Hydrologic Budgets

About 92 percent of annual precipitation in the study area is returned to the atmosphere via evapotranspiration.

This section of the report summarizes hydrologic budgets for ground water, surface water, and the combined ground-water/surface-water system that were developed by previous investigators. Hydrologic budgets provide an accounting of the inflow to, outflow from, and storage change in a hydrologic unit such as an aquifer or drainage basin. Detailed hydrologic budgets for the Madison and Minnelusa aquifers in the Black Hills of South Dakota and Wyoming for water years 1987-96 were presented by Carter, Driscoll, Hamade, and Jarrell (2001). Basic budgets for the Black Hills of South Dakota for water years 1950-98 were presented by Driscoll and Carter (2001) for: (1) the Madison and Minnelusa aquifers; (2) other bedrock aquifers; (3) selected streams; and (4) combined ground-water/surface-water system. All hydrologic budgets were developed from the following basic continuity equation, which states that for any designated volume:

Sum of inflows - Sum of outflows
= Change in storage

Thus, a positive change in storage results when inflows exceed outflows.

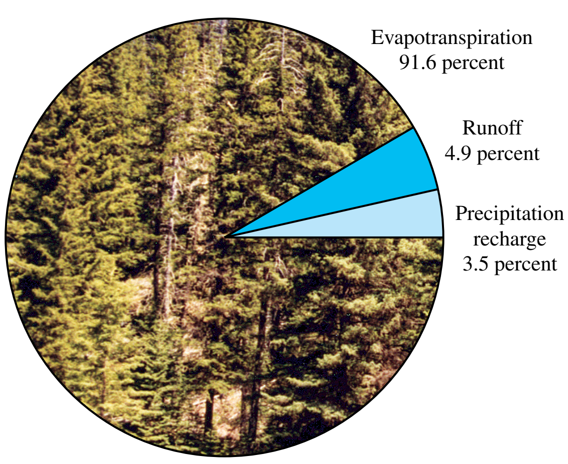


Figure 102. Evapotranspiration, runoff, and precipitation recharge as percentages of average annual precipitation.

Methods for Estimating Basin Yield and Recharge

Total yield, which is considered to be the sum of runoff plus recharge, was estimated over selected areas using the "yield-efficiency algorithm" discussed in a previous section of the report describing annual yield characteristics. Estimates of precipitation, total yield, and evapotranspiration for the entire study area are presented in table 8. For water years 1950-98, precipitation averaged 18.98 inches per year or just over 5.2 million acre-ft per year. This is equivalent to an average flow rate of about 7,240 cubic feet per second, which is about one-third of the average flow of the Missouri River that enters South Dakota. Of this amount, total yield averaged about 440,600 acre-feet per year (about 608 cubic feet per second), which is equivalent to about 1.59 inches per year over the study area. Thus, evapotranspiration is estimated as 17.39 inches per year, which accounts for about 92 percent of annual precipitation (fig. 102).

Total yield was apportioned between precipitation recharge and runoff on the basis of recharge factors (estimated percentage of total yield that results in recharge) for each aquifer (table 9). With the exception of localized aquifers in the crystalline core area, as discussed later, recharge was estimated by multiplying the total yield by the recharge factor. The remainder of total yield (if any) was assumed to contribute to runoff from the outcrop area. Of the total average annual precipitation in the study area (fig. 102), runoff accounts for about 4.9 percent (352 cubic feet per second), and precipitation recharge accounts for about 3.5 percent (256 cubic feet per second).

As previously discussed, direct runoff from outcrops of the Madison Limestone and Minnelusa Formation seldom occurs. Thus, all precipitation on these outcrops that is not evapotranspirated was assumed to recharge the aquifers, with a resulting recharge factor assumed as 1.00. The recharge factor for the Minnekahta aquifer also was assumed to be 1.00, based on similar formation properties between the Minnekahta Limestone and Madison Limestone. Recharge factors for the Inyan Kara and Deadwood aquifers were assumed to be 0.80 because the formations contain more shale layers (which impede recharge) than the Madison, Minnelusa, and Minnekahta Formations. The Sundance aquifer within the Jurassic-sequence semiconfining unit is a productive aquifer, but only constitutes about one-half of the outcrop area of the total unit. Thus, a recharge factor of 0.40 (one-half of 0.80) was assumed for the entire Jurassic-sequence semiconfining unit. Likewise, the Newcastle Sandstone contains a productive aquifer within the Cretaceous-sequence confining unit; however, the Newcastle Sandstone constitutes only a small portion of the total unit in outcrop area. Thus, a recharge factor of 0.05 was assumed for the entire Cretaceous-sequence confining unit.

Recharge does occur to numerous localized aquifers within the crystalline core area, especially where extensive fracturing and weathering have occurred. These aquifers are not considered regional, however, as indicated by the fact that wells constructed in Precambrian rocks in western South Dakota outside of the Black Hills have not encountered measurable amounts of ground water (Rahn, 1985). Thus, regional ground-water flow in the Precambrian rocks was assumed

"Recharge factors" are used to estimate the percentage of total yield that becomes recharge to a given aquifer, with the remaining fraction contributing to runoff from outcrop areas. The largest recharge factors (1.00) are for the Madison, Minnelusa, and Minnekahta aquifers, where direct runoff is assumed negligible and yield consists entirely of recharge.

Table 8. Estimates of average precipitation, precipitation recharge, runoff, total yield, and evapotranspiration for the study area, water years 1950-98

[Modified from Driscoll and Carter (2001)]

Units		Precipitation recharge	Runoff	Total yield (Precipitation recharge + runoff)	Evapo-transpiration
Acre-feet per year	5,245,400	185,500	255,100	440,600	4,804,800
Cubic feet per second	7,240.4	256	352	608.2	6,632.2
Inches per year	18.98	0.67	0.92	1.59	17.39

to be negligible although some flow may occur in the upper weathered zone. Recharge to localized aquifers in the crystalline core area was assumed equal to well withdrawals from this unit.

