Prepared in cooperation with the Natural Resources Conservation Service—North Dakota

Small Basin Annual Yield and Percentage of Snowmelt Runoff in North Dakota, 1931–2016

Scientific Investigations Report 2019–5144

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By Tara Williams-Sether and Spencer L. Wheeling

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Area	
inch (in.)	2.54	centimeter (cm)
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)

Datum

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

Supplemental Information

A water year is the period from October 1 to September 30 and is designated by the year in which it ends; for example, water year 2015 was from October 1, 2014, to September 30, 2015.

Abbreviations

MOVE.3	Maintenance of Variance Extension Type III
USGS	U.S. Geological Survey

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Abstract

The North Dakota hydrology manual prepared by the U.S. Department of Agriculture, Soil Conservation Service, presents methodologies primarily used for developing hydrology for onfarm conservation practices, watershed projects, Resource Conservation and Development project measures, and river basin studies. The manual includes data necessary for determining hydrologic factors and developing a design discharge for a given site and intended purpose. The U.S. Geological Survey, in cooperation with the North Dakota Natural Resources Conservation Service, developed methods to reproduce and update the annual yield maps for chapter 7 of the North Dakota hydrology manual. Annual yields, in acre-feet per square mile, for the 50- and 80-percent exceedance probabilities and expected percentage of snowmelt runoff isolines were estimated using U.S. Geological Survey streamflow data from 1931 to 2016 for 71 selected streamgages with drainage areas of 505 square miles or less. An application of a modified Maintenance of Variance Extension Type III was used to estimate missing annual streamflow volumes. An alternate expected percentage of snowmelt runoff isolines was estimated using High Plains Climatic Center precipitation and snowmelt data from 1931 to 2016 for 85 selected sites. The final expected percentage of snowmelt runoff isolines was estimated using streamflow data instead of precipitation and snowfall depth data. A snowmelt runoff seasonal period of March–May produced better isoline slopes than a November–May runoff seasonal period. Slopes of the expected percentage of snowmelt runoff isolines were sensitive to amounts of missing record. Suitable isoline slopes appeared when the missing record was set to 50 percent (43 years) and 66 percent (57 years) for the 86-year period of 1931–2016.

Introduction and Background

The North Dakota hydrology manual (Soil Conservation Service, 1974) was prepared by the U.S. Department of Agriculture, Soil Conservation Service, to assist in planning and design measures for soil and water conservation practices and flood prevention measures in North Dakota. The manual includes data necessary for determining hydrologic factors and developing a design discharge for a given site and intended purpose. The methodology presented in the manual is primarily used for developing hydrology for onfarm conservation practices, watershed projects, Resource Conservation and Development project measures, and river basin studies. The maps of chapter 7 of the North Dakota hydrology manual are of particular interest to the North Dakota Natural Resources Conservation Service.

Annual runoff from a watershed has a direct relation to the watershed yield. Yield is defined as a flow volume over a set period. Chapter 7 of the North Dakota hydrology manual describes watershed yield as being used in the planning and design of water resource projects, commonly involving irrigation; recreational water storage; and municipal and industrial water supplies. The term watershed yield, however, is somewhat loosely used in the literature and can refer either to a long-term average (for example, 1971–2000 average annual streamflow) or can be synonymous with runoff volume for a specific period (such as flow for May 1999; Natural Resources Conservation Service, 2009).

Watershed water yield can be estimated several ways. Methods chosen depend upon data availability and the desired seasonal periods. Three ways to estimate watershed water yield are (1) runoff (yield) maps, (2) regression equations, and (3) water balance. The methods used to develop the annual yield maps (fig. 1) in chapter 7 of the North Dakota hydrology manual (hereafter referred to as the “chapter 7 annual yield maps”) are unknown, because no documentation is provided within the manual; however, U.S. Geological Survey (USGS) streamgages were used in the development of the chapter 7 annual yield maps.

Determination and documentation of annual yield map development methods along with updated chapter 7 annual yield maps would provide essential data for identifying and mitigating wetlands, locally for individual land owners and across North Dakota. This information would also increase understanding of development of annual yield maps and expected percentage of snowmelt runoff isolines for North Dakota. To address these needs, the USGS, in cooperation with the North Dakota Natural Resources Conservation Service, completed a study to determine small basin annual yield and percentage of snowmelt runoff in North

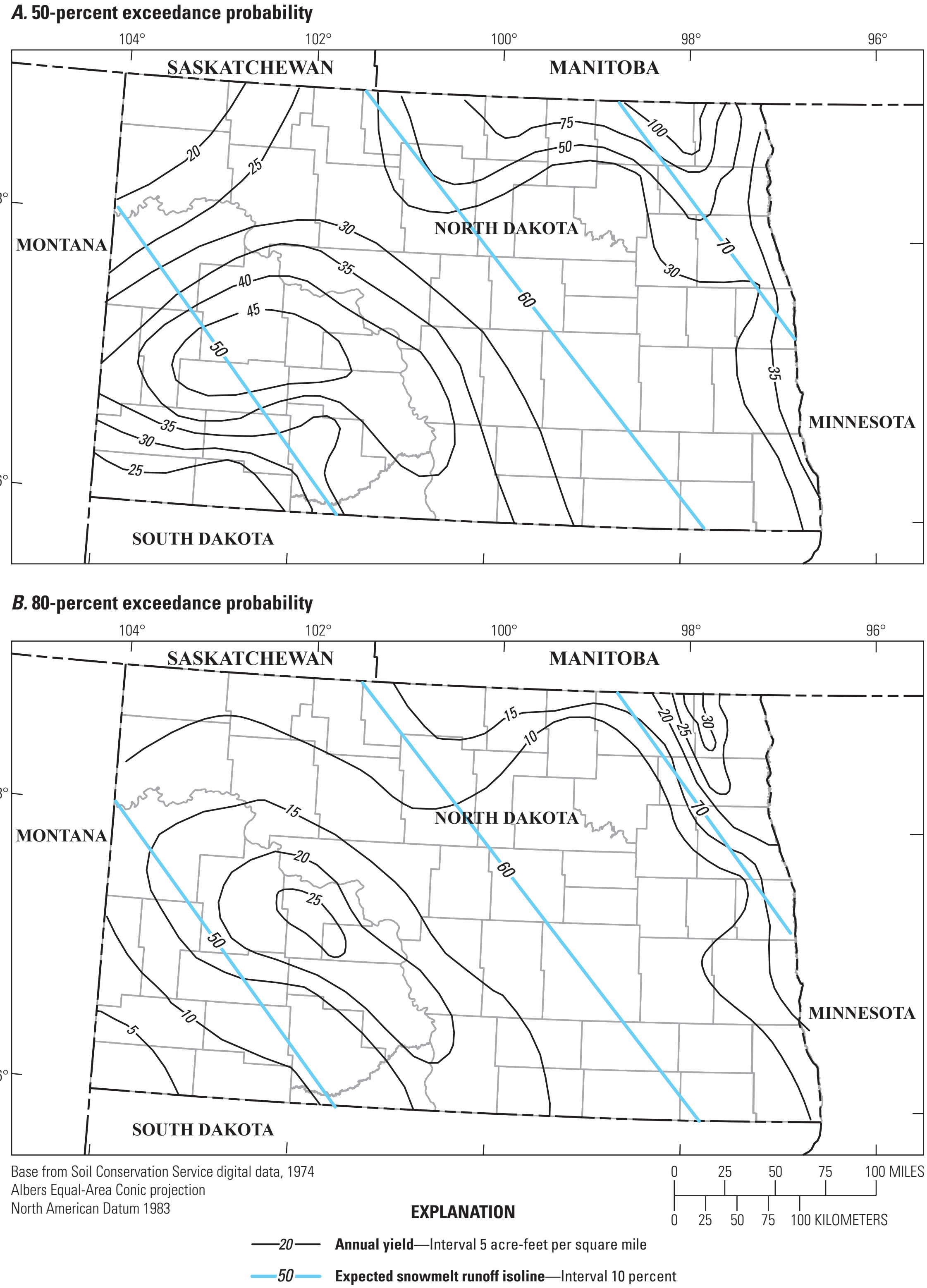


Figure 1. Annual yield maps in chapter 7 of the North Dakota hydrology manual (modified from Soil Conservation Service, 1974). *A*, 50-percent exceedance probability; *B*, 80-percent exceedance probability.

Dakota. This study had two specific objectives. The first objective was to attempt to reproduce the chapter 7 annual yield maps. The second objective was to use streamflow data from 1931 to 2016 to produce updated maps similar to the earlier maps.

Purpose and Scope

The purpose of this report is to present and describe small basin annual yield and percentage of snowmelt runoff in North Dakota for 1931–2016 using annual yield maps. This report also describes methods used to develop the annual yield maps that reproduce and update the chapter 7 annual yield maps of the North Dakota hydrology manual (Soil Conservation Service, 1974). The chapter 7 annual yield maps consist of two parts: (1) an annual yield contour map and (2) an expected percentage of snowmelt runoff isoline map. Annual yield and expected percentage of snowmelt runoff isoline estimates were based on daily mean streamflow data from 131 selected USGS streamgages in North Dakota and parts of Montana, South Dakota, and Minnesota. Alternate expected percentage of snowmelt runoff isoline estimates were based on 85 selected climate stations in North Dakota. Available climatic data from 1931 to 2016 were used.

Methods

The chapter 7 annual yield maps present two types of information: (1) the annual yield, in acre-feet per square mile, for the 50- and 80-percent exceedance probabilities and (2) the expected percentage of snowmelt runoff. Annual yield for the 50- and 80-percent exceedance probabilities and expected percentage of snowmelt runoff was estimated for 30-year normal periods 1941–70, 1981–2010, and 1987–2016. Additionally, the 86-year period 1931–2016 also was analyzed. Because the exact period of data used in the development of the chapter 7 annual yield maps was unknown, the 30-year normal period of 1941–70 was chosen to determine possible methodologies of the chapter 7 annual yield map development because the North Dakota hydrology manual was developed before 1974.

Streamflow records from the selected streamgages (U.S. Geological Survey, 2017) used in this study varied in length, and a consistent record length from 1931 to 2016 was desired. Consistent streamflow record lengths were achieved using a modified Maintenance of Variance Extension Type III (MOVE.3; Sando and McCarthy, 2018) to extend annual streamflow volume records. The modified MOVE.3 procedures generally follow the MOVE.3 methods of Vogel and Stedinger (1985), which involve synthesis of missing records for a short-record streamgage based on information collected from a single, longer-record streamgage (Sando and McCarthy, 2018). The modified MOVE.3 procedures require at least 7 or 8 years of concurrent peak-flow records for the target and index streamgages with a Pearson correlation coefficient greater than 0.80; and in some cases, uses a mixed-streamgage approach for the MOVE.3 procedure such that multiple index streamgages are used to synthesize missing records for a single target streamgage (Sando and McCarthy, 2018). Further details of the modified MOVE.3 procedures are discussed in Sando and McCarthy (2018).

A Weibull plotting formula (Loucks and others, 1981) was applied to determine the percentage exceedance probability of the annual yield, in acre-feet per square mile, for each data period chosen (1941–70, 1981–2010, 1987–2016, and 1931–2016). Linear interpolation was used where needed to estimate annual yield values at the 50- and 80-percent exceedance probabilities. Percentage exceedance probability values were plotted at streamgage locations using latitude and longitude, and the program Surfer® 15 (Golden Software, 2018) was used to generate a contour map using kriging methodology (Oliver and Webster, 1990). Kriging is a method of spatial interpolation that was used to generate an estimated surface model from the percentage exceedance probability value (z-value) of a scattered set of data points and is further explained within the Surfer program.

Daily mean streamflow records (U.S. Geological Survey, 2017) were used to determine the expected percentage of snowmelt runoff. The expected percentage of runoff attributed to snowmelt was calculated for each site using a period of record averaged ratio of summed daily streamflow per total annual streamflow for a selected period. Seasonal periods of November–May, March–May, and February–May 15 and an annual period (based on water year, which is October 1 to September 30) were used to determine the ratios. The period of record for each site used available data through 2016 and included expected percentage runoff averages for the chosen 30-year normal periods of 1941–70, 1981–2010, and 1987–2016 and the 86-year period of 1931–2016. The expected percentage of snowmelt runoff averages were plotted at streamgage locations using latitude and longitude and isolines generated by fitting a linear regression through the planar data using the Surfer® 15 program.

Monthly and annual climate records of precipitation and snowfall also were used to determine an alternate expected percentage of snowmelt runoff isoline. Snowfall depths were converted to water equivalents using a ratio of 10 inches (in.) of snow to 1 in. of water depth (National Weather Service, 2019). The expected percentage of runoff attributed to snowmelt was calculated for each site using a period of record averaged ratio of total snow water equivalent per total precipitation for the selected 30-year normal periods of 1941–70 and 1981–2000 and the 86-year period of 1931–2016. A seasonal period (November–May) and an annual period (by water year, October–September) were used to determine the ratios. The expected percentage of snowmelt runoff averages for 1941–70 were plotted at climate station locations using latitude and longitude and isolines generated by fitting a linear regression through the planar data using the Surfer® 15 program (Golden Software, 2018).

Data Sources

The data used in this study consisted of (1) daily mean streamflow records for 131 selected streamgages in North Dakota and parts of Montana, South Dakota, and Minnesota (fig. 2, table 1); (2) monthly and annual precipitation and snow depth totals for selected climate stations in North Dakota (fig. 3, table 2); and (3) selected basin characteristics (table 1). All available streamflow and climatic data were retrieved through 2016. Daily mean streamflow records were retrieved from the USGS National Water Information System (U.S. Geological Survey, 2017), a comprehensive and distributed application that supports the acquisition, processing, and long-term storage of water data.

The selected basin characteristics in table 1 (latitude, longitude, and drainage area) for the 131 selected streamgages were retrieved from Williams-Sether (2015) where available. Drainage areas for streamgages not included in Williams-Sether (2015) were estimated using State applications of StreamStats (U.S. Geological Survey, 2018). StreamStats is a USGS web application that provides access to an assortment of geographic information systems analytical tools that are useful for water-resources planning and management and for engineering and design purposes.

Monthly and annual precipitation and snow depth data of sites listed in table 2 were retrieved from the High Plains Regional Climate Center (High Plains Regional Climate Center, 2018). The High Plains Regional Climate Center provides the public with several ways to access climate data and information. Through various data acquisition methods, users can access a variety of climate data products such as near real-time and historical climate data; national and regional climate data maps; agricultural climate products; and monthly, quarterly, and annual regional climate summaries.

Annual Streamflow Volume

Annual streamflow volumes, in acre-feet, for the 131 selected streamgages were calculated by summing daily mean records, in cubic feet per second, and multiplying by 1.9835 (conversion from cubic feet per second to acre-feet) for each water year of record. Calculating the annual streamflow volumes per year required that a full water year (October 1 through September 30 of the following year) of daily mean record existed for the selected streamgages. However, sometimes a full annual record was not available and only seasonal (for example, March 1 through September 30) daily mean values existed. When the summed annual volume record count was less than 365 days (or 366 days for a leap year) but included at least 214 days, an averaged ratio method was applied to convert the 214-day (as an example) summed annual volume to a volume based on a 365-day count. For example, a streamgage has 214 days of data records during the year. For the exact same days (214), the volume sums were determined for all years that had 365 days. Ratios of volumes for 365/214-day counts were averaged over the years that had full counts of 365 days. A graphical plot was made of the 365/214 ratio versus the 214-day count volumes to identify any years that may be outliers. Visually identified outlying years were removed, and the average 365/214 ratio was recalculated. The final averaged 365/214 ratio value was then multiplied by all years that had 214-day count volumes to convert them to 365-day count volumes. The process was repeated as needed for other day counts greater than 214 days, such as 273 days. An example of this procedure is provided in appendix 1.

The modified MOVE.3 procedure (Sando and McCarthy, 2018) was then used to estimate annual streamflow volumes for the years where daily count was less than 214 days. A minimum of 7 years of concurrent annual volume records for the target and index streamgages with a slightly relaxed Pearson correlation coefficient of 0.70 were used in the modified MOVE.3 procedure. A description of the record-extension procedures and R code to run the modified MOVE.3 procedure are provided in appendix 2.

Annual Yield

The 50- and 80-percent exceedance probabilities for annual yield, in acre-feet per square mile, were determined by applying the Weibull plotting formula (Loucks and others, 1981) to each streamgage for each data period chosen. For each streamgage, the annual streamflow volumes, in acre-feet, were divided by the streamgage drainage area, in square miles. The values were then ranked from largest to smallest and assigned the associated plotting percentages calculated by equation 1.

$$P = \frac{n}{m+1} \times 100 \tag{1}$$

where

P	is the Weibull plotting percentage,
n	is the rank number, and
m	is the number of data in period.

The 50- and 80-percent exceedance probabilities were determined by interpolation of the ranked annual yield values based upon the Weibull plotting percentages for each period. An example is provided in table 3.

