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Extending Seasonal Discharge Records for Streamgage Sites on the North Fork Fortymile and Middle Fork Fortymile Rivers, Alaska, through Water Year 2019

Scientific Investigations Report 2020–5003

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

Cover:
Downstream view of the North Fork Fortymile River's confluence with the Middle Fork Fortymile River (right), Alaska. (Photograph by Heather Best, U.S. Geological Survey, May 19, 2019.)

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By Janet H. Curran

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
Volume		
cubic foot (ft^3)	28.32	cubic decimeter (dm^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
Flow rate		
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C = (°F – 32) / 1.8.

Datums

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

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

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

Abbreviations

MOVE.3	Maintenance of variance extension type 3
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NSE	modified Nash-Sutcliffe efficiency coefficient
NWIS	National Water Information System
RMSE	Root mean square error
USGS	U.S. Geological Survey
WY	Water year

Extending Seasonal Discharge Records for Streamgage Sites on the North Fork Fortymile and Middle Fork Fortymile Rivers, Alaska, through Water Year 2019

By Janet H. Curran

Abstract

Daily mean discharge values were estimated for May 20–September 30 for 1976–82 and 2006–18 for the U.S. Geological Survey North Fork Fortymile River and Middle Fork Fortymile River streamgage sites in Alaska. A relation between study streamgage discharge and discharge for an index streamgage on the main-stem Fortymile River for a concurrent period in 2019 was developed using the maintenance of variance extension type 3 (MOVE.3) record extension technique. The relation for North Fork Fortymile River discharges incorporated a 1-day-earlier offset to index streamgage discharges. No offset was applied to the index streamgage discharges for use with the Middle Fork Fortymile River discharges. The developed MOVE.3 regressions were used to estimate daily mean discharges at the study streamgage sites during the study season for the longer period of record of the index streamgage. The modified Nash-Sutcliffe efficiency coefficients for the estimated records were 0.38 and 0.63 for the North Fork Fortymile River and Middle Fork Fortymile River streamgages, respectively.

Introduction

Daily mean discharge is a common metric of streamflow that forms the basis of analysis for a wide variety of water resource management purposes, including engineering design, environmental assessment, and development of legal agreements of water use. Many agency agreements and legal statutes rely on discharge statistics that can quantify historical water availability and express wetted channel conditions. Discharge values determined from data collected at U.S. Geological Survey (USGS) streamgages often provide the record from which discharge statistics needed for analysis can be computed. Long records of daily mean discharge can represent natural variations that occur on annual to decadal scales better than short records, but long records are not available for many locations where such information is needed. To account for longer-term natural variations at a shorter-record location, record extension techniques can be used to estimate discharge. Record extension relates discharges at a streamgage of interest to concurrent discharge at a streamgage having a longer period of record, referred to as an "index streamgage" (Hirsch, 1979; Hirsch, 1982). That relation can then be applied to the longer period of record from the index streamgage to estimate a discharge record for the study streamgage. Record extension requires a concurrent period of record with a closely-correlated index streamgage and a longer period of record for the index streamgage from which to estimate discharge for the short-record streamgage.

Within the Fortymile River Basin in east-central Alaska, the USGS collected discharge data for part of 2019 at streamgages on two streams, the North Fork Fortymile River and the Middle Fork Fortymile River (fig. 1). Longer estimates of daily mean discharge for these study streams are needed for compilation of streamflow statistics desired for management of the streams. In cooperation with the Bureau of Land Management, the USGS developed estimated daily mean discharge records for streamgages on the North Fork and Middle Fork Fortymile Rivers.

Purpose and Scope

This report describes the development of a method for estimating daily mean discharge for two streamgages of interest in the Fortymile River Basin using the maintenance of variation extension type 3 (MOVE.3) record extension technique. It documents the selection of a season of analysis and an index streamgage, presents estimates of historical daily mean discharge for an extended period of record, and presents an evaluation of the accuracy of the estimated records. Within the limitations discussed, the results of this study are suitable for use in preparation of discharge statistics, including the number of days that daily mean discharge falls between a higher and lower discharge threshold during the season used in this report.