Within the crystalline core area, numerous erosional remnants of sedimentary outcrops occur that are "isolated" from regional ground-water flow systems as described in a previous section of the report (fig. 19). Precipitation recharge was prescribed only for "connected" outcrops and was not prescribed for isolated outcrops. Infiltration of precipitation on isolated outcrops was assumed to contribute to streamflow, which eventually has potential to provide streamflow recharge to the Madison and Minnelusa aquifers. Additional methods beyond identification of isolated and connected outcrop areas were used in quantifying precipitation recharge for the Deadwood aquifer as described by Driscoll and Carter (2001). Additional details regarding precipitation recharge are discussed in the following sections of the report.

Ground-Water Budgets

Hydrologic budgets were developed for the five major, sedimentary bedrock aquifers in the study area (Deadwood, Madison, Minnelusa, Minnekahta, and Inyan Kara aquifers) and for additional minor aquifers within the Jurassic-sequence semiconfining unit and Cretaceous-sequence confining unit. A budget also was developed for localized aquifers within the crystalline core area, which is dominated by Precambrian igneous and metamorphic rocks, but also includes Tertiary igneous rocks, erosional remnants of various sedimentary rocks, and minor, unconsolidated sedimentary deposits. These localized aquifers are subsequently referred to as the crystalline core aquifers. A combined budget was developed for the Madison and Minnelusa aquifers because most of the budget components cannot be quantified individually for these two aquifers.

Budgets were developed for water years 1950-98, during which changes in ground-water storage were assumed to be negligible. Various components considered for ground-water budgets are schematically illustrated in figure 103 for the Madison aquifer. Inflows may include recharge, leakage from vertically adjacent aquifers, and lateral ground-water inflows across the study area boundary. Recharge occurs at or near land surface and includes infiltration of precipitation on outcrops of the bedrock units and streamflow recharge, which occurs where streams cross the outcrops. Streamflow recharge was considered an inflow component only for the Madison and Minnelusa aquifers. Although the Minnekahta aquifer also receives limited recharge from streamflow losses, this recharge probably is very small relative to streamflow recharge for the Madison and Minnelusa aquifers and could not be quantified.

Table 9. Recharge factors and outcrop areas for bedrock aquifers

[From Driscoll and Carter (2001). --, not applicable]

Aquifer unit	Recharge factor[1]	Outcrop area (acres)
Localized aquifers in crystalline core area (Precambrian/Tertiary/Other[2])	--	616,800
Deadwood	0.80	66,200
Madison	1.00	292,600
Minnelusa	1.00	300,000
Minnekahta	1.00	72,100
Inyan Kara	.80	219,700
Jurassic-sequence semiconfining unit	.40	75,800
Cretaceous-sequence confining unit	.05	716,100

[1]Fraction of total yield estimated to result in recharge, with remainder (if any) assumed to contribute to runoff.
[2]Other consists of other units within the crystalline core area, including: (1) isolated outcrops of the Deadwood Formation, Madison Limestone, Minnelusa Formation, and Minnekahta Limestone above the loss zones; and (2) unconsolidated sedimentary deposits.

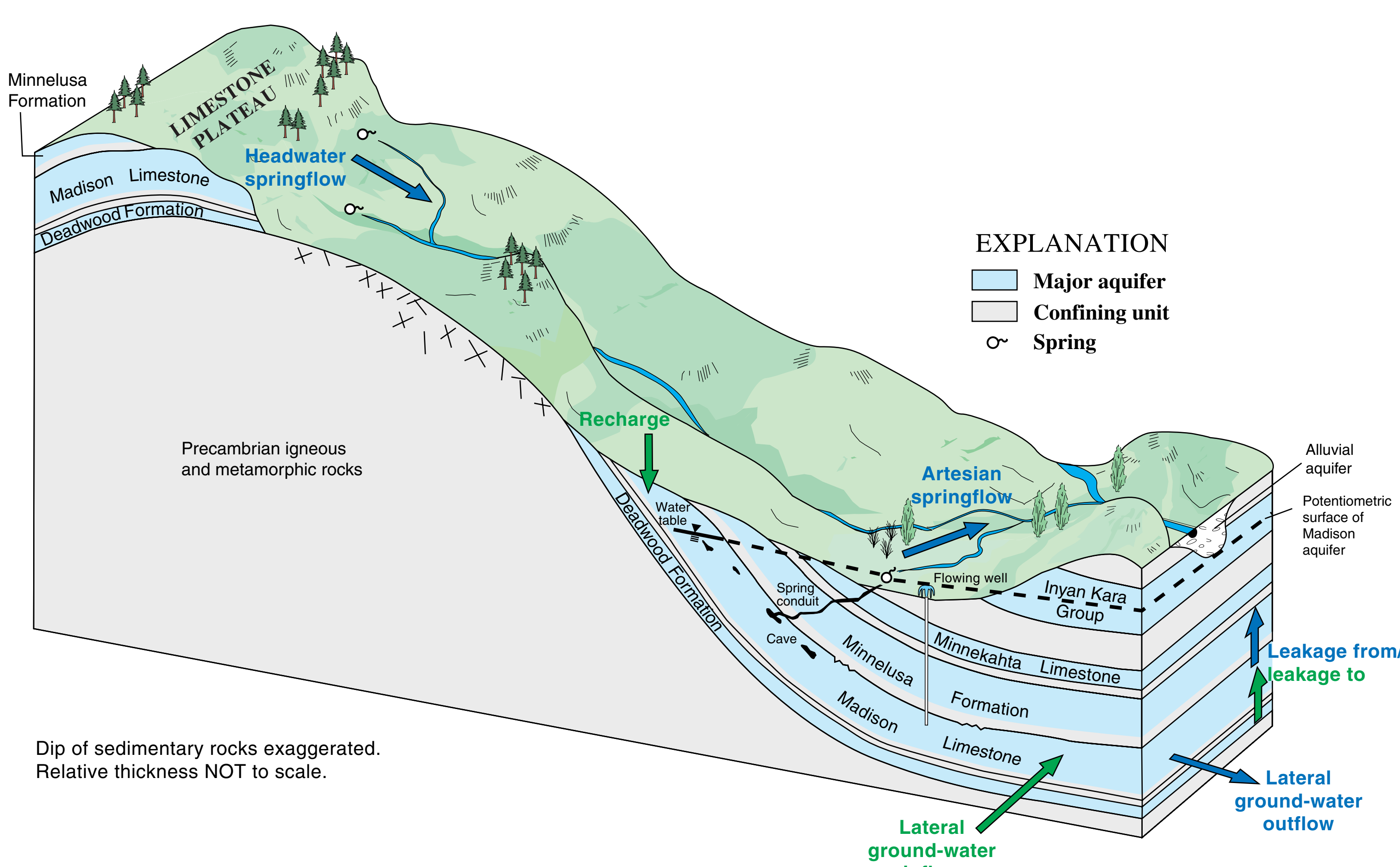


Figure 103. Components considered for ground-water budgets. Budget components are shown for the Madison aquifer, with inflow components shown in green and outflow components shown in blue.