Snowmelt Runoff

Daily mean streamflow data and climatic data, respectively, were used to determine the expected percentage of snowmelt runoff. Using streamflow data, the expected percentage of snowmelt runoff was calculated for each selected streamflow site using a period of record averaged ratio of summed daily mean streamflow per total annual streamflow for a selected period. Seasonal periods of November–May, March–May, and February–May 15 and an annual period (by water year, October–September) were used to determine the

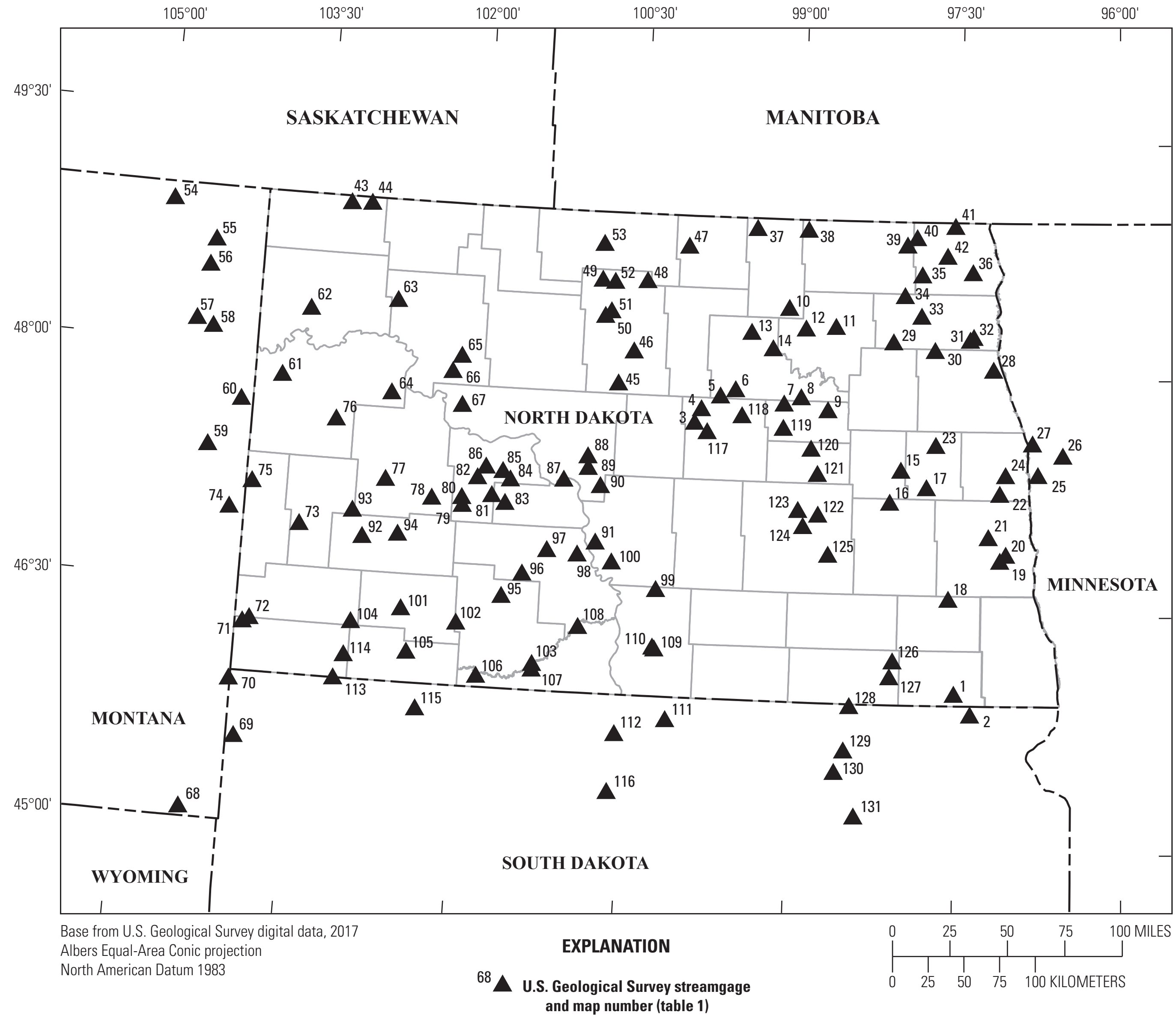


Figure 2. Locations of streamgages used to estimate annual yield percentage exceedance probabilities and expected percentage of snowmelt runoff.

Table 1. Hydrologic and basin characteristics for streamgages used.

[Data from Williams-Sether (2015) unless otherwise noted. N. Dak., North Dakota; S. Dak., South Dakota; Minn., Minnesota; Mont., Montana; no., number]

Map number (fig. 2)	U.S. Geological Survey station number	U.S. Geological Survey station name	Latitude (decimal degrees)	Longitude (decimal degrees)	Drainage area (square miles)
1	05051600	Wild Rice River near Rutland, N. Dak.	46.0220	−97.5115	503
2	05051650	La Belle Creek near Veblen, S. Dak.	45.8925	−97.3619	9.45
3	05054500	Sheyenne River above Harvey, N. Dak.	47.7026	−99.9492	423
4	05055000	Sheyenne River near Harvey, N. Dak.	47.7903	−99.8908	500
5	05055100	North Fork Sheyenne River near Wellsburg, N. Dak.	47.8761	−99.7185	461
6	05055200	Big Coulee near Maddock, N. Dak.	47.9194	−99.5798	132
7	05055500	Sheyenne River at Sheyenne, N. Dak.	47.8392	−99.1251	1,492
8	05055520	Big Coulee near Fort Totten, N. Dak.	47.8826	−98.9677	16.3
9	05056000	Sheyenne River near Warwick, N. Dak.	47.8053	−98.7165	2,080
10	05056100	Mauvais Coulee near Cando, N. Dak.	48.4480	−99.1026	398
11	05056200	Edmore Coulee near Edmore, N. Dak.	48.3363	−98.6605	303
12	05056239	Starkweather Coulee near Webster, N. Dak.	48.3204	−98.9405	265
13	05056300	Little Coulee at Leeds, N. Dak.	48.2875	−99.4478	180
14	05056390	Little Coulee near Brinsmade, N. Dak.	48.1879	−99.2432	251
15	05057000	Sheyenne River near Cooperstown, N. Dak.	47.4331	−98.0283	2,812
16	05057200	Baldhill Creek near Dazey, N. Dak.	47.2289	−98.1251	722
17	05059600	Maple River near Hope, N. Dak.	47.3255	−97.7895	20.5
18	05059700	Maple River near Enderlin, N. Dak.	46.6217	−97.5740	832
19	05060000	Maple River near Mapleton, N. Dak.	46.8667	−97.1058	1,466
20	05060100	Maple River below Mapleton, N. Dak.	46.9053	−97.0526	1,473
21	05060500	Rush River at Amenia, N. Dak.	47.0153	−97.2139	99.6
22	05062200	Elm River near Kelso, N. Dak.	47.2907	−97.1128	173
23	05064900	Beaver Creek near Finley, N. Dak.	47.5947	−97.7092	152
24	05066500	Goose River at Hillsboro, N. Dak.	47.4094	−97.0612	1,217
25	05067500	Marsh River near Shelly, Minn.	47.4120	−96.7632	233

Table 1. Hydrologic and basin characteristics for streamgages used.—Continued

[Data from Williams-Sether (2015) unless otherwise noted. N. Dak., North Dakota; S. Dak., South Dakota; Minn., Minnesota; Mont., Montana; no., number]

Map number (fig. 2)	U.S. Geological Survey station number	U.S. Geological Survey station name	Latitude (decimal degrees)	Longitude (decimal degrees)	Drainage area (square miles)
26	[1]05068500	Sand Hill Ditch at Beltrami, Minn.	47.5361	−96.5337	307
27	05069000	Sand Hill River at Climax, Minn.	47.6121	−96.8148	461
28	05083000	Turtle River at Manvel, N. Dak.	48.0777	−97.1827	550
29	05083600	Middle Branch Forest River near Whitman, N. Dak.	48.2472	−98.1193	49.3
30	05084000	Forest River near Fordville, N. Dak.	48.1974	−97.7301	355
31	05084500	Forest River near Minto, N. Dak.	48.2664	−97.4032	388
32	05085000	Forest River at Minto, N. Dak.	48.2847	−97.3709	499
33	05088000	South Branch Park River near Park River, N. Dak.	48.4139	−97.8615	214
34	05089100	Middle Branch Park River near Union, N. Dak.	48.5430	−98.0207	12.8
35	05089500	Cart Creek at Mountain, N. Dak.	48.6770	−97.8618	13.2
36	05092200	Pembina County drain 20 near Glasston, N. Dak.	48.6966	−97.3856	66.7
37	05098700	Hidden Island Coulee near Hansboro, N. Dak.	48.9497	−99.4257	25.8
38	05098800	Cypress Creek near Sarles, N. Dak.	48.9497	−98.9425	60.5
39	05099400	Little South Pembina River near Walhalla, N. Dak.	48.8652	−98.0067	175
40	05099600	Pembina River at Walhalla, N. Dak.	48.9136	−97.9171	3,325
41	05100000	Pembina River at Neche, N. Dak.	48.9899	−97.5570	3,393
42	05101500	Tongue River at Cavalier, N. Dak.	48.7986	−97.6268	167
43	05113500	Long Creek near Crosby, N. Dak.	48.9750	−103.2681	856
44	05113600	Long Creek near Noonan, N. Dak.	48.9812	−103.0762	1,058
45	05120200	Wintering River near Bergen, N. Dak.	47.9302	−100.6713	144
46	05120500	Wintering River near Karlsruhe, N. Dak.	48.1379	−100.5399	406
47	05122500	Willow Creek at Dunseith, N. Dak.	48.8202	−100.0635	155
48	05123400	Willow Creek near Willow City, N. Dak.	48.5889	−100.4420	1,061
49	05123510	Deep River near Upham, N. Dak.	48.5840	−100.8628	933

Table 1. Hydrologic and basin characteristics for streamgages used.—Continued

[Data from Williams-Sether (2015) unless otherwise noted. N. Dak., North Dakota; S. Dak., South Dakota; Minn., Minnesota; Mont., Montana; no., number]

Map number (fig. 2)	U.S. Geological Survey station number	U.S. Geological Survey station name	Latitude (decimal degrees)	Longitude (decimal degrees)	Drainage area (square miles)
50	05123600	Egg Creek near Granville, N. Dak.	48.3551	−100.8224	246
51	05123700	Cut Bank Creek at North Lake outlet near Granville, N. Dak.	48.3861	−100.7671	534
52	05123750	Cut Bank Creek at Upham, N. Dak.	48.5747	−100.7446	610
53	05123900	Boundary Creek near Landa, N. Dak.	48.8125	−100.8627	246
54	06182500	Big Muddy Creek at Daleview, Mont.	48.9109	−104.9391	276
55	06183450	Big Muddy Creek near Antelope, Mont.	48.6729	−104.5121	955
56	[1]06183700	Big Muddy Creek diversion canal near Medicine Lake, Mont.	48.5096	−104.5490	11.4
57	06185110	Big Muddy Creek near mouth near Culbertson, Mont.	48.1645	−104.6295	2,717
58	06185500	Missouri River near Culbertson, Mont.	48.1235	−104.4733	89,858
59	06329200	Burns Creek near Savage, Mont.	47.3723	−104.4300	234
60	06329500	Yellowstone River near Sidney, Mont.	47.6774	−104.1554	69,099
61	06329597	Charbonneau Creek near Charbonneau, N. Dak.	47.8509	−103.7941	152
62	06331000	Little Muddy River below Cow Creek near Williston, N. Dak.	48.2845	−103.5736	707
63	06332000	White Earth River at White Earth, N. Dak.	48.3757	−102.7674	473
64	06332515	Bear Den Creek near Mandaree, N. Dak.	47.7873	−102.7687	74.0
65	06332520	Shell Creek near Parshall, N. Dak.	48.0492	−102.1379	171
66	06332523	East Fork Shell Creek near Parshall, N. Dak.	47.9486	−102.2149	164
67	06332770	Deepwater Creek at mouth near Raub, N. Dak.	47.7378	−102.1077	204
68	06334000	Little Missouri River near Alzada, Mont.	45.0763	−104.4097	905
69	06334500	Little Missouri River at Camp Crook, S. Dak.	45.5481	−103.9712	1,974
70	06334630	Box Elder Creek at Webster, Mont.	45.9070	−104.0574	1,097
71	06335000	Little Beaver Creek near Marmarth, N. Dak.	46.2739	−103.9767	595
72	06335500	Little Missouri River at Marmarth, N. Dak.	46.2980	−103.9165	4,669

Table 1. Hydrologic and basin characteristics for streamgages used.—Continued

[Data from Williams-Sether (2015) unless otherwise noted. N. Dak., North Dakota; S. Dak., South Dakota; Minn., Minnesota; Mont., Montana; no., number]

Map number (fig. 2)	U.S. Geological Survey station number	U.S. Geological Survey station name	Latitude (decimal degrees)	Longitude (decimal degrees)	Drainage area (square miles)
73	06336000	Little Missouri River at Medora, N. Dak.	46.9166	−103.5318	6,209
74	06336500	Beaver Creek at Wibaux, Mont.	46.9899	−104.1838	376
75	06336600	Beaver Creek near Trotters, N. Dak.	47.1631	−103.9931	602
76	06337000	Little Missouri River near Watford City, N. Dak.	47.5959	−103.2640	8,342
77	06339100	Knife River at Manning, N. Dak.	47.2368	−102.7707	204
78	06339300	Knife River at Marshall, N. Dak.	47.1381	−102.3350	739
79	06339490	Elm Creek near Golden Valley, N. Dak.	47.1051	−102.0509	94.2
80	06339500	Knife River near Golden Valley, N. Dak.	47.1544	−102.0596	1,220
81	06339560	Brush Creek near Beulah, N. Dak.	47.1785	−101.7851	24.4
82	06340000	Spring Creek at Zap, N. Dak.	47.2861	−101.9255	554
83	06340200	West Branch Otter Creek near Beulah, N. Dak.	47.1343	−101.6601	25.8
84	06340500	Knife River at Hazen, N. Dak.	47.2850	−101.6225	2,254
85	06340520	Antelope Creek above Hazen, N. Dak.	47.3353	−101.6952	47.2
86	06340528	West Branch Antelope Creek no. 4 near Zap, N. Dak.	47.3569	−101.8527	9.08
87	06340905	Coal Lake Coulee near Hensler, N. Dak.	47.3025	−101.1315	72.1
88	06341400	Turtle Creek near Turtle Lake, N. Dak.	47.4583	−100.9201	290
89	06341410	Turtle Creek above Washburn, N. Dak.	47.3850	−100.9122	445
90	06341800	Painted Woods Creek near Wilton, N. Dak.	47.2737	−100.7917	191
91	06342450	Burnt Creek near Bismarck, N. Dak.	46.9150	−100.8137	111
92	06343000	Heart River near South Heart, N. Dak.	46.8652	−102.9484	311
93	06344600	Green River near New Hradec, N. Dak.	47.0269	−103.0538	157
94	06345000	Green River near Gladstone, N. Dak.	46.8958	−102.6253	364
95	06347000	Antelope Creek near Carson, N. Dak.	46.5453	−101.6454	238
96	06347500	Big Muddy Creek near Almont, N. Dak.	46.6941	−101.4676	439

Table 1. Hydrologic and basin characteristics for streamgages used.—Continued

[Data from Williams-Sether (2015) unless otherwise noted. N. Dak., North Dakota; S. Dak., South Dakota; Minn., Minnesota; Mont., Montana; no., number]

Map number (fig. 2)	U.S. Geological Survey station number	U.S. Geological Survey station name	Latitude (decimal degrees)	Longitude (decimal degrees)	Drainage area (square miles)
97	06348500	Sweetbriar Creek near Judson, N. Dak.	46.8511	−101.2532	157
98	06349000	Heart River near Mandan, N. Dak.	46.8337	−100.9738	3,317
99	06349215	Long Lake Creek above Long Lake near Moffit, N. Dak.	46.6330	−100.2420	341
100	06349500	Apple Creek near Menoken, N. Dak.	46.7944	−100.6574	1,444
101	06350000	Cannonball River at Regent, N. Dak.	46.4267	−102.5504	581
102	06351000	Cannonball River below Bentley, N. Dak.	46.3592	−102.0422	1,148
103	06351200	Cannonball River near Raleigh, N. Dak.	46.1269	−101.3332	1,640
104	06351680	White Butte Fork Cedar Creek near Scranton, N. Dak.	46.3229	−102.9963	43.3
105	06352000	Cedar Creek near Haynes, N. Dak.	46.1552	−102.4757	557
106	06352500	Cedar Creek near Pretty Rock, N. Dak.	46.0320	−101.8324	1,347
107	06353000	Cedar Creek near Raleigh, N. Dak.	46.0917	−101.3337	1,776
108	06354000	Cannonball River at Breien, N. Dak.	46.3760	−100.9346	4,093
109	06354500	Beaver Creek at Linton, N. Dak.	46.2575	−100.2336	727
110	06354580	Beaver Creek below Linton, N. Dak.	46.2686	−100.2518	765
111	06354860	Spring Creek near Herreid, S. Dak.	45.8145	−100.1082	2,029
112	06354882	Oak Creek near Wakpala, S. Dak.	45.7119	−100.5592	355
113	06355000	North Fork Grand River at Haley, N. Dak.	45.9605	−103.1193	528
114	06355310	Buffalo Creek tributary near Gascoyne, N. Dak.	46.1111	−103.0393	15.5
115	06355500	North Fork Grand River near White Butte, S. Dak.	45.8022	−102.3624	1,200
116	06361000	Moreau River at Promise, S. Dak.	45.3450	−100.6029	5,240
117	06467600	James River near Manfred, N. Dak.	47.6461	−99.8296	113
118	06467900	Big Slough at Hamberg, N. Dak.	47.7557	−99.5121	59.8
119	06468000	James River at New Rockford, N. Dak.	47.6849	−99.1254	556
120	06468170	James River near Grace City, N. Dak.	47.5581	−98.8629	888

Table 1. Hydrologic and basin characteristics for streamgages used.—Continued

[Data from Williams-Sether (2015) unless otherwise noted. N. Dak., North Dakota; S. Dak., South Dakota; Minn., Minnesota; Mont., Montana; no., number]

Map number (fig. 2)	U.S. Geological Survey station number	U.S. Geological Survey station name	Latitude (decimal degrees)	Longitude (decimal degrees)	Drainage area (square miles)
121	06468250	James River above Arrowwood Lake near Kensal, N. Dak.	47.3993	−98.7976	1,034
122	06468500	James River near Pingree, N. Dak.	47.1417	−98.7837	1,670
123	06469400	Pipestem Creek near Pingree, N. Dak.	47.1673	−98.9687	658
124	06469500	Pipestem Creek near Buchanan, N. Dak.	47.0664	−98.9190	719
125	06470000	James River at Jamestown, N. Dak.	46.8896	−98.6819	2,799
126	06470800	Bear Creek near Oakes, N. Dak.	46.2254	−98.0712	417
127	06470833	Pilot Drain at Oakes, N. Dak.	46.1249	−98.0973	0.04
128	06471200	Maple River at North Dakota-South Dakota State line	45.9368	−98.4534	480
129	06471500	Elm River at Westport, S. Dak.	45.6561	−98.4970	1,505
130	06471800	Foot Creek near Aberdeen, S. Dak.	45.5192	−98.5775	173
131	06472000	James River near Stratford, S. Dak.	45.2416	−98.3915	8,780

[1]Drainage area estimated using respective State StreamStats applications (U.S. Geological Survey, 2018).

ratios. Period of record averages were determined for 30-year normal periods of 1941–70, 1981–2010, and 1987–2016 and the 86-year period of 1931–2016.

