Groundwater and Streamflow Information Program

Dynamic Rating Method for Computing Discharge and Stage from Time-Series Data

Scientific Investigations Report 2024–5129

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

Cover. U.S. Geological Survey hydrologic technician, Peyton Hendrix, measures discharge with acoustic Doppler current profiler on the Comite River in Louisiana during the 2016 flood. Photograph by James Fountain, U.S. Geological Survey Surface Water Specialist.

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By Marian M. Domanski, Robert R. Holmes, Jr., Elizabeth N. Heal, and Travis M. Knight

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U.S. Geological Survey, Reston, Virginia: 2025

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Suggested citation:
Domanski, M.M., Holmes, R.R., Jr., Heal, E.N., and Knight, T.M., 2025, Dynamic rating method for computing discharge and stage from time-series data: U.S. Geological Survey Scientific Investigations Report 2024–5129, 92 p., https://doi.org/10.3133/sir20245129.

Associated data for this publication:
Domanski, M.M., Holmes, R.R., and Heal, E.N., 2022, Dynamic rating method for computing discharge from time series stage data-site datasets: U.S. Geological Survey data release, https://doi.org/10.5066/P955QRPQ.

Domanski, M.M., Holmes, R.R., and Heal, E.N., 2022, Dynamic stage to discharge rating model archive: U.S. Geological Survey data release, https://doi.org/10.5066/P9YUV9DG.

Domanski, M.M., Holmes, R.R., Heal, E.N., and Knight, T.M., 2025, Dynamic rating model archive: U.S. Geological Survey data release, https://doi.org/10.5066/P9X7QZFG.

Knight, T. M., Domanski, M.M., and Heal, E.N., 2025, DynRat: U.S. Geological Survey software release, https://doi.org/10.5066/P13FOADX.

ISSN 2328-0328 (online)

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88), National Geodetic Vertical Datum of 1929 (NGVD 1929), and World Geodetic System (WGS 1984).

Supplemental Information

A water year is the 12-month period from October 1 through September 30 of the following year and is designated by the calendar year in which it ends.

Abbreviations

ADCP	acoustic Doppler current profiler
DEM	digital elevation model
DYNMOD	Fread's original method
DYNPOUND	dynamic rating method
HEC–RAS	Hydrologic Engineering Center River Analysis System
MSLE	mean squared logarithmic error
USGS	U.S. Geological Survey
UTC	coordinated universal time
WSC	U.S. Geological Survey Water Science Center

Dynamic Rating Method for Computing Discharge and Stage from Time-Series Data

By Marian M. Domanski,[1] Robert R. Holmes, Jr.,[2] Elizabeth N. Heal,[3] and Travis M. Knight[4]

Abstract

Ratings are used for several reasons in water-resources investigations. The simplest rating relates discharge to the stage of a river (the stage-discharge relation). From a pure hydrodynamics perspective, all rivers and streams have some form of hysteresis in the relation between stage and discharge because flow becomes unsteady as a flood wave passes. The stage-discharge relation is unable to represent hysteresis. However, a dynamic rating method can capture hysteresis, which is driven by the variable energy slope of a flood wave.

A dynamic rating method called DYNPOUND, which accommodates compact and compound channel geometry, was developed by simplifying the one-dimensional Saint-Venant equations. The DYNPOUND method was developed in the Python programming language and computes discharge from stage and stage from discharge. Stage and discharge time series computed with this dynamic rating method were compared to the U.S. Geological Survey (USGS) published stage and discharge time series. The results from the DYNPOUND method were also compared to in-person field measurements of stage and discharge made at 10 USGS streamgages.

DYNPOUND was calibrated for 10 USGS streamgages using published discharge time-series data computed with a simple rating method. The calibration objective was to minimize the mean squared logarithmic error (MSLE) of the DYNPOUND-computed discharge with respect to the discharge time series computed by a simple rating method. For each site, the calibration process also included comparing all field measurements within a selected water year to the corresponding DYNPOUND-computed discharge data points. The MSLE of the DYNPOUND-computed discharge time series for the 10 sites ranged from 8.51×10^{-4} to 1.36×10^{-1}. For each site, an event-based period was selected to compare the discharge time series computed with the dynamic rating method to discharge field measurements made at the streamgages; the range of MSLE for the 10 DYNPOUND-computed discharge sites was from 4.79×10^{-4} to 2.30×10^{-2}.

Introduction

A relation using a continuous surrogate measure to estimate discharge is termed a “rating.” Ratings are used for a variety of reasons in water-resources investigations, but they are predominantly used at streamgages, where autonomously measured stage is used to compute discharge by use of a rating (Kennedy, 1984). No widely accepted method for direct discrete continuous measurement of discharge in natural channels is available. Commonly then, the rating is developed and calibrated using discharge measurements made onsite by field staff. When direct discrete continuous discharge measurements are not available, discharge is typically determined by continuous surrogate measures of one or more variables such as stage, water-surface slope, rate of change in stage, or index velocity; all measurements of these surrogate variables are collected at a streamgage. The derivation of discharge through these surrogate variables uses various models to create and implement the rating (Rantz and others, 1982).

The simplest rating relates discharge to stage of the river (simple rating). Hydrologists and engineers have long recognized hysteresis (loop effect) in relations between stage and discharge (Jones, 1915; Corbett, 1943; Fread, 1973; Faye and Cherry, 1980; Rantz and others, 1982; Kennedy, 1984). From a hydrodynamics perspective, disregarding channel-bed mobility, all rivers and streams have some form of hysteresis (loop effect) in the relation between stage and discharge. This also applies to prismatic channels without floodplains because flow is unsteady as the flood wave passes (fig. 1). The hysteresis is sometimes small enough to be hidden within the error of the measurements. Likewise, when the discharge event period is long enough, the hysteresis averages out. For example, a mean daily discharge value will often mitigate the effects of hysteresis, which are more evident in instantaneous hourly or 15-minute discharge values as explained in Faye and Cherry (1980, p. 19):

[1]Former U.S. Geological Survey.

[2]Retired U.S. Geological Survey.

[3]Lower Mississippi-Gulf Water Science Center.

[4]Hydrologic Networks Branch.

(The hysteretic relation of stage to discharge indicates that estimates of instantaneous dynamic discharge based on rating curves can be [substantially] in error. On the other hand, estimaes of mean dynamic discharge based on rating curves may not be so severely affected by hysteresis because integration of the underestimated flow during the rising stages is frequently compensated for by a corresponding overestimate during falling stages.)

For both reasons, simple ratings are often adequate to compute discharge for most streamgages. Simple ratings do not work when a unique relation between stage and discharge is lacking, such as for streamgages on low-gradient streams, streams with variable backwater, streams with large amounts of channel or overbank storage, streams with highly unsteady flow (rapid rises via flood wave movement), or streams with highly mobile beds (Holmes, 2017). In these situations, a complex rating is often required. A complex rating relates discharge to stage and other variables because of the lack of a unique, univariate relation between stage and discharge. Complex rating methods vary from simply adding a second independent variable in the process of computing discharge to sophisticated computer models solving the Saint-Venant equations, which are conservation-of-momentum and conservation-of-mass partial differential equations (French, 1985). For the governing differential assumptions, Fread (1973) developed what was termed a “dynamic loop” rating method for channels with compact geometry (no floodplain); this method computes discharge from a time series of stage measurements at a single streamgage. This rating method accounts for the variable energy slope defined by Fread (1975, p. 214) as being “associated with the dynamic inertia and pressure forces of the unsteady flood discharge” as opposed to rating loops imposed by alluvial bedform dynamics or scour and fill processes.

This report documents the development and testing of an expansion of Fread’s (1973) original dynamic loop method that includes channels with noncompact channel geometry (channels with floodplains). Testing the expanded method consists of comparing DYNPOUND-computed discharge and stage to simulated and U.S. Geological Survey (USGS) Water Science Center (WSC)-computed discharge and WSC-measured stage. Simulated discharge and stage time series were generated using the modeling software, Hydrologic Engineering Center River Analysis System (HEC–RAS; U.S. Army Corps of Engineers, 2016), that computes results using the one-dimensional Saint-Venant equations. Discrete discharge measurements and the associated stage value provide the observed (field measurement) discharge at streamgage sites.

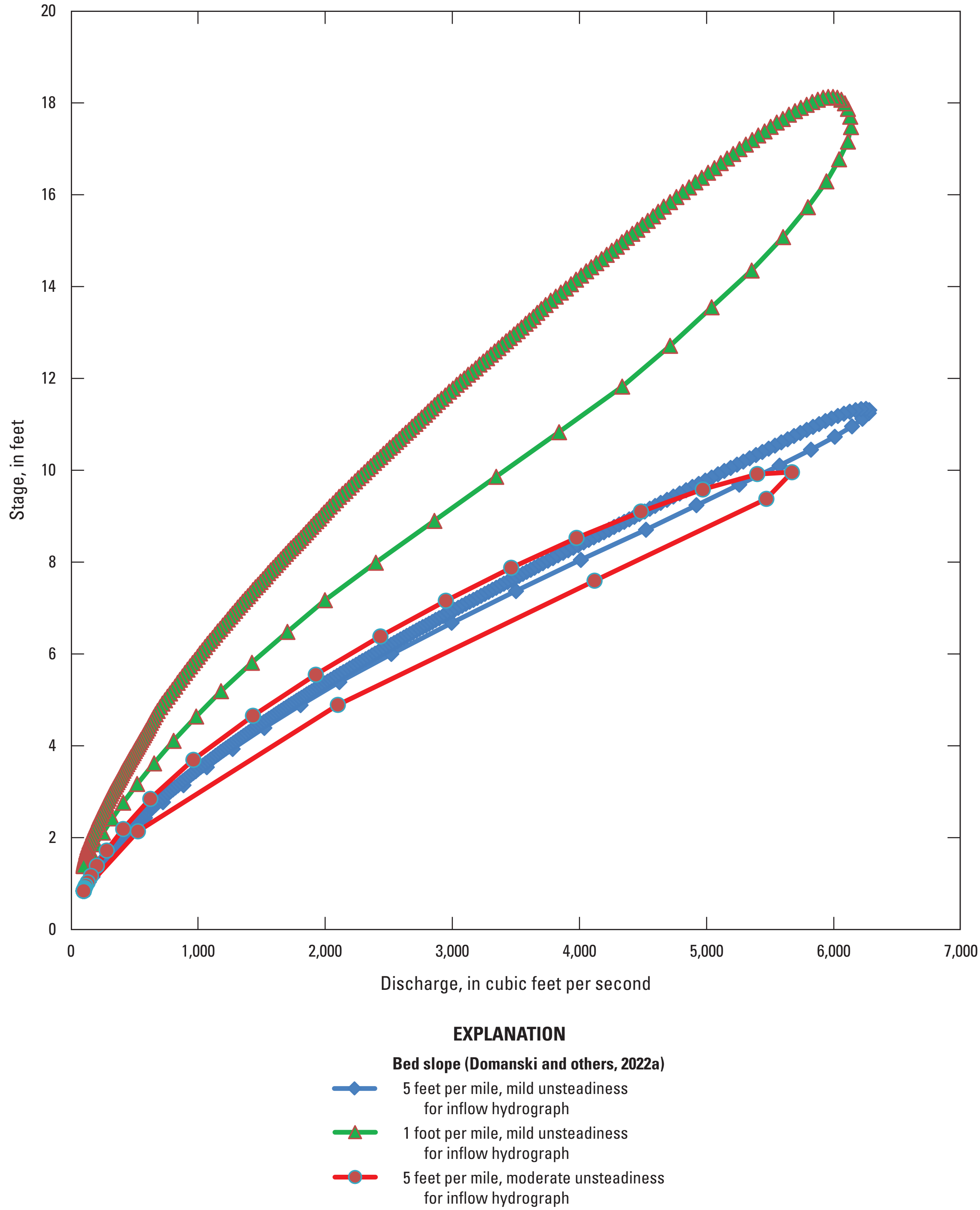


Figure 1. Graph showing the theoretical determination of the relation between stage and discharge for a 100-foot-wide rectangular prismatic channel using a one-dimensional unsteady fully dynamic open-channel hydraulic model with varying bed slopes and rates of unsteadiness (rate of change in local velocity with respect to time) for the inflow hydrograph at the upstream end.

