators have identified the Madison Limestone and Minnelusa Formation as the primary bedrock outcrops to which streamflow losses occur. The "total loss" thresholds listed in table 36, with several exceptions, occur primarily to the Madison or Minnelusa. Loss thresholds to the Minnekahta Limestone are estimated for Spring Creek, Boxelder Creek, and False Bottom Creek; however, these losses may include large losses to extensive alluvial deposits. Losses to the Minnekahta Limestone are difficult to isolate from losses to extensive alluvial deposits that commonly occur near outcrops of the Minnekahta. Because the total thickness of the Minnekahta is only about 20-40 ft (fig. 2), outcrops generally occur over relatively short stream reaches and are difficult to bracket with measurement sites. Loss thresholds for the other 21 streams listed in table 36 also may include alluvial losses, which are assumed to be small relative to bedrock losses, based on field observations by the authors.

Table 35. Calculations of streamflow losses for Bear Butte Creek

[ft^3/s, cubic feet per second; ( ), losses between specified sites calculated by performing indicated arithmetic operations; u/s, upstream; d/s, downstream; --, no data available]

Date	Upstream station site 77		Intermediate station site 78		Upstream tributary site 79		Intermediate station site 80		Upstream tributary site 81	
	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s
5-04-94	--	63	--	--	--	--	--	--	--	--
4-25-96	0725	29.0	1155	25.1	1105	5.68	1410	25.4	1320	1.40
5-07-96	1235	19.2	1020	15.4	1115	1.40	1245	14.0	1150	0.84

Date	Upstream tributary site 82		Downstream station site 83		Loss to Madison, in ft^3/s (77 - 78)	Loss to u/s Minnelusa, in ft^3/s (78 + 79 - 80)	Loss to d/s Minnelusa[1], in ft^3/s (80 + 81 + 82 - 83)	Total loss to Minnelusa[1], in ft^3/s (78 + 79 + 81 + 82 - 83)	Total loss, in ft^3/s (77 + 79 + 81 + 82 - 83)
	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s					
5-04-94	--	--	1345	80.4	--	--	--	--	--
4-25-96	1340	1.32	1505	24.6	3.9	5.4	3.5	8.9	12.8
5-07-96	1215	0.99	1340	11.0	3.8	2.8	4.8	7.6	11.4
				Mean loss	3.8	4.1	4.2	8.2	12.1
				Median loss	3.8	4.1	4.2	8.2	12.1

[1]May include losses to the Minnekahta Limestone.

Table 36. Summary of approximate loss thresholds from Black Hills streams to bedrock aquifers

[ft^3/s, cubic feet per second; --, data not available; e, estimated; >, greater than; <, less than; Ddwd, Deadwood Formation; Mdsn, Madison Limestone; Mnls, Minnelusa Formation; Mnkt, Minnekahta Limestone]

Stream name	Bedrock aquifers within measurement reach	Approximate loss thresholds to bedrock aquifers (ft^3/s)			
		Total loss	Mdsn loss	Mnls loss	Mnkt loss
Beaver Creek[1]	Ddwd[2], Mdsn, Mnls, Mnkt	5	--	--	--
Reaves Gulch	Ddwd[2], Mdsn	>.2	>0.2	--	--
Highland Creek	Ddwd[2], Mdsn, Mnls, Mnkt	e10	--	--	--
South Fork Lame Johnny Creek[3]	Ddwd, Mdsn, Mnls, Mnkt[2]	1.4	--	--	--
North Fork Lame Johnny Creek	Ddwd, Mdsn	2.3	--	--	--
French Creek	Ddwd[2], Mdsn, Mnls, Mnkt[2]	15	11	4	--
Battle Creek	Ddwd[2], Mdsn	12	12	--	--
Grace Coolidge Creek	Ddwd[2], Mdsn, Mnls	21	18	3	--
Bear Gulch[1]	Ddwd[2], Mdsn	.4	--	--	--
Spokane Creek	Ddwd, Mdsn, Mnls, Mnkt	2.2	--	--	--
Spring Creek	Mdsn, Mnls, Mnkt	28	21	3	4
Rapid Creek	Ddwd[2], Mdsn, Mnls	10	--	--	--
Victoria Creek	Ddwd, Mdsn	1.0	--	--	--
Boxelder Creek	Mdsn, Mnls, Mnkt	50	>25	<20	<5
Elk Creek	Ddwd, Mdsn, Mnls, Mnkt[2]	19	11	8	--
Little Elk Creek	Ddwd[2], Mdsn, Mnls, Mnkt[2]	3.3	.7	2.6	--
Bear Gulch[4]	Ddwd[2], Mdsn, Mnls, Mnkt	4	--	--	--
Beaver Creek[4]	Ddwd[2], Mdsn, Mnls, Mnkt	9	--	--	--
Iron Creek	Ddwd[2], Mdsn	0	--	--	--
Spearfish Creek	Ddwd[2], Mdsn, Mnls	[5]23	--	--	--
Higgins Gulch	Mnls, Mnkt[2]	0	--	0	0
False Bottom Creek	Ddwd[2], Mdsn, Mnls, Mnkt	e15	1.4	7.2	e7
Whitewood Creek	Ddwd[2], Mdsn, Mnls, Mnkt[2]	0	--	--	--
Bear Butte Creek	Ddwd[2], Mdsn, Mnls, Mnkt[2]	12	4	8	--

[1]Located in southern Black Hills.
[2]Only part of outcrop is located within measurement reach.
[3]Includes Flynn Creek.
[4]Located in northern Black Hills.
[5]Includes thresholds of 21 ft^3/s in the main-stem channel and 2 ft^3/s in the diversion aqueduct.

Most of the stream reaches considered include outcrops of the Deadwood Formation (table 36). Many of the upstream measurement sites are located immediately upstream from the outcrop of the Madison Limestone; however, in some cases the entire Deadwood section is included within the measurement reach. Streamflow measurements indicate that losses to the Deadwood Formation are minimal along Boxelder Creek (table 21). Qualitative information for several other streams also indicates that losses to the Deadwood probably are minimal. Meadow Creek (tributary to Elk Creek) and Little Elk Creek both have relatively long stream reaches within outcrops of the Deadwood (fig. 27). Both streams have perennial, or nearly perennial flow within the Deadwood reaches and field observations have indicated no apparent loss zones. Similarly, the channel of Spearfish Creek is incised into the Deadwood Formation for many miles upstream from the outcrop of the Madison Limestone (fig. 29). Streamflow records for several gaging stations along upper Spearfish Creek and its tributaries (not considered within this report) indicate that streamflow gains consistently occur. Thus, it is concluded that streamflow losses to the Deadwood Formation generally are minimal.

FACTORS AFFECTING LOSS RATES

Previous investigators have offered various hypotheses regarding factors that may affect streamflow losses to bedrock outcrops. Gries (1969) hypothesized that loss rates may be proportional to the rate of streamflow. Crooks (1968) and Gries (1969) also hypothesized that loss rates may decrease after extended periods of flow across a loss zone. Potential effects of flow rate and duration of flow are discussed in the following sections for selected streams for which relevant data are available.