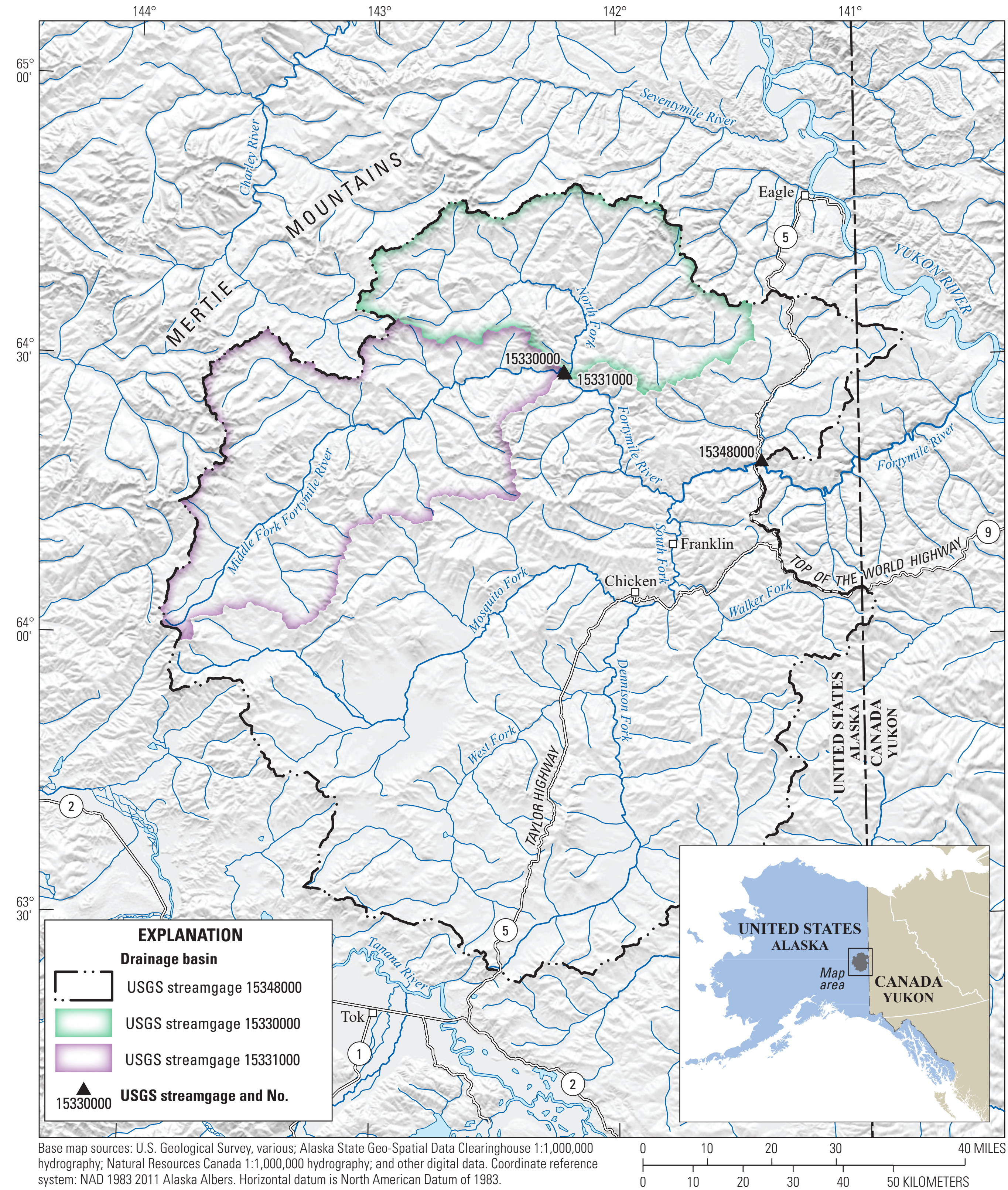

Figure 1. Location of study streamgages in the Fortymile River Basin, Alaska. [USGS, U.S. Geological Survey]

Description of Study Area

The Fortymile River, a tributary to the Yukon River, drains more than 6,000 square miles (mi^2) in east-central Alaska and Canada about 150 miles east of Fairbanks (fig. 1). The river contains numerous tributaries, including the North Fork Fortymile River, which originates in the northern part of the basin, and the Middle Fork Fortymile River, which drains the northwestern part of the basin and is a tributary of the North Fork. The North Fork Fortymile River joins the South Fork Fortymile River to form the main-stem Fortymile River upstream of the Taylor Highway (fig. 1). Fortymile River Basin topography includes the hilly terrain of the Mertie Mountains, which range in altitude from about 3,000 to 6,000 ft along the western and northern parts of the basin, and gently-sloped flats containing extensive wetlands in the southern part of the basin. Wetlands also occupy the wide valley bottom of the upper reaches of the Middle Fork Fortymile River.