Dynamic Rating Method Theory

By making simplifying assumptions, Fread (1973) used the conservation of mass and momentum equations to develop a method to estimate the friction slope from a single streamgage's time series of stage and knowledge of how the flood wave moved through a short section of channel at the streamgage location. The simplifying assumptions made are as follows:

1. lateral inflow and outflow are negligible;
2. the channel width is assumed constant in the streamwise direction (direction of flow);
3. energy losses from channel friction and turbulence are described by Manning's equation;
4. the geometry of the section is assumed permanent (scour and fill and bedform effects are negligible);
5. the bulk of the flood wave moves approximately as a kinematic wave, which implies the friction slope is approximately equal to the bed slope, and the wave propagates only in the downstream direction; and
6. the flow at the section is controlled by the channel geometry, the friction slope, the bed slope, and the shape of the flood wave.

The development of Fread's original method and a discussion of that method (DYNMOD) are in two publications by Fread (1973, 1975). The same assumptions made by Fread are used to develop the method described in this report (DYNPOUND). The development of the method follows.

The one-dimensional flow in a stream can be described by the Saint-Venant equations (Cunge and others, 1980), which consist of an equation that represents the one-dimensional streamwise form of the conservation of mass as

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x} = 0 \qquad (1)$$

and an equation that represents the one-dimensional streamwise form of the conservation of momentum as

$$\frac{\partial Q}{\partial t}+\frac{\partial(\beta Q^2/A)}{\partial x}+gA\frac{\partial h}{\partial x}+gAS_f = 0 \qquad (2)$$

where

A is the wetted cross-section area of the channel, in square feet;

t is the time, in seconds;

Q is the discharge, in cubic feet per second;

x is the streamwise distance along the channel, in feet;

β is the non-uniform velocity distribution coefficient;

g is the acceleration of gravity, in feet per second squared;

h is the water-surface elevation above a datum plane, in feet; and

S_f is the friction slope, in feet per feet (dimensionless).

The variable β is the non-uniform velocity distribution coefficient and is defined by equation 3 for a cross section divided into N discrete subsections, where the subscript i is the ith discrete subsection (Cunge and others, 1980). Equation 3 is derived under the assumptions that

1. the discharge for the total cross section is equal to the sum of discharges in each subsection, and
2. S_f for the total cross section is equal to S_f for each subsection.

$$\beta = \frac{A}{K^2}\sum_i^N\frac{K_i^2}{A_i} \qquad (3)$$

In equation 3, K is conveyance and is defined by equation 4 for the whole cross section and equation 5 for the ith subsection.

$$K = \frac{1.486}{n}AR^{2/3} \qquad (4)$$

$$K_i = \frac{1.486}{n_i}A_iR_i^{2/3} \qquad (5)$$

where

n is the Manning's roughness coefficient; and

R is the hydraulic radius, in feet.

If the channel geometry, water-surface elevation, and Manning's roughness coefficient (n) are known, then β and K are known. The roughness coefficient hereinafter within the narrative is termed the "n-value."

Because the method uses data from a single streamgage, the above assumptions are used to adjust equations 1 and 2 so that differential terms with respect to the downstream distance, x in $(\frac{\partial Q}{\partial x}, \frac{\partial(\beta Q^2/A)}{\partial x}, \frac{\partial h}{\partial x})$, are replaced with approximations that eliminate the need for these terms. The process starts by taking the partial derivative with respect to x in the second term in equation 2, which yields equation 6.

$$\frac{\partial(\beta Q^2/A)}{\partial x} = \frac{Q^2}{A}\frac{\partial\beta}{\partial x}+\beta\frac{2Q}{A}\frac{\partial Q}{\partial x}-\beta\frac{Q^2}{A^2}\frac{\partial A}{\partial x} \qquad (6)$$

Using the chain rule, the partial derivative of β with respect to x yields $\frac{\partial \beta}{\partial x} = \frac{\partial \beta}{\partial y}\frac{\partial y}{\partial x}$. If $\frac{\partial \beta}{\partial y}$, the change in nonuniform velocity distribution coefficient with respect to depth and $\frac{\partial y}{\partial x}$, the change in depth with respect to streamwise distance are both assumed to be much less than one, then the product of the two is considered to be negligible with respect to the rest of the terms, so the term $\frac{Q^2}{A}\frac{\partial \beta}{\partial x}$ is dropped and equation 6 reduces to equation 7.

$$\frac{\partial(\beta Q^2/A)}{\partial x} = \beta\frac{2Q}{A}\frac{\partial Q}{\partial x} - \beta\frac{Q^2}{A^2}\frac{\partial A}{\partial x} \tag{7}$$

Moving the partial derivative of cross-sectional area with respect to time to the right-hand side of equation 1 yields equation 8.

$$\frac{\partial Q}{\partial x} = -\frac{\partial A}{\partial t} \tag{8}$$

Using the chain rule in taking the partial derivative of A with respect to x and using the assumption of $\frac{\partial A}{\partial y} = B$ (Henderson, 1966) yields equation 9.

$$\frac{\partial A}{\partial x} = \frac{\partial A}{\partial y}\frac{\partial y}{\partial x} = B\frac{\partial y}{\partial x} \tag{9}$$

Substituting equations 8 and 9 into equation 7 yields equation 10.

$$\frac{\partial(\beta Q^2/A)}{\partial x} = -\beta\frac{2Q}{A}\frac{\partial A}{\partial t} - \beta B\frac{Q^2}{A^2}\frac{\partial y}{\partial x} \tag{10}$$

The water-surface elevation slope, $\frac{\partial h}{\partial x}$, which is in the third term of equation 2, is equivalent to the slope of the water depth minus bed slope, S_0, as shown in equation 11.

$$\frac{\partial h}{\partial x} = \frac{\partial y}{\partial x} - S_0 \tag{11}$$

Discharge is related to K and S_f by $Q = K_T S_f^{1/2}$, where K_T is the sum of the conveyance of each sub-section. Solving this equation for S_f gives equation 12 S_f in terms of Q and K_T.

$$S_f = \left(\frac{Q}{K_T}\right)^2 \tag{12}$$

Substituting equations 10, 11, and 12 into equation 2, dividing through by the product gA, and rearranging the result yields equation 13.

$$\frac{1}{gA}\frac{\partial Q}{\partial t} - \beta\frac{2Q}{gA^2}\frac{\partial A}{\partial t} + \left(1 - \beta B\frac{Q^2}{gA^3}\right)\frac{\partial y}{\partial x} + \left(\frac{Q}{K_T}\right)^2 - S_o = 0 \tag{13}$$

The pressure term, $\frac{\partial y}{\partial x}$, is the remaining partial derivative with respect to x. Henderson (1966) shows that for a flood wave moving approximately as a kinematic wave (assumption 5), the pressure term can be represented as

$$\frac{\partial y}{\partial x} = -\left(\frac{1}{c}\right)\frac{\partial h}{\partial t} - \left(\frac{2}{3}\right)\frac{S_0}{r^2} \tag{14}$$

where

c is the flood wave velocity, in feet per second; and

r is defined as the dimensionless ratio of S_0 to the average wave slope (S_W).

The flood wave velocity can be represented (Henderson, 1966) as equation 15.

$$c = \frac{dQ}{dA} \tag{15}$$

Under the kinematic wave assumption, S_f is equal to S_0, so discharge is related to conveyance by $Q = K S_0^{1/2}$ (Henderson, 1966). Taking the derivative of Q in this relation gives

$$c = S_0^{1/2}\frac{dK}{dA} \tag{16}$$

For this method, K in equation 16 is computed as K_T.The second term in equation 14 is a small correction to account for the fact that flood waves do not move as a kinematic wave. The second term is dependent on a value of r that requires not only determination of S_0 but also the S_W. Information from a typical flood wave at the streamgage is needed to estimate the S_W as the height of a flood wave divided by the half length of the flood wave, which is represented by the following equation:

$$S_W = \frac{h_p - h_0}{\tau V_k} \tag{17}$$

where

h_p is the stage at the peak of a typical flood, in feet;

h_0 is the stage before the beginning of the typical flood, in feet;

V_k is the velocity of the flood wave, in feet per second; and

τ is the elapsed time between the beginning of the typical flood to the peak of the flood, in seconds.

V_k is defined by

$$V_k = K_c\frac{Q}{A} \tag{18}$$

where K_c is the celerity coefficient (Fread, 1973). The velocity of the flood wave is estimated from equation 18 with the assumption that K_c has a value of 1.3 (Corbett, 1943) and average values used for the flow and area such that

$$V_K = 1.3\frac{Q_P + Q_0}{2\overline{A}} \tag{19}$$

where

Q_p is the peak discharge for a typical flood, in cubic feet per second;

Q_0 is the discharge before the beginning of the typical flood, in cubic feet per second; and

$\overline{A}$ is the wetted cross-section area associated with the average stage, $(h_p + h_0)/2$

Using equations 17 and 19, the following relation is determined as

$$r = 0.65\frac{(Q_p + Q_0)}{(h_p - h_0)\overline{A}}\tau S_0 \tag{20}$$

Equations 14, 16, and 20 are used to calculate $\frac{\partial y}{\partial x}$. Finally, the development of a discretized version of equation 13 and a solution method are discussed in the next section.

Solution Method

To compute an unknown stage or discharge for a time t_j, which is sometime after a time t_{j-1}, the method requires the following:

- known constants, which are S_0, r, and g;
- a known discharge value Q_{j-1} observed at a time t_{j-1};
- a known stage value h_{j-1} observed at a time t_{j-1};
- A, B, β, and K as known functions of stage.

An additional known value is required depending on the unknown value to be computed. If an unknown discharge Q_j at time t_j is to be computed, then a known stage h_j is required. If an unknown stage h_j at time t_j is to be computed, then a known discharge Q_j is required.

Equation 13 contains continuous derivatives that need to be discretized to compute time-series values. Beginning with the derivative in the first term, $\frac{\partial Q}{\partial t}$ can be discretized as

$$\frac{\partial Q}{\partial t} \approx \frac{Q_j - Q_{j-1}}{t_j - t_{j-1}} \tag{21}$$

The derivative in the second term, $\frac{\partial A}{\partial t}$, becomes

$$\frac{\partial A}{\partial t} \approx \frac{A_j - A_{j-1}}{t_j - t_{j-1}} \tag{22}$$

where

A_j is the cross-sectional area for stage h_j.

The pressure term $\frac{\partial y}{\partial x}$ in equation 13 is computed from equation 14, which requires c and the derivative $\frac{\partial h}{\partial t}$ to be computed. Equation 16 is used to compute c and contains the derivative $\frac{dK}{dA}$, which becomes

$$\frac{dK}{dA} \approx \frac{\Delta K_j}{\Delta A_j} \tag{23}$$

where

$$\Delta K_j = K_{h_j+\frac{\Delta h}{2}} - K_{h_j-\frac{\Delta h}{2}} \text{ and} \tag{24}$$

$$\Delta A_j = A_{h_j+\frac{\Delta h}{2}} - A_{h_j-\frac{\Delta h}{2}} \tag{25}$$

For the implementation of this method, Δh=0.01 foot. After the derivative of K with respect to A is computed, equation 16 is used to compute the c. The partial derivative of stage with respect to time is computed as

$$\frac{\partial h}{\partial t} \approx \frac{h_j - h_{j-1}}{t_j - t_{j-1}} \tag{26}$$

The discrete form of equation 14 becomes

$$\frac{\partial y}{\partial x} \approx -\frac{1}{S_0^{1/2}}\frac{\Delta h}{\Delta K_j}\frac{h_j - h_{j-1}}{t_j - t_{j-1}} - \frac{2\,S_0}{3\,r^2} \tag{27}$$

Substituting all discrete approximations of derivatives into equation 13 yields equation 28.

$$\frac{1}{gA_j}\frac{Q_j - Q_{j-1}}{t_j - t_{j-1}} - \beta_j\frac{2\,Q_j}{gA_j^2}\frac{A_j - A_{j-1}}{t_j - t_{j-1}} - \left(1 - \beta_j B_j \frac{Q_j^2}{gA_j^3}\right)\left(\frac{1}{S_0^{1/2}}\frac{\Delta A_j}{\Delta K_j}\frac{h_j - h_{j-1}}{t_j - t_{j-1}} + \frac{2\,S_0}{3\,r^2}\right) + \left(\frac{Q_j}{K_j}\right)^2 - S_0 = 0 \tag{28}$$

Equation 28 is a nonlinear function of the unknown variable (Q_j or h_j) because all other values of r are known. The root of equation 28, and thus the value of the unknown variable, is determined using the secant method (Dahlquist and Björck, 1974).

The solution method to equation 28 was implemented (Domanski and others, 2025) in the Python programming language (Python Software Foundation, 2023). The results shown in this report were computed using the Python implementation (Domanski and others, 2025), and the software for its maintenance track is available through Knight and others (2025).