South Fork Lame Johnny Creek (including Flynn Creek)

Although few flow measurements are available for the South Fork of Lame Johnny Creek and Flynn Creek (table 8), the limited evidence indicates that loss rates are not affected by the flow rate or duration of flow. Measured flows downstream from the loss zone (site 8) ranged from 1.20 to 30.9 ft^3/s, while calculated losses ranged from only 0.63 to 3.44 ft^3/s. Because the smallest and largest losses both were associated with the higher flow rates, there is little indication that loss rates are affected by the flow rate. In addition, various reports from several observers and hydrographers indicate that the South Fork of Lame Johnny Creek flowed nearly continuously through the loss zone from June 1995, through May 1996; however, available measurement data (table 8) provides no indication that the loss rate decreased during this time. Thus, it is concluded that losses on South Fork Lame Johnny Creek and Flynn Creek are not measurably affected by flow rate or duration of flow through the loss zone.

French Creek

Hydrographs of daily streamflow for site 11 are presented in figure 32. Hydrographs are presented for selected water years with sustained periods of high flow, for which multiple individual measurements of losses are available. Measured losses for specific dates (table 10), as well as the approximate loss threshold of 15 ft^3/s for French Creek, also are shown in figure 32. Measured loss rates during WY91 decrease with time; however, measured losses for WY84, 93, 95, and 96 are nearly constant during extended periods of flow through the loss zone. It also is evident that, with the possible exception of WY91, measured losses are independent of upstream flow. Thus, considering all of the available data collectively, it is concluded that loss rates for French Creek generally are unaffected by flow rate or duration of flow.

Battle Creek

A hydrograph of daily streamflow for WY96 for site 14 is presented in figure 33. Measured losses to the Madison Limestone for specific dates and the estimated loss threshold to the Madison (table 11) also are shown. WY96 is the only period for which multiple measurements of losses to the Madison Limestone along Battle Creek are available. The first three measured losses are very near the approximate threshold of 12 ft^3/s; however, the fourth measured loss for WY96 is slightly lower, at about 10 ft^3/s. Thus, with the exception of the fourth measurement, loss rates probably are not affected by flow rate or duration of flow. Because flow at the upstream station was less than the approximate threshold for the fourth measurement, it is possible that there may be a narrow flow range for which the loss threshold is smaller.

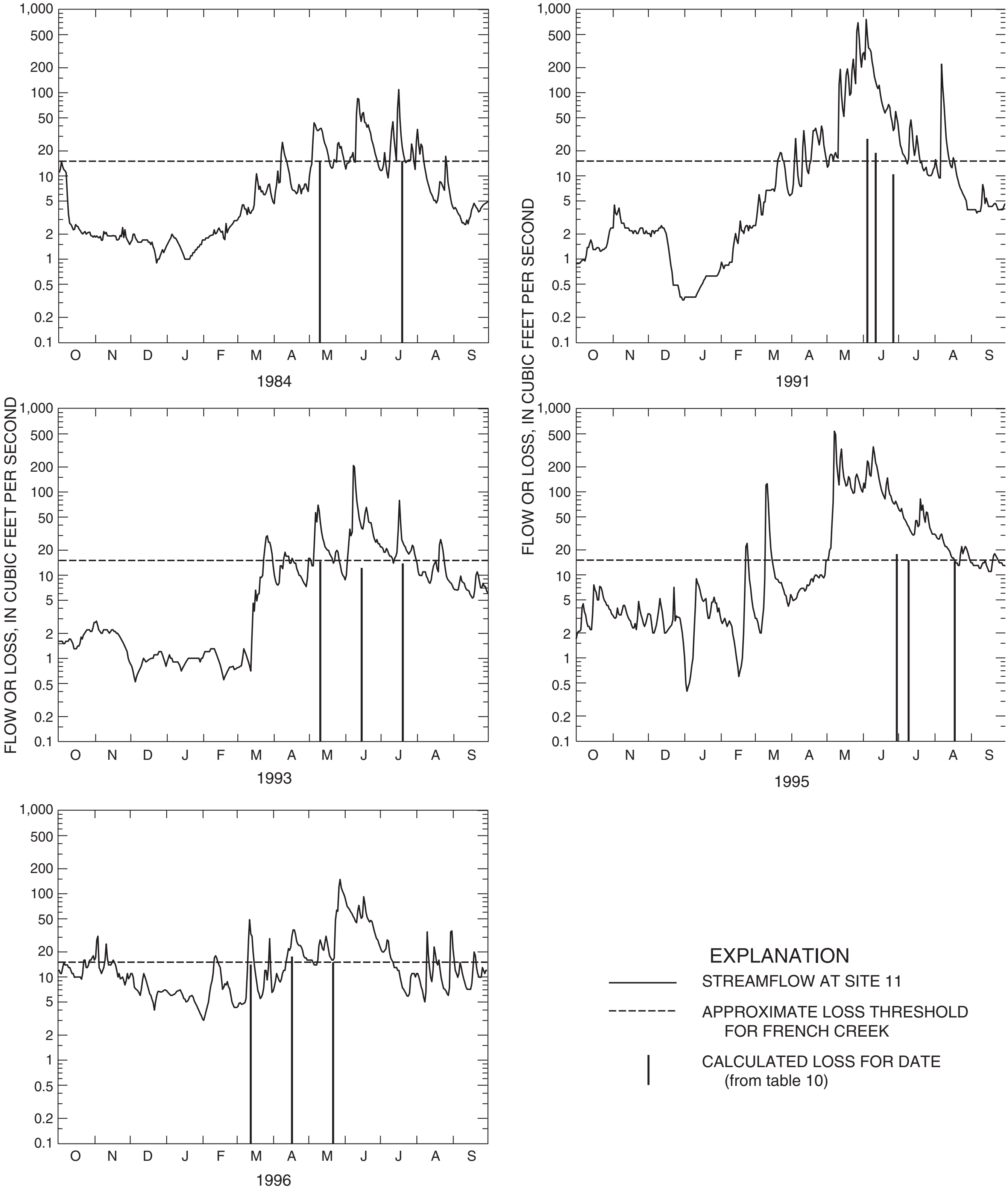


Figure 32. Daily hydrographs for site 11 (French Creek near Fairburn), relative to calculated losses (sites 11-13) for selected water years.