Climatic data were modified to account for missing records and nonnumerical data qualifiers. The monthly precipitation and snow depth records, labeled as trace (T), were treated as zeros. Yearly seasonal (November–May) and annual (October–September) precipitation totals were not determined if a missing record was noted within the months of selected periods (November–May and October–September). Yearly seasonal and annual snow depth totals were omitted if a missing record of more than 5 days was noted within the months of selected periods (November–May and October–September). Snow depth totals for June–September were considered to be negligible and treated as zero if labeled as missing. Using climatic data, the expected percentage of snowmelt runoff was calculated for each selected climatic site using a period of record averaged ratio of total snow water equivalent per total precipitation for the selected 30-year normal periods of 1941–70 and 1981–2000 and the 86-year period of 1931–2016.

Map Generation

All data used in this study were projected, gridded, and mapped using Surfer® 15 (Golden Software, 2018). Before generating the annual yield and expected percentage of snowmelt runoff maps, the base maps and datasets were projected to the Albers Equal-Area Conic, in meters. A grid file was then created and used to produce a grid-based map. The grid-based map was created by providing the software program randomly spaced longitudinal coordinate, latitudinal coordinate, and gridded value (annual yield or expected percentage of snowmelt runoff; X, Y, and Z, respectively) data (from the datasets), which were then used to generate a regularly spaced grid file composed of grid nodes. The grid nodes were specific to an XY location and contained a Z value.

Golden Software Scripter™ (Golden Software, 2018) is a program for creating and executing scripts. Instructions are written in a Visual BASIC programming format. Almost everything that can be done manually with a mouse and keyboard in Surfer® 15 can be automated through Scripter™ by scripts (Golden Software, 2018). A script is a text file that contains a series of instructions carried out by a script interpreter program (Scripter™) when the script is run. Scripter™ was mainly used to automate the repetitive task of generating

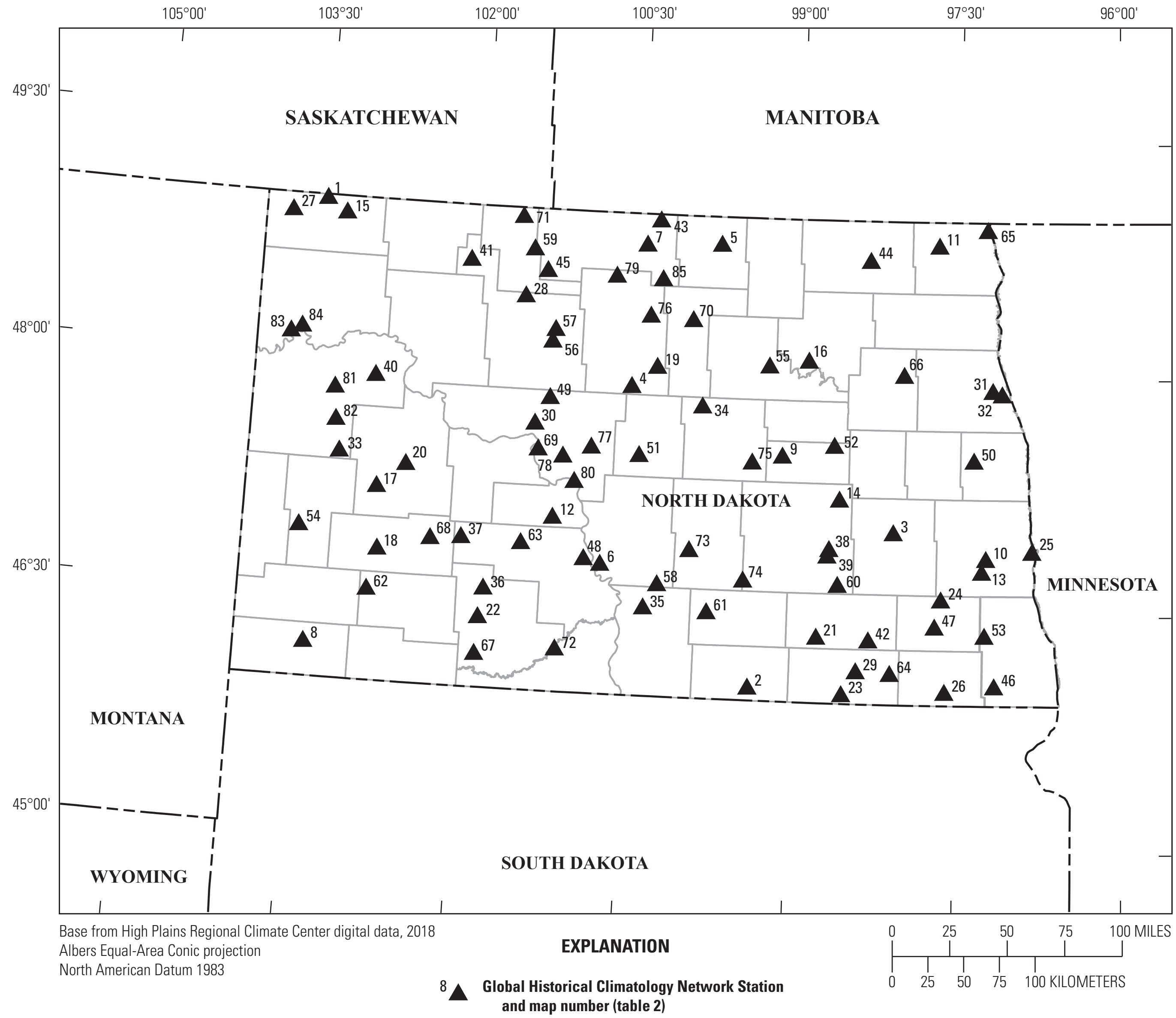


Figure 3. Locations of climatic stations used to estimate alternate expected percentage of snowmelt runoff.

Table 2. Climatic stations used.

Map number (fig. 3)	Global Historical Climatology Network number	Station name	Latitude (decimal degrees)	Longitude (decimal degrees)
1	USC00320189	Ambrose 3 north	48.9975	−103.4877
2	USC00320382	Ashley	46.0405	−99.3741
3	USC00320450	Baldhill Dam	47.0360	−98.0831
4	USC00320492	Balfour 2 southwest	47.9180	−100.5400
5	USC00320626	Belcourt Keya Radio	48.8411	−99.7508
6	USW00024011	Bismarck Municipal airport	46.7825	−100.7572
7	USC00320941	Bottineau	48.8216	−100.4525
8	USC00320995	Bowman	46.1825	−103.4061
9	USC00321362	Carrington 4 north	47.5088	−99.1211
10	USC00321408	Casselton Agronomy Farm	46.8769	−97.2328
11	USC00321435	Cavalier 7 northwest	48.8624	−97.7015
12	USC00321456	Center 4 southeast	47.0644	−101.2119
13	USC00321477	Chaffee 5 northeast	46.7958	−97.2686
14	USC00321816	Courtenay 1 northwest	47.2408	−98.5838
15	USC00321871	Crosby	48.9144	−103.2977
16	USC00322148	Devils Lake Municipal airport	48.1167	−98.9000
17	USC00322193	Dickinson Ranch headquarters	47.1944	−102.8413
18	USW00024012	Dickinson Theodore Roosevelt Regional airport	46.7994	−102.7972
19	USC00322304	Drake 9 northeast	48.0475	−100.3100
20	USC00322365	Dunn Center 1 east	47.3466	−102.5869
21	USC00322482	Edgeley 3 west-northwest	46.3694	−98.7661
22	USC00322588	Elgin	46.4088	−101.8419
23	USC00322605	Ellendale	46.0108	−98.5261
24	USC00322695	Enderlin 2 west	46.6166	−97.6388
25	USW00014914	Fargo Hector International airport	46.9253	−96.8111
26	USC00323117	Forman 5 south-southeast	46.0333	−97.5950
27	USC00323196	Fortuna 1 west	48.9080	−103.8055
28	USC00323217	Foxholm 7 north	48.4583	−101.5697
29	USC00323287	Fullerton 1 east-southeast	46.1580	−98.4000
30	USC00323376	Garrison	47.6538	−101.4198
31	USW00014916	Grand Forks International airport	47.9428	−97.1839
32	USC00323621	Grand Forks University (National Weather Service)	47.9217	−97.0975
33	USC00323705	Grassy Butte 2 east-northeast	47.4011	−103.2072
34	USC00324013	Harvey 4 northeast	47.8083	−99.8758
35	USC00324083	Hazelton 4 northwest	46.5203	−100.3478
36	USC00324091	Heart Butte Dam	46.5916	−101.8074
37	USC00324102	Hebron	46.9075	−102.0382
38	USW00014919	Jamestown Municipal airport	46.9258	−98.6691
39	USC00324418	Jamestown State Hospital.	46.8844	−98.6850
40	USC00324571	Keene 3 south	47.8966	−102.9208
41	USC00324646	Kenmare 1 west-southwest	48.6691	−102.0975
42	USC00324937	LaMoure	46.3547	−98.2927
43	USC00324879	Lake Metigoshe State Park	48.9797	−100.3344

Table 2. Climatic stations used.—Continued

Map number (fig. 3)	Global Historical Climatology Network number	Station name	Latitude (decimal degrees)	Longitude (decimal degrees)
44	USC00324958	Langdon Experiment Farm	48.7622	−98.3447
45	USC00325002	Lansford	48.6272	−101.3764
46	USC00325186	Lidgerwood	46.0725	−97.1461
47	USC00325220	Lisbon	46.4444	−97.6928
48	USC00325479	Mandan Experiment Station	46.8127	−100.9097
49	USC00325638	Max	47.8213	−101.2922
50	USC00325660	Mayville	47.4988	−97.3513
51	USC00325710	McClusky	47.4825	−100.4444
52	USC00325730	McHenry	47.5808	−98.6422
53	USC00325754	McLeod 3 east	46.3911	−97.2391
54	USC00325813	Medora	46.9161	−103.5263
55	USC00325848	Minnewaukan	48.0780	−99.2655
56	USC00325993	Minot Experiment Station	48.1802	−101.2963
57	USW00024013	Minot International airport	48.2552	−101.2733
58	USC00326015	Moffit 3 southeast	46.6705	−100.2294
59	USC00326025	Mohall	48.7602	−101.5090
60	USC00326105	Montpelier	46.7005	−98.5839
61	USC00326255	Napoleon	46.5066	−99.7691
62	USC00326315	New England	46.5413	−102.8691
63	USC00326365	New Salem 5 northwest	46.8925	−101.4897
64	USC00326620	Oakes	46.1458	−98.0919
65	USW00014924	Pembina	48.9663	−97.2476
66	USC00327027	Petersburg 2 north	48.0356	−98.0096
67	USC00327311	Pretty Rock	46.1758	−101.8561
68	USC00327530	Richardton Abbey	46.8886	−102.3191
69	USC00327585	Riverdale	47.4914	−101.3775
70	USC00327704	Rugby	48.3541	−99.9925
71	USC00328047	Sherwood	48.9623	−101.6310
72	USC00328065	Shields	46.2330	−101.1291
73	USC00328366	Steele 4 north	46.8948	−99.9482
74	USC00328415	Streeter 5 northwest	46.7154	−99.4475
75	USC00328608	Sykeston	47.4647	−99.3983
76	USC00328792	Towner 2 northeast	48.3706	−100.3907
77	USC00328840	Turtle Lake	47.5213	−100.8883
78	USC00328872	Underwood	47.4550	−101.1461
79	USC00328913	Upham 3 north	48.6147	−100.7263
80	USC00329195	Washburn	47.2981	−101.0300
81	USC00329233	Watford City	47.8038	−103.2891
82	USC00329246	Watford City 14 south	47.6000	−103.2597
83	USC00329430	Williston Experiment Farm	48.1375	−103.7372
84	USW00094014	Williston Sloulin Field International airport	48.1738	−103.6366
85	USC00329445	Willow City	48.6060	−100.2910

Table 3. Example application of Weibull plotting for U.S. Geological Survey station 05066500 for the 1941–70 period of record.

[The annual streamflow volumes are determined through methods listed in appendix 1 and (or) 2. Annual yield is determined by dividing the annual volumes by drainage area (1,217 square miles). The annual yields are then ranked from largest to smallest values. The Weibull plotting percentage is determined by dividing the rank of annual yield by number of data in period (30) +1. The interpolated annual yields associated with the 50- and 80-percent exceedance probabilities are determined by interpolation of associated numbers (highlighted in yellow) in the "Rank of annual yield" and "Weibull plotting percentage" columns. --, no data]

Water year	Annual streamflow volume, in acre-feet	Annual yield, in acre-feet per square mile	Rank	Rank of annual yield from largest to smallest values, in acre-feet per square mile	Weibull plotting percentage computed using equation 1	Percentage exceedance probability, in percent	Interpolated annual yield, in acre-feet per square mile
1941	37,449.273	30.772	1	234.681	3.226	--	--
1942	24,296.487	19.964	2	110.841	6.452	--	--
1943	29,642.812	24.357	3	100.466	9.677	--	--
1944	9,880.607	8.119	4	100.188	12.903	--	--
1945	12,511.323	10.280	5	96.181	16.129	--	--
1946	18,349.359	15.078	6	94.338	19.355	--	--
1947	37,371.520	30.708	7	88.359	22.581	--	--
1948	121,928.324	100.188	8	59.192	25.806	--	--
1949	44,944.523	36.931	9	36.931	29.032	--	--
1950	285,606.744	234.681	10	34.262	32.258	--	--
1951	27,999.284	23.007	11	30.772	35.484	--	--
1952	30,536.379	25.092	12	30.708	38.710	--	--
1953	20,012.722	16.444	13	27.284	41.935	--	--
1954	12,615.853	10.366	14	25.092	45.161	--	--
1955	17,524.223	14.400	15	24.357	48.387	50	24.21
1956	24,259.593	19.934	16	24.060	51.613	--	--
1957	7,099.740	5.834	17	23.007	54.839	--	--
1958	5,813.440	4.777	18	19.964	58.065	--	--
1959	5,244.572	4.309	19	19.934	61.290	--	--
1960	33,204.385	27.284	20	16.444	64.516	--	--
1961	6,622.708	5.442	21	15.078	67.742	--	--
1962	72,036.951	59.192	22	14.400	70.968	--	--
1963	12,319.915	10.123	23	10.366	74.194	--	--
1964	29,281.419	24.060	24	10.280	77.419	--	--
1965	122,267.502	100.466	25	10.123	80.645	80	10.15
1966	134,894.066	110.841	26	8.119	83.871	--	--
1967	107,532.914	88.359	27	5.834	87.097	--	--
1968	41,697.018	34.262	28	5.442	90.323	--	--
1969	117,052.286	96.181	29	4.777	93.548	--	--
1970	114,809.126	94.338	30	4.309	96.774	--	--

all the grid files, to confine the grid size and grid nodes to be consistent for each dataset gridded, and to maintain consistency in gridding future datasets.