Evaluation Using Model-Generated Test Scenarios

Simulated scenario test datasets were created from one-dimensional unsteady Hydrologic Engineering Center River Analysis System (HEC–RAS; U.S. Army Corps of Engineers, 2016) simulation results. The purpose of creating the simulated test datasets was to compare the results computed with the dynamic rating method (DYNPOUND) described in this report to results computed using the HEC–RAS model one-dimensional unsteady shallow water equations, of which the dynamic rating method is a simplification. The simulated test datasets were obtained from Domanski and others (2022a; 2025). The source code and calibration parameters for the stage-to-discharge DYNMOD and original DYNPOUND rating methods, along with the HEC–RAS project files, are available in Domanski and others (2022b). The source code and calibration parameters for the newly improved DYNPOUND rating method and updated HEC–RAS project files are available from Domanski and others (2025). The dynamic rating software, DynRat, was developed using the original source code and is available in Knight and others (2025). The improved DYNPOUND method has the functionality to specify stage and n-value pairs for a cross section or subsection, with noteworthy shifts in flow patterns at specific stages but no obvious change in geometry. Additionally, the method computes both stage-to-discharge and discharge-to-stage time series.

A prismatic channel geometry (fig. 2), with floodplains on each side and a main channel with a total length of 80 miles, was used for four different scenarios with different combinations of S_0 and r (table 1). An n-value of 0.035 was used for all cross sections. The cross sections in the channels were split into three subsections to compute for β and to smooth out the stage-conveyance relation (fig. 3c). The subsection stationing includes the two bank stations so that two subsections contain the left and right overbank areas and one subsection contains the main channel.

Different inflow hydrographs were developed for the evaluation to test the range of unsteadiness in the simulated responses from the three computation methods: HEC–RAS, DYNMOD, and DYNPOUND. A normal depth boundary condition was used at the downstream end of each scenario with the appropriate S_0 assigned to the normal depth relation.

All scenarios were simulated in HEC–RAS. The HEC–RAS computed stage and discharge time series at the cross-section (40 miles downstream from the inflow point, midway between the most upstream and most downstream cross sections of the 80-mile reach) were extracted and used to compute and compare the discharge with the dynamic rating methods. The midpoint of the cross section was selected to reduce the effects of the boundary conditions on the simulation results. The Manning's n-value, S_0, and r values used in the development of the HEC–RAS scenarios were assigned to the parameters in the dynamic rating discharge computations.

Dataset Development

The width of the main channel of the simulated cross section was 300 feet (ft), the floodplains have a total width of 600 ft, and the total width of the cross section was 900 ft. The bankfull depth of the main channel was 30 ft. The subsection

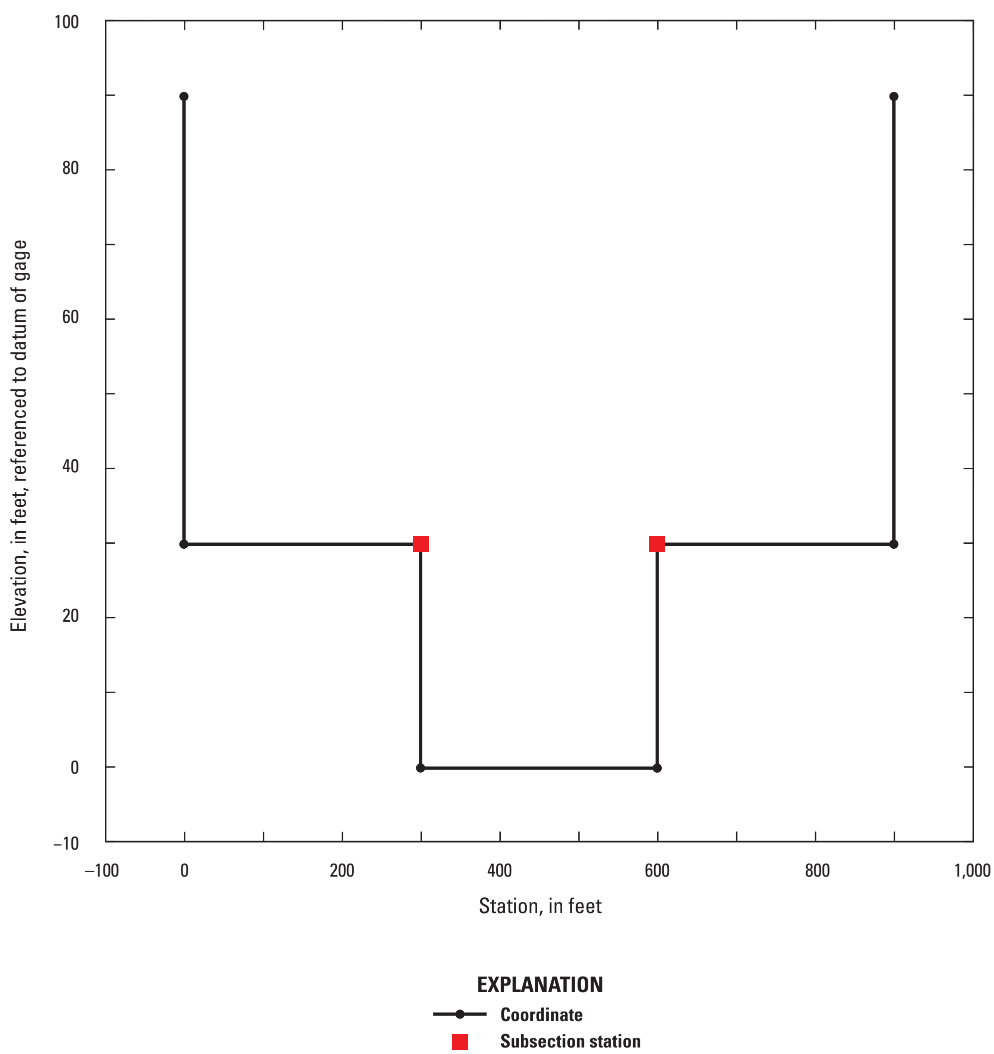


Figure 2. Graph showing a representative cross section for simulated test datasets.

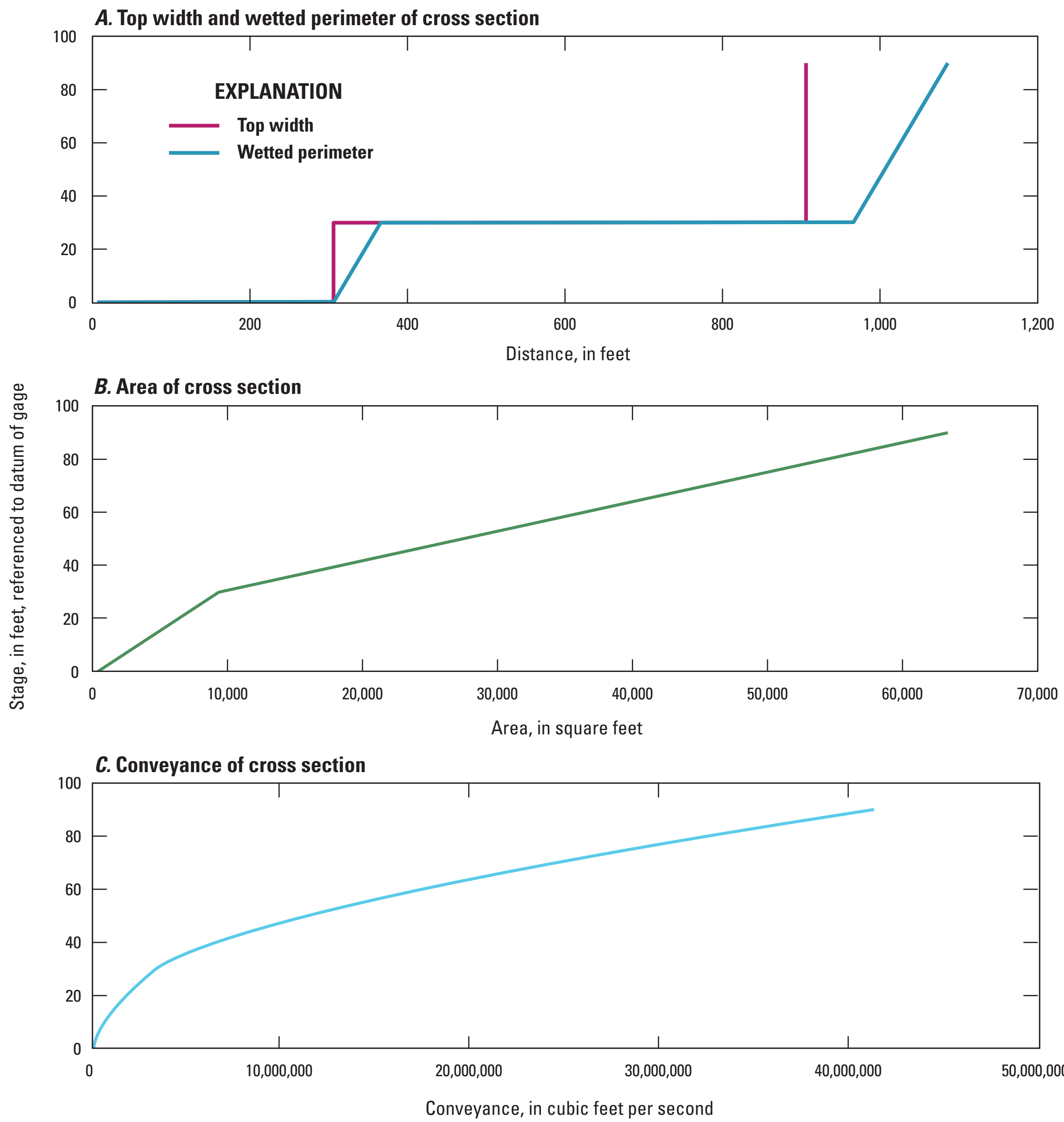


Figure 3. Graphs showing stage plotted against four variables. *A*, top width and wetted perimeter; *B*, area; and *C*, conveyance.

Table 1. Bed slope and ratio of bed slope to average wave slope of simulated test data scenarios.

[*r*, ratio of bed slope to average wave slope]

Scenario	Bed slope	*r*
1	0.0001	10
2	0.0001	100
3	0.001	10
4	0.001	100

stations coincide with the bank stations at 300 and 600 ft (fig. 2). An *n*-value of 0.035 was used for all scenarios in the cross section.

Four sets of hydrographs, which were used as upstream boundary conditions for each scenario, were developed to simulate stage and discharge time series under varied channel slope and unsteadiness conditions in the test scenarios (figs. 4–7; Domanski and others, 2022b; Domanski and others, 2025). The value of unsteadiness can be characterized by r, which is the ratio of S_0 to S_w (eq. 17). The larger the value of r for a particular S_0, the lower the unsteadiness of the hydrograph; that is, the time from the onset of the flooding to the flood peak increases with increasing value of r. To determine the actual inflow hydrographs used for the scenarios, a flood wave slope was computed from a S_0 and an assumed value of r (table 1). The rising and falling limbs of the stage hydrograph were computed using the constant value of the slope of the flood wave between the end points of 75 percent of the bankfull main channel depth (22.5 ft) to the peak stage (60 ft). The peak stage was chosen such that the total wetted area in the floodplain equaled the wetted area in the upstream channel location. Manning's equation from the stage hydrograph was used to compute the discharge hydrographs for the upstream boundary condition.

Evaluation

A preliminary analysis of the four test scenarios was performed using the DYNMOD method, in which jumps in discharge were observed in the time series (Domanski and others, 2022b). The first jump, from a higher to a lower discharge, took place when the stage rose from below to above the channel bank elevation, and the second jump, from a lower to higher discharge, took place once the elevation fell below the bank elevation. These jumps happened because of abrupt changes in the relations of top width, wetted perimeter, and area with stage (fig. 3). For more information about these test scenarios and the DYNMOD method, refer to Domanski and others (2022b).

Overall, the magnitude of the mean percent error was much greater in the results computed with the DYNMOD method (Domanski and others, 2022b). The error is smaller in the time series computed with the DYNPOUND method because this method relies on the conveyance, as well as area and top width (refer to eq. 13). The function of conveyance with stage can be developed so that changes are less abrupt by creating subsections in the cross section, as was done for the simulated test scenarios.

The DYNPOUND method performed well compared to the full one-dimensional unsteady flow equations within HEC–RAS for all four scenarios. The mean percent error for the DYNPOUND-computed discharge was approximately 2.01×10^{-1} percent. The mean percent error for the DYNPOUND-computed stage was -1.05×10^{-1} percent. (table 2).

Scenarios 1 (fig. 4) and 3 (fig. 6) have values of r equaling 10 (table 1) and, therefore, are highly unsteady and show pronounced hysteresis in the stage versus discharge curves. Scenarios 2 (fig. 5) and 4 (fig. 7), which have values of r equaling 100 (table 1), do not show hysteresis. Furthermore, the DYNPOUND method performs better for discharge and stage in scenarios 2 and 4 than it does in scenarios 1 and 3 (table 2). Scenarios 2 and 4 effectively have one-to-one stage-discharge relations.