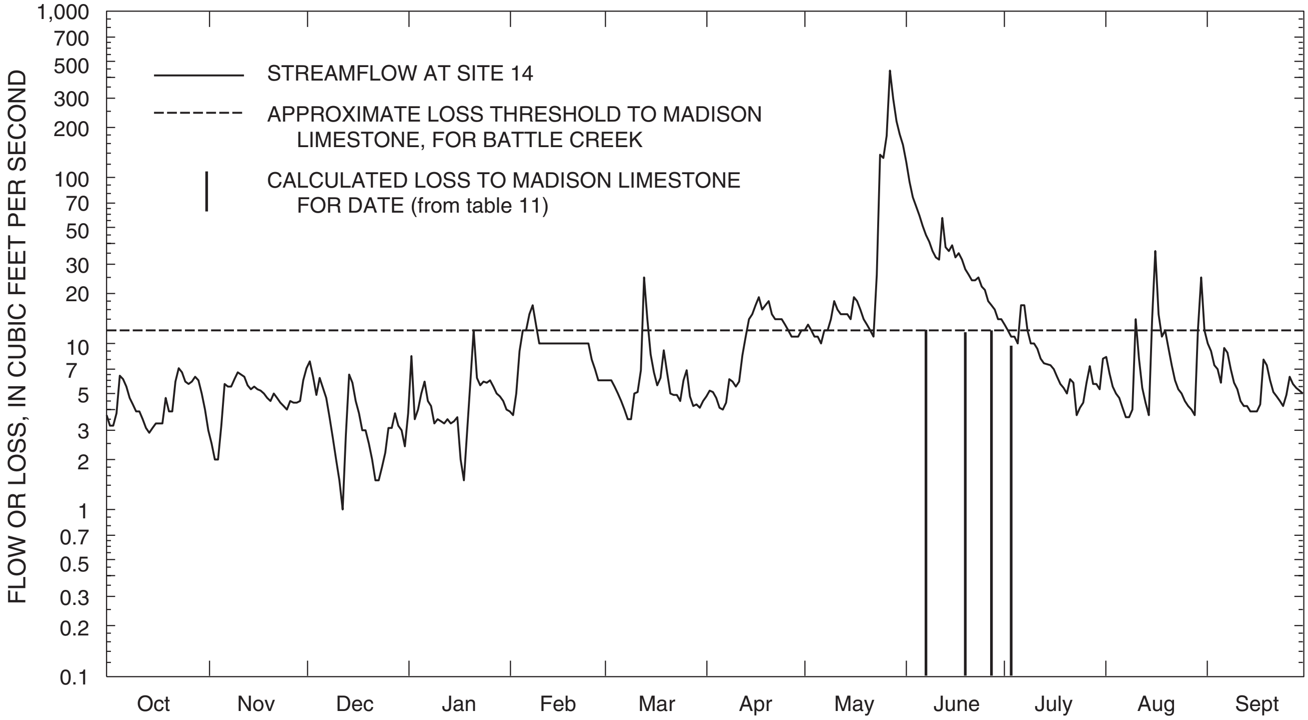


Figure 33. Daily hydrographs for site 14 (Battle Creek near Keystone), relative to calculated losses to the Madison Limestone (sites 14-15), water year 1996.

Grace Coolidge Creek

A hydrograph of daily streamflow for WY96 for site 17 is presented in figure 34. Measured losses to the Madison Limestone for specific dates and the approximate loss threshold to the Madison (table 12) also are shown. WY96 is the only water year for which more than two finite loss calculations to the Madison Limestone along Grace Coolidge Creek are available. Although measured losses during WY96 are somewhat variable, there is insufficient evidence to conclude that loss rates to the Madison Limestone along Grace Coolidge Creek are affected by flow rate or duration of flow.

As discussed in a previous section on Grace Coolidge Creek, measured losses during WY90-95 are significantly smaller than during WY78 (table 13) and WY96 (table 12). The apparent change in loss rates during WY90-95 probably resulted from deposition of large quantities of fine-grained sediment mobilized after the Galena Fire, as previously discussed.

Measured losses to the Madison Limestone for WY90-95 (table 12) are plotted in figure 35 as a function of flow at site 17. The losses are quite variable, ranging from 4.6 to 10.3 ft^3/s, and cannot be related to flow rate with a regression line. Thus, there is no evidence that loss rates to the Madison along Grace Coolidge Creek during WY90-95 were affected by upstream flow rates.

Spring Creek

A hydrograph of daily streamflow for site 24 for WY96, measured losses used in calculation of the mean and median values (table 16), and the approximate bedrock loss threshold of 28 ft^3/s are presented in figure 36. The first three measured losses for WY96 are very similar to the approximate loss threshold; the fourth measured loss of 23.7 ft^3/s on August 19 is slightly smaller. The smaller loss rate on August 19 probably can be attributed to effects of changes in channel or alluvial storage associated with attenuation of a small peak at site 24 during August 16-20 (fig. 18). Thus, it is concluded that loss rates are unaffected by duration of flow through the loss zone area.

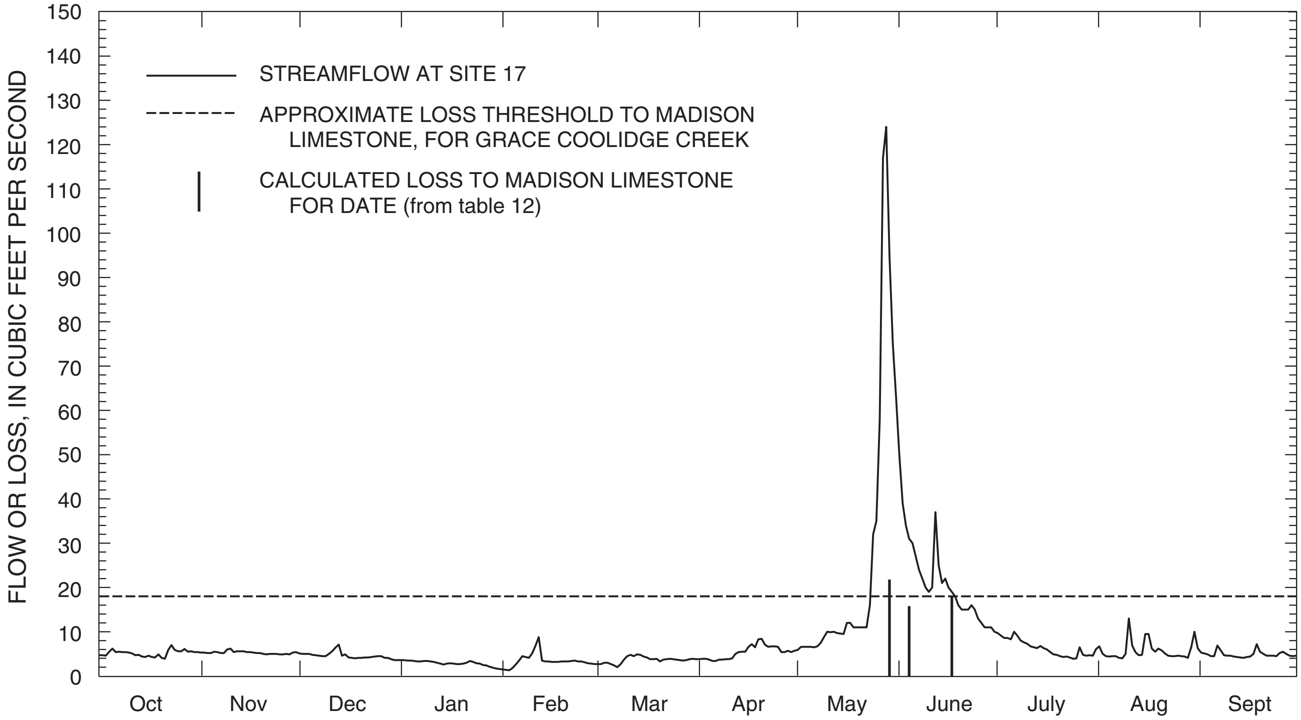


Figure 34. Daily hydrographs for site 17 (Grace Coolidge Creek near Game Lodge), relative to calculated losses to the Madison Limestone (sites 17-18), water year 1996.

Total bedrock loss values for Spring Creek are plotted in figure 37, as a function of streamflow at site 24. Figure 37 includes all losses used in the calculation of mean and median loss values (table 16). The linear regression line has a small, positive slope, which results primarily from an anomalously large loss value of 46 ft^3/s measured on May 14, 1993. Thus, it is concluded that bedrock losses for Spring Creek generally are not affected by upstream flow rates.