Photograph by Van A. Lindquist, West Dakota Water Development District

Figure 104. Headwater springflow is common in the Limestone Plateau area. Most headwater springs, like this one contributing to Rhoads Fork, generally occur near the base of the Madison Limestone along the eastern edge of the Limestone Plateau area.

Photograph by Joyce E. Williamson

Figure 105. Artesian springflow, such as that at Evans Plunge, is common around the periphery of the Black Hills. Most artesian springs originate primarily from the Madison and Minnelusa aquifers. The Madison aquifer is the primary source of warm water (approximately 87 degrees Fahrenheit) to Evans Plunge, which was built in 1890 over numerous artesian springs. Originally, the warm, mineralized water at Evans Plunge was promoted as a cure-all for a multitude of illnesses.

Outflows include springflow, well withdrawals, leakage to vertically adjacent aquifers, and lateral ground-water outflow across the study area boundary. Springflow includes headwater springs and artesian springs. Headwater springs (fig. 104), which generally occur near the base of the Madison Limestone in the Limestone Plateau area, were considered an outflow component for only the Deadwood, Madison, and Minnelusa aquifers. Artesian springs, such as Evans Plunge (fig. 105), were considered an outflow component for only the Madison and Minnelusa aquifers.

Leakage to and from vertically adjacent aquifers, which is difficult to quantify and cannot be distinguished from lateral ground-water inflows or outflows across the study area boundaries, probably is small relative to other budget components in most cases. Thus, for budget purposes, leakage was included with ground-water inflows and outflows. Assuming that the change in storage is equal to zero, the sum of the inflows is equal to the sum of the outflows, and the hydrologic budget equation can be rewritten as:

$$\text{Ground-water}_{outflow} - \text{Ground-water}_{inflow} = \text{Recharge} - \text{Headwater springflow} - \text{Artesian springflow} - \text{Well withdrawals}$$

Table 10. Average ground-water budgets for bedrock aquifers, water years 1950-98

[From Driscoll and Carter (2001). --, no data]

Units	Precipitation	Evapotranspiration	Total yield	Runoff	Precipitation recharge	Streamflow recharge	Total recharge	Well withdrawals and springflow[1]	Net study area outflow
Crystalline Core (Precambrian, Tertiary, and Other Minor Units)									
Acre-feet per year	1,084,500	964,200	120,300	116,700	3,600	0	3,600	3,600	0.0
Cubic feet per second	1,497	1,331	166	161	5	0	5	5	0
Inches per year	21.10	18.76	2.34	2.27	0.07	0	0.07	--	--
Deadwood									
Acre-feet per year	128,200	110,100	18,100	3,600	14,500	0	14,500	10,100	4,400
Cubic feet per second	177	152	25	5	20	0	20	[1]14	6
Inches per year	23.24	19.96	3.28	0.65	2.63	0	2.63	--	--
Madison and Minnelusa									
Acre-feet per year	1,021,500	876,600	144,900	0	144,900	66,600	211,500	169,500	41,900
Cubic feet per second	1,410	1,210	200	0	200	92	292	[1]234	58
Inches per year	20.69	17.76	2.93	0	2.93	1.35	4.28	--	--
Minnekahta									
Acre-feet per year	120,300	113,800	6,500	0	6,500	0	6,500	700	5,800
Cubic feet per second	166	157	9	0	9	0	9	1	8
Inches per year	20.02	18.94	1.08	0	1.08	0	1.08	--	--
Inyan Kara									
Acre-feet per year	326,700	312,200	14,500	2,900	11,600	0	11,600	1,400	10,200
Cubic feet per second	451	431	20	4	16	0	16	2	14
Inches per year	17.84	17.05	0.79	0.16	0.63	0	0.63	--	--
Jurassic-Sequence Semiconfining Unit									
Acre-feet per year	115,900	110,000	5,800	3,600	2,200	0	2,200	700	1,500
Cubic feet per second	160	152	8	5	3	0	3	1	2
Inches per year	18.35	17.43	0.92	0.57	0.35	0	0.35	--	--
Cretaceous-Sequence Confining Unit									
Acre-feet per year	1,028,700	980,900	47,800	45,600	2,200	0	2,200	1,400	800
Cubic feet per second	1,420	1,354	66	63	3	0	3	2	1
Inches per year	17.24	16.44	0.80	0.76	0.04	0	0.04	--	--
Overall Budget for Bedrock Aquifers									
Acre-feet per year	3,825,900	3,468,000	357,900	172,400	185,500	66,600	252,100	187,600	64,600
Cubic feet per second	5,281	4,787	494	238	256	92	348	259	89
Inches per year	19.46	17.64	1.82	0.88	0.94	1.35	1.28	--	--

[1]Includes estimated springflow of 13 cubic feet per second for Deadwood aquifer and 206 cubic feet per second for Madison and Minnelusa aquifers. For other aquifers, springflow is considered negligible and estimates include only well withdrawals.

The terms on the right side of this equation generally can be quantified more accurately than the terms on the left. Therefore, net ground-water flow (outflow minus inflow) from the study area was calculated as the residual, using estimates for the other budget components.

Individual ground-water budgets and an overall budget for all bedrock aquifers in the study area are presented in table 10. Combined average recharge for all bedrock aquifers was estimated as 348 cubic feet per second. Total well withdrawals and springflow account for 259 cubic feet per second; thus, net ground-water outflow from the study area was calculated as 89 cubic feet per second. For the Deadwood aquifer, well withdrawals and springflow were estimated as 14 cubic feet per second, which consists primarily of springflow in headwater areas of about 13 cubic feet per second. For the Madison and Minnelusa aquifers, springflow of 206 cubic feet per second is much larger than well withdrawals of 28 cubic feet per second. For all other aquifers, springflow is small and was neglected; only well withdrawals are included in this component in table 10.