The Fortymile River Basin has a continental climate characterized by cold, dry winters and warm summers. In the basin draining to the USGS Fortymile River streamgage near the Taylor Highway (15348000, Fortymile River near Steele Creek, Alaska), the mean January temperature for 1971–2000 (Gibson, 2009a) is -9 degrees Fahrenheit and the mean July temperature is 54 degrees Fahrenheit. Precipitation averaged 15 inches per year in the basin for 1971–2000 (Gibson, 2009b), which includes snow in the winter. Basin average precipitation is highest in the summer months of June–August.

The USGS streamgages on the North Fork Fortymile River (15330000, North Fork Fortymile River above Middle Fork near Franklin, Alaska) and the Middle Fork Fortymile River (15331000, Middle Fork Fortymile River near mouth near Chicken, Alaska) are each located a short distance upstream from the confluence of the two rivers. Hydrographs for the two study streamgages and the main-stem Fortymile River during the concurrent period show patterns of abruptly rising then falling discharge over several days that generally represent discharge response to precipitation (fig. 2). Despite the proximity of the study streamgages, slight differences appear in the timing of their discharge patterns. Basin differences including topography, the spatial distribution of wetlands, drainage area, or stream length could at least partly explain the apparently faster response to precipitation at the North Fork Fortymile River streamgage relative to the Middle Fork Fortymile River and Fortymile River streamgage sites.

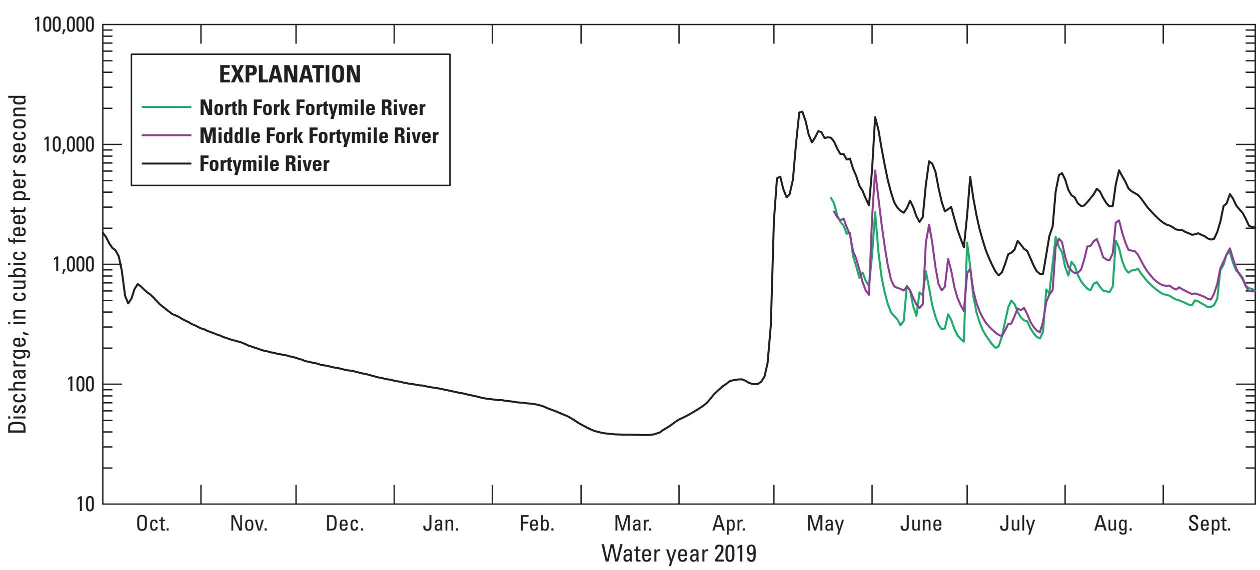

Figure 2. Hydrographs of daily mean discharges available for water year 2019 for U.S. Geological Survey streamgages 15330000 (North Fork Fortymile River above Middle Fork near Franklin, Alaska); 15331000 (Middle Fork Fortymile River near mouth near Chicken, Alaska); and 15348000 (Fortymile River near Steele Creek, Alaska).

Methods for Estimating Extended Daily Mean Discharge Records

Hydrologic data for analysis consisted of daily mean discharge for study streamgages and potential index streamgages and were obtained from the USGS National Water Information System database (NWIS) at https://nwis.waterdata.usgs.gov/ak/nwis/sw (U.S. Geological Survey, 2019). For correlation and record extension analysis, daily mean discharge data were transformed using a common logarithm to improve data distribution. Except where specified, analyses used the R language and programming environment version 3.6.1 (R Core Team, 2019). Record extension was conducted for a limited season using an index station that met selection criteria and a record extension technique developed for use with hydrologic data, as described in the following sections.