Rapid Creek

Monthly streamflow losses for Rapid Creek between sites 30 and 33 for WY89-96 were presented previously in figure 23. Monthly losses during WY89-92 generally were about 10 ft^3/s; however, losses during WY93-96 generally were about 8 ft^3/s, except during periods affected by tributary inflows. As discussed in the previous section on Rapid Creek, precipitation within the Rapid Creek drainage was larger during WY93-96 than during WY89-92, which probably resulted in increased springflow and increased tributary inflow. Thus, the apparent decrease in loss rate for Rapid Creek, which flows nearly continuously through its loss zone, probably is unrelated to duration of flow.

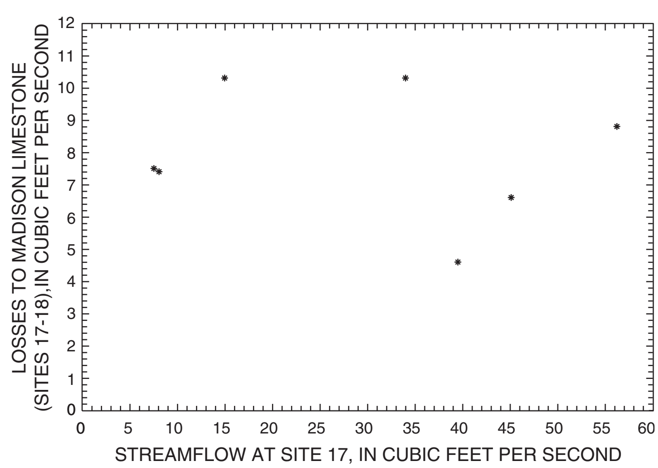


Figure 35. Calculated losses to the Madison Limestone for Grace Coolidge Creek (sites 17-18), as a function of streamflow at site 17, water years 1990-95.

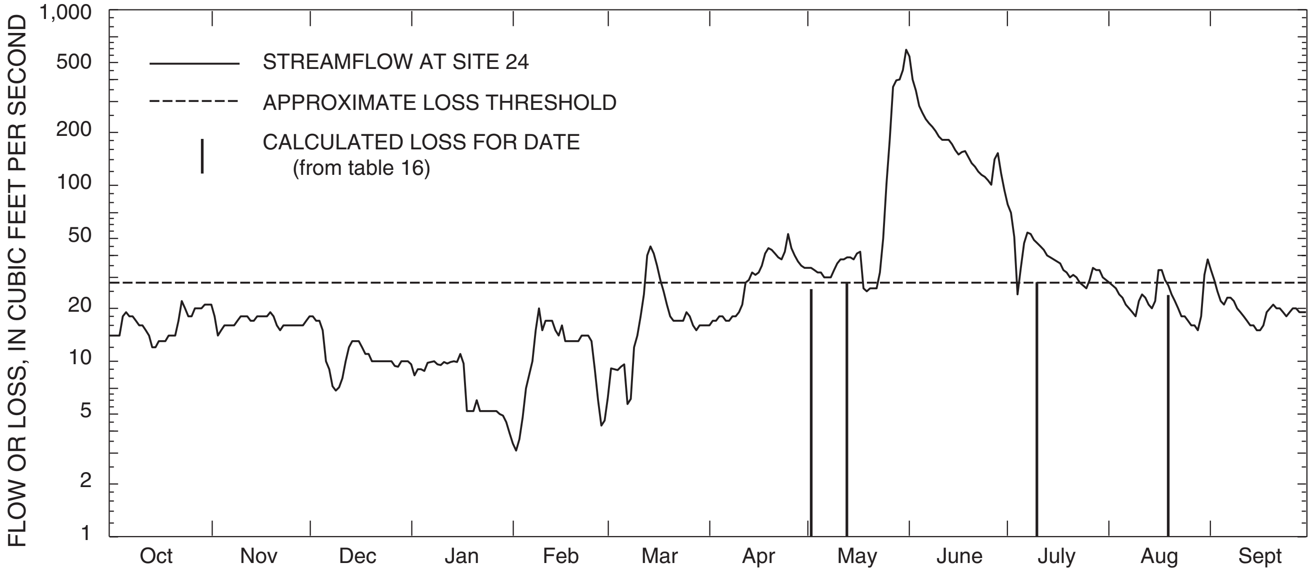


Figure 36. Daily hydrographs for site 24 (Spring Creek near Keystone), relative to calculated losses (sites 17-18), water year 1996.

Monthly losses for Rapid Creek were previously shown to be inversely related to streamflow (fig. 21). Annual loss rates generally decrease during periods of increased precipitation (fig. 20) because of increased tributary inflow and ground-water discharge. Calculated monthly losses and streamflow (fig. 21) are poorly related ($r^2 = 0.39$) because streamflow is controlled by releases from Pactola Reservoir. Although calculated losses are somewhat related to flow rate, the actual bedrock loss rate does not appear to be affected by streamflow of Rapid Creek.

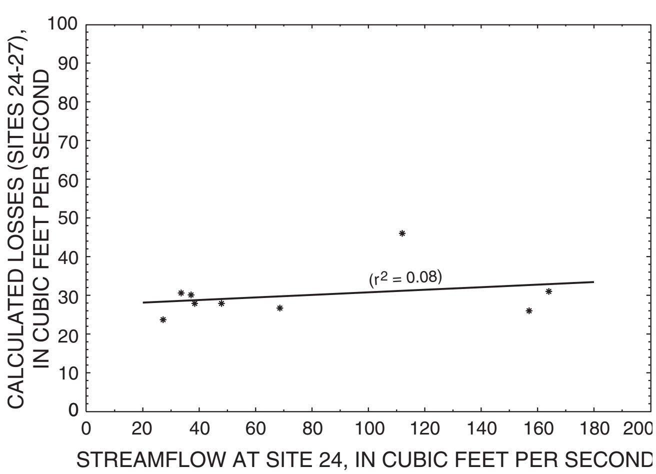


Figure 37. Calculated losses for Spring Creek (sites 24-27), as a function of streamflow at site 24 (Spring Creek near Keystone).

Boxelder Creek and Elk Creek

As discussed in previous sections, springflow is known to occur within the outcrops of the Madison Limestone and Minnelusa Formation along both Boxelder Creek and Elk Creek. In the case of both streams, streamflow gains have been observed across various subreaches, which shows that ground-water discharge (springflow) within a loss zone can have a significant effect on calculated loss rates. Although calculated (net) loss rates are shown to decrease as a result of springflow during prolonged, wet climatic conditions, it has not been determined whether actual loss rates decrease as well. Stream reaches with large adjacent outcrops of the Madison Limestone and Minnelusa Formation, such as Boxelder Creek and Elk Creek, have potential for large springflow within the loss zones, because of large potential for localized recharge from precipitation.

Summary of Factors

Considering information for all stream reaches collectively, it is concluded that bedrock losses generally are not measurably affected by flow rates or duration of flow through loss zones. Calculated losses for measurements made during high-flow conditions generally have larger variability than calculated losses during low-flow conditions; however, consistent relations between loss rates and flow rates have not been identified. Some of this variability probably results from decreased measurement accuracy during high flows. Additional variability also can be caused by tributary inflows and changes in channel and alluvial storage that may occur during high-flow conditions.