The Madison and Minnelusa aquifers, which have the largest outcrop areas of the major aquifers in the study area, dominate the overall ground-water budgets as shown in figure 106. Average total recharge to all bedrock aquifers was estimated as 348 cubic feet per second, of which about 84 percent is recharge to the Madison and Minnelusa aquifers. Average well withdrawals and springflow is about 259 cubic feet per second, of which about 90 percent is from the Madison and Minnelusa aquifers. Average net ground-water outflow from the study area for all bedrock aquifers is about 89 cubic feet per second and ranges from zero (assumed) for the crystalline core aquifers to about 58 cubic feet per second (65 percent) for the Madison and Minnelusa aquifers. In contrast, average runoff from outcrops is dominated by the crystalline core area (fig. 106), with negligible runoff from outcrops of the Madison, Minnelusa, and Minnekahta aquifers.

The Madison and Minnelusa aquifers dominate the overall ground-water budget. These aquifers account for about 90 percent of well withdrawals and springflow in the study area.

Combined average recharge to bedrock aquifers in the Black Hills area is estimated as 348 cubic feet per second. Well withdrawals and springflow account for about 259 cubic feet per second, which is dominated by springflow from the Madison and Minnelusa aquifers. Thus, net ground-water outflows (outflows minus inflows) are calculated as 89 cubic feet per second.

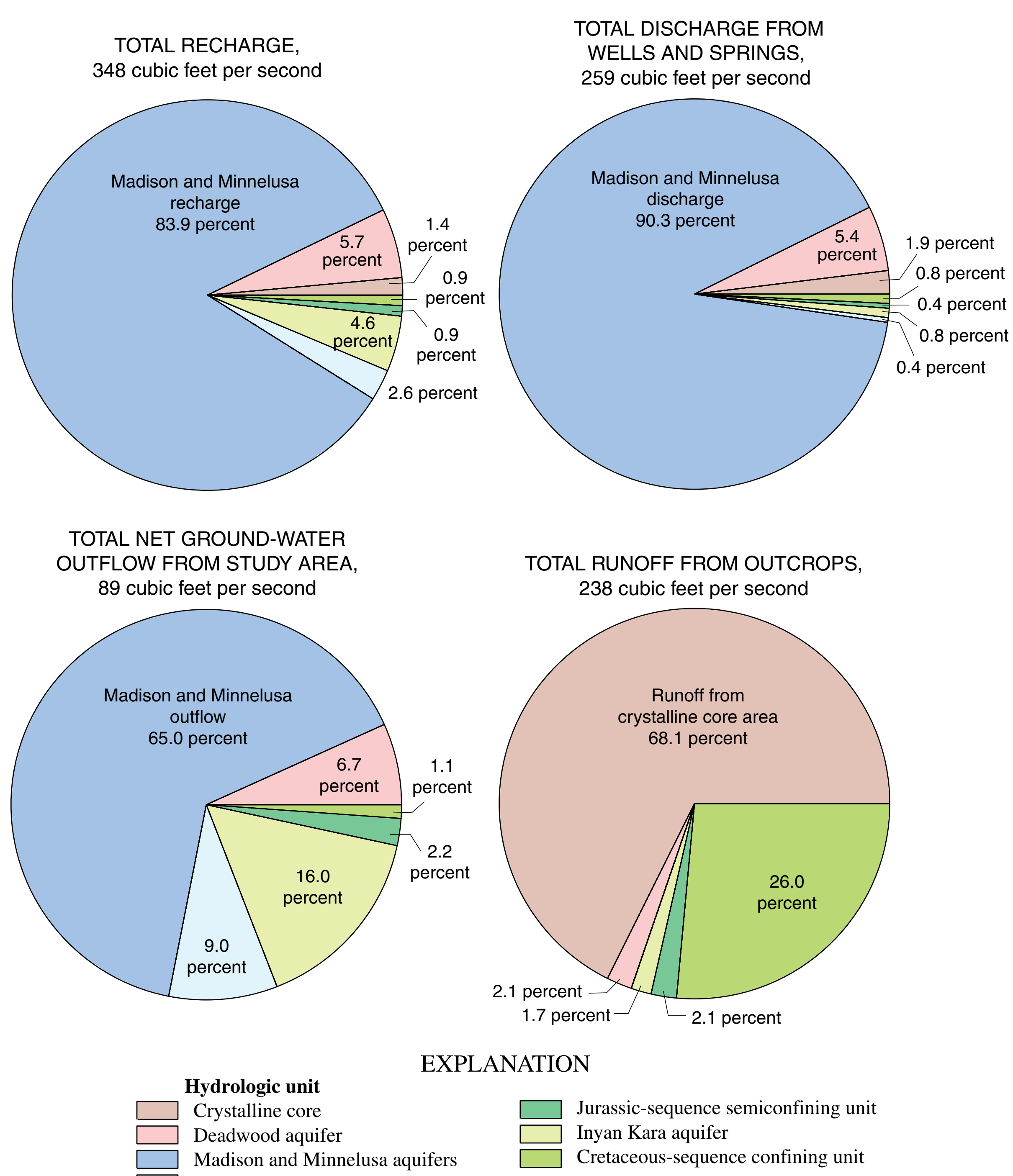


Figure 106. Average annual budget components for bedrock aquifers for water years 1950-98. Ground-water budgets are dominated by the Madison and Minnelusa aquifers. The largest runoff occurs within the crystalline core of the Black Hills.

More detailed hydrologic budgets for the Madison and Minnelusa aquifers are provided in table 11. The first budget is similar to that presented in table 10, but provides several additional details, including an estimate of average headwater springflow (78 cubic feet per second) that was obtained by applying estimates of precipitation recharge to the area east of the ground-water divide on the Limestone Plateau (fig. 83). Average net recharge of 214 cubic feet per second was calculated by subtracting average headwater springflow from the sum of average streamflow and precipitation recharge. A distinction between average well withdrawals and artesian springflow (28 and 128 cubic feet per second, respectively) also is provided.