The optimal gridding method to use for this study was determined by running a premade script provided by Golden Software in Scripter™ on a dataset to assist in the gridding method decision. The main goal was to choose the grid that seemed to be the most realistic representation of the data that contained smooth contours. The script created a side-by-side visual comparison of all 12 available gridding methods. Grids that seemed to be unrealistic or contained sharp-turning contours were discarded. The remaining grids were evaluated by examining the grid residuals to determine which grid had the best fit to the data. This study used the Surfer® 15 kriging method with default options to grid streamflow data and the Surfer® 15 polynomial regression to grid expected percentage of snowmelt runoff data. The kriging method grids data by assigning each grid node a value based on the known data points neighboring the node. Each data point is weighted by its distance away from the node; the farther away data points are from the node, the less weight those points will have in the estimation of the value for the node. The polynomial regression method grids data to produce a grid that shows large-scale trends and patterns contained within the dataset. This is a preferred method for generating a trend surface analysis and was used to generate the isolines for expected percentage of snowmelt runoff

Annual Yields and Percentage of Snowmelt Runoff

The main purpose of this study was to determine how the chapter 7 annual yield map and expected percentage of snowmelt runoff isolines were developed for the North Dakota hydrology manual and to update the chapter 7 annual yield maps (fig. 1; Soil Conservation Service, 1974). Maps likely were developed before 1974; therefore, initial attempts were made using data from 1941 to 1970. Using the climatic data to determine the expected percentage of snowmelt runoff isolines resulted in a gradient that increased from southeast to northwest (fig. 4). In contrast, the expected percentage of snowmelt isoline gradient shown in the original chapter 7 annual yield maps (fig. 1) increases from southwest to northeast.

A subsequent effort was made using streamflow data from the 131 selected streamgages to determine the expected percentage of snowmelt runoff isolines (fig. 5); however, not all 131 streamgages had complete daily streamflow records, so streamgages were removed from the list if more than 10 years of daily streamflow records were missing from the 1941–70 computations. Removing streamgages with more than 10 years of missing record produced a map that more closely resembled the original map shown in figure 1 and increasing isolines from southwest to northeast. Isoline slopes and percentages were not exact fits to the original lines, likely because the exact streamgages and lengths of records used before 1974 were unknown. The expected percentage of snowmelt runoff isoline determined using a November–May period (fig. 5*A*) showed a flatter slope and a greater percentage of runoff than the original (fig. 1), but the expected percentage of snowmelt runoff isoline determined using a March–May period (fig. 5*B*) showed steeper line slopes and percentages that were closer to the original (fig. 1).

Because the chapter 7 annual yield maps are mainly used for small drainages, the streamflow dataset used for the expected percentage of snowmelt runoff isoline attempt was reduced to exclude drainage basins larger than 505 square miles (mi^2). Maps of expected percentage of snowmelt runoff isolines generated after excluding drainage areas larger than 505 mi^2 (fig. 6) showed a gradient that increased from the southeast to the northwest, opposite of what was shown in figures 1 and 5. This shift in isoline gradient indicates that expected percentage of snowmelt runoff isoline computations are dependent upon (1) the number of streamgages being used, (2) the runoff period being used, (3) the period of record being used, and (4) the number of missing years allowed within the period of record. Examination of the results illustrated in figures 2–6 led to a streamgage dataset with drainage areas of 505 mi^2 or less for the 1931–2016 period of record and a runoff period of March–May used for the final expected percentage of snowmelt runoff computations.

Initial attempts to duplicate the annual yield for the 50- and 80-percent exceedance probabilities using data from 1941–70 with 10-percent or less missing record and kriging methods to generate the contour lines are shown in figure 7. Although the resulting maps were similar to the original map (with highs and lows in similar places), an exact match was unattainable because the number of sites and record lengths used were unknown. Variability of the contours was dependent upon the number of streamgages being used and the period of record used to calculate exceedance probabilities.

Potential contouring problems may exist in the form of steep gradients (dark zones in fig. 7). The primary cause for the contouring problems likely is the juxtaposition of large and small percentage exceedance probabilities associated with streamgages near each other. However, the variability of recorded data with extreme flow years (low or high) and the variability of the annual flow volumes estimated using streamflow volume record-extension procedures (MOVE.3) also may contribute to contouring problems in figure 7. Closer examination of the contour maps showed steep gradient areas at locations of streamgages with larger drainage basins and those that had more than 50 percent of the period of record annual volumes estimated by MOVE.3. Data used to generate the updated contour maps were restricted to drainage areas of 505 mi^2 or less and the 1931–2016 period of record with 10-percent or less missing record to be consistent with the expected percentage of snowmelt runoff isoline data.

Updated combined maps of the annual yield contours and expected percentage of snowmelt runoff isolines using data from 1931 to 2016 are shown in figures 8–11. Streamgages

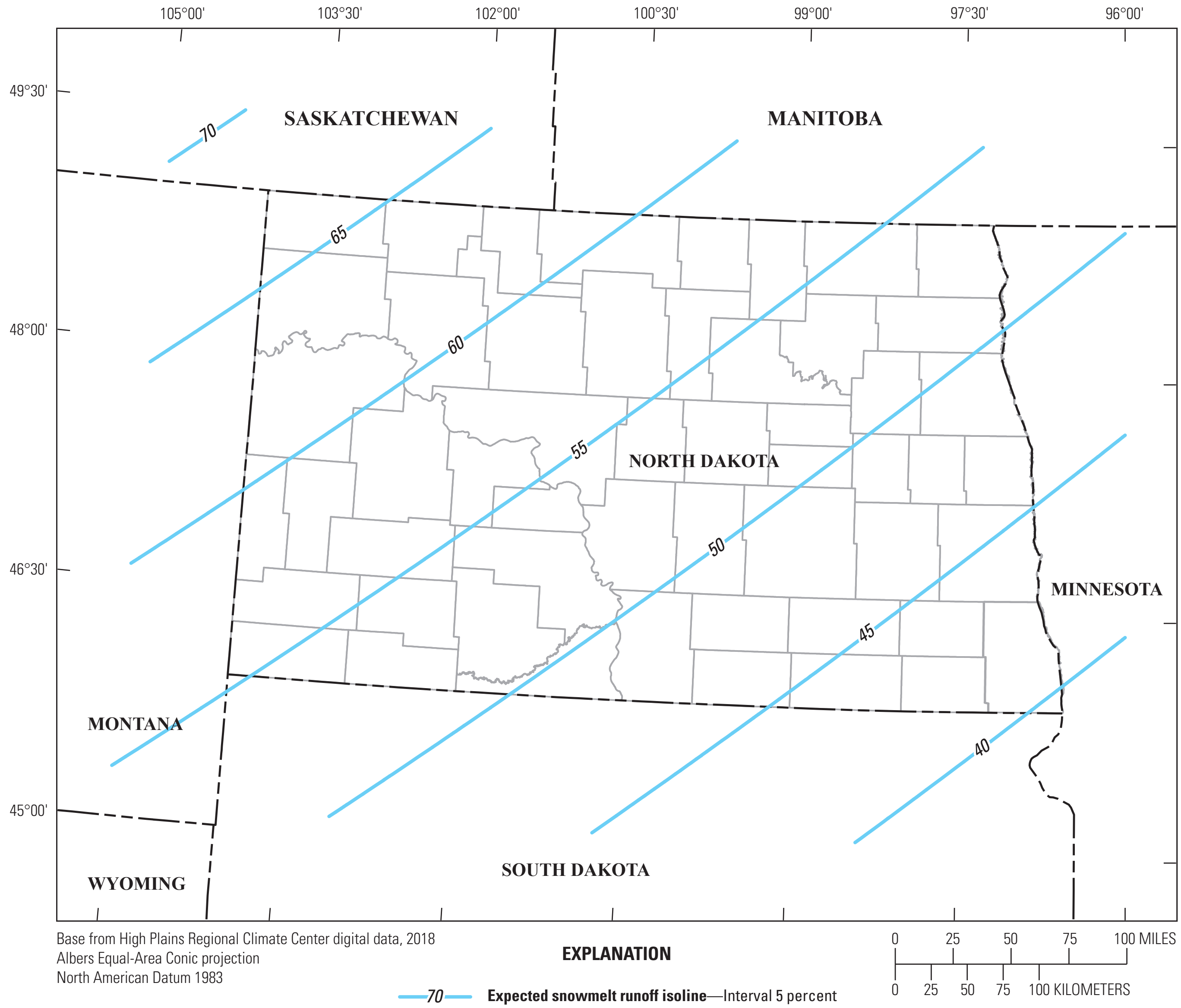


Figure 4. Expected percentage of snowmelt runoff isolines for 1941–70 using November–May climatic data.

with 10-percent or less missing calculated and estimated annual volumes were used to generate figures 8 and 9 because a full 86-year record length resulted in a sparse dataset. The expected percentage of snowmelt runoff calculations were allowed to be missing a record of 28 years (33 percent), 43 years (50 percent), and 57 years (66 percent) because few streamgages had a complete 86-year record length. Maps generated using different missing data thresholds were then compared to examine the effect of missing streamgages and record on the average expected percentage of snowmelt runoff calculations in terms of isoline slope and percentage. Streamgages that had 10-percent or less missing annual volume record and 50 percent or less of the annual volumes estimated by MOVE.3 were used to generate figures 10 and 11. Again, the expected percentage of snowmelt runoff calculations were allowed to be missing a record of 28 years (33 percent), 43 years (50 percent), and 57 years (66 percent). Maps can be compared to illustrate how using streamgages with less estimated annual volume affects generated isolines.

Maps generated using streamgages with 50 percent or less estimated annual volumes from MOVE.3 indicated less contouring problems of steep gradients caused by large and small percentage exceedance probabilities for streamgages that are near each other. The expected percentage of snowmelt runoff isoline slopes were similar to those of the original chapter 7 annual yield map when 50 percent and 66 percent of the period of record (1931–2016) was allowed to be missing.

***A.* November–May streamflow data**

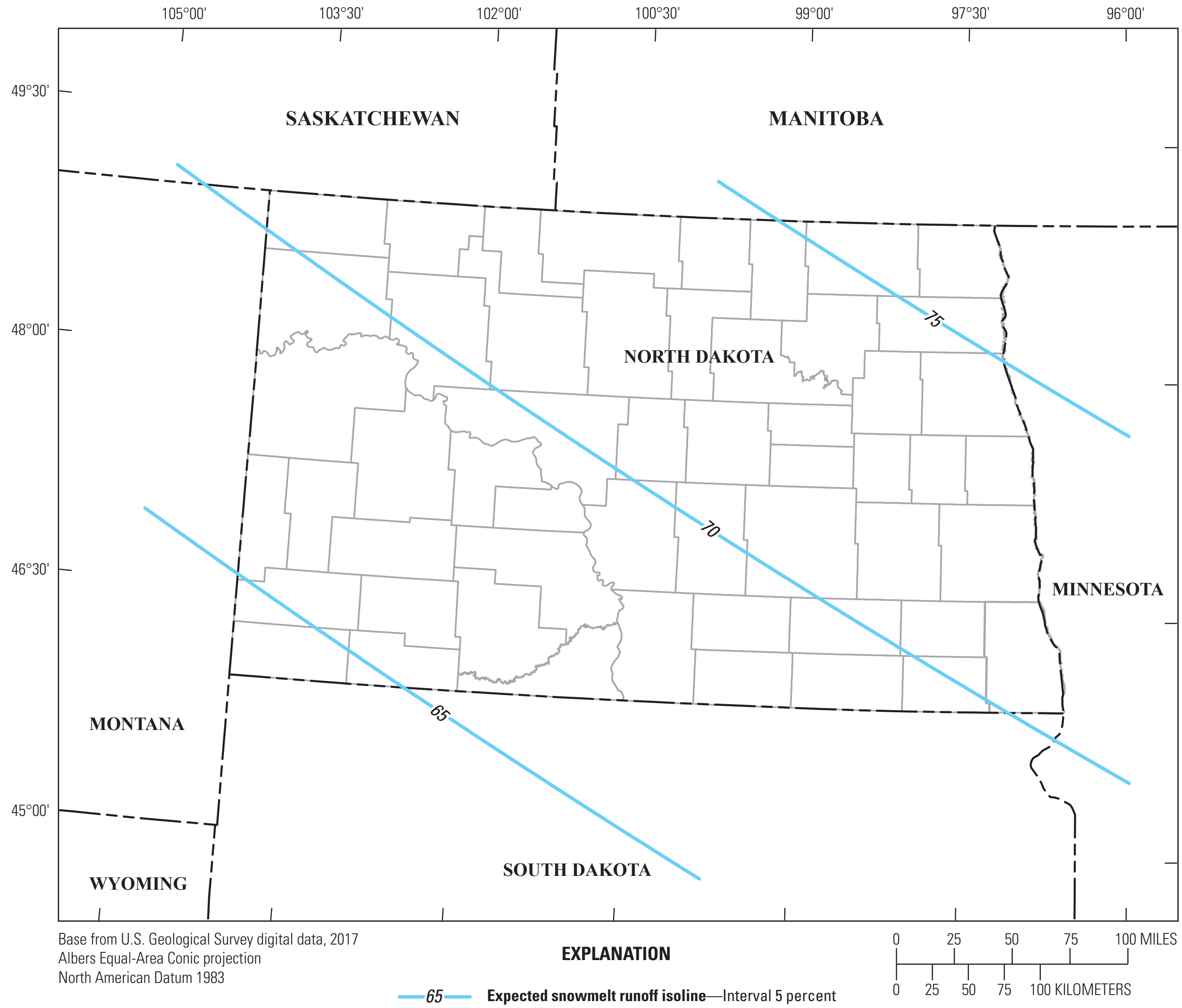


Figure 5. Expected percentage of snowmelt runoff isolines for 1941–70 using streamflow data. *A*, November–May streamflow data; *B*, March–May streamflow data.

B. **March–May streamflow data**

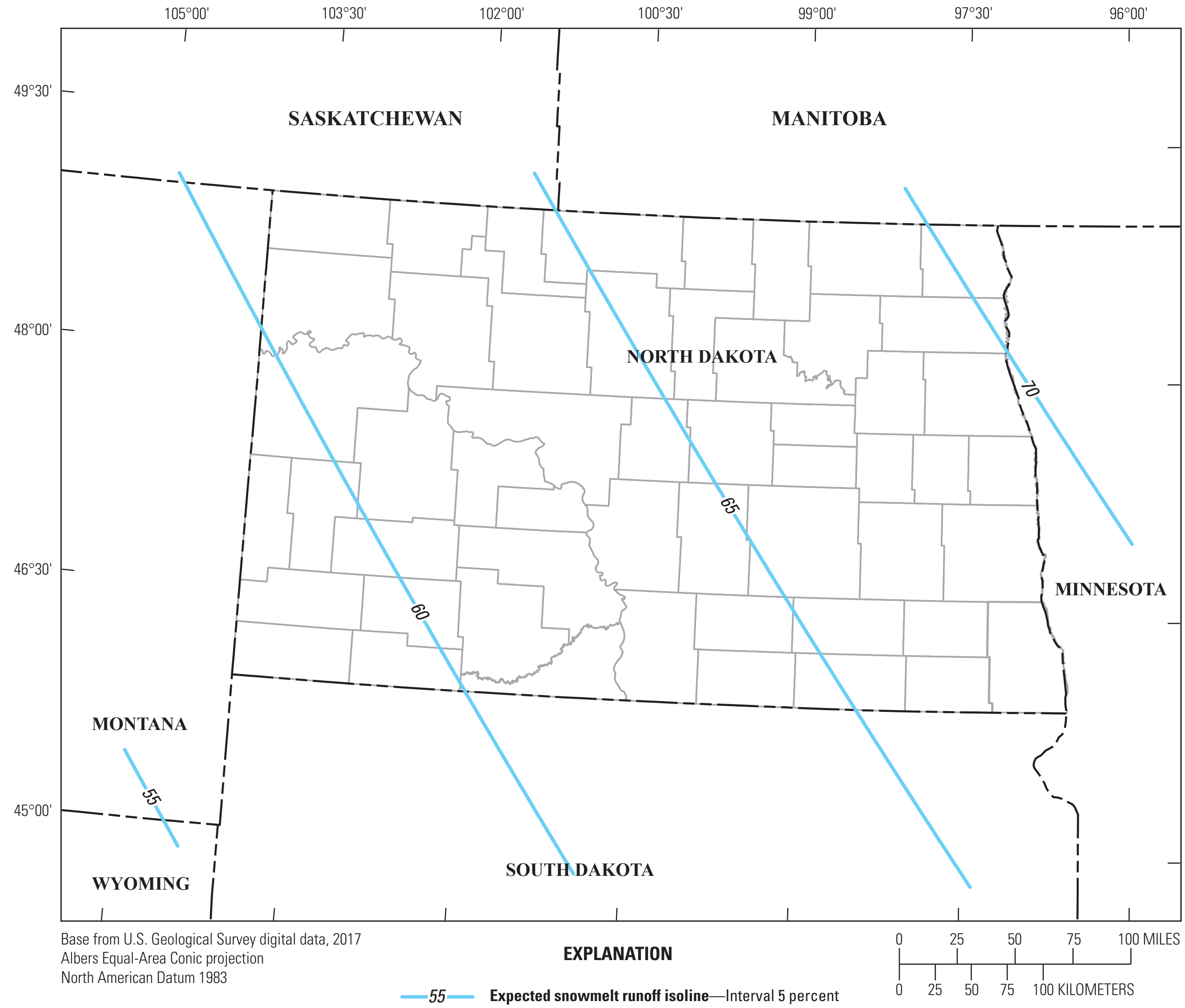


Figure 5. Expected percentage of snowmelt runoff isolines for 1941–70 using streamflow data. *A*, November–May streamflow data; *B*, March–May streamflow data.—Continued