Calculated loss rates are shown to decrease, in some cases, during periods of extended flow through loss zones. Decreased (net) loss rates, however, generally can be attributed to springflow within a loss zone, which occurs during prolonged periods of wet climatic conditions. Stream reaches with large adjacent outcrops of the Madison Limestone and Minnelusa Formation, which have large potential for localized recharge, have the greatest potential for large springflow within loss zones. Rapid Creek provides additional evidence that effects of localized recharge on adjacent outcrop areas may be a larger factor than duration of flow through a loss zone. Rapid Creek flows nearly continuously through its loss zone; however, the loss rate in Rapid Creek is relatively constant. Although outcrop areas of the Madison and Minnelusa adjacent to Rapid Creek are small, relative to Boxelder Creek and Elk Creek, slight decreases in the net loss rate for Rapid Creek are discernible during prolonged periods of wet climatic conditions.

SUMMARY AND CONCLUSIONS

Losses occur in numerous streams that cross outcrops of various sedimentary rocks that are exposed around the periphery of the Black Hills of South Dakota. These streamflow losses are recognized as an important source of local recharge to regional bedrock aquifers. Most streams lose all of their flow up to some threshold rate. When streamflow exceeds this threshold, flow is maintained through loss zones located within bedrock outcrops. Streamflow records for 86 measurement sites are used to determine bedrock loss thresholds for 24 area streams, which have individual loss thresholds that range from negligible (no loss) to as much as 50 ft^3/s. Loss thresholds generally are shown to be relatively constant, without measurable effects from flow rate or duration of flow through loss zones.

Although most losses occur within outcrops of the Madison Limestone and Minnelusa Formation, small losses may occur to other bedrock outcrops. It is concluded that losses to the Deadwood Formation probably are minimal. Losses to the Minnekahta Limestone generally are small, relative to losses to the Madison and Minnelusa; however, they are difficult to quantify because of potential losses to extensive alluvial deposits that commonly are located near Minnekahta outcrops. Potential losses to aquifers in the Inyan Kara Group were not investigated.

Streamflow losses are calculated by subtracting downstream flow from upstream flow (plus inflows, when applicable), which yields a positive residual for net losses. Several variables can affect loss calculations; however, the effects of many of these variables generally are small relative to streamflow losses that may occur to bedrock outcrops. Differences between alluvial inflows and outflows are assumed to be negligible. This assumption generally is valid, except for streams in which the extent of alluvial deposits varies significantly from upstream to downstream. A larger potential source of error is the inability to distinguish bedrock losses from losses to alluvial deposits. Losses that occur when initially filling unsaturated alluvial deposits downstream from loss zones can be especially large, with documented losses to alluvial deposits in the range of tens of cubic feet per second and storage capacities in the range of hundreds of acre-feet. The inability to account for tributary inflow, springflow, and changes in channel and alluvial storage also can cause large errors in calculations of bedrock losses.

Although bedrock loss thresholds are concluded to be relatively constant, losses calculated using individual measurements or flow records for any given stream can exhibit considerable variability. Most of this variability probably results from an inability to accurately account for all of the variables involved. Calculated losses for long stream reaches, especially those with extensive alluvial deposits, generally have the largest variability. It also is evident that calculated losses for measurements made during high-flow conditions have larger variability than calculated losses for low-flow conditions; however, consistent relations between losses and streamflow have not been identified. Calculated losses are shown to decrease, in some cases, during periods of extended flow through loss zones; however, this decrease generally can be attributed to springflow (ground-water discharge) within a loss zone, which may occur during prolonged periods of wet climatic conditions. In several cases, streamflow gains are documented that can be attributed to springflow within loss zones. Stream reaches with large adjacent outcrops of the Madison Limestone and Minnelusa Formation, which have large potential for localized recharge, are shown to have the greatest potential for large springflow within loss zones.

Changes in loss thresholds that have resulted from changes in channel conditions are documented for three streams. The loss threshold for Grace Coolidge Creek probably was reduced by deposition of large quantities of fine-grained sediment mobilized after the Galena Fire, which occurred during July 1988. Streamflow losses along Spring Creek apparently were temporarily reduced as a result of efforts to seal the channel with bentonite and rocks during 1937-40. Historic accounts by Newton and Jenney (1880) document losses on Whitewood Creek that no longer occur, possibly as a result of deposition of mine tailings into Whitewood Creek.

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SUPPLEMENTAL INFORMATION

Table 37. Daily flow data, in cubic feet per second, used in estimation of losses for Highland Creek

[ft^3/s, cubic feet per second; ( ), values calculated by performing indicated arithmetic operation]

Date	(1) Flow at site 5	(2) Estimated bedrock springflow	(3) Calculated flow above spring (col. 1 - col. 2)	(4) Flow at site 1	(5) Beaver Creek flow below loss zone (col. 4 - 5 ft^3/s)	(6) Estimated tributary inflow (col. 3 - col. 5)	(7) Estimated flow at site 4
5-1-95	11	11	0	3.1	0	0	2
5-2-95	11	11	0	3.4	0	0	3
5-3-95	10	10	0	3.9	0	0	3
5-4-95	10	10	0	4.9	0	0	3
5-5-95	11	11	0	4.9	0	0	3
5-6-95	11	11	0	5.4	0	-0	3
5-7-95	11	11	0	6.4	1	-1	4
5-8-95	12	12	0	6.6	2	-2	4
5-9-95	11	11	0	6.3	1	-1	4
5-10-95	11	11	0	8.1	3	-3	4
5-11-95	11	11	0	9.9	5	-5	5
5-12-95	11	11	0	11	6	-6	6
5-13-95	12	12	0	8.2	3	-3	4
5-14-95	11	11	0	8.8	4	-4	5
5-15-95	11	11	0	13	8	-8	6
5-16-95	11	11	0	12	7	-7	6
5-17-95	11	11	0	10	5	-5	5
5-18-95	11	11	0	12	7	-7	6
5-19-95	11	11	0	12	7	-7	6
5-20-95	11	11	0	13	8	-8	6
5-21-95	11	11	0	18	13	-13	8
5-22-95	11	11	0	14	9	-9	7
5-23-95	11	11	0	13	8	-8	6
5-24-95	11	11	0	15	10	-10	7
5-25-95	11	11	0	15	10	-10	7
5-26-95	12	12	0	18	13	-13	8
5-27-95	11	11	0	17	12	-12	8
5-28-95	11	11	0	19	14	-14	8
5-29-95	11	11	0	21	16	-16	9
5-30-95	11	11	0	25	20	-20	11
5-31-95	11	11	0	26	21	-21	11
6-1-95	11	11	0	29	24	-24	12
6-2-95	11	11	0	33	28	-28	14
6-3-95	12	12	0	30	25	-25	12
6-4-95	13	13	0	28	23	-23	12
6-5-95	12	12	0	31	26	-26	13
6-6-95	12	12	0	36	31	-31	15

Table 37. Daily flow data, in cubic feet per second, used in estimation of losses for Highland Creek —Continued

[ft^3/s, cubic feet per second; ( ), values calculated by performing indicated arithmetic operation]