Table 11 also provides a budget for an expanded area that includes large outcrop areas in Wyoming (fig. 86). For the expanded area, average precipitation recharge (271 cubic feet per second) is considerably larger than for the study area; however, average streamflow recharge in the expanded area (98 cubic feet per second) is only slightly larger. Average headwater springflow (72 cubic feet per second) is slightly smaller because measured average flows of about 6 cubic feet per second for Beaver and Cold Springs Creek are excluded. Both streams originate as headwater springs in South Dakota; however, both streams are depleted by streamflow losses that provide recharge to the Minnelusa aquifer just downstream (west) of the Wyoming border. Average artesian springflow (169 cubic feet per second) is larger and primarily accounts for artesian springflow measured along Stockade Beaver Creek and Sand Creek (fig. 34). Average net ground-water outflow (100 cubic feet per second) is larger and reflects additional recharge within the expanded area.

Charts showing percent distributions of the inflow and outflow components for the Madison and Minnelusa aquifers in the expanded area (South Dakota and Wyoming) are presented in figure 107. Precipitation recharge accounts for about 73 percent of the recharge in the expanded area. Artesian springflow is the single largest discharge component and accounts for about 46 percent of the total outflows for the expanded area. Headwater springflow accounts for about 20 percent of the total outflow for the expanded area. Thus, most of the total outflow from the Madison and Minnelusa aquifers is from springflow, which then provides flow to area streams. Ground water flowing out of the expanded area accounts for about 27 percent of the total outflows. Well withdrawals account for about 8 percent of the total outflows.

Well withdrawals from bedrock aquifers serve many categories of water use, including municipal, self supply (domestic), irrigation, livestock, industrial, mining, and thermoelectric power. Detailed water-use estimates for the Madison and Minnelusa aquifers for water years 1987-96 were presented by Carter, Driscoll, Hamade, and Jarrell (2001). The largest measurable well withdrawals from the Madison and Minnelusa aquifers are for municipal and irrigation uses (fig. 108). Unaccounted withdrawals also are large, which include well withdrawals that typically are not accounted under usual water-use reporting procedures (Amundson, 1998). The largest unreported withdrawals have been for uncontrolled flowing wells, which have been substantially reduced during recent years (Jim Goodman, South Dakota Department of Environment and Natural Resources, oral commun., 2000).

Many of the budget components were based on hydrologic measurements with relatively short periods of record. Precipitation data indicate that prolonged drought conditions occurred prior to many available hydrologic records, such as streamflow and water-level data. Carter, Driscoll, and Hamade (2001), thus, estimated recharge for the Madison and Minnelusa aquifer for water years 1931-98 (fig. 109) to incorporate particularly dry conditions that occurred during the 1930's and 1950's. Estimates of streamflow recharge, precipitation recharge, and combined recharge from both sources for the Black Hills of South Dakota and Wyoming are shown in figure 109. The 1931-98 averages are smaller than the 1950-98 averages (table 11) because of prolonged droughts during the 1930's. Streamflow recharge is relatively steady; however, precipitation recharge is highly variable, depending on annual precipitation amounts.

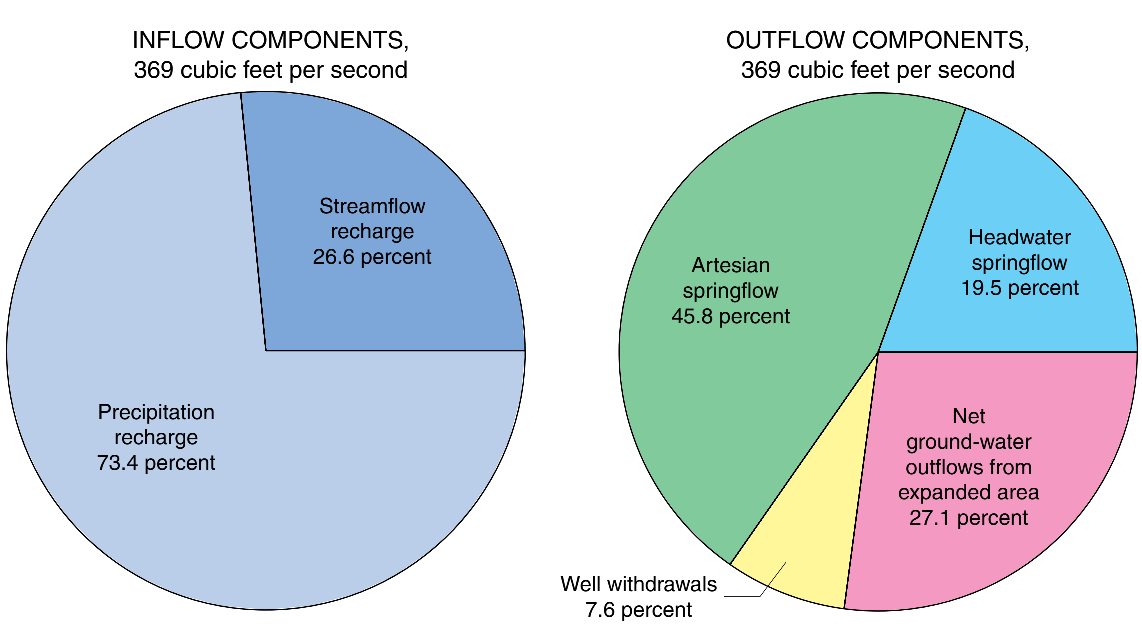


Figure 107. Average annual budget components for the Madison and Minnelusa aquifers in South Dakota and Wyoming for water years 1950-98.

Artesian springflow is the single largest discharge component from the Madison and Minnelusa aquifers. In South Dakota and Wyoming, artesian springflow accounts for 46 percent of the total discharge from these aquifers.