A. **November–May streamflow data**

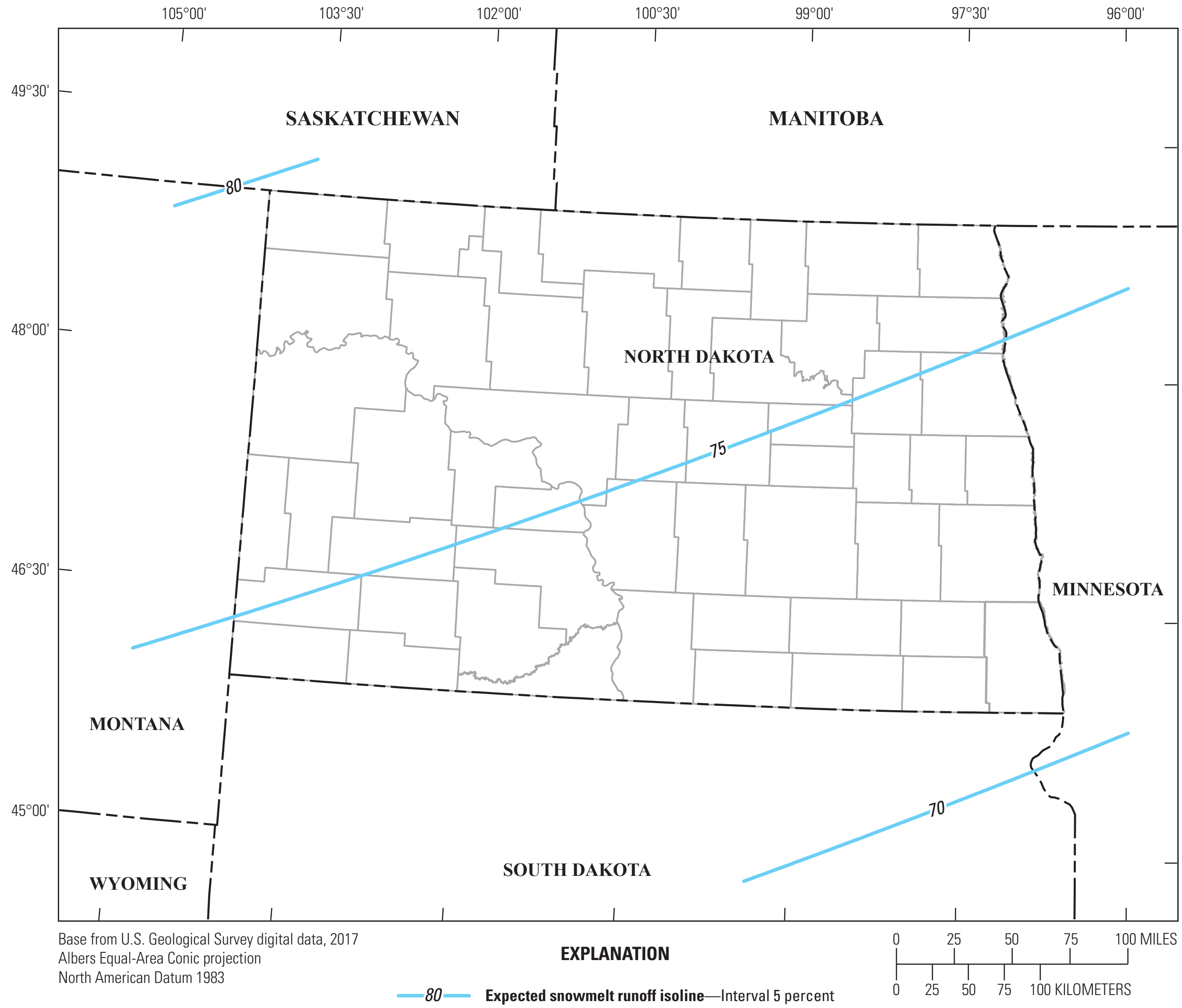


Figure 6. Expected percentage of snowmelt runoff isolines for 1941–70 with drainage areas of 505 square miles or less using streamflow data. *A*, November–May streamflow data; *B*, March–May streamflow data.

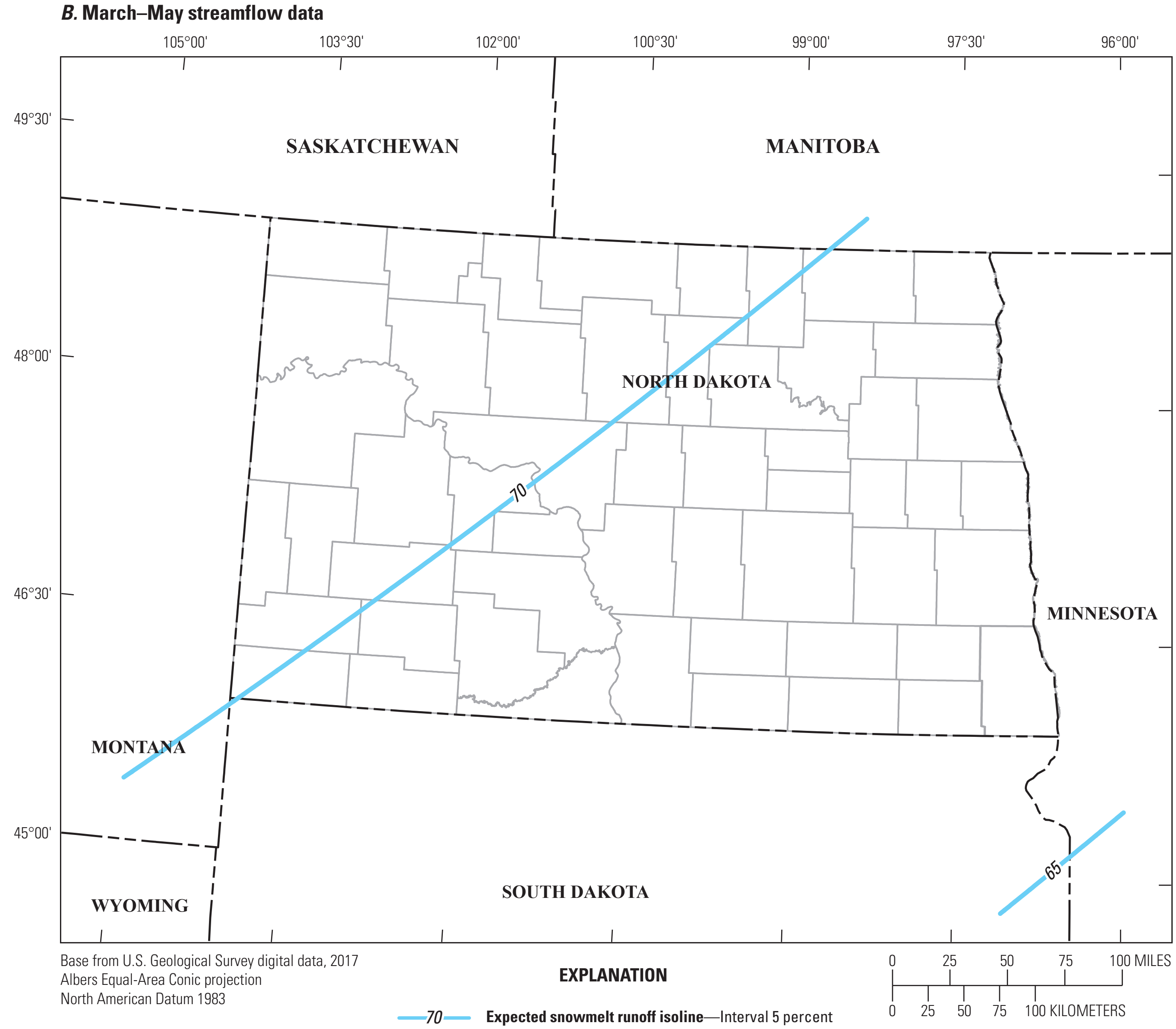


Figure 6. Expected percentage of snowmelt runoff isolines for 1941–70 with drainage areas of 505 square miles or less using streamflow data. *A*, November–May streamflow data; *B*, March–May streamflow data.—Continued

A. **50-percent exceedance probability**

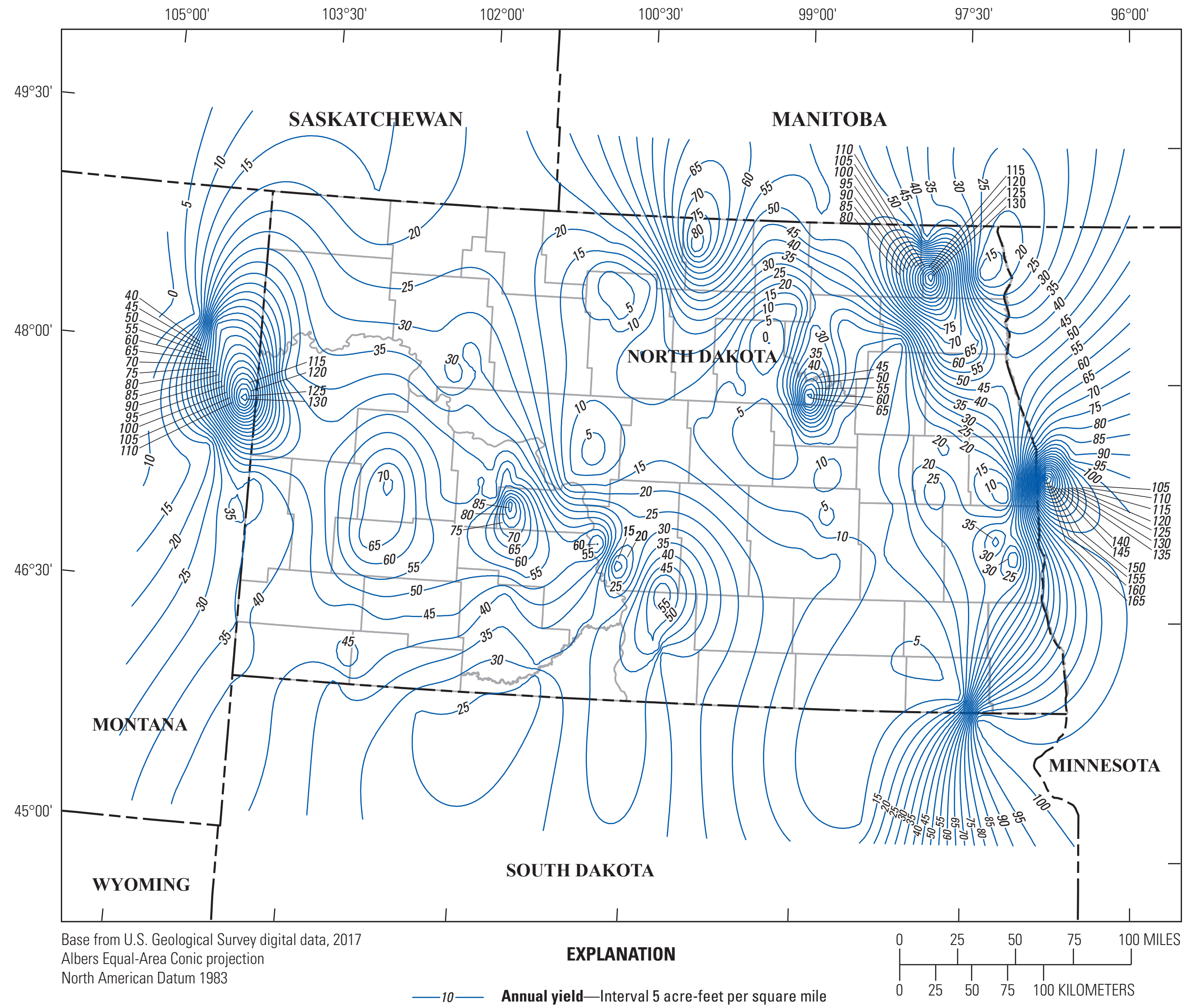
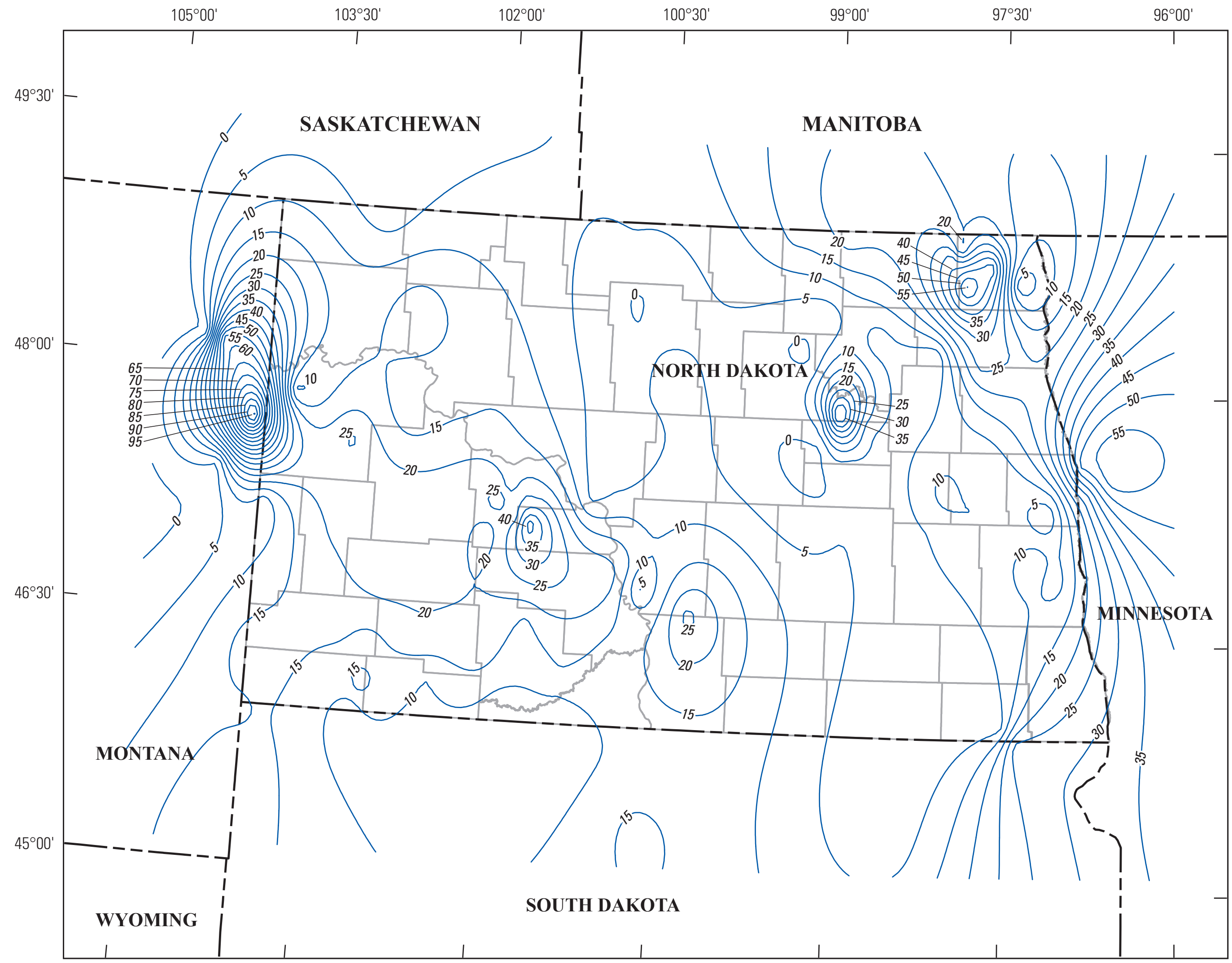


Figure 7. Annual yield using 131 selected streamgages and a period of record of 1941–70 with 10-percent or less missing record. *A*, 50-percent exceedance probability; *B*, 80-percent exceedance probability.