Selection of Season of Analysis

The study season of May 20–September 30 was chosen to match the concurrent period of gaging for the two streamgage records to be extended. The North Fork Fortymile River streamgage record includes an additional day of data (May 19, 2019) that was ignored for the convenience of a single study season. Inspection of discharge patterns for the longer period of record at the Fortymile River streamgage downstream shows that the study season has consistently represented a subset of the open-water season, or ice-free period. Hydrographs of discharge for the available period of record at each study streamgage and for water year[1] (WY) 2019 for the Fortymile River streamgage, where a water year is defined as the period from October 1 to September 30 and designated by the calendar year in which it ends, show the relationship of the study season to the open-water season for WY2019 (fig. 2).

The Fortymile River streamgage has a total of 21 years of record in two periods, WY1976–82 and WY2006–19. For the full period of record at the Fortymile River streamgage, the initial flush of snowmelt-driven discharges, which are often the highest discharges of the year, occurred shortly before May 20. The end of the water year and the end of the data collection period for the study streamgages (September 30) was typically near the end of open-water season but before freezing conditions substantially reduced discharge.

[1] The 12-month period from October 1 for any given year to September 30 of the following year. The water year is designated by the calendar year in which it ends. Thus, the year ending September 30, 2019, is called the "2019" water year.

Selection of Index Streamgage

For each study streamgage, one or more longer-record streamgages were sought to serve as index streamgages for extending daily mean discharge. Streamgages considered as potential index streamgages consisted of USGS streamgages in and near the Fortymile River Basin that had a period of record overlapping the study streamgage records and a period of record outside the study streamgage period of record. Additional selection criteria included proximity to the study streamgage, the strength and linearity of the correlation of daily mean discharges with concurrent daily mean discharges at the study streamgage, hydrologic similarity to the study streamgage over a range of low to high discharges, and the length of record available for extension beyond the concurrent record. A combination of multiple index streamgages for a single study streamgage was also considered during the selection process. Information for the selected index streamgage–the main-stem Fortymile River streamgage–and the study streamgages is shown in table 1, and the locations of the streamgages are shown in figure 1.

Log-scale scatterplots of concurrent daily mean discharge for the study and index streamgage (fig. 3) were examined for linearity, scatter, and outliers. Log-scale plots of daily mean discharge at study and index streamgages for the concurrent period (fig. 2) were examined for similarity in seasonal discharge patterns, and log-scale plots of daily mean discharge for the full index streamgage period of record were examined for annual variability in seasonal discharge patterns. The Fortymile River streamgage data were offset 1 day earlier when used as an index streamgage for the North Fork Fortymile River streamgage to account for the earlier arrival, on average, of discharge patterns at the North Fork Fortymile River. To account for the omission of the last day of the record in the offsetting process, the Fortymile River streamgage discharge for the first day after the study season (October 1, 2019) was inserted as the value for the last day of the offset record, September 30, 2019. Pearson's correlation coefficients (r) computed for the logarithms of daily mean discharge at the study streamgage sites and index streamgage site without offsets were 0.766 and 0.926 for the North Fork Fortymile River and Middle Fork Fortymile River streamgage, respectively (table 2). Application of the 1-day-earlier offset to index discharges improved the correlation coefficient for the North Fork Fortymile River streamgage to 0.809 (table 2).

Table 1. Drainage area and period of discharge record for U.S. Geological Survey study streamgages and index streamgage in the Fortymile River Basin, Alaska.

[Abbreviations: AK, Alaska; mi², square mile; USGS, U.S. Geological Survey]

USGS streamgage number	Streamgage name	Drainage area, in mi²	Period of discharge record: Month and day	Period of discharge record: Water years
	Study streamgages			
15330000	North Fork Fortymile River above Middle Fork near Franklin, AK	750	May 19–September 30	2019
15331000	Middle Fork Fortymile River near mouth near Chicken, AK	1,070	May 20–September 30	2019
	Index streamgage			
15348000	Fortymile River near Steele Creek, AK	5,850	October 1–September 30	1976–82, 2006–19

Table 2. Correlation coefficients (Pearson's *r*) between logarithms of daily mean discharge at study and index streamgages in the Fortymile River Basin, Alaska.