Date	(1) Flow at site 5	(2) Estimated bedrock springflow	(3) Calculated flow above spring (col. 1 - col. 2)	(4) Flow at site 1	(5) Beaver Creek flow below loss zone (col. 4 - 5 ft^3/s)	(6) Estimated tributary inflow (col. 3 - col. 5)	(7) Estimated flow at site 4
6-7-95	12	12	0	33	28	-28	14
6-8-95	12	12	0	34	29	-29	14
6-9-95	14	14	0	61	56	-56	24
6-10-95	47	16	31	85	80	-49	33
6-11-95	45	16	29	71	66	-37	28
6-12-95	42	16	26	59	54	-28	23
6-13-95	42	16	26	52	47	-21	21
6-14-95	41	16	25	45	40	-15	18
6-15-95	39	16	23	37	32	-9	15
6-16-95	36	16	20	33	28	-8	14
6-17-95	35	16	19	30	25	-6	12
6-18-95	33	16	17	27	22	-5	11
6-19-95	32	16	16	25	20	-4	11
6-20-95	30	16	14	23	18	-4	10
6-21-95	33	16	17	24	19	-2	10
6-22-95	41	16	25	36	31	-6	15
6-23-95	41	16	25	31	26	-1	13
6-24-95	38	16	22	27	22	0	11
6-25-95	40	16	24	30	25	-1	12
6-26-95	36	16	20	23	18	2	10
6-27-95	33	16	17	21	16	1	9
6-28-95	35	16	19	26	21	-2	11
6-29-95	40	16	24	31	26	-2	13
6-30-95	37	16	21	24	19	2	10
7-1-95	33	16	17	21	16	1	9
7-2-95	31	16	15	20	15	0	9
7-3-95	32	16	16	20	15	1	9
7-4-95	29	16	13	19	14	-1	8
7-5-95	28	16	12	17	12	0	8
7-6-95	26	16	10	16	11	-1	7
7-7-95	25	16	9	15	10	-1	7
7-8-95	24	16	8	15	10	-2	7
7-9-95	23	16	7	14	9	-2	7
7-10-95	23	16	7	14	9	-2	7
7-11-95	22	16	6	13	8	-2	6
7-12-95	22	16	6	13	8	-2	6
7-13-95	22	16	6	13	8	-2	6

Table 37. Daily flow data, in cubic feet per second, used in estimation of losses for Highland Creek —Continued

[ft^3/s, cubic feet per second; ( ), values calculated by performing indicated arithmetic operation]

Date	(1) Flow at site 5	(2) Estimated bedrock springflow	(3) Calculated flow above spring (col. 1 - col. 2)	(4) Flow at site 1	(5) Beaver Creek flow below loss zone (col. 4 - 5 ft^3/s)	(6) Estimated tributary inflow (col. 3 - col. 5)	(7) Estimated flow at site 4
7-14-95	22	16	6	13	8	-2	6
7-15-95	22	16	6	13	8	-2	6
7-16-95	28	16	12	19	14	-2	8
7-17-95	28	16	12	21	16	-4	9
7-18-95	27	16	11	18	13	-2	8
7-19-95	27	16	11	20	15	-4	9
7-20-95	30	16	14	25	20	-6	11
7-21-95	30	16	14	20	15	-1	9
7-22-95	28	16	12	19	14	-2	8
7-23-95	29	16	13	19	14	-1	8
7-24-95	27	16	11	16	11	0	7
7-25-95	26	16	10	17	12	-2	8
7-26-95	28	16	12	20	15	-3	9
7-27-95	26	16	10	15	10	0	7
7-28-95	24	16	8	13	8	0	6
7-29-95	22	16	6	12	7	-1	6
7-30-95	21	16	5	12	7	-2	6
7-31-95	21	16	5	11	6	-1	6
8-1-95	21	16	5	12	7	-2	6
8-2-95	20	16	4	11	6	-2	6
8-3-95	19	16	3	10	5	-2	5
8-4-95	19	16	3	9.8	5	-2	5
8-5-95	18	16	2	9.8	5	-3	5
8-6-95	18	16	2	10	5	-3	5
8-7-95	18	16	2	9.8	5	-3	5
8-8-95	18	16	2	9.0	4	-2	5
8-9-95	17	16	1	8.3	3	-2	5
8-10-95	16	16	0	8.2	3	-3	4
8-11-95	16	16	0	7.7	3	-3	4
8-12-95	16	16	0	7.7	3	-3	4
8-13-95	15	15	0	7.7	3	-3	4
8-14-95	15	15	0	6.8	2	-2	4
8-15-95	15	15	0	6.5	2	-2	4
8-16-95	15	15	0	6.5	2	-2	4
8-17-95	15	15	0	6.2	1	-1	4
8-18-95	15	15	0	5.7	1	-1	4
8-19-95	15	15	0	5.7	1	-1	4

Table 37. Daily flow data, in cubic feet per second, used in estimation of losses for Highland Creek —Continued

[ft^3/s, cubic feet per second; ( ), values calculated by performing indicated arithmetic operation]

Date	(1) Flow at site 5	(2) Estimated bedrock springflow	(3) Calculated flow above spring (col. 1 - col. 2)	(4) Flow at site 1	(5) Beaver Creek flow below loss zone (col. 4 - 5 ft^3/s)	(6) Estimated tributary inflow (col. 3 - col. 5)	(7) Estimated flow at site 4
8-20-95	14	14	0	5.4	0	0	3
8-21-95	14	14	0	5.4	0	0	3
8-22-95	14	14	0	5.4	0	0	3
8-23-95	14	14	0	6.1	1	-1	4
8-24-95	14	14	0	7.4	2	-2	4
8-25-95	13	13	0	6.5	2	-2	4
8-26-95	23	14	9	14	9	0	7
8-27-95	16	14	2	12	7	-5	6
8-28-95	15	14	1	9.4	4	-3	5
8-29-95	14	14	0	8.5	4	-4	4
8-30-95	13	13	0	7.4	2	-2	4
8-31-95	14	14	0	6.8	2	-2	4
9-1-95	14	14	0	6.5	2	-2	4
9-2-95	14	14	0	6.2	1	-1	4
9-3-95	13	13	0	5.7	1	-1	4
9-4-95	14	14	0	5.7	1	-1	4
9-5-95	14	14	0	5.9	1	-1	4
9-6-95	13	13	0	5.6	1	-1	4
9-7-95	13	13	0	5.2	0	0	3
9-8-95	13	13	0	5.2	0	0	3
9-9-95	13	13	0	5.2	0	0	3
9-10-95	13	13	0	5.2	0	0	3
9-11-95	13	13	0	7.5	2	-2	4
9-12-95	13	13	0	6.1	1	-1	4
9-13-95	13	13	0	5.2	0	0	3
9-14-95	13	13	0	5.0	0	0	3
9-15-95	13	13	0	4.9	0	0	3
9-16-95	13	13	0	4.5	0	0	3
9-17-95	13	13	0	4.5	0	0	3
9-18-95	13	13	0	5.0	0	0	3

Table 38. Daily streamflow and calculated losses, in cubic feet per second, for selected sites on Grace Coolidge Creek, water year 1978

[( ), values calculated by performing indicated arithmetic operation; --, no data available]