Scenario 1

At approximately 30 ft, where flow begins to exceed the main channel, DYNPOUND-computed discharge and stage time series show a "jog" in the relation (fig. 8). This is likely due to the abrupt change in channel geometry and the application of a single *n*-value for the entire channel. The scenario 1 stage-discharge relation indicates hysteresis in the HEC–RAS results because of unsteady flow effects captured by the dynamic ratings simulations (fig. 9).

Scenario 2

Scenario 2's computed hydrographs indicate a lack of hysteresis (figs. 10 and 11). The stage-discharge relation of the HEC–RAS results for scenario 2 is effectively one-to-one because the distance between the discharge values computed at a given stage is small (fig. 11).

Scenario 3

Scenario 3's stage discharge relation computed by HEC–RAS shows hysteresis with a similar "jog" to scenario 1, at 30 ft, when the channel geometry changes (fig. 12 and fig. 13).

Scenario 4

The stage-discharge relation of the scenario 4 time series (fig. 14) as computed using HEC–RAS does not show hysteresis and can effectively be considered a one-to-one relation (fig. 15).

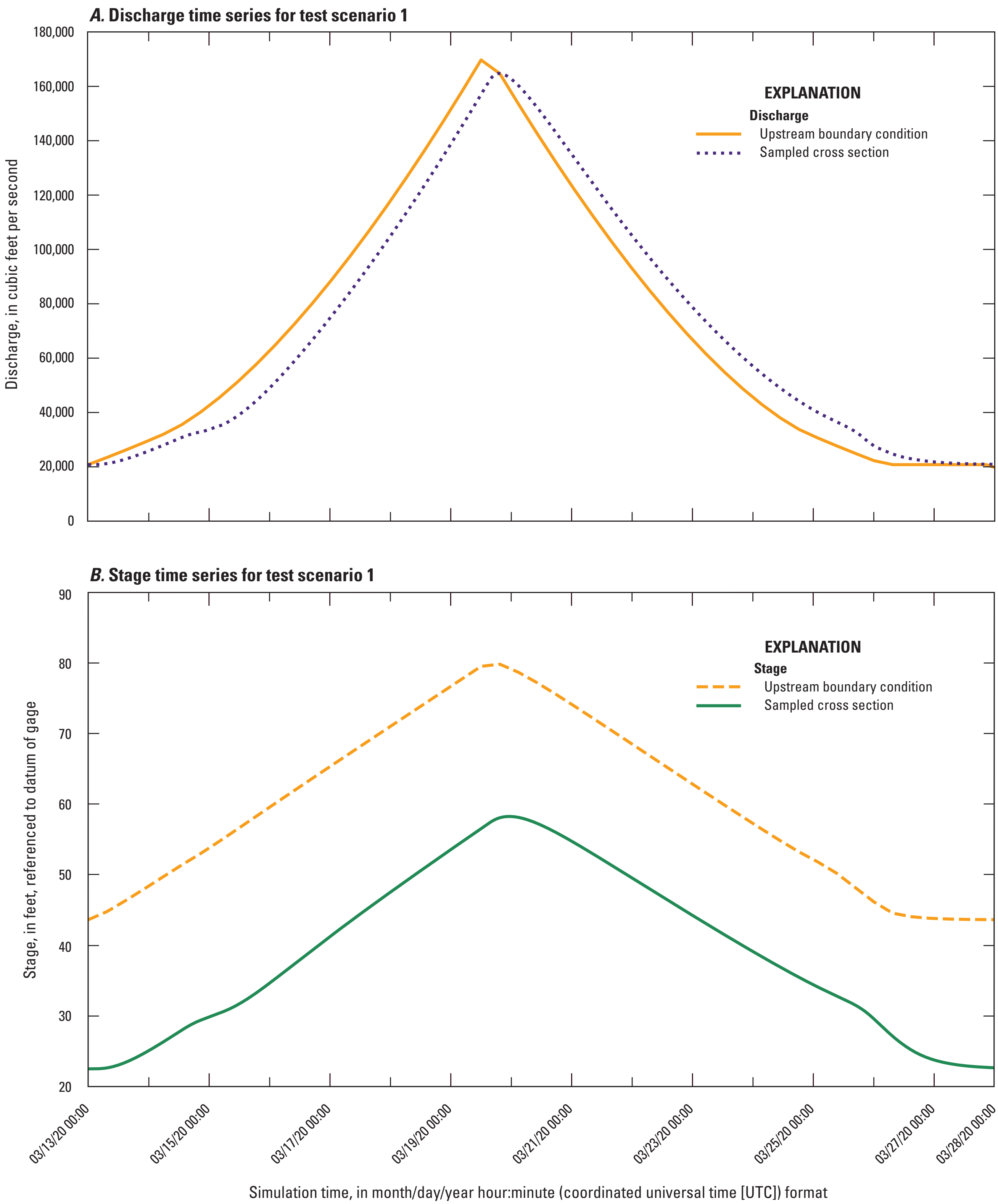


Figure 4. Graphs showing time series for simulated test scenario 1 (Domanski and others, 2025). *A*, discharge and *B*, stage.

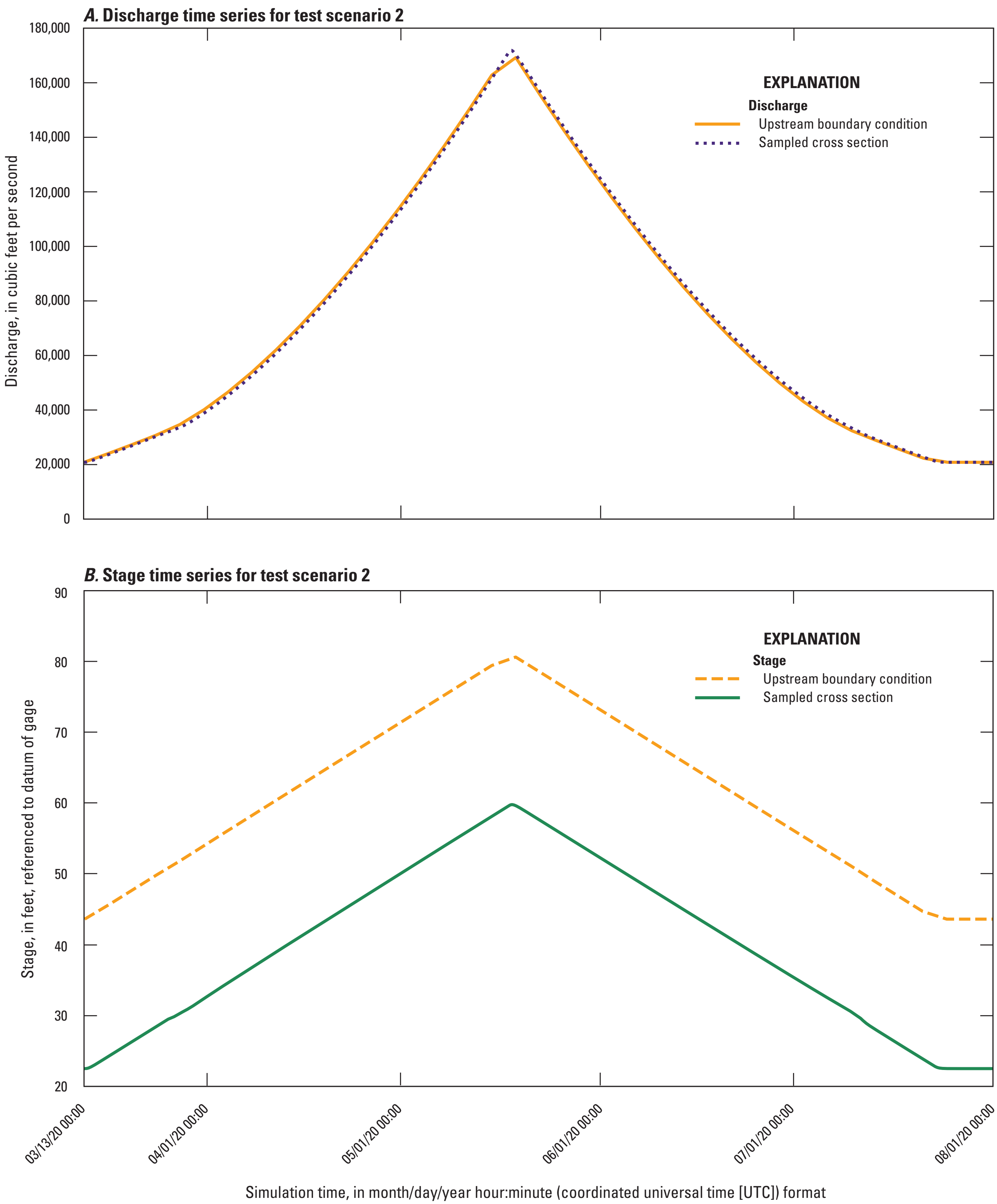


Figure 5. Graphs showing time series for simulated test scenario 2 (Domanski and others, 2025). *A*, discharge and *B*, stage.

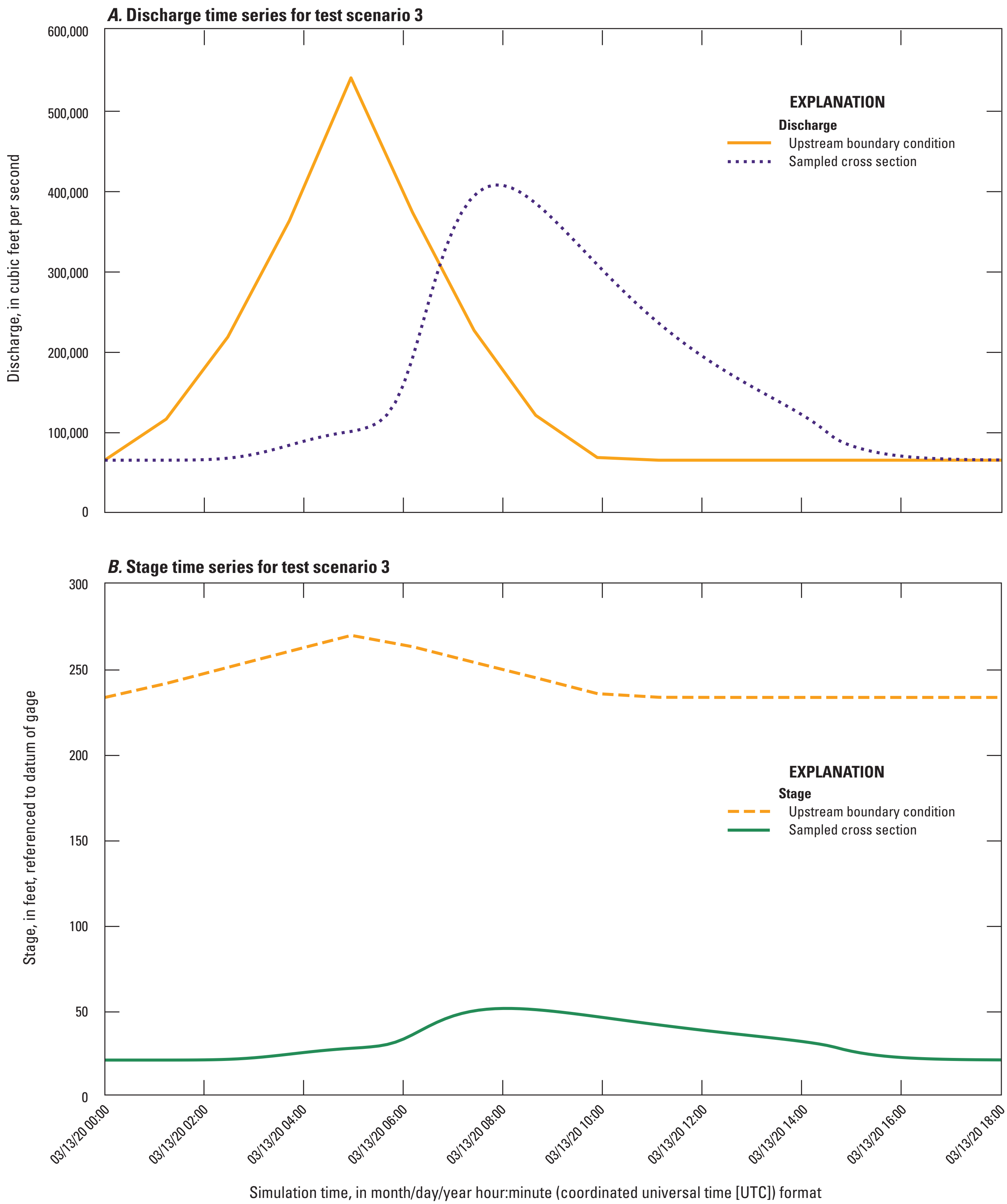


Figure 6. Graphs showing time series for simulated test scenario 3 (Domanski and others, 2025). *A*, discharge and *B*, stage.