[mi², square mile; AK, Alaska; –, not applicable; USGS, U.S. Geological Survey]

Study USGS streamgage number	Study streamgage name	Study streamgage drainage area, in mi²	Index USGS streamgage identifier	Index streamgage name	Index streamgage drainage area, in mi²	Pearson's correlation coefficient, no offset	Pearson's correlation coefficient, 1-day-earlier offset to index streamgage data
15330000	North Fork Fortymile River above Middle Fork near Franklin, AK	750	15348000	Fortymile River near Steele Creek, AK	5,850	0.766	0.809
15331000	Middle Fork Fortymile River near mouth near Chicken, AK	1,070	15348000	Fortymile River near Steele Creek, AK	5,850	0.926	–

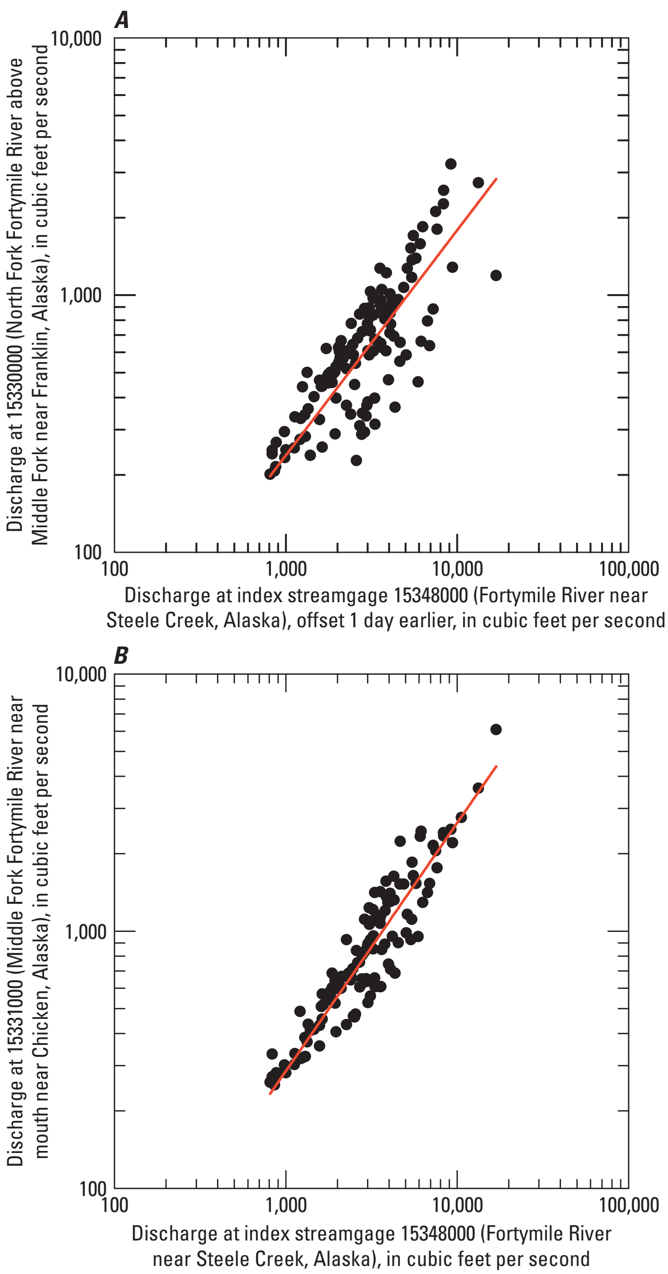

Figure 3. Plot of concurrent measured discharge and the maintenance of variance extension type 3 (MOVE.3) regression line at U.S. Geological Survey (*A*) streamgages 15330000 (North Fork Fortymile River above Middle Fork near Franklin, Alaska) and 15348000 (Fortymile River near Steele Creek, Alaska), offset 1 day earlier, and (*B*) streamgages 15331000 (Middle Fork Fortymile River near mouth near Chicken, Alaska) and 15348000 (Fortymile River near Steele Creek, Alaska).