Date	Flow at site 17	Flow at site 18	Loss to Madison (17 - 18)	Flow at site 19	Loss to Minnelusa (18 - 19)	Total loss (17 - 19)
5-1-78	40	--	--	0	--	--
5-2-78	31	--	--	0	--	--
5-3-78	25	--	--	0	--	--
5-4-78	54	--	--	0	--	--
5-5-78	61	--	--	5.7	--	55
5-6-78	64	--	--	19	--	45
5-7-78	59	--	--	22	--	37
5-8-78	55	--	--	17	--	38
5-9-78	65	--	--	26	--	39
5-10-78	76	--	--	42	--	34
5-11-78	62	--	--	32	--	30
5-12-78	47	--	--	20	--	27
5-13-78	36	15	21	13	2	23
5-14-78	30	10	20	8	2	22
5-15-78	24	6.4	18	4.1	2.3	20
5-16-78	19	3.5	16	1.1	2.4	18
5-17-78	19	2.6	16	.06	2.5	19
[1]5-18-78	75	69	6	44	25	31
[1]5-19-78	68	65	3	43	22	25
[1]5-20-78	50	36	14	26	10	24
5-21-78	41	24	17	18	6	23
5-22-78	34	15	19	11	4	23
5-23-78	29	11	18	8.3	3	21
5-24-78	32	14	18	10	4	22
5-25-78	25	7.6	17	5.2	2.4	20
5-26-78	20	4.8	15	2.9	1.9	17
5-27-78	18	3.5	14	1.5	2.0	16
5-28-78	21	5.4	16	3.5	1.9	18
5-29-78	17	3.3	14	1.4	1.9	16
5-30-78	28	8.2	20	5.5	2.7	23
5-31-78	27	8.3	19	5.5	2.8	22
6-1-78	22	5.5	16	3.4	2.1	19
6-2-78	22	4.2	18	2.1	2.1	20
6-3-78	17	3.0	14	.97	2.0	16
6-4-78	17	2.2	15	.22	2.0	17
6-5-78	17	1.5	16	.04	1.5	17
6-6-78	16	.89	15	.01	.88	16
6-7-78	14	.1	14	0	--	--
6-8-78	13	0	--	0	--	--
6-9-78	11	0	--	0	--	--
6-10-78	10	0	--	0	--	--
		Mean loss	17		2	19
		Median loss	17		2	19

[1]Measurements excluded from mean and median calculations.

Table 39. Daily streamflow and calculated losses, in cubic feet per second, for selected sites on Grace Coolidge Creek, water year 1979

[( ), values calculated by performing indicated arithmetic operation; --, no data available]

Date	Flow at site 17	Flow at site 18	Loss to Madison (17 - 18)	Flow at site 19	Loss to Minnelusa (18 - 19)	Total loss (17 - 19)
7-1-79	2.1	0	--	0	--	--
7-2-79	1.8	0	--	0	--	--
7-3-79	2.7	0	--	0	--	--
7-4-79	104	61	43	36	25	68
7-5-79	58	17	41	8.2	9	50
7-6-79	29	2.8	26	.43	2.4	29
7-7-79	20	.10	20	0	--	--
7-8-79	19	0	--	0	--	--
7-9-79	14	0	--	0	--	--
7-10-79	11	0	--	0	--	--
7-11-79	8.2	0	--	0	--	--
7-12-79	7.2	0	--	0	--	--
7-13-79	17	0	--	0	--	--
7-14-79	10	0	--	0	--	--
7-15-79	7.5	0	--	0	--	--
7-16-79	25	0	--	0	--	--
7-17-79	29	0	--	0	--	--
7-18-79	18	0	--	0	--	--
7-19-79	15	0	--	0	--	--
7-20-79	12	0	--	0	--	--
7-21-79	11	0	--	0	--	--
7-22-79	11	0	--	0	--	--
7-23-79	14	0	--	0	--	--
7-24-79	23	0	--	0	--	--
7-25-79	21	0	--	0	--	--
7-26-79	19	0	--	0	--	--
7-27-79	28	0	--	0	--	--
7-28-79	35	0	--	0	--	--
7-29-79	36	1.4	35	.01	1.4	36
7-30-79	32	.32	32	0	--	--
7-31-79	52	15	37	7.8	7	44
8-1-79	39	8.4	31	5.6	2.8	33
8-2-79	39	2.8	36	.90	1.9	38
8-3-79	23	.20	23	0	--	--
8-4-79	20	0	--	0	--	--
8-5-79	18	0	--	0	--	--
8-6-79	15	0	--	0	--	--
8-7-79	15	0	--	0	--	--
8-8-79	16	0	--	0	--	--
8-9-79	2.0	0	--	0	--	--
8-10-79	9.6	0	--	0	--	--

Table 40. Calculations of total streamflow losses for Boxelder Creek, water years 1988-94

[ft^3/s, cubic feet per second; ( ), losses between specified sites calculated by performing indicated arithmetic operation; >, potential loss greater than indicated because of zero flow at downstream site; --, no data available]

Date	Upstream station site 34		Downstream station site 38		Total loss, in ft^3/s (34 - 38)	Hydrograph changes[1]
	Time, in hours	Flow, in ft^3/s	Time, in hours	Flow, in ft^3/s		
1/04/88	1130	0.97	1340	0	>0.97	
3/24/88	1240	11.5	1400	0	>11.5	
4/19/88	1300	9.36	1425	0	>9.36	
6/21/88	1200	3.08	1300	0	>3.08	
8/30/88	0905	.72	1030	0	>.72	
11/28/88	1440	2.12	--	0	>2.12	
8/14/89	1300	.94	1100	0	>.94	
3/14/90	1345	10.9	1145	0	>10.9	
4/17/90	1215	9.69	1343	0	>9.69	
6/13/90	1130	7.34	1305	0	>7.34	
7/12/90	1025	2.56	1030	0	>2.56	
12/11/90	1200	1.60	0840	0	>1.60	
2/12/91	0835	1.09	1035	0	>1.09	
6/04/91	1255	106	1000	42.8	63	0%
6/07/91	1335	145	1050	115	30	-24%
3/05/92	0940	17.0	1312	0	>17.0	
5/11/92	1405	11.3	1140	0	>11.3	
6/09/92	0810	5.27	1500	0	>5.27	
12/02/92	1245	3.12	1155	0	>3.12	
2/09/94	0915	7.70	1415	0	>7.70	

[1]Hydrograph changes calculated using daily mean streamflow at site 34: [(current day - previous day) / previous day] x 100%.