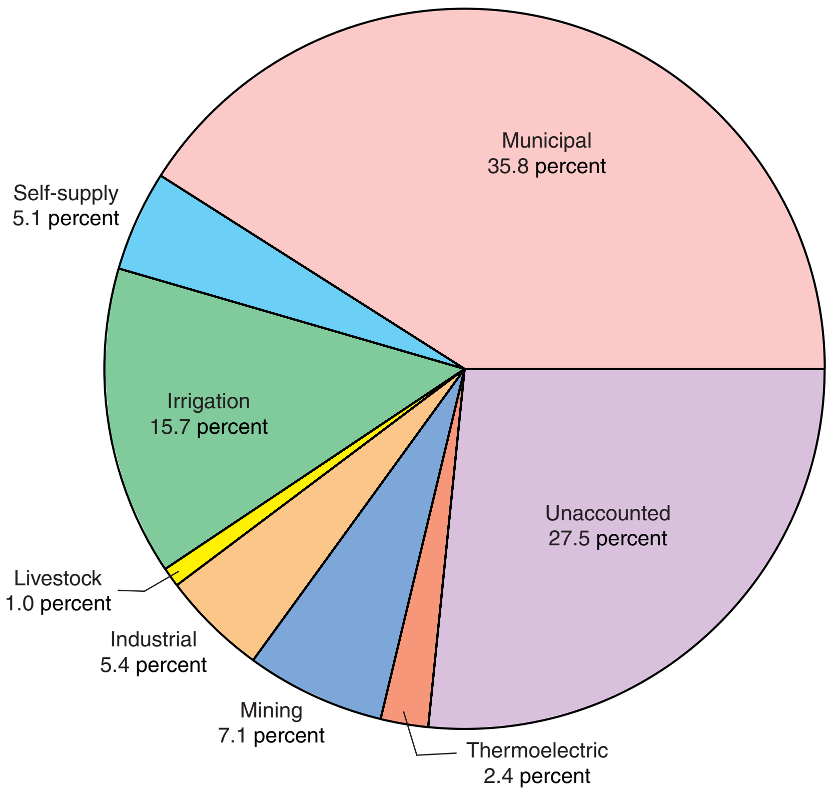


Figure 108. Water use from the Madison and Minnelusa aquifers, by category, for South Dakota counties in the Black Hills area for water years 1987-96 (from Carter, Driscoll, Hamade, and Jarrell, 2001).

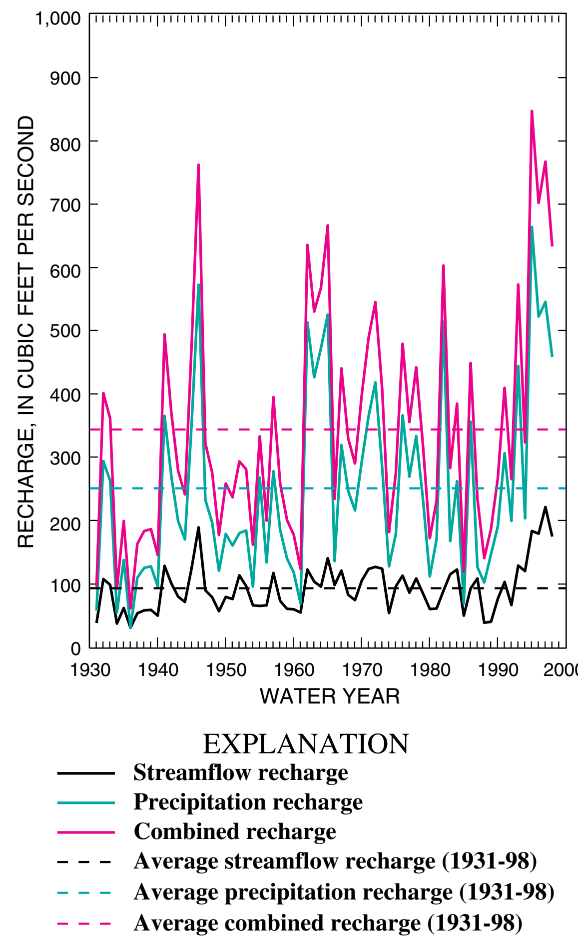


Figure 109. Annual recharge to the Madison and Minnelusa aquifers, in the Black Hills of South Dakota and Wyoming, water years 1931-98 (from Carter, Driscoll, and Hamade, 2001). Prolonged periods of below-average recharge occurred during the 1930's and 1950's.

Hydrologic data generally are not available for prolonged drought periods in the Black Hills area. Recharge estimates for the Madison and Minnelusa aquifers indicate prolonged periods of minimal recharge during the 1930's and 1950's. Hydrologic effects of extended drought conditions like these are largely unknown, however.

Table 11. Detailed average hydrologic budgets for the Madison and Minnelusa aquifers, water years 1950-98

[From Driscoll and Carter (2001)]

Units	Streamflow recharge	Precipitation recharge	Headwater springflow	Net recharge	Well withdrawals	Artesian springflow	Net ground-water outflow from study area/ expanded area
Study Area (Black Hills of South Dakota)							
Acre-feet per year	66,600	144,900	56,500	155,000	20,300	92,800	41,900
Cubic feet per second	92	200	78	214	[2]28	128	58
Expanded Area (Black Hills of South Dakota and Wyoming)							
Acre-feet per year	71,000	196,300	52,200	215,100	20,300	122,400	72,400
Cubic feet per second	98	271	[1]72	297	[2]28	169	100

[1]Excludes 6 cubic feet per second headwater springflow for Beaver Creek and Cold Springs Creek, which occurs in South Dakota but subsequently recharges the Minnelusa aquifer a short distance downstream in Wyoming.
[2]Identical estimate used for well withdrawals in both areas. Areas considered in Wyoming primarily are recharge areas, where well withdrawals are minor.