***B.* 80-percent exceedance probability**



Base from U.S. Geological Survey digital data, 2017
Albers Equal-Area Conic projection
North American Datum 1983

EXPLANATION

—10— **Annual yield**—Interval 5 acre-feet per square mile

0 25 50 75 100 MILES
0 25 50 75 100 KILOMETERS

Figure 7. Annual yield using 131 selected streamgages and a period of record of 1941–70 with 10-percent or less missing record. *A*, 50-percent exceedance probability; *B*, 80-percent exceedance probability.—Continued

A. **Missing 33 percent of record**

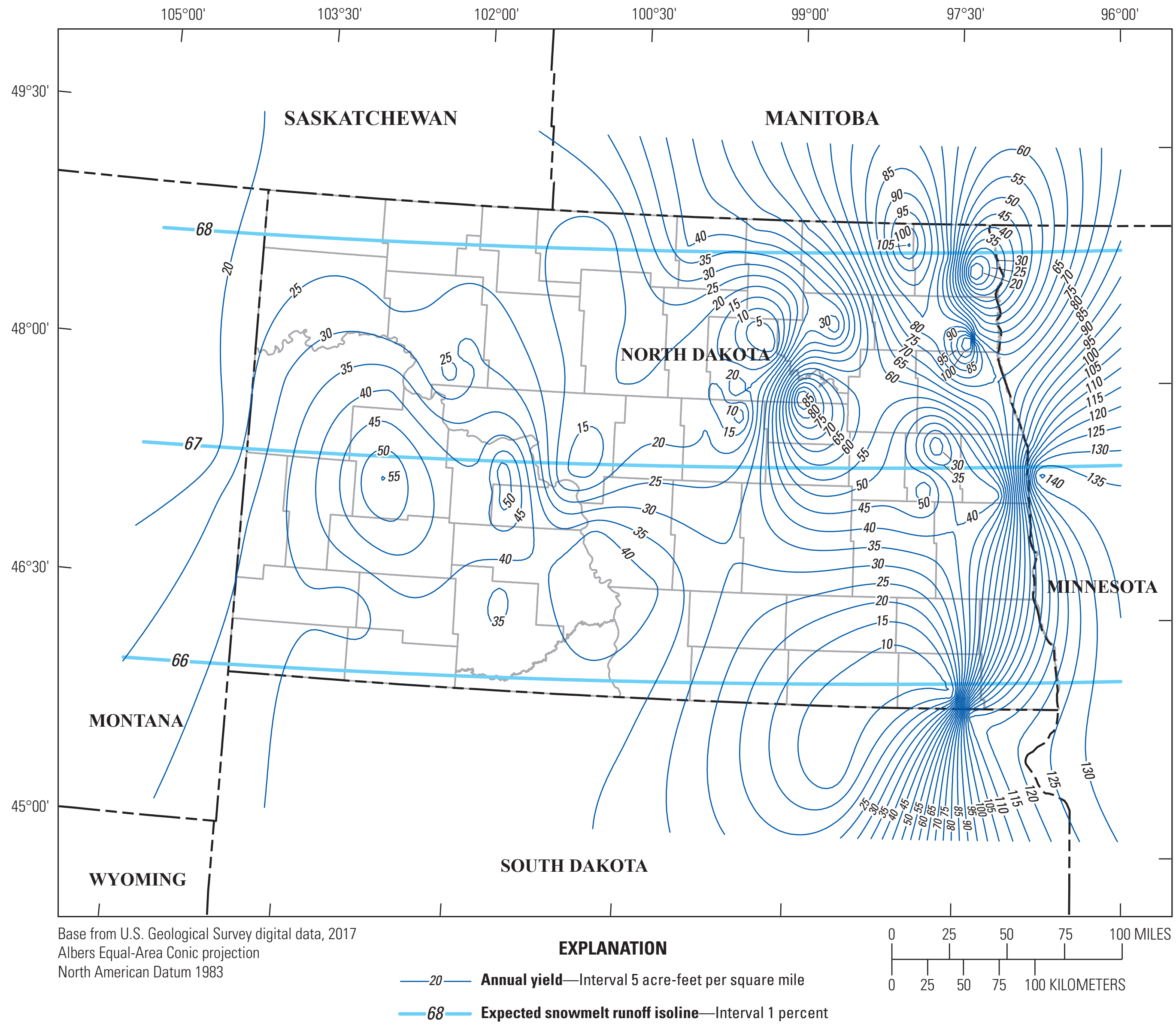


Figure 8. Annual yield at the 50-percent exceedance probability using 1931–2016 data with streamgages that have 10-percent or less missing calculated and estimated annual volumes and a drainage area of 505 square miles or less and allowing the 1931–2016 data to have a missing record for expected percentage of snowmelt runoff. *A*, missing 33 percent of record; *B*, missing 50 percent of record; *C*, missing 66 percent of record.

B. Missing 50 percent of record

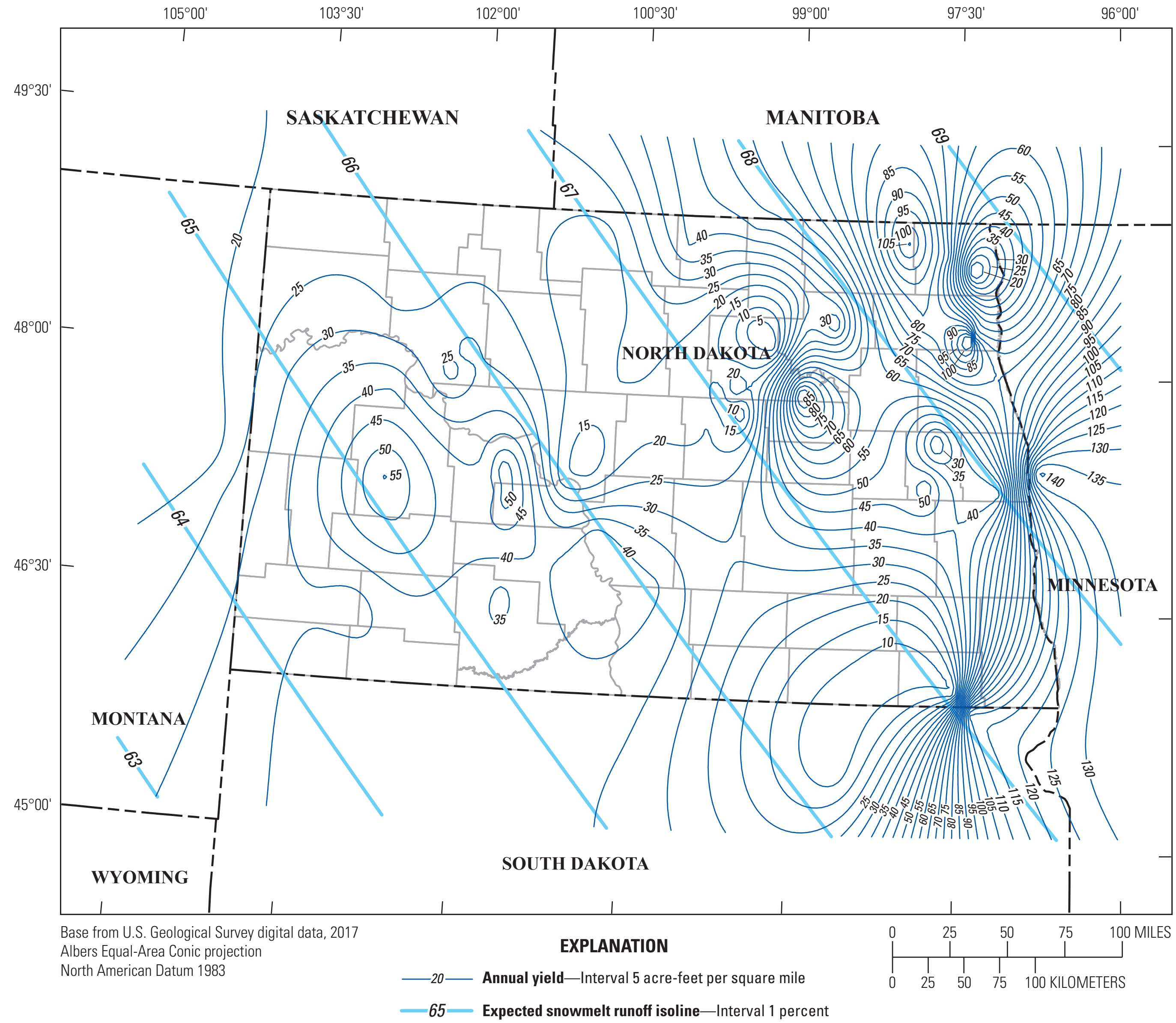


Figure 8. Annual yield at the 50-percent exceedance probability using 1931–2016 data with streamgages that have 10-percent or less missing calculated and estimated annual volumes and a drainage area of 505 square miles or less and allowing the 1931–2016 data to have a missing record for expected percentage of snowmelt runoff. *A*, missing 33 percent of record; *B*, missing 50 percent of record; *C*, missing 66 percent of record.—Continued

C. **Missing 66 percent of record**

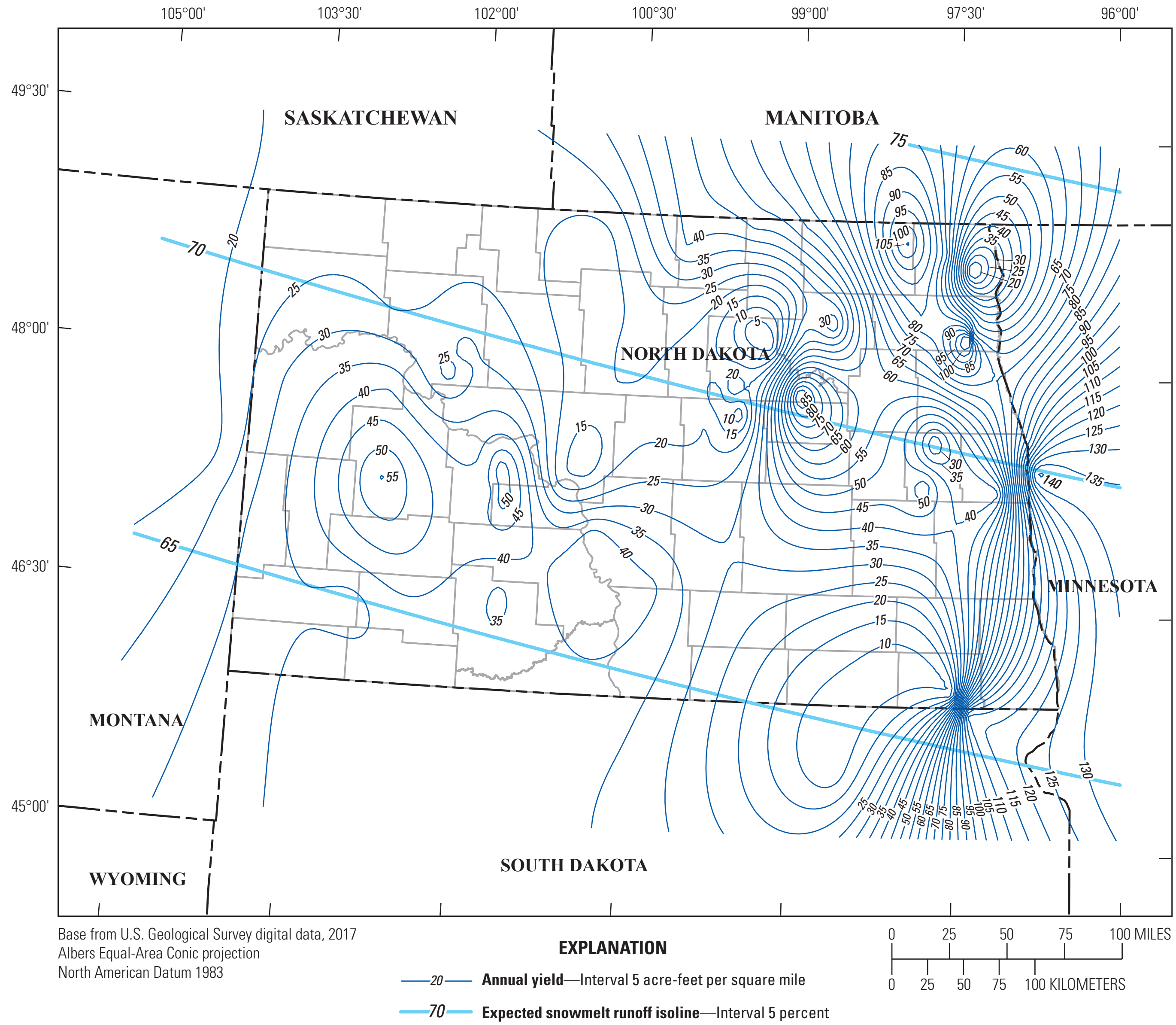


Figure 8. Annual yield at the 50-percent exceedance probability using 1931–2016 data with streamgages that have 10-percent or less missing calculated and estimated annual volumes and a drainage area of 505 square miles or less and allowing the 1931–2016 data to have a missing record for expected percentage of snowmelt runoff. *A*, missing 33 percent of record; *B*, missing 50 percent of record; *C*, missing 66 percent of record.—Continued

A. **Missing 33 percent of record**

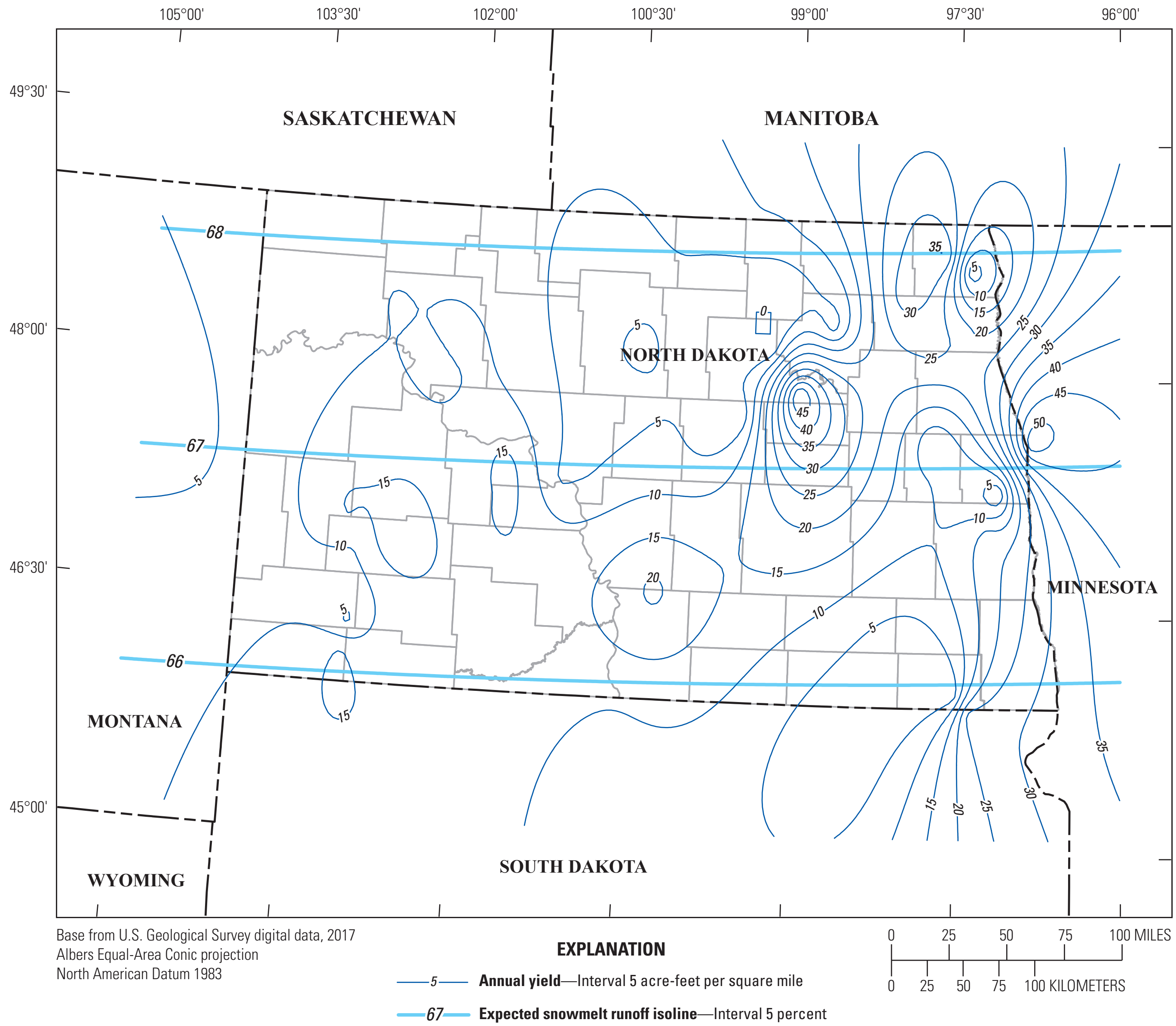


Figure 9. Annual yield at the 80-percent exceedance probability using 1931–2016 data with streamgages that have 10-percent or less missing calculated and estimated annual volumes and a drainage area of 505 square miles or less and allowing the 1931–2016 data to have a missing record for expected percentage of snowmelt runoff. *A*, missing 33 percent of record; *B*, missing 50 percent of record; *C*, missing 66 percent of record.