Record Extension Technique

Record extension produces estimates of discharge for a study stream location from a longer record of discharge at one or more index stream locations. Methods for extending discharge records usually employ some form of linear regression to establish the relation between concurrent observed discharge at the study and index locations or streamgages. Although ordinary least squares regression can be used, the line of organic correlation method implemented by maintenance of variance extension (MOVE) techniques provides a better estimate of extended discharge records by seeking to maintain the variance of the observed study streamgage discharges in the estimated discharges (Hirsch, 1982; Vogel and Stedinger, 1985; Helsel and Hirsch, 2002). The MOVE.3 regression incorporates the mean and standard deviation of the concurrent discharges and the mean and standard deviation of the nonconcurrent index streamgage discharges (Vogel and Stedinger, 1985; Granato, 2009) and results in an equation that uses the logarithms of daily mean discharge, which then can be rewritten in the form of the equation for a straight line:

$$log_{10}Q = m(log_{10}Q_{index}) + b \tag{1}$$

where

- Q is the estimated daily mean discharge at the study streamgage, in cubic feet per second (ft^3/sec),
- b is the intercept of the regression line,
- Q_{index} is the observed daily mean discharge at the index streamgage, in ft^3/s, and
- m is the slope of the regression line.

To simplify for use extending daily mean discharge in arithmetic units, eq. 1 can be transformed from logarithmic to arithmetic units to produce the following:

$$Q = 10^b Q_{index}{}^m \tag{2}$$

All MOVE.3 regressions were developed using the USGS Streamflow Record Extension Facilitator (SREF) software (Granato, 2009). The resulting equations for estimating daily mean discharge at the study streamgages using the Fortymile River streamgage are:

$$Q_{15330000} = 0.5649\,Q_{15348000offset1}{}^{0.8751} \tag{3}$$

and

$$Q_{15331000} = 0.3657\,Q_{15348000}{}^{0.9644} \tag{4}$$

where

- subscripts for Q are the USGS streamgage numbers, and
- *offset1* indicates the data are shifted 1 day earlier.

For this seasonal record extension, an important restriction on equations 3 and 4 is that the equations are only intended for use with index streamgage values ($Q_{15348000}$) that occurred during the study season, May 20–September 30. Outside these date ranges, different processes might govern discharge and the relation between study and index streamgage discharges might vary. Particularly, very low discharges from winter conditions and very high discharges from snowmelt conditions before the study season are not represented by the observed discharges used to develop this equation.

Extended Daily Mean Discharge Records and Error Analysis

Daily mean discharge at the two study streamgages during the study season was estimated for the full period of record of the index streamgage, 1976–82 and 2006–19, using the MOVE.3 regressions in equations 3 and 4, respectively (appendix 1). The extended estimates (estimated data through 2018) can be merged with the observed data for the concurrent period in 2019, available from NWIS, to form a composite dataset. The estimated discharges for the concurrent period were used to compare to the observed discharges for the concurrent period as a measure of accuracy.

Comparison of Observed and Estimated Records

The fit of the estimated discharges to the concurrent observed discharges varied across the range of discharges, as can be seen from the variability of the scatter in fig. 3 plots at various discharge ranges. On average, the estimated discharges for the concurrent period of record are similar to the observed discharges; the means of the observed and estimated discharges are within 7 percent or less of each other (table 3). Median estimated discharges are larger than median observed discharges for the Middle Fork Fortymile River streamgage record. Observed and estimated discharges were plotted as a hydrograph of daily means (fig. 4) to further examine their fit. The estimated discharges underestimated many of the highest discharges for the North Fork Fortymile River streamgage record. Figure 4 shows that the MOVE.3 regressions generally overestimated discharges early in the season and underestimated discharges later in the season. This variation in the fit of the estimated discharges could be related to basin-specific factors such as a difference in runoff-generating processes across the season between basins or uneven spatial distribution of rainfall, but investigation of these differences was beyond the scope of this study.

Table 3. Summary statistics of the concurrent observed and estimated daily mean discharge records at two study streamgages in the Fortymile River Basin, Alaska.

[AK, Alaska; ft^3/s, cubic feet per second; USGS, U.S. Geological Survey]

		Daily mean discharge					
		Mean		Median		Standard deviation	
Study USGS streamgage number	Study streamgage name	Observed, in ft^3/s	Estimated, in ft^3/s	Observed, in ft^3/s	Estimated, in ft^3/s	Observed, in ft^3/s	Estimated, in ft^3/s
15330000	North Fork Fortymile River above Middle Fork near Franklin, AK	722	673	599	607	507	400
15331000	Middle Fork Fortymile River near mouth near Chicken, AK	964	929	685	813	747	631