Table 41. Monthly streamflow and calculated losses, in cubic feet per second, for Whitewood Creek, water years 1983-95

[( ), values calculated by performing indicated arithmetic operation]

Date	Flow at site 75	Flow at site 76	Total loss (75 - 76)
Nov-82	34.7	41.6	-6.9
Dec-82	20.2	20.3	-.1
Jan-83	17.1	12.5	4.6
Feb-83	16.0	18.0	-2.0
Mar-83	38.6	47.4	-8.8
Apr-83	101	108	-7
May-83	153	150	3
Jun-83	35.2	36.7	-1.5
Jul-83	21.5	23.1	-1.6
Aug-83	24.3	24.9	-.6
Sep-83	18.2	19.5	-1.3
Oct-83	16.6	19.5	-2.9
Nov-83	13.8	16.1	-2.3
Dec-83	8.90	10.3	-1.4
Jan-84	13.2	11.9	1.3
Feb-84	12.4	14.0	-1.6
Mar-84	18.4	20.5	-2.1
Apr-84	40.0	42.4	-2.4
May-84	213	129	84
Jun-84	102	101	1
Jul-84	29.4	31.2	-1.8
Aug-84	19.1	17.5	1.6
Sep-84	14.7	14.7	.0
Oct-84	13.6	16.5	-2.9
Nov-84	11.5	13.6	-2.1
Dec-84	11.4	12.8	-1.4
Jan-85	10.1	13.0	-2.9
Feb-85	9.40	12.0	-2.6
Mar-85	12.2	16.0	-3.8
Apr-85	20.6	22.2	-1.6
May-85	14.7	15.0	-.3
Jun-85	13.9	13.4	.5
Jul-85	10.4	10.6	-.2
Aug-85	11.8	9.45	2.4
Sep-85	10.7	11.4	-.7
Oct-85	12.5	13.0	-.5
Nov-85	10.3	9.85	.5
Dec-85	8.95	8.84	0.11
Jan-86	10.0	11.7	-1.8
Feb-86	12.0	14.6	-2.6
Mar-86	20.9	22.3	-1.4

Table 41. Monthly streamflow and calculated losses, in cubic feet per second, for Whitewood Creek, water years 1983-95 —Continued

[( ), values calculated by performing indicated arithmetic operation]

Date	Flow at site 75	Flow at site 76	Total loss (75 - 76)
Apr-86	66.6	69.2	-2.6
May-86	50.2	50.8	-.6
Jun-86	41.5	37.7	3.8
Jul-86	19.0	16.9	2.1
Aug-86	13.7	16.3	-2.6
Sep-86	16.4	16.5	-.1
Oct-86	15.1	16.2	-1.1
Nov-86	13.3	16.4	-3.1
Dec-86	10.7	14.6	-3.9
Jan-87	11.7	12.3	-.6
Feb-87	11.6	13.1	-1.5
Mar-87	15.9	18.5	-2.6
Apr-87	59.9	48.7	11.2
May-87	34.2	41.4	-7.2
Jun-87	18.9	30.0	-11.1
Jul-87	13.3	19.3	-6.0
Aug-87	13.5	17.2	-3.7
Sep-87	11.7	14.3	-2.6
Oct-87	11.3	14.8	-3.5
Nov-87	12.6	14.2	-1.6
Dec-87	12.0	13.9	-1.9
Jan-88	11.2	12.1	-.9
Feb-88	13.4	15.3	-1.9
Mar-88	16.5	22.8	-6.3
Apr-88	29.9	34.8	-4.9
May-88	62.1	60.5	1.6
Jun-88	20.2	24.1	-3.9
Jul-88	14.4	15.4	-1.0
Aug-88	11.5	12.3	-.8
Sep-88	13.2	15.0	-1.8
Oct-88	14.3	16.1	-1.8
Nov-88	14.2	15.8	-1.6
Dec-88	12.8	13.6	-.8
Jan-89	12.5	12.2	.3
Feb-89	14.5	13.6	.9
Mar-89	17.2	18.7	-1.5
Apr-89	23.6	26.3	-2.7
May-89	56.5	59.7	-3.2
Jun-89	21.1	22.0	-.9
Jul-89	17.7	16.0	1.7
Aug-89	14.2	12.7	1.5

Table 41. Monthly streamflow and calculated losses, in cubic feet per second, for Whitewood Creek, water years 1983-95 —Continued

[( ), values calculated by performing indicated arithmetic operation]

Date	Flow at site 75	Flow at site 76	Total loss (75 - 76)
Sep-89	14.5	13.2	1.3
Oct-89	11.5	13.0	-1.5
Nov-89	12.1	15.8	-3.7
Dec-89	9.57	10.4	-.8
Jan-90	11.8	13.5	-1.7
Feb-90	12.4	14.5	-2.1
Mar-90	19.0	21.9	-2.9
Apr-90	33.1	35.5	-2.4
May-90	47.5	52.7	-5.2
Jun-90	21.0	24.3	-3.3
Jul-90	14.6	18.3	-3.7
Aug-90	12.3	11.7	.6
Sep-90	10.4	10.9	-.5
Oct-90	11.3	14.2	-2.9
Nov-90	10.7	13.5	-2.8
Dec-90	9.91	7.63	2.28
Jan-91	10.1	10.6	-.5
Feb-91	11.4	14.3	-2.9
Mar-91	13.9	18.6	-4.7
Apr-91	23.0	27.4	-4.4
May-91	54.4	73.6	-19.2
Jun-91	60.3	55.6	4.7
Jul-91	14.4	15.6	-1.2
Aug-91	12.5	12.1	.4
Sep-91	10.6	11.1	-.5
Oct-91	10.7	11.4	-.7
Nov-91	11.5	14.2	-2.7
Dec-91	10.9	15.6	-4.7
Jan-92	9.31	14.5	-5.2
Feb-92	10.5	14.3	-3.8
Mar-92	14.7	15.5	-.8
Apr-92	20.2	23.7	-3.5
May-92	22.1	28.4	-6.3
Jun-92	17.4	19.1	-1.7
Jul-92	12.9	16.1	-3.2
Aug-92	10.3	12.4	-2.1
Sep-92	9.64	11.5	-1.9
Oct-92	8.90	11.3	-2.4
Nov-92	9.87	11.4	-1.5
Dec-92	9.10	8.58	.52
Jan-93	9.55	7.77	1.78

Table 41. Monthly streamflow and calculated losses, in cubic feet per second, for Whitewood Creek, water years 1983-95 —Continued

[( ), values calculated by performing indicated arithmetic operation]

Date	Flow at site 75	Flow at site 76	Total loss (75 - 76)
Feb-93	9.87	8.57	1.30
Mar-93	13.7	17.2	-3.5
Apr-93	33.6	44.4	-10.8
May-93	76.2	78.0	-1.8
Jun-93	104	79.3	25
Jul-93	30.5	31.4	-.9
Aug-93	17.7	19.8	-2.1
Sep-93	13.8	15.4	-1.6
Oct-93	14.1	15.5	-1.4
Nov-93	12.5	13.2	-.7
Dec-93	11.7	9.94	1.8
Jan-94	11.8	9.74	2.1
Feb-94	13.0	12.2	.8
Mar-94	38.8	49.5	-10.7
Apr-94	107	111	-4
May-94	83.3	81.0	2.3
Jun-94	24.7	22.8	1.9
Jul-94	13.7	18.8	-5.1
Aug-94	10.5	11.9	-1.4
Sep-94	9.41	11.3	-1.9
Oct-94	38.7	41.4	-2.7
Nov-94	16.0	18.3	-2.3
Dec-94	13.4	15.0	-1.6
Jan-95	11.7	14.5	-2.8
Feb-95	13.0	15.4	-2.4
Mar-95	18.5	21.2	-2.7
Apr-95	29.0	31.8	-2.8
May-95	291	384	-93
Jun-95	86.1	95.4	-9.3
Jul-95	37.0	38.9	-1.9
Aug-95	21.0	16.4	4.6
Sep-95	14.7	14.6	.1
		Mean loss	-2
		Median loss	-2