***B.* Missing 50 percent of record**

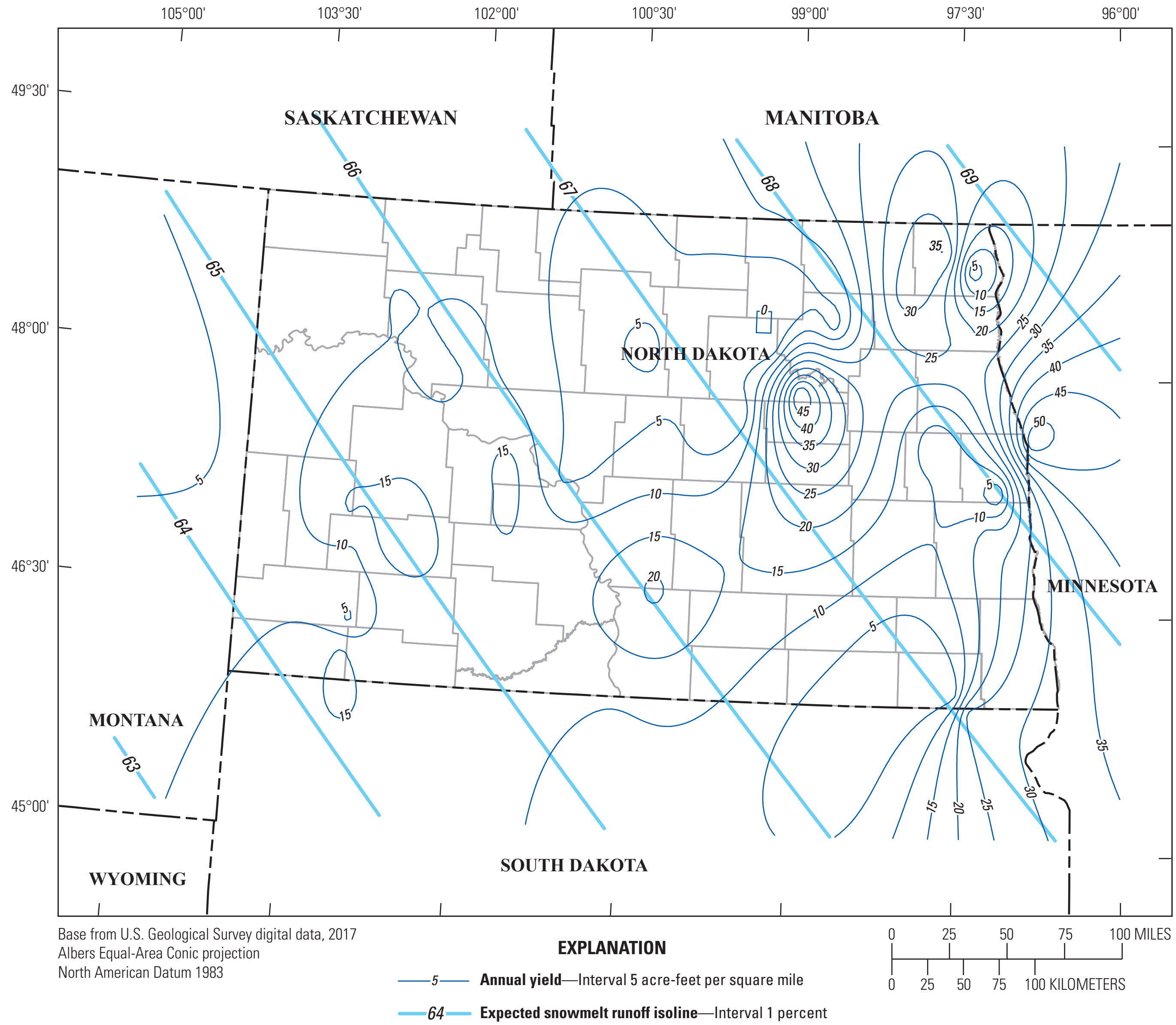


Figure 9. Annual yield at the 80-percent exceedance probability using 1931–2016 data with streamgages that have 10-percent or less missing calculated and estimated annual volumes and a drainage area of 505 square miles or less and allowing the 1931–2016 data to have a missing record for expected percentage of snowmelt runoff. *A*, missing 33 percent of record; *B*, missing 50 percent of record; *C*, missing 66 percent of record.—Continued

***C.* Missing 66 percent of record**

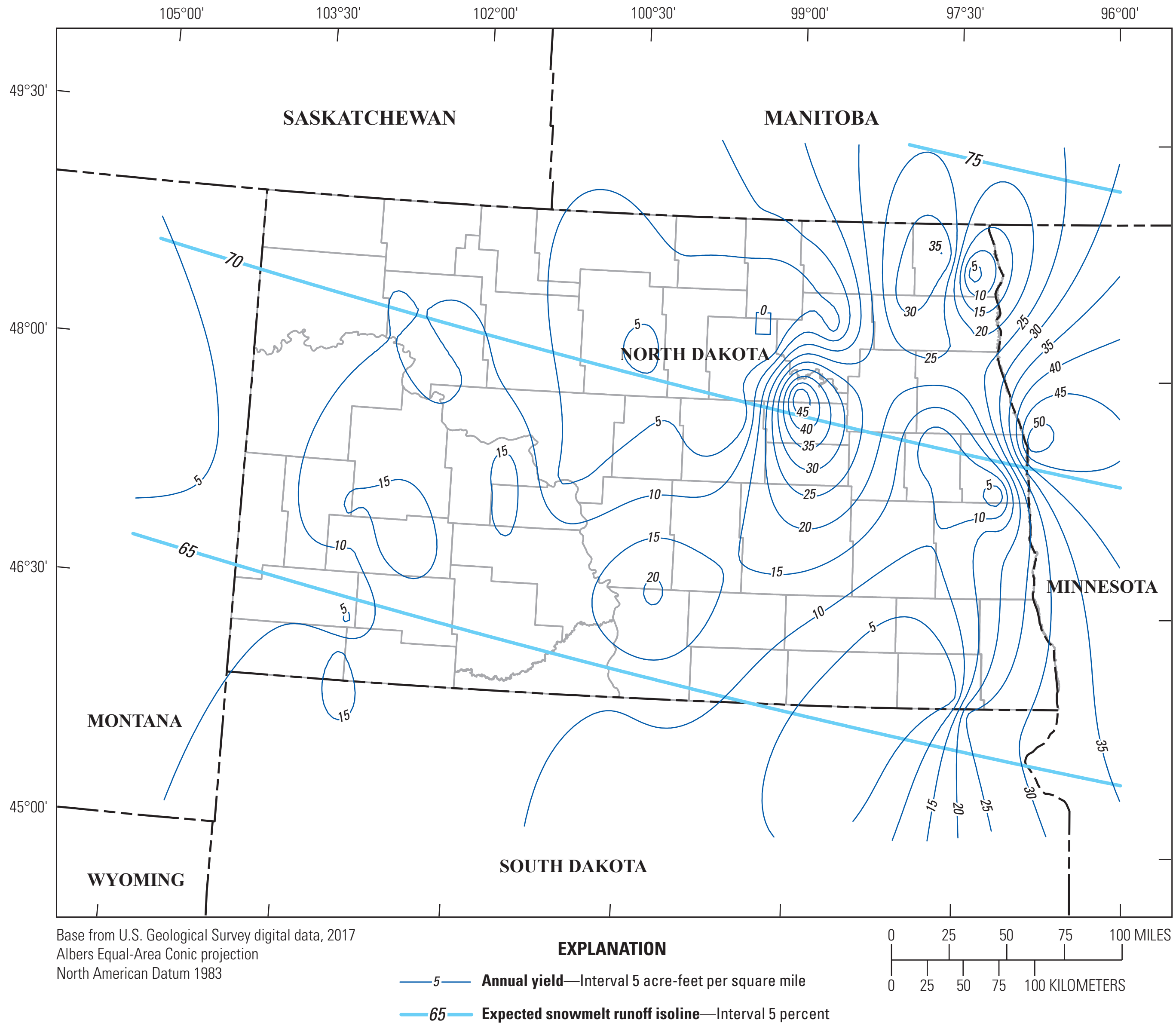


Figure 9. Annual yield at the 80-percent exceedance probability using 1931–2016 data with streamgages that have 10-percent or less missing calculated and estimated annual volumes and a drainage area of 505 square miles or less and allowing the 1931–2016 data to have a missing record for expected percentage of snowmelt runoff. *A*, missing 33 percent of record; *B*, missing 50 percent of record; *C*, missing 66 percent of record.—Continued

***A.* Missing 33 percent of record**

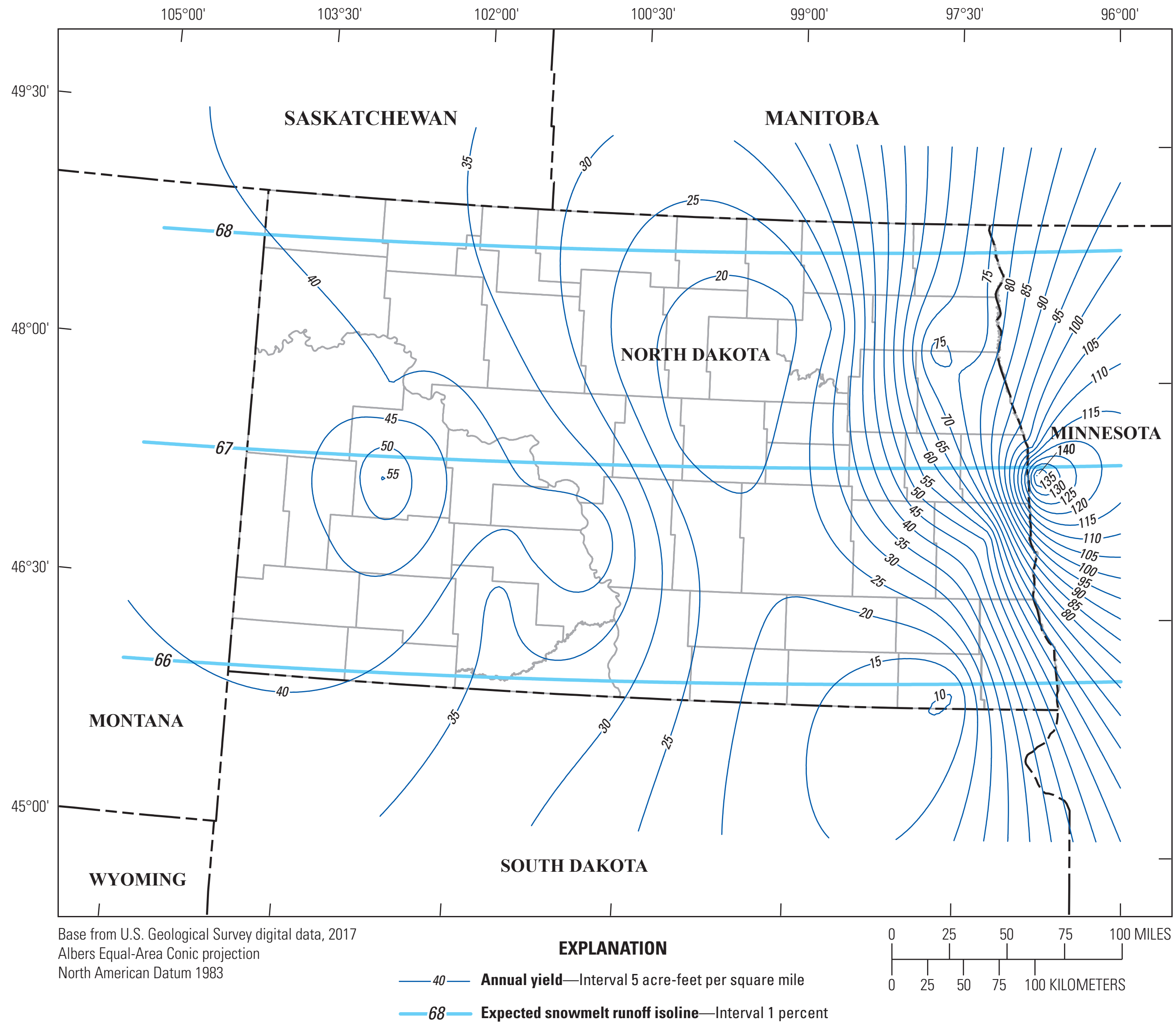


Figure 10. Annual yield at the 50-percent exceedance probability using 1931–2016 data with streamgages that have 10-percent or less missing annual volume record and 50 percent or less of Maintenance of Variance Extension Type III annual volume estimations and a drainage area of 505 square miles or less and allowing the 1931–2016 data to have a missing record for expected percentage of snowmelt runoff. *A*, missing 33 percent of record; *B*, missing 50 percent of record; *C*, missing 66 percent of record.

***B.* Missing 50 percent of record**

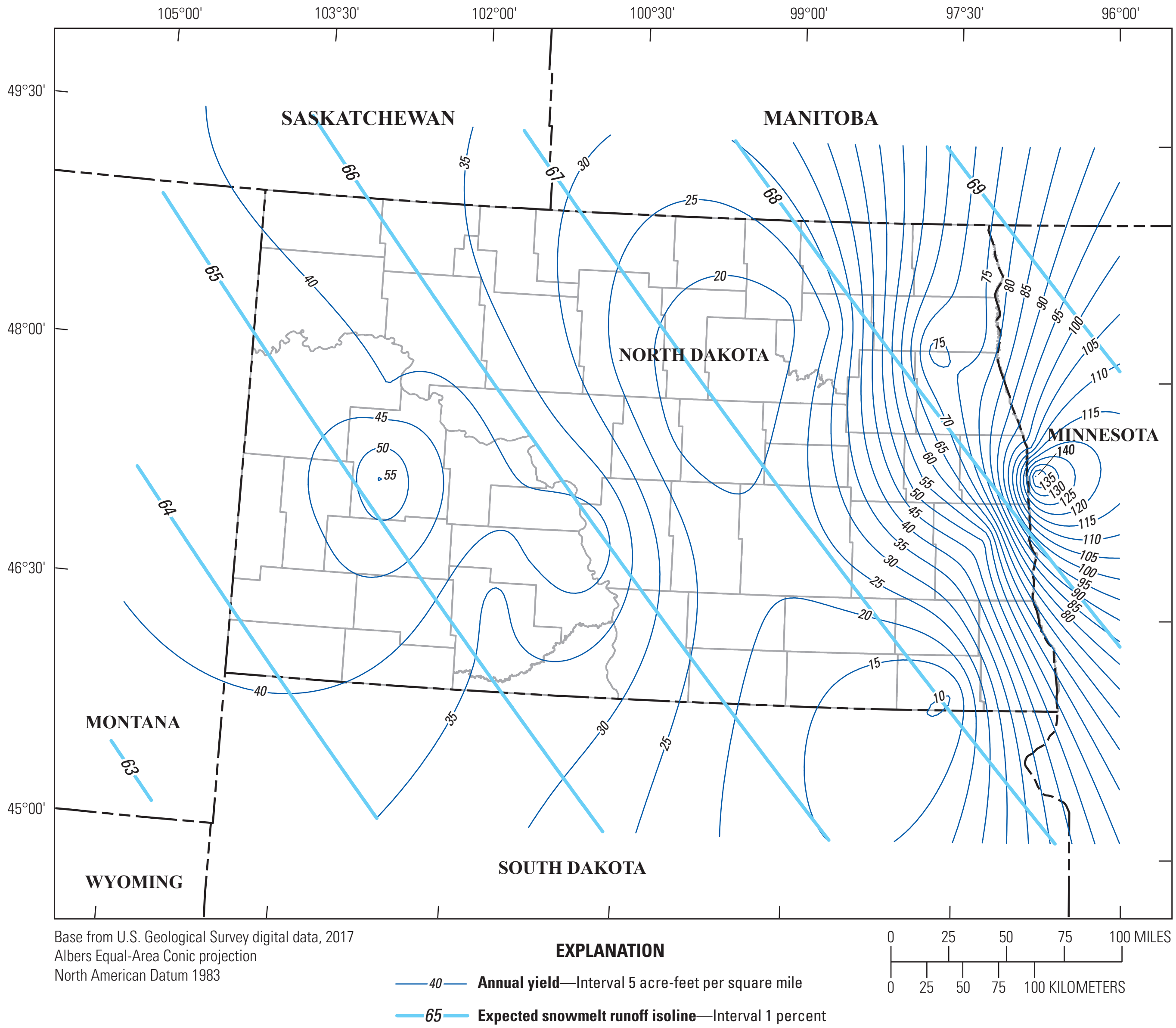


Figure 10. Annual yield at the 50-percent exceedance probability using 1931–2016 data with streamgages that have 10-percent or less missing annual volume record and 50 percent or less of Maintenance of Variance Extension Type III annual volume estimations and a drainage area of 505 square miles or less and allowing the 1931–2016 data to have a missing record for expected percentage of snowmelt runoff. *A*, missing 33 percent of record; *B*, missing 50 percent of record; *C*, missing 66 percent of record.—Continued

C. **Missing 66 percent of record**

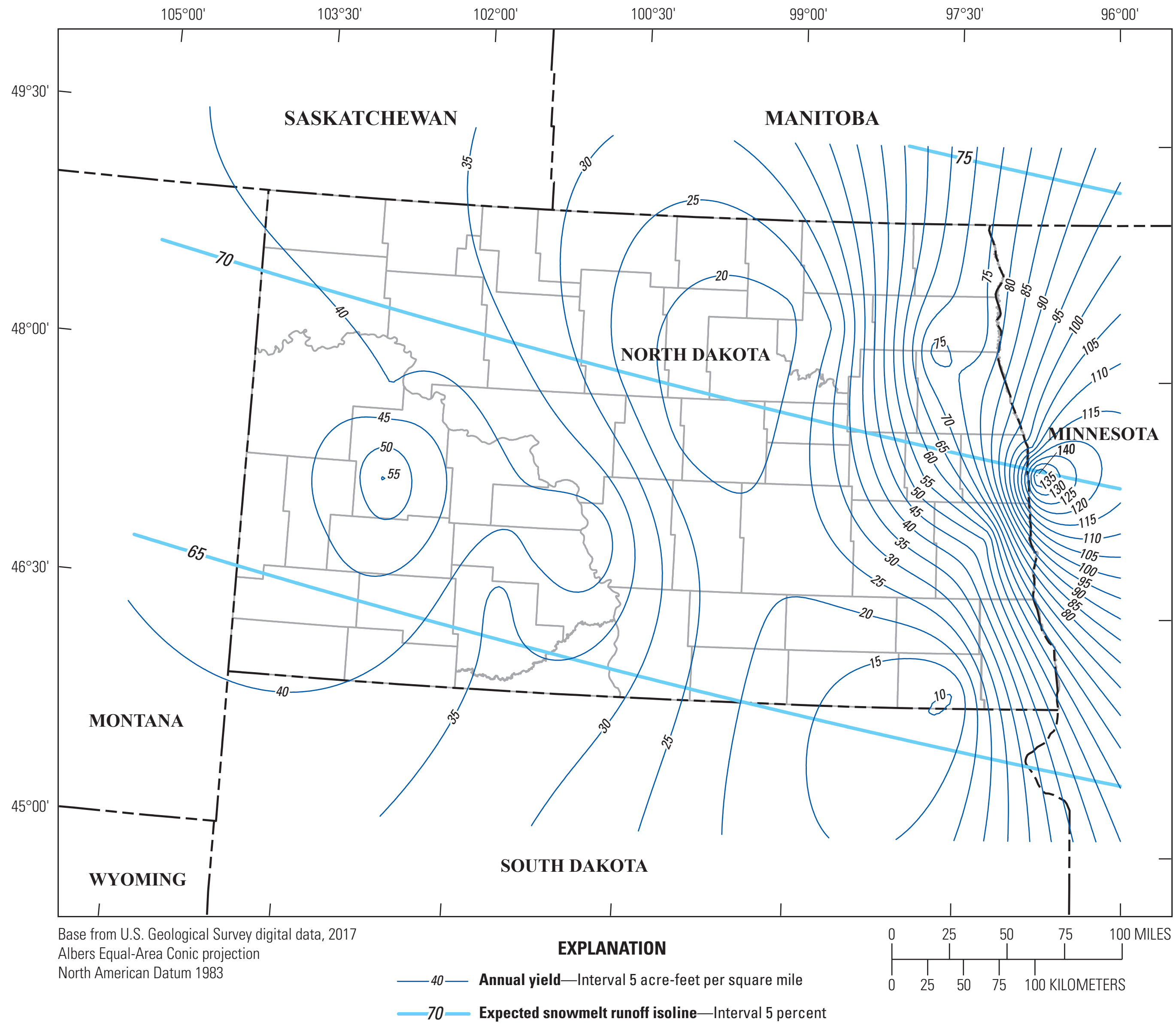


Figure 10. Annual yield at the 50-percent exceedance probability using 1931–2016 data with streamgages that have 10-percent or less missing annual volume record and 50 percent or less of Maintenance of Variance Extension Type III annual volume estimations and a drainage area of 505 square miles or less and allowing the 1931–2016 data to have a missing record for expected percentage of snowmelt runoff. *A*, missing 33 percent of record; *B*, missing 50 percent of record; *C*, missing 66 percent of record.—Continued