Accuracy and Limitations of Extended Records

Several measures are available to evaluate the fit of a MOVE.3 regression model and the accuracy of the predicted records. The root mean square error (RMSE) between the observed discharge used to develop the model and the concurrent predicted discharge is a common measure of accuracy. The RMSE is the mean of the absolute distance between the observed and estimated discharges and is lower for models that have a better fit. The RMSE values for the North Fork and Middle Fork Fortymile River streamgage models are shown in table 4. The modified Nash-Sutcliffe efficiency coefficient (NSE) provides a measure of the predictive ability of a model (Legates and McCabe, 1999). Computed from the observed and estimated discharges for the study streamgage, the modified NSE ranges from 1 for a perfect fit of modeled to observed data to minus infinity for a model having no predictive ability. A modified NSE of 0 indicates that the mean of the observed data is as good a predictor as the model. The modified NSE is computed as

$$modified\ NSE = 1 - \frac{\Sigma_{i=1}^{n}\left|Y_i - Y_p\right|}{\Sigma_{i=1}^{n}\left|Y_i - \overline{Y}\right|} \quad (5)$$

where

- n is the number of measurements,
- Y_i is the ith observed daily mean discharge,
- Y_p is the estimated daily mean discharge, and
- $\overline{Y}$ is the average of the observed daily mean discharges.

The modified NSE for the North Fork and Middle Fork Fortymile River streamgage MOVE.3 models are shown in table 4.

In addition to measures of accuracy, the user should consider the limitations of the data used to develop equations when using estimates to construct discharge statistics. Mean discharge during the concurrent period was lower than the long-term mean for the same season at the Fortymile River streamgage. The range of daily mean discharge for the concurrent period was also less than the range of daily mean discharge for the same season in the rest of the record. The highest daily mean discharge for the Fortymile River streamgage for the concurrent period was 16,900 ft^3/s, whereas daily mean discharges for the study season for the full period of record reached 62,700 ft^3/s. Estimated daily mean discharges corresponding to days when index streamgage discharges exceeded 16,900 ft^3/s required extrapolation of the upper end of the relation between study and index streamgage discharges. Confidence in the upper end of the relation is typically lower because fewer large discharges occur naturally than mid-range discharges and because the timing and spatial extent of periods of large discharge is variable. The extrapolation of the MOVE.3 regression for discharges larger than an index streamgage value of 16,900 ft^3/s, corresponding to 2,830 ft^3/s at the North Fork Fortymile River streamgage and 4,370 ft^3/s at the Middle Fork Fortymile River streamgage, creates additional uncertainty for these large discharges, which represent 5 percent of the extended record. Careful interpretation of discharge statistics using the extrapolated discharges at the upper end of the relation is advised. Extrapolation was also required for discharges at the lower end of the relation but affected fewer records (the smallest 2 percent of the extended period of record). The lower end of the relation is typically subject to less uncertainty. However, discharge statistics using estimated daily mean discharges extrapolated from index daily mean discharges less than the smallest index streamgage daily mean discharge for the concurrent period (809 ft^3/s), or discharges less than 198 ft^3/s at the North Fork Fortymile River streamgage and 233 ft^3/s at the Middle Fork Fortymile River streamgage, should be interpreted with caution.

Table 4. Root mean square error and modified Nash-Sutcliffe efficiency coefficients for MOVE.3 regression models at two study streamgages in the Fortymile River Basin, Alaska.

Study USGS streamgage number	Study streamgage name	Index USGS streamgage identifier	Index streamgage name	Offset applied to index streamgage data	Root mean square error	Modified Nash-Sutcliffe efficiency coefficient
15330000	North Fork Fortymile River above Middle Fork near Franklin, AK	15348000	Fortymile River near Steele Creek, AK	1 day earlier	330	0.38
15331000	Middle Fork Fortymile River near mouth near Chicken, AK	15348000	Fortymile River near Steele Creek, AK	0	286	0.63