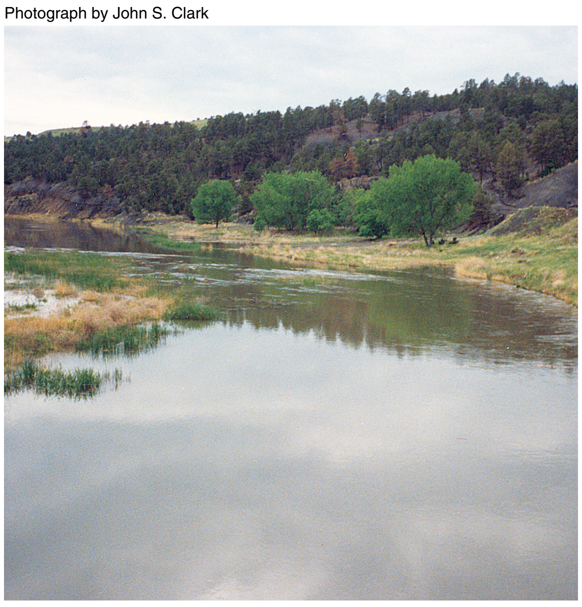
Net tributary flows generated within the study area were estimated as 201 cubic feet per second in the Cheyenne River drainage basin and 107 cubic feet per second in the Belle Fourche River drainage basin. Some tributary flows generated within the study area are consumed for a variety of purposes, especially irrigation. Net tributary flows represent streamflow exiting the study area.

Surface-Water Budgets

Surface-water budgets were developed for two major drainage basins in the study area—the Cheyenne and Belle Fourche Rivers (fig. 110). The Belle Fourche River Basin (including Bear Butte Creek) drains approximately the northern one-quarter of the study area. The Cheyenne River Basin (including Elk Creek) drains the southern part of the study area. The surface-water inflows and outflows for the study area, as well as tributary flows generated within the study area, were estimated by Driscoll and Carter (2001). Storage changes for the four large Bureau of Reclamation reservoirs (Angostura, Deerfield, Pactola, and Belle Fourche) located within the study area were considered in developing the surface-water budgets.

Average surface-water budgets for water years 1950-98 are provided in table 12. Inflows to the study area averaged about 106 and 146 cubic feet per second in the Cheyenne and Belle Fourche River drainages, respectively, with combined inflows averaging about 252 cubic feet per second. Net tributary flows generated within the study area were estimated as about 201 and 107 cubic feet per second in the Cheyenne and Belle Fourche River drainages, respectively, with combined tributary flows of about 308 cubic feet per second. Storage in major reservoirs during this period increased by about 7 cubic feet per second, primarily because several of the major reservoirs were new and had not filled as of 1950. Considering the storage changes, total outflows from the study area were estimated as about 554 cubic feet per second, with outflows of about 303 cubic feet per second for the Cheyenne River drainage and 251 cubic feet per second for the Belle Fourche River drainage.

Photograph by John S. Clark



Photograph by Joyce E. Williamson

Figure 110. The Cheyenne River (upper photograph) and the Belle Fourche River (lower photograph) are the major drainage basins for the study area.

Combined Ground-Water and Surface-Water Budget

Combined average ground- and surface-water budgets are presented in figure 111A, which includes a detailed budget that shows complex ground- and surface-water interactions, and in figure 111B, which shows a more simplified budget. These budgets also are used to show **consumptive uses** of water that occur within the study area. Total consumptive use within the study area from both ground-water and surface-water resources was estimated as 218 cubic feet per second, which includes well withdrawals (40 cubic feet per second), reservoir evaporation (38 cubic feet per second), and consumptive withdrawals from streams (140 cubic feet per second). Consumptive uses consist primarily of consumptive irrigation withdrawals, which do not include unconsumed irrigation return flows. Most well withdrawals are consumed; however, in some locations (such as Rapid City), some portion of municipal withdrawals may be unconsumed and returned to streams via wastewater treatment effluent.

A schematic diagram is presented as figure 112 that shows the progression of average streamflow relative to surface geology and **streamflow depletions**. Streamflow upstream from loss zones to the Madison and Minnelusa aquifers averages 251 cubic feet per second, which consists of headwater springflow from the Madison and Minnelusa aquifers (72 cubic feet per second) and Deadwood aquifer (13 cubic feet per second) in the Limestone Plateau area, and of direct runoff from the Deadwood Formation (5 cubic feet per second) and crystalline core area (161 cubic feet per second). Streamflow losses to the Madison and Minnelusa aquifers average 92 cubic feet per second; thus, combined streamflow downstream from loss zones averages about 159 cubic feet per second.

Artesian springflow (128 cubic feet per second) and runoff from outcrops beyond the Madison Limestone and Minnelusa Formation (186 cubic feet per second) provide additional streamflow beyond the loss zones (fig. 112). Thus, average streamflow prior to major depletions, which result primarily from irrigation operations, is about 473 cubic feet per second. Reservoir evaporation and consumptive withdrawals of 178 cubic feet per second reduce average tributary flows to the Cheyenne and Belle Fourche Rivers to 295 cubic feet per second. The tributary flows of 295 cubic feet per second in figure 112 differ from the study area tributary flows of 308 cubic feet per second in table 12 by the reservoir storage change (7 cubic feet per second) and by combined flows for Beaver and Cold Springs Creeks (6 cubic feet per second). The flows of Beaver and Cold Springs Creeks do not contribute to the flow of the Cheyenne and Belle Fourche Rivers because streamflow losses occur a short distance downstream from the Wyoming border, as previously discussed.

Table 12. Average surface-water budgets for study area, water years 1950-98

[From Driscoll and Carter (2001). All values are in cubic feet per second]

Basin	Study area inflows	+ Study area tributaries	- Change in storage	= Study area outflows
Cheyenne River	105.8	201.2	4.5	302.5
Belle Fourche River	146.4	107.3	2.7	251.0
Combined	252.2	308.5	7.2	553.5