A. **Missing 33 percent of record**

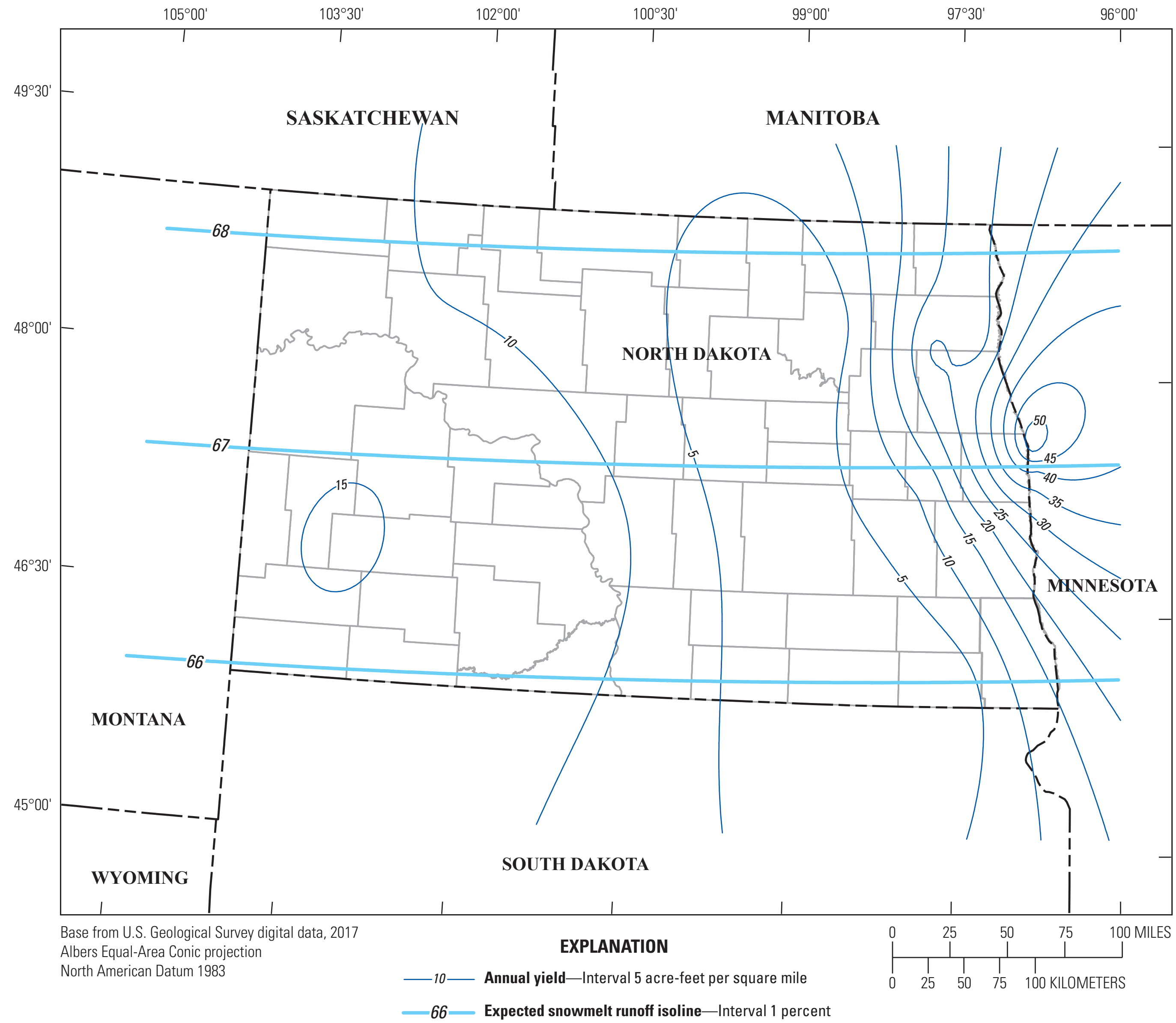


Figure 11. Annual yield at the 80-percent exceedance probability using 1931–2016 data with streamgages that have 10-percent or less missing annual volume record and 50 percent or less of Maintenance of Variance Extension Type III annual volume estimations and a drainage area of 505 square miles or less and allowing the 1931–2016 data to have a missing record for expected percentage of snowmelt runoff. *A*, missing 33 percent of record; *B*, missing 50 percent of record; *C*, missing 66 percent of record.

***B.* Missing 50 percent of record**

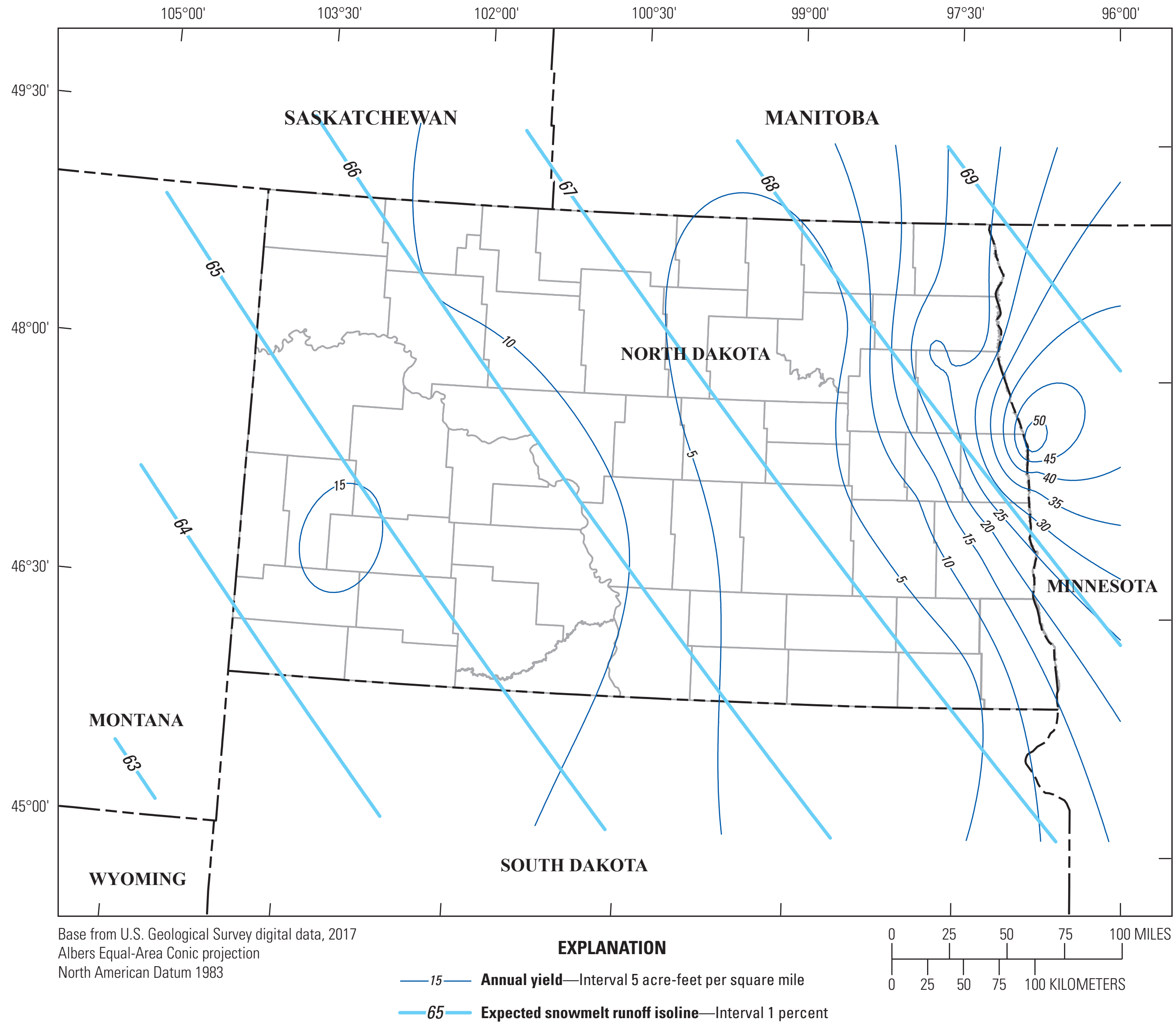


Figure 11. Annual yield at the 80-percent exceedance probability using 1931–2016 data with streamgages that have 10-percent or less missing annual volume record and 50 percent or less of Maintenance of Variance Extension Type III annual volume estimations and a drainage area of 505 square miles or less and allowing the 1931–2016 data to have a missing record for expected percentage of snowmelt runoff. *A*, missing 33 percent of record; *B*, missing 50 percent of record; *C*, missing 66 percent of record.—Continued

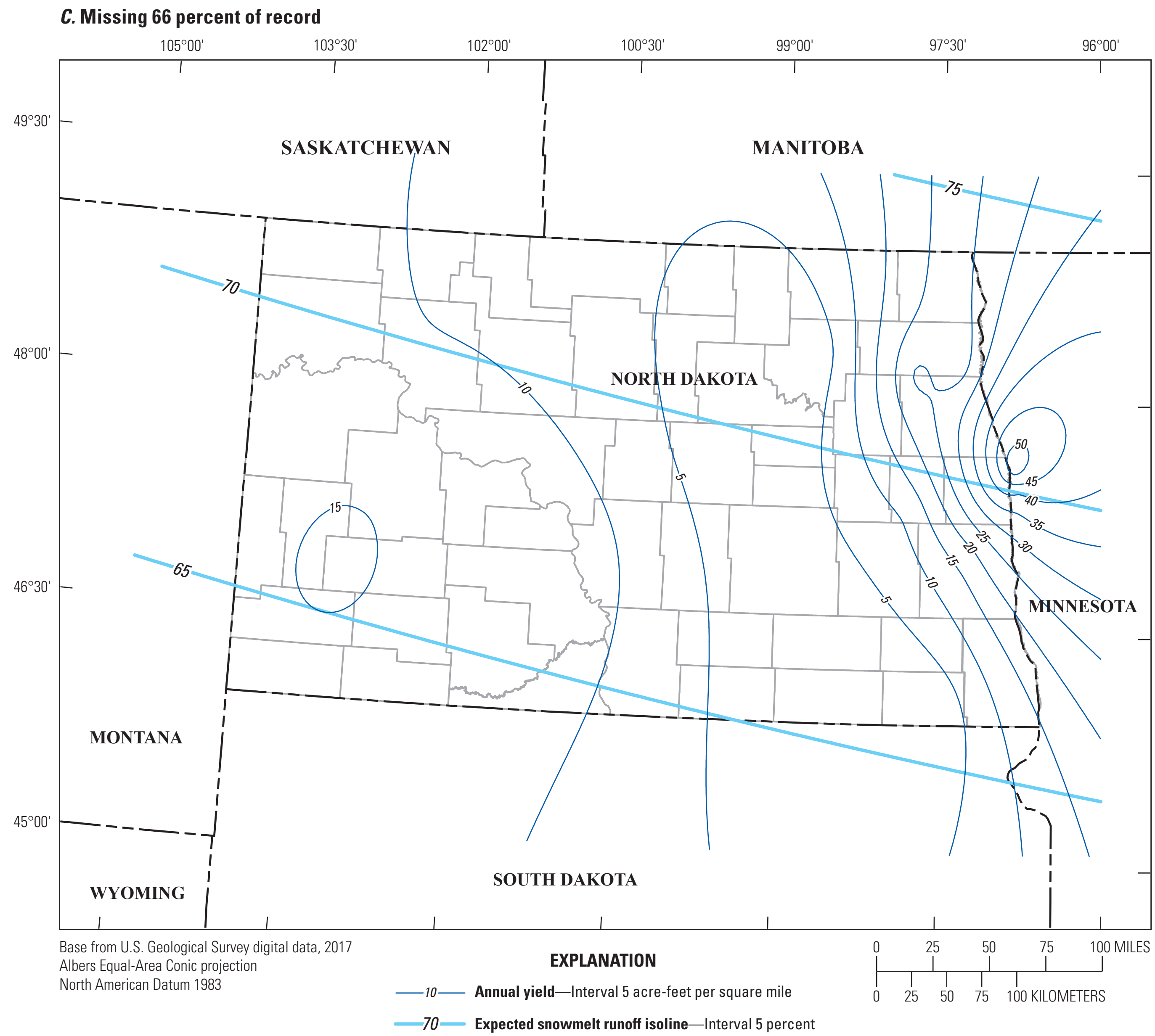


Figure 11. Annual yield at the 80-percent exceedance probability using 1931–2016 data with streamgages that have 10-percent or less missing annual volume record and 50 percent or less of Maintenance of Variance Extension Type III annual volume estimations and a drainage area of 505 square miles or less and allowing the 1931–2016 data to have a missing record for expected percentage of snowmelt runoff. *A*, missing 33 percent of record; *B*, missing 50 percent of record; *C*, missing 66 percent of record.—Continued

Summary

The North Dakota hydrology manual prepared by the U.S. Department of Agriculture, Soil Conservation Service, presents methodologies used primarily for developing hydrology for onfarm conservation practices, watershed project, Resource Conservation and Development project measures, and river basin studies. The manual includes data necessary for determining hydrologic factors and developing a design discharge for a given site and intended purpose. The U.S. Geological Survey, in cooperation with the North Dakota Natural Resources Conservation Service, developed methods to reproduce and update the annual yield maps for chapter 7 of the North Dakota hydrology manual. Annual yields, in acre-feet per square mile, were estimated for the 50-percent and 80-percent exceedance probabilities using a Weibull plotting formula and U.S. Geological Survey streamflow data for the 1931–2016 period of record for 131 selected streamgages in North Dakota and parts of Montana, South Dakota, and Minnesota. Streamgages used in generating the final maps were restricted to sites with drainage areas of 505 square miles or less. Missing years of annual streamflow volume were estimated with the application of a modified Maintenance of Variance Extension Type III procedure. Maps generated using streamgages that had 10-percent or less missing annual volume record and 50 percent or less of the period of record (1931–2016) annual volumes estimated by Maintenance of Variance Extension Type III showed less contouring problems of steep gradients caused by large and small percentage exceedance probabilities for streamgages that are near each other. Expected percentage of snowmelt runoff isolines were estimated using High Plains Climatic Center precipitation and snowmelt data from 1931 to 2016 for 85 selected climatic sites and using U.S. Geological Survey streamflow data from 1931 to 2016 for 131 selected streamgages and were compared. The final expected percentage of snowmelt runoff isolines were estimated using streamflow data instead of precipitation and snowfall depth data. A snowmelt runoff seasonal period of March–May produced isolines that better approximated those of the original chapter 7 maps than a November–May runoff period. Expected percentage of snowmelt runoff isolines were sensitive to amounts of missing period of record. Suitable isoline slopes resulted when a missing period of record was set to 50 percent (43 years) and 66 percent (57 years) for the 86-year period of 1931–2016.

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Appendix 1. Methods Used to Generate and Adjust Annual Streamflow Volumes Used in Move.3

This appendix contains an Excel spreadsheet (available for download at https://doi.org/10.3133/sir20195144) that shows an example of computations used to generate annual streamflow volumes (by water year) and the ratio method used to adjust streamflow volumes for years with less than full year records. The spreadsheet contains two tabs; tab 1 is a listing of U.S. Geological Survey National Water Information System daily mean streamflow from 1956 to 2016 for U.S. Geological Survey station 05056100 (U.S. Geological Survey, 2017), and tab 2 shows the computations used to generate the final annual streamflow volumes that were used in the MOVE.3 analysis.

Table 1.1. Example data and computations for U.S. Geological Survey station 05056100 (available for download at https://doi.org/10.3133/sir20195144).

Reference Cited

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Appendix 2. R Code Script and Supporting Data for the Modified Maintenance of Variance Extension Type III, MOVE.3, Application

This appendix contains a link to a zipped folder, MOVE3_R-code, that has the readme text, example streamflow volumes input file, and R code script used in the MOVE.3 analysis. The files are available for download at https://doi.org/10.3133/sir20195144.

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