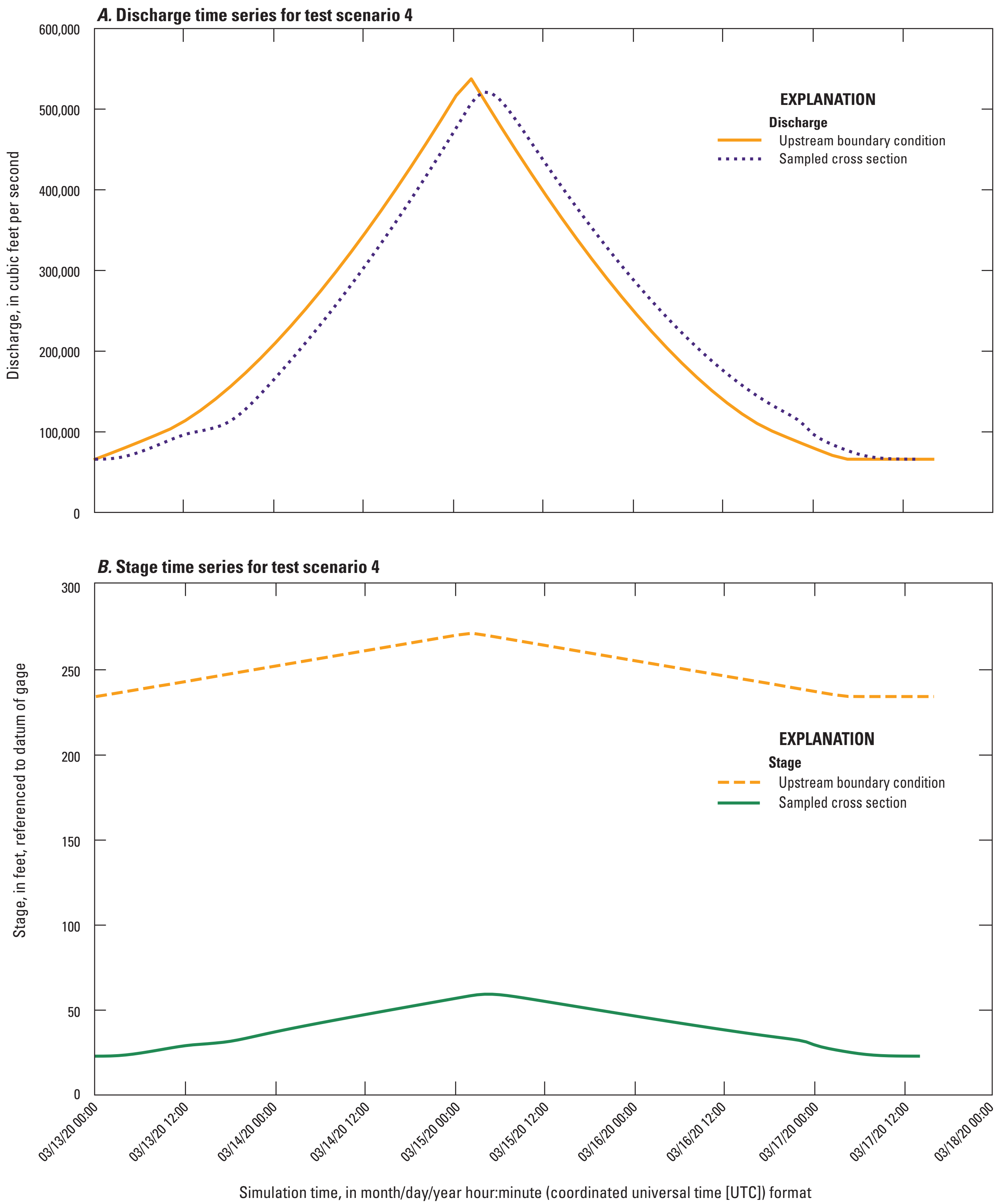
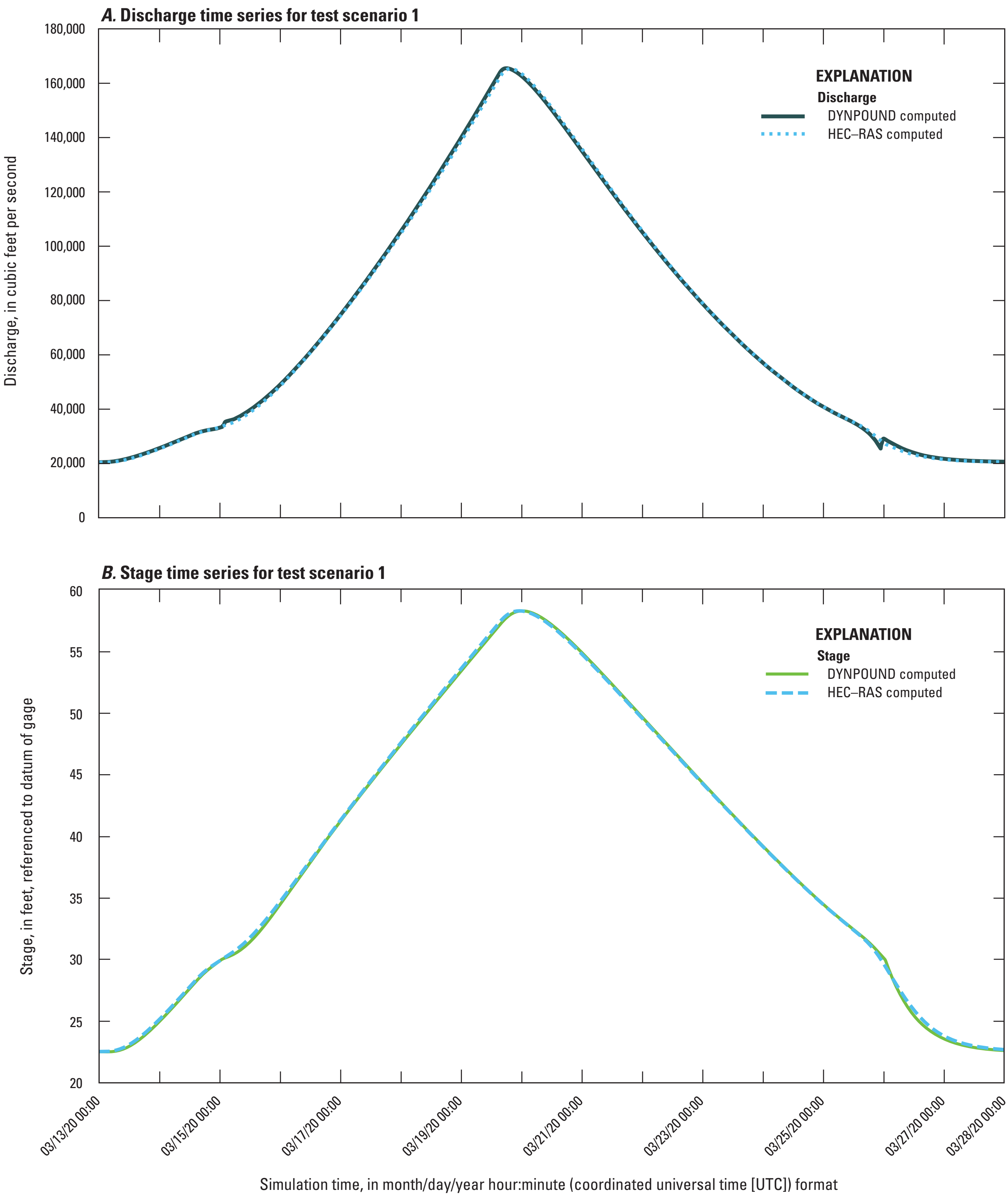


Figure 7. Graphs showing time series for simulated test scenario 4 (Domanski and others, 2025). *A*, discharge and *B*, stage.

Table 2. Performance statistics for the DYNPOUND computation method.

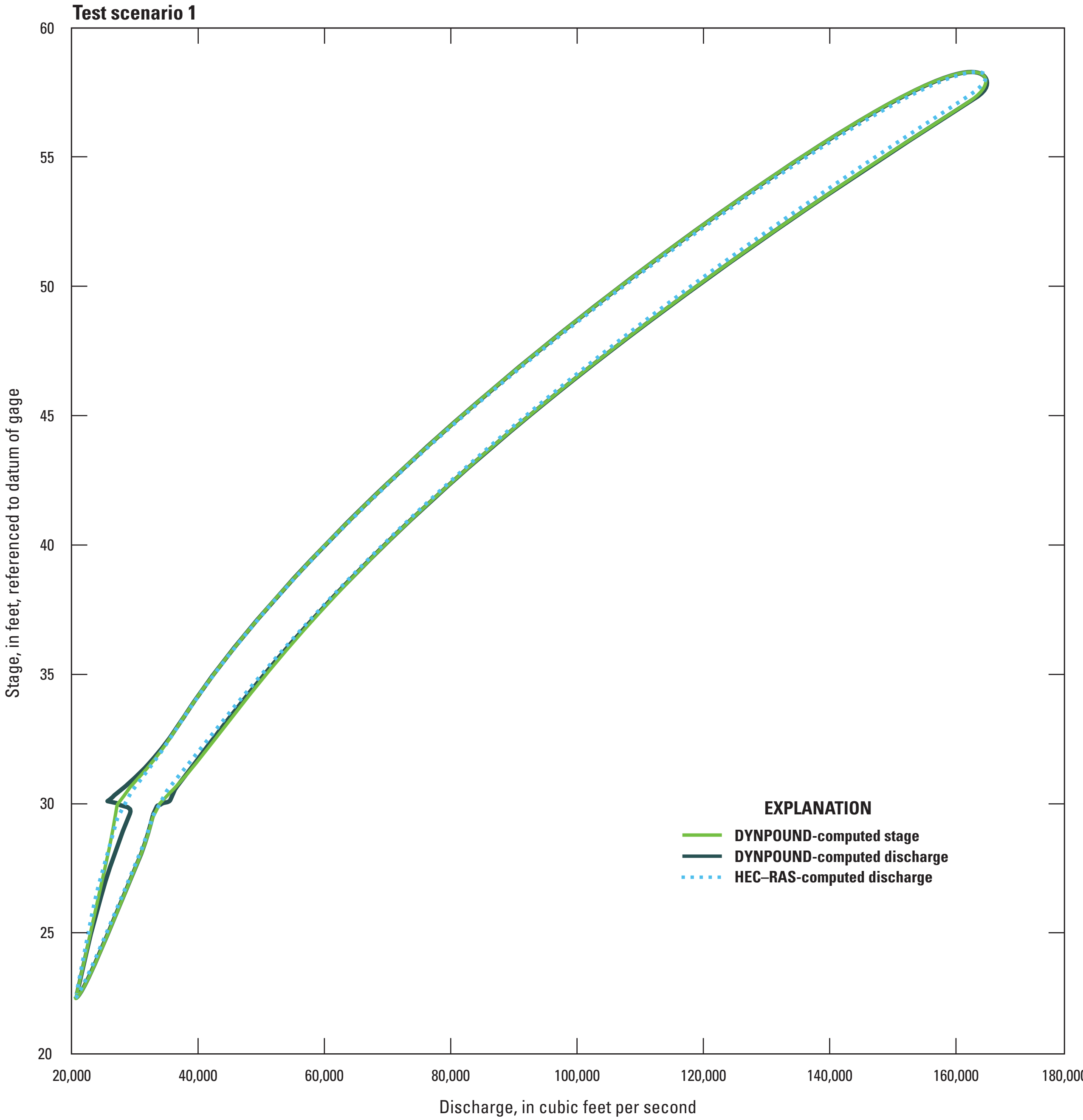
[DYNPOUND is the newly developed method that solves for stage and discharge in compact and compound channels. MSLE, mean squared logarithmic error]

Scenario	DYNPOUND discharge			DYNPOUND stage		
	Mean percent error	Maximum absolute percent error	MSLE	Mean percent error	Maximum absolute percent error	MSLE
1	4.47×10^{-1}	6.08	2.02×10^{-4}	-2.36×10^{-1}	1.77	2.60×10^{-5}
2	-9.07×10^{-3}	0.46	7.84×10^{-7}	3.67×10^{-3}	0.32	1.63×10^{-7}
3	3.70×10^{-1}	2.74	4.31×10^{-5}	-1.89×10^{-1}	0.65	1.09×10^{-5}
4	-5.44×10^{-3}	0.12	2.47×10^{-7}	1.99×10^{-3}	0.20	7.24×10^{-8}
Mean	2.01×10^{-1}	2.35	6.16×10^{-5}	-1.05×10^{-1}	0.74	9.28×10^{-6}



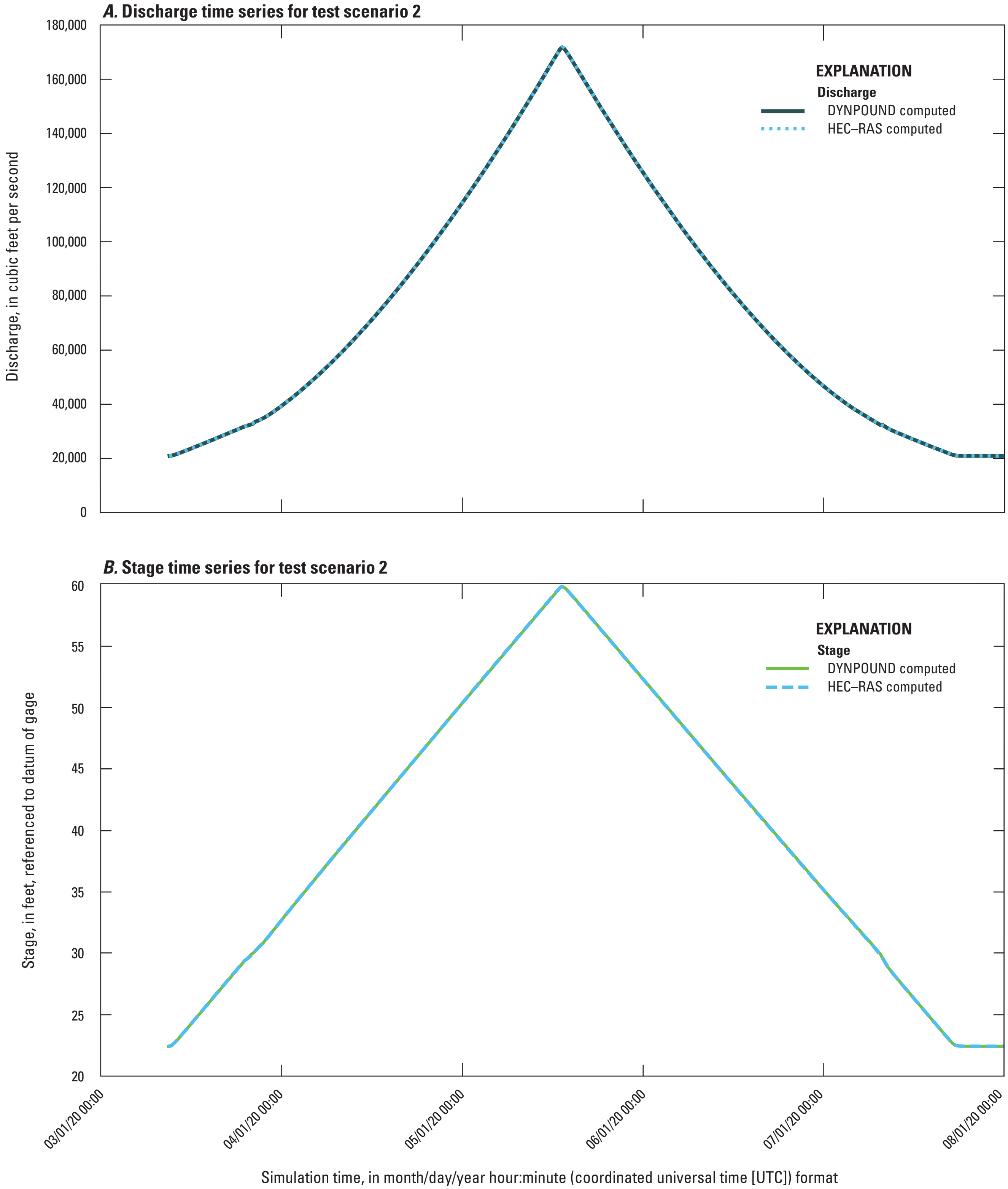
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
HEC–RAS, Hydrologic Engineering Center River Analysis System.

Figure 8. Graphs showing time series for simulated scenario 1 (Domanski and others, 2025). *A*, Discharge computed with the DYNPOUND method; *B*, stage computed with the DYNPOUND method.



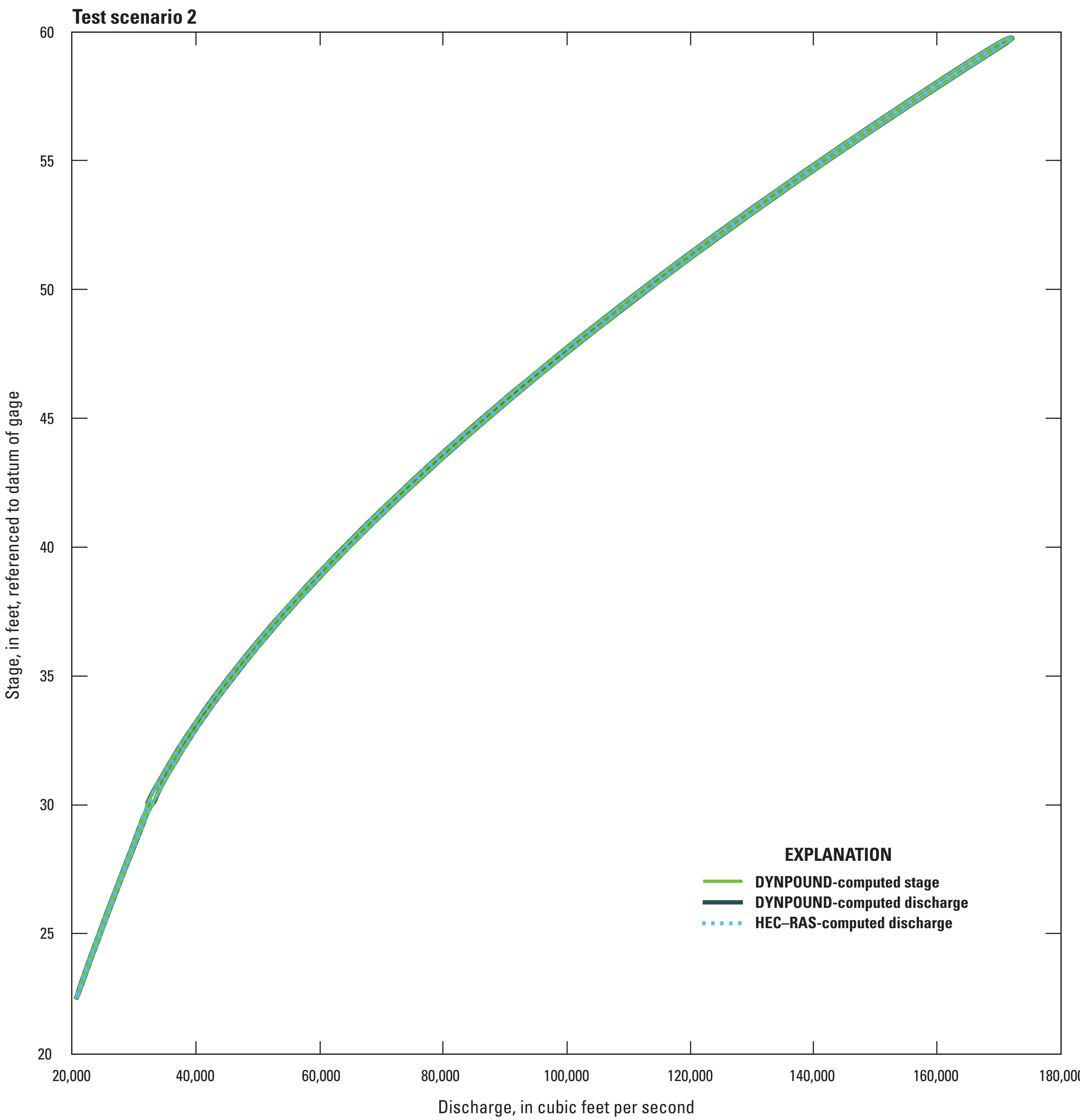
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
HEC–RAS, Hydrologic Engineering Center River Analysis System.

Figure 9. Graph showing the relation between stage and computed discharge and discharge and computed stage for simulated scenario 1 (Domanski and others, 2025).



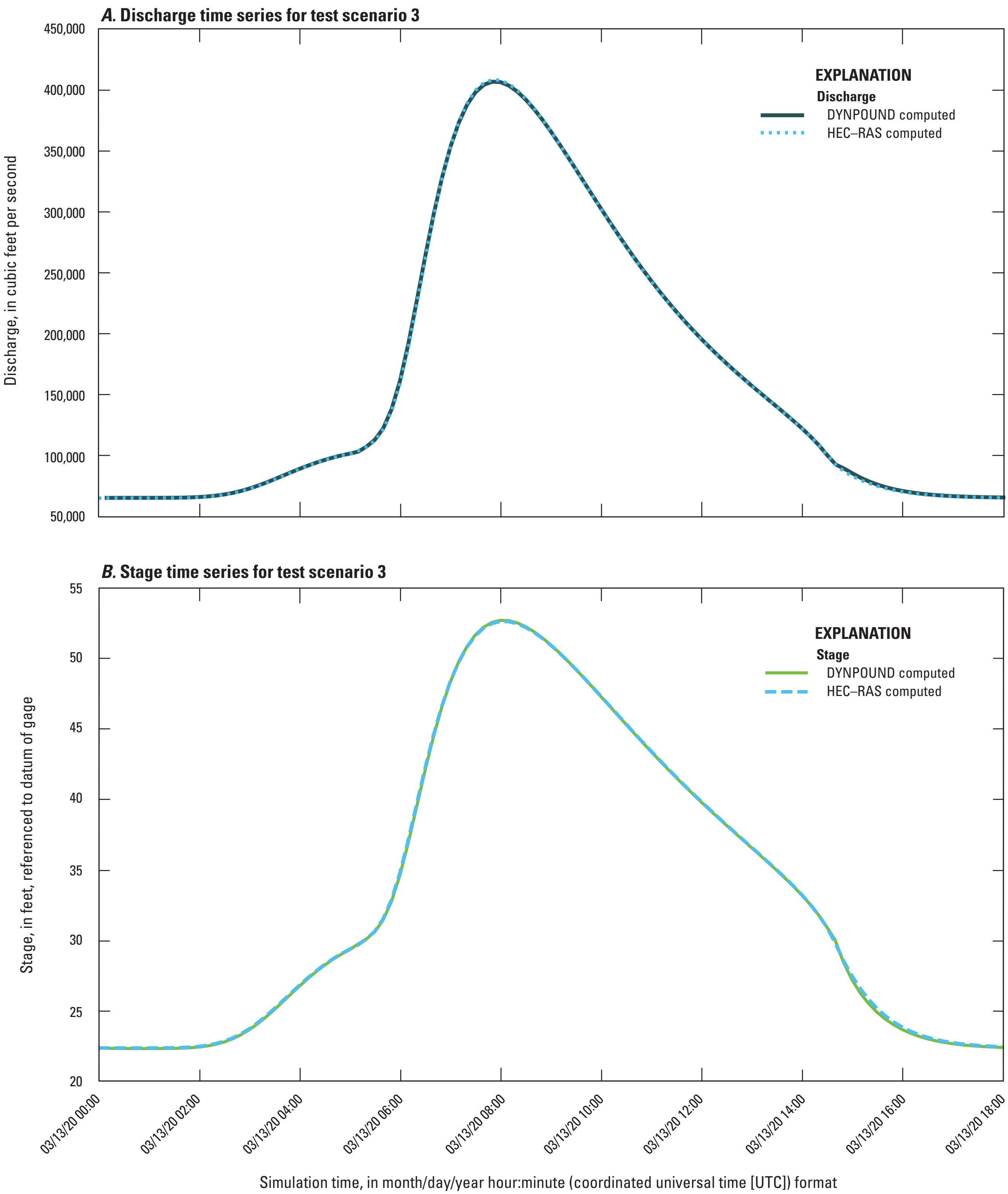
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
HEC–RAS, Hydrologic Engineering Center River Analysis System.

Figure 10. Graphs showing time series for simulated scenario 2 (Domanski and others, 2025). *A*, Discharge computed with the DYNPOUND method; *B*, Stage computed with the DYNPOUND method.



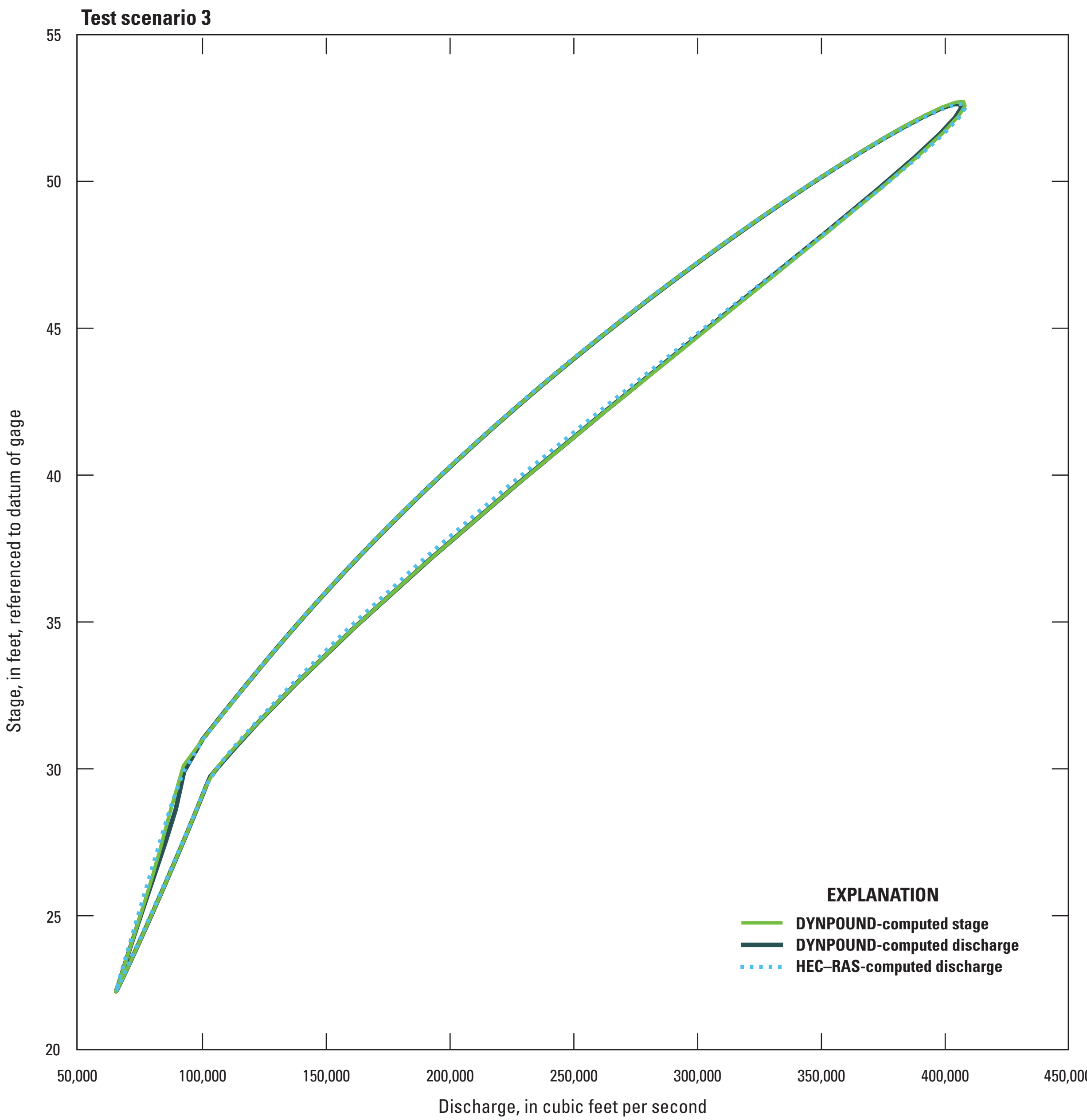
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
HEC–RAS, Hydrologic Engineering Center River Analysis System.

Figure 11. Graph showing the relation between stage and computed discharge and discharge and computed stage for simulated scenario 2 (Domanski and others, 2025).



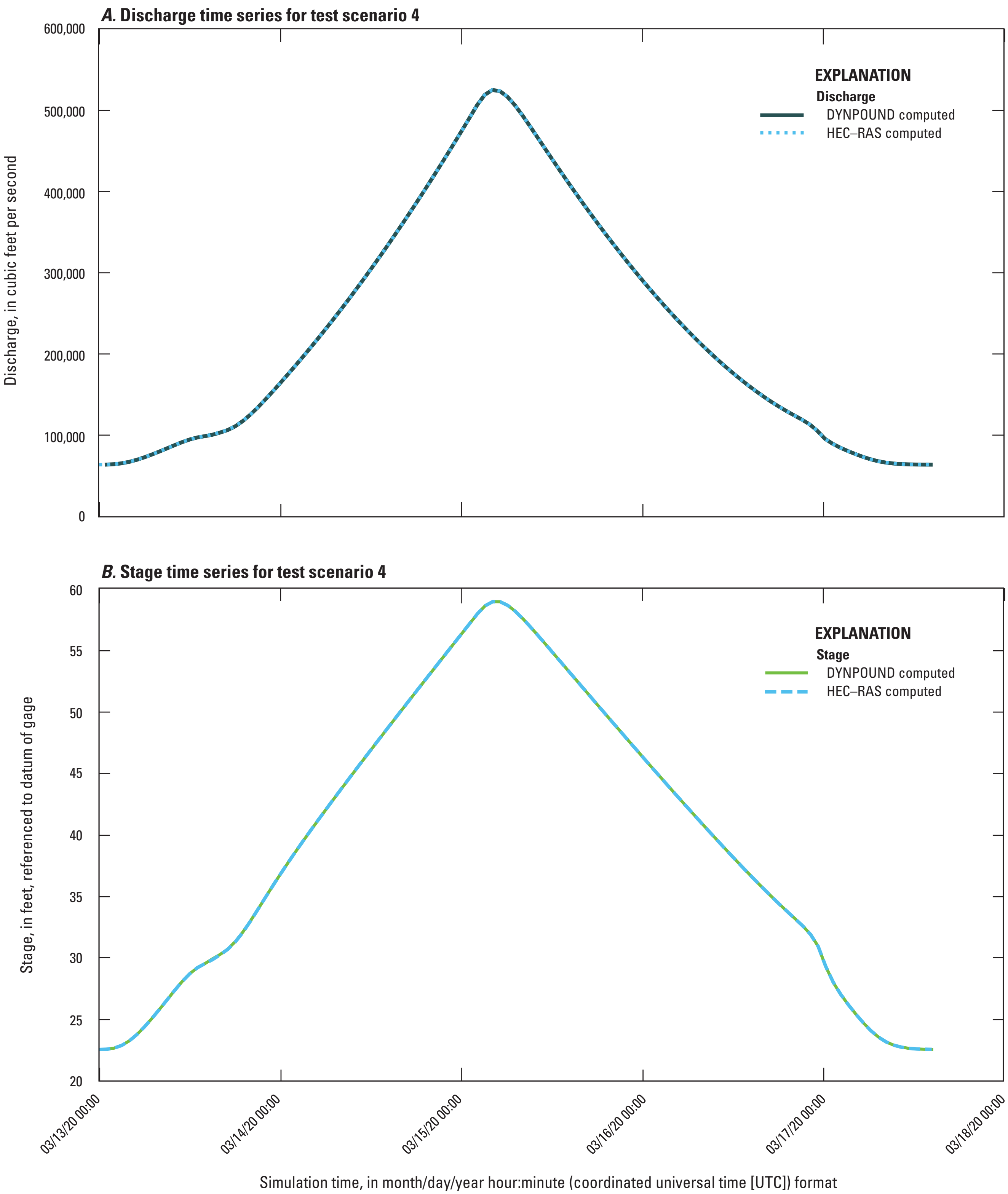
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
HEC–RAS, Hydrologic Engineering Center River Analysis System.

Figure 12. Graphs showing time series for simulated scenario 3 (Domanski and others, 2025). *A*, Discharge computed with the DYNPOUND method; *B*, Stage computed with the DYNPOUND method.



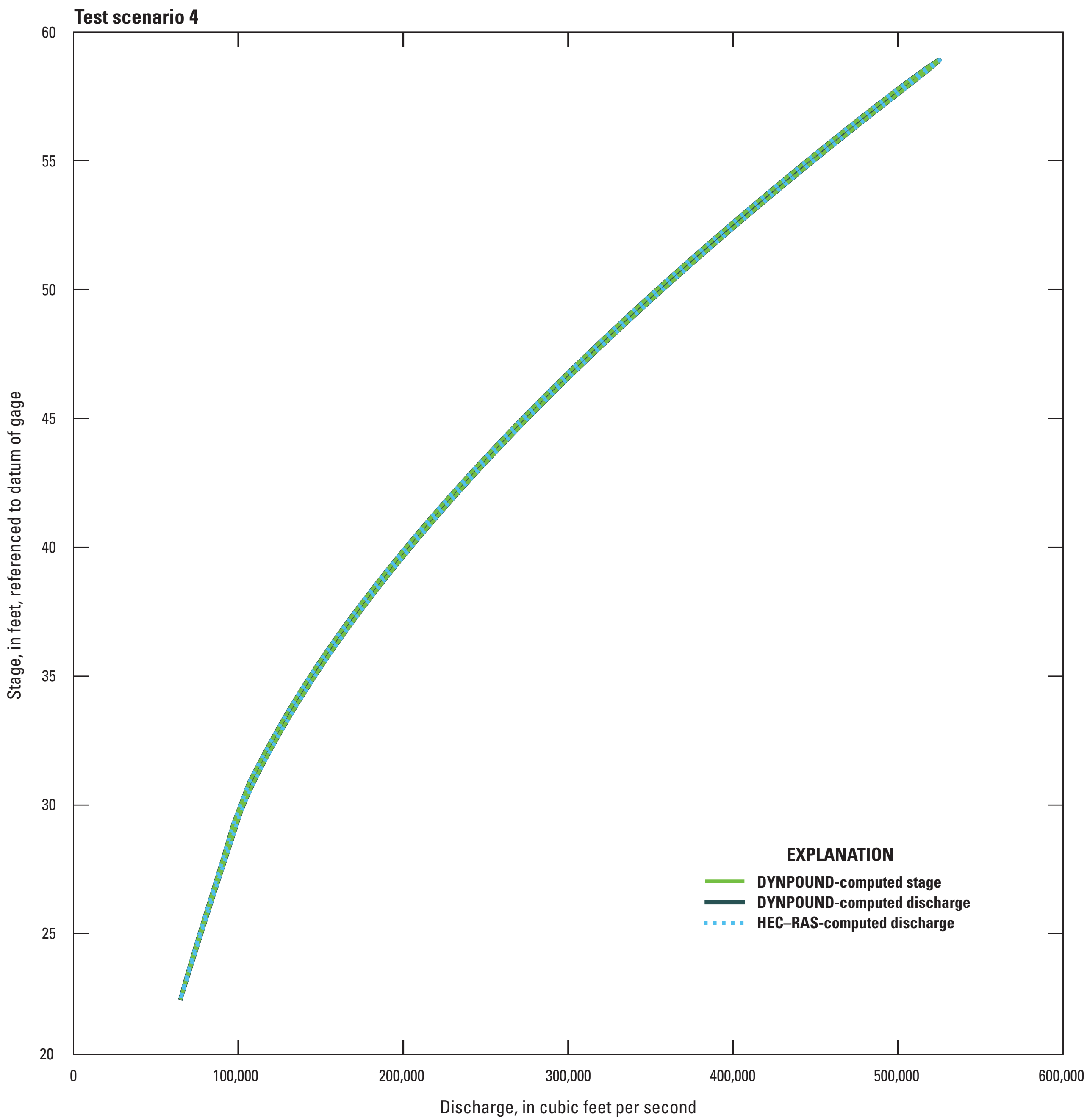
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
HEC–RAS, Hydrologic Engineering Center River Analysis System.

Figure 13. Graph showing the relation between stage and computed discharge and discharge and computed stage for simulated scenario 3 (Domanski and others, 2025).



DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
HEC–RAS, Hydrologic Engineering Center River Analysis System.

Figure 14. Graphs showing time series for simulated scenario 4 (Domanski and others, 2025). *A*, Discharge computed with the DYNPOUND method; *B*, stage computed with the DYNPOUND method.



DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
HEC–RAS, Hydrologic Engineering Center River Analysis System.

Figure 15. Graph showing the relation between stage and computed discharge and discharge and computed stage for simulated scenario 4 (Domanski and others, 2025).

Evaluation Using Field Data

Field measurements of discharge and stage and WSC-computed discharge and WSC-measured stage from 10 USGS streamgages were used to evaluate the DYNPOUND method (U.S. Geological Survey, 2020). These streamgages represent a variety of geographic locations and geomorphic conditions. The 10 streamgage sites chosen for evaluation were Meherrin River near Bryants Corner, Virginia (USGS streamgage 02052090); Tug Fork at Kermit, West Virginia (USGS streamgage 03214500); Tittabawassee River at Midland, Michigan (USGS streamgage 04156000); Red River of the North at Fargo, North Dakota (USGS streamgage

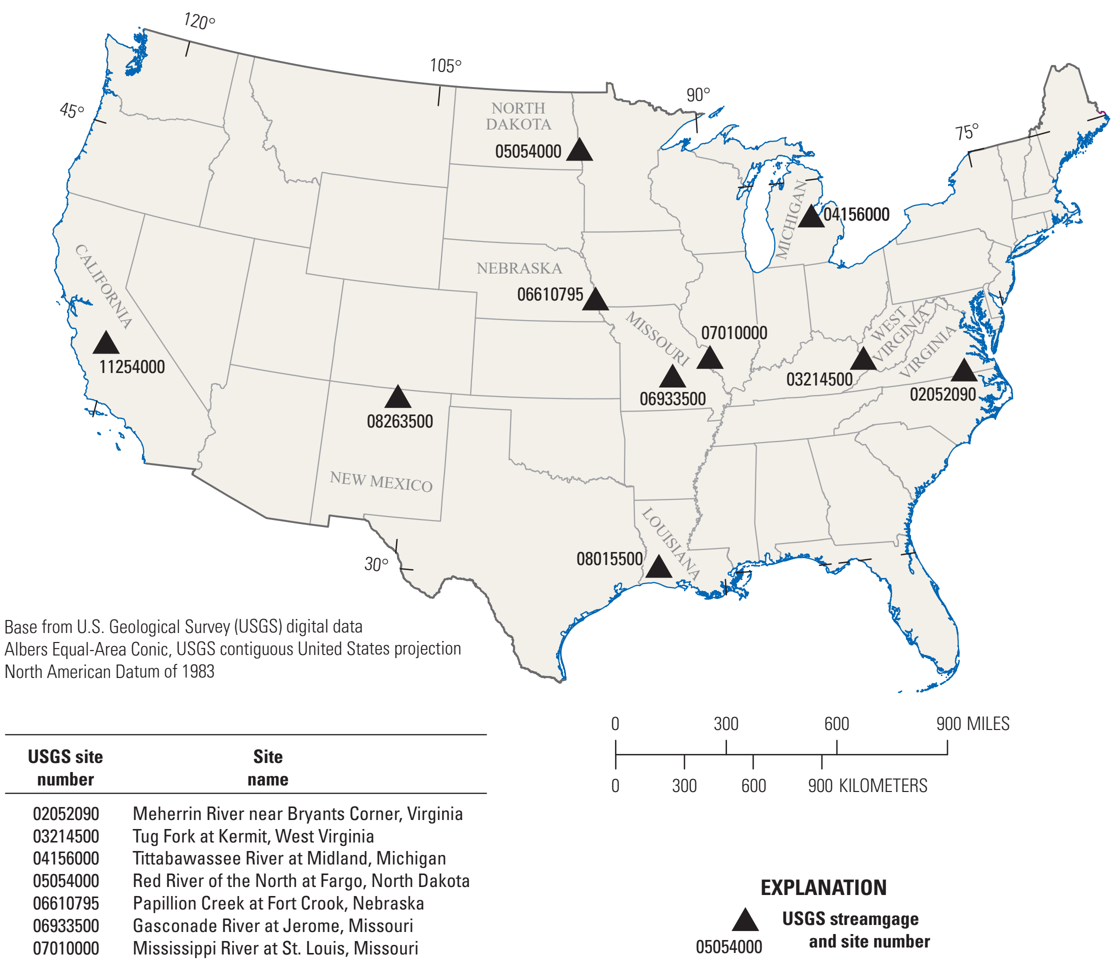
05054000); Papillion Creek at Fort Crook, Nebraska (USGS streamgage 06610795); Gasconade River at Jerome, Missouri (USGS streamgage 06933500); Mississippi River at St. Louis, Missouri (USGS streamgage 07010000); Calcasieu River near Kinder, Louisiana (USGS streamgage 08015500); Rio Grande near Cerro, New Mexico (USGS streamgage 08263500); and San Joaquin River near Mendota, California (USGS streamgage 11254000) (fig. 16 and table 3).

Dataset Development

Site datasets consisted of WSC-computed discharge and WSC-measured stage time series, field measurements of discharge and stage, cross-section geometry, and bed slope. Time series and field measurements were obtained from the National Water Information System (NWIS; U.S. Geological Survey, 2020). Cross-section geometry and bed slope were computed for each site using a combination of acoustic Doppler profiler (ADCP) software, AreaComp2 USGS utility (U.S. Geological Survey, 2015), ArcGIS Pro (Esri, 2021), and HEC–RAS (U.S. Army Corps of Engineers, 2016).

Cross-Section Geometry

To obtain cross-section geometry, an ADCP discharge measurement was selected for each site that generally corresponded to a high-flow event. The ADCP measurement was then converted into a "station, depth" coordinate format and imported into AreaComp2. AreaComp2 was used to convert the "station, depth" coordinates to "station, elevation" (in stage datum) coordinates. Next, a digital elevation model (DEM; U.S. Geological Survey, 2017; Michigan State University, 2020; U.S. Department of Agriculture, 2021) was imported into RAS Mapper within HEC–RAS, which was used to generate a "station, elevation" (in stage datum) cross section (fig. 17). This cross section created from the DEM



USGS site number	Site name
02052090	Meherrin River near Bryants Corner, Virginia
03214500	Tug Fork at Kermit, West Virginia
04156000	Tittabawassee River at Midland, Michigan
05054000	Red River of the North at Fargo, North Dakota
06610795	Papillion Creek at Fort Crook, Nebraska
06933500	Gasconade River at Jerome, Missouri
07010000	Mississippi River at St. Louis, Missouri
08015500	Calcasieu River near Kinder, Louisiana
08263500	Rio Grande near Cerro, New Mexico
11254000	San Joaquin River Near Mendota, California

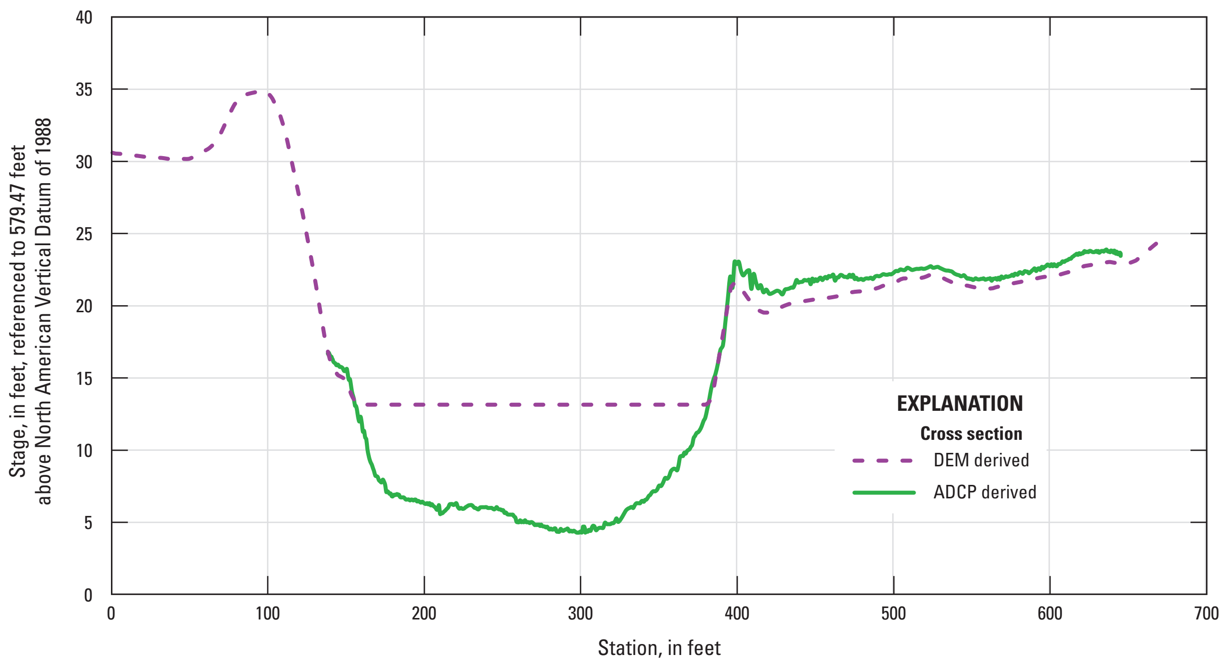
Figure 16. Map of U.S. Geological Survey streamgage sites used to evaluate discharge computed with the dynamic rating methods (U.S. Geological Survey, 2020). USGS, U.S. Geological Survey.

Table 3. Streamgage number and name, drainage area, and slope of the field sites used to evaluate the DYNPOUND dynamic rating method.

[Data from U.S. Geological Survey, 2020. DYNPOUND is the newly developed method that solves for stage and discharge in compact and compound channels. mi^2, square mile]

Streamgage number	Streamgage name	Drainage area (mi^2)	Bed slope[1]
02052090	Meherrin River near Bryants Corner, Virginia	807	0.00037809
03214500	Tug Fork at Kermit, West Virginia	1,277	0.000352
04156000	Tittabawassee River at Midland, Michigan	2,400	0.000139
05054000	Red River of the North at Fargo, North Dakota	6,800	0.000145
06610795	Papillion Creek at Fort Crook, Nebraska	384	0.00025438
06933500	Gasconade River at Jerome, Missouri	2,840	0.00040953
07010000	Mississippi River at St. Louis, Missouri	697,000	0.000110
08015500	Calcasieu River near Kinder, Louisiana	1,700	0.00018992
08263500	Rio Grande near Cerro, New Mexico	8,440	0.00360
11254000	San Joaquin River near Mendota, California	3,940	0.000248

[1]Bed slope was calculated using elevation contour, topographical maps, and the National Hydrography Dataset (U.S. Geological Survey, 2017; Domanski and others, 2022a).



DEM, Digital elevation model.
ADCP, Acoustic doppler current profiler.

Figure 17. Graph showing cross sections derived from an acoustic doppler profiler (ADCP) and a digital elevation model (DEM) at Tittabawassee River at Midland, Michigan (U.S. Geological Survey streamgage 04156000).

was combined with the cross section created from the ADCP transect to create a cross section that contained the main channel and overbank sections (fig. 18).

The cross section created from the ADCP measurement most accurately represented the channel, and the cross section created from the DEM was used to represent the larger floodplain. In some cases, a stage measurement was made during a peak-flow event that was high enough to capture some of the floodplain. If that happened, then "station, elevation" (in stage datum) coordinates from the ADCP measurement superseded the overlapping coordinates from the DEM. Geospatially locating ADCP transects at sites without geolocation data associated with ADCP measurements was difficult. If a cross section created from the DEM was used exclusively, it generally lacked accurate channel geometry. If a cross section created from the ADCP was used, it generally lacked floodplain geometry. Sometimes cross sections with these limitations did not produce accurate results in either of the dynamic rating computation methods. When associated geolocation data for an ADCP measurement was lacking and the location of the cross section was otherwise unable to be located, the cross-section geometry was taken from the DEM exclusively, and properties of the channel geometry were estimated.

Bed Slope

Bed slope (S_0) was calculated using elevation contours, historical topographical maps, and the National Hydrography Dataset flowline geospatial files (U.S. Geological Survey, 2017; Domanski and others, 2022a). Points were chosen upstream and downstream from each streamgage where an elevation contour line crossed the channel; reach lengths varied depending on available map contours, ranging from approximately 4,582 to 781,450 ft (Domanski and others, 2022a). To compute S_0, the following equation was used:

$$S_0 = \frac{E_{us} - E_{ds}}{L_r} \tag{34}$$

where

S_0 is bed slope, in feet per feet (dimensionless);

E_{us} is upstream elevation, in feet;

E_{ds} is downstream elevation, in feet; and

L_r is length of reach, in feet.

Evaluation

Discharge and stage time series were computed with the DYNPOUND method for streamgages where cross-section geometry was created and real-time stage and discharge data were being collected. These time series were computed at 10 streamgages in California, Louisiana, Michigan, Missouri, Nebraska, New Mexico, North Dakota, Virginia, and West Virginia.