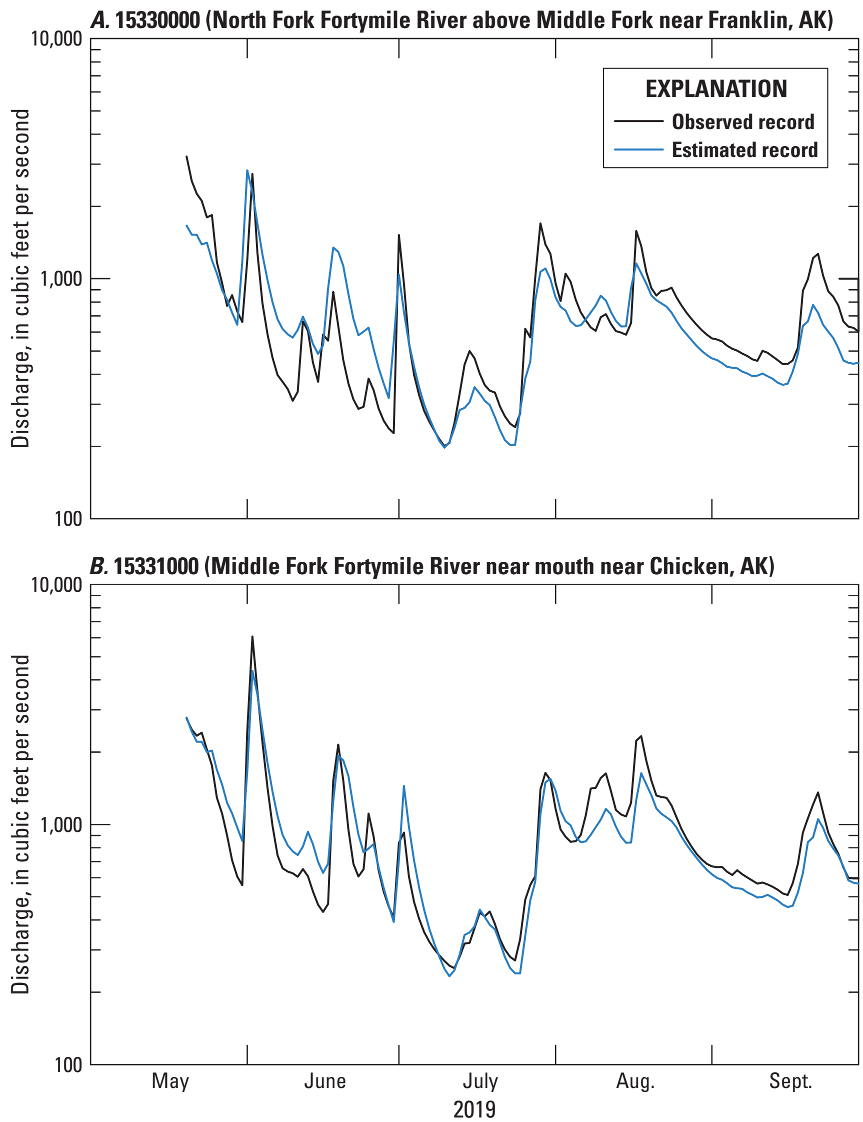

Figure 4. Plot of observed and estimated discharges for the concurrent period of record at (*A*) North Fork Fortymile River above Middle Fork near Franklin, Alaska, and (*B*) Middle Fork Fortymile River near mouth near Chicken, Alaska.

Summary

Daily mean discharge records collected for one season in 2019 for two study streamgage sites in the Fortymile River Basin were extended to provide an additional 20 years of estimated seasonal daily mean discharge record. The extended records were estimated using the MOVE.3 record extension technique and a longer period of record at a single index streamgage (15348000, Fortymile River near Steele Creek, Alaska) located downstream of the study streamgages. Index streamgage records were offset 1 day earlier for one study streamgage to account for differences in timing of discharge patterns. The Pearson correlation coefficient for concurrent discharges at the two study streamgages (15330000, North Fork Fortymile River above Middle Fork near Franklin, Alaska; and 15331000, Middle Fork Fortymile River near mouth near Chicken, Alaska) and the index streamgage (after application of an offset for use with the North Fork Fortymile River streamgage) was 0.809 and 0.926, respectively. The modified Nash-Sutcliffe coefficient of efficiency for the MOVE.3 regression models for estimating discharge was 0.38 and 0.63, respectively.

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Appendix 1. Extended Seasonal Daily Mean Discharge Records for Two Streamgages in the Fortymile River Basin, Alaska

Table A1 is a comma-separated values (.csv) file that presents estimated daily mean discharge records for two study streamgages in the Fortymile River Basin for May 20–September 30 for 1976–1982 and 2006–19. The study streamgages are U.S. Geological Survey (USGS) 15330000 (North Fork Fortymile River above Middle Fork near Franklin, Alaska) and 15331000 (Middle Fork Fortymile River near mouth near Chicken, Alaska). The estimated values presented here were computed from maintenance of variation extension type 3 (MOVE.3) record extension regressions described in the body of this report and data from USGS streamgage 15348000 (Fortymile River near Steele Creek, Alaska). Differences in rounding can produce slight variations between values in table A1 and values produced by equations 3 and 4 in the body of the text. The extended records can be combined with observed data for a composite record for analysis of discharge statistics.

Table A1. Extended seasonal daily mean discharge records for two streamgages in the Fortymile River Basin, Alaska.

[Table A1 is a comma separated value (CSV) file file available for download at https://doi.org/10.3133/sir20205003]

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