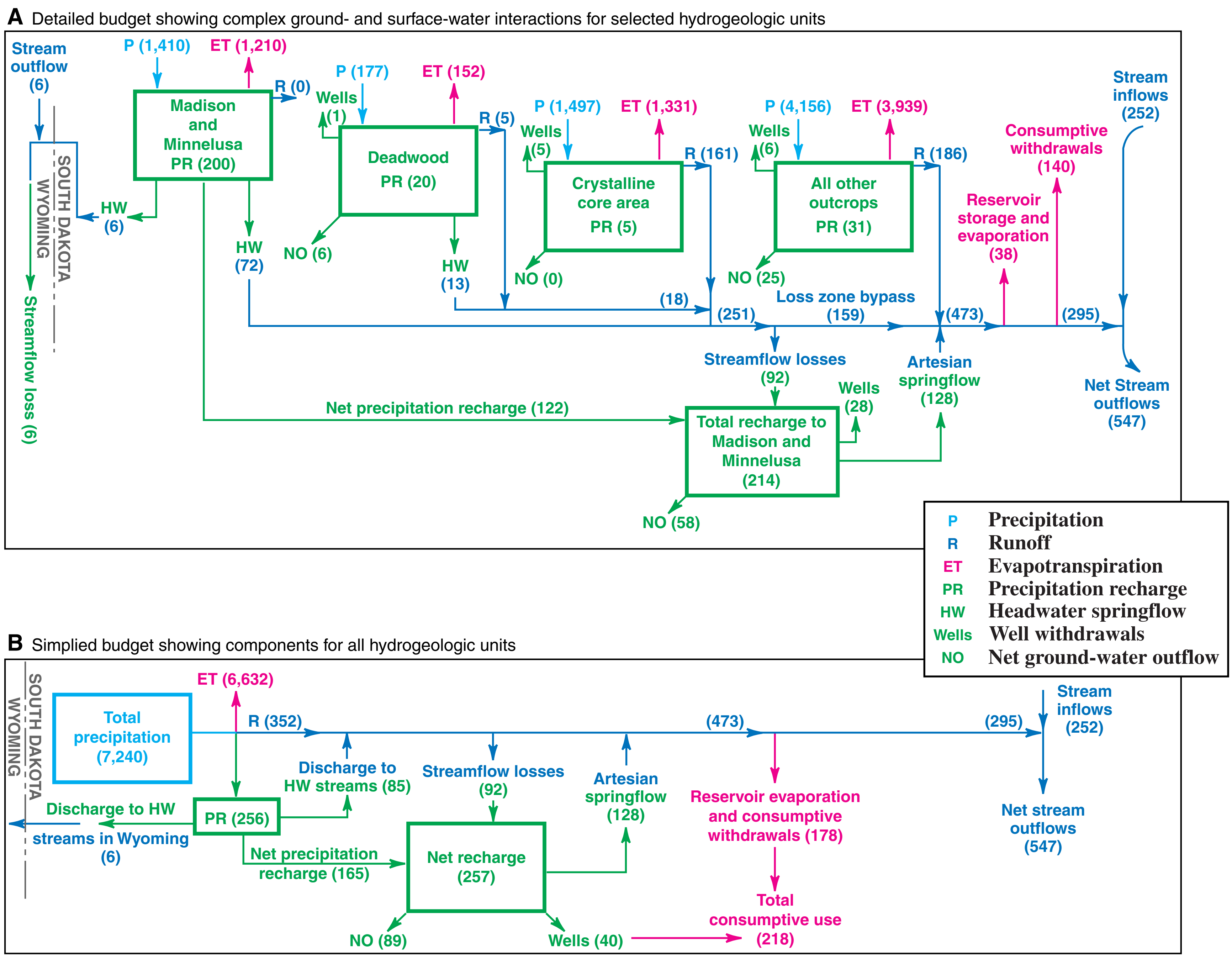


Figure 111. Schematic diagram showing average hydrologic budget components for the study area, water years 1950-98 (from Driscoll and Carter, 2001). All values in cubic feet per second.

Total consumptive use from both ground-water and surface-water sources was estimated as 218 cubic feet per second, which includes well withdrawals of 40 cubic feet per second, reservoir evaporation of 38 cubic feet per second, and consumptive streamflow withdrawals of 178 cubic feet per second.

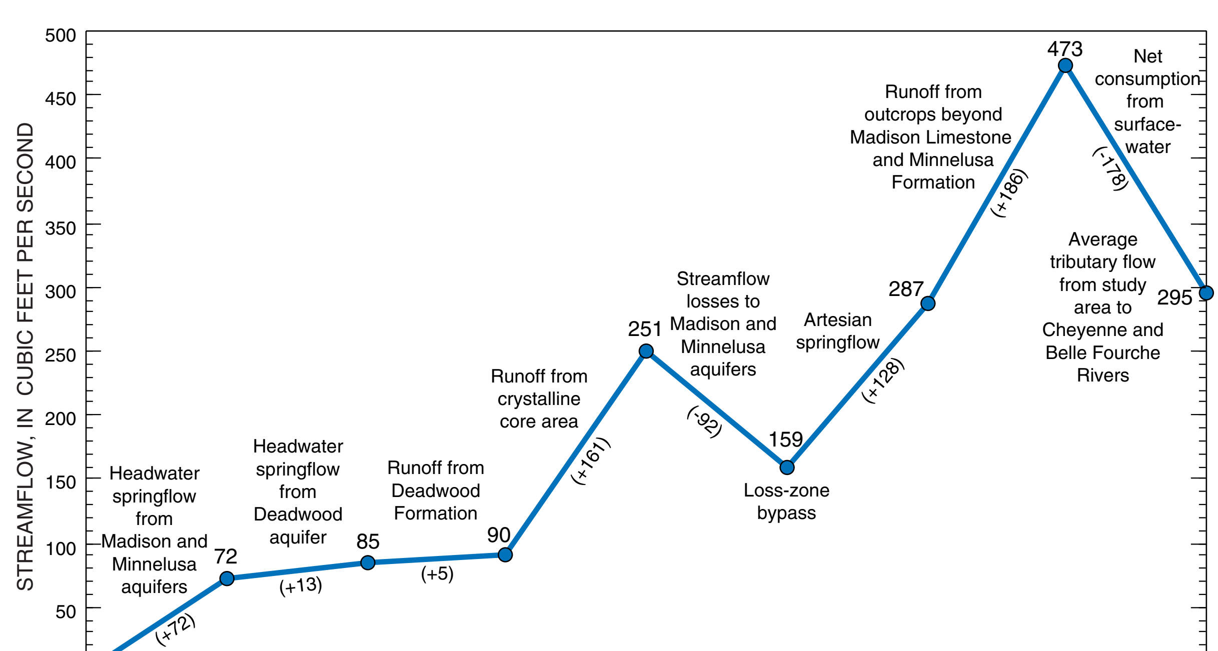


Figure 112. Schematic diagram showing generalized average streamflow relative to surface geology and depletions, water years 1950-98 (from Driscoll and Carter, 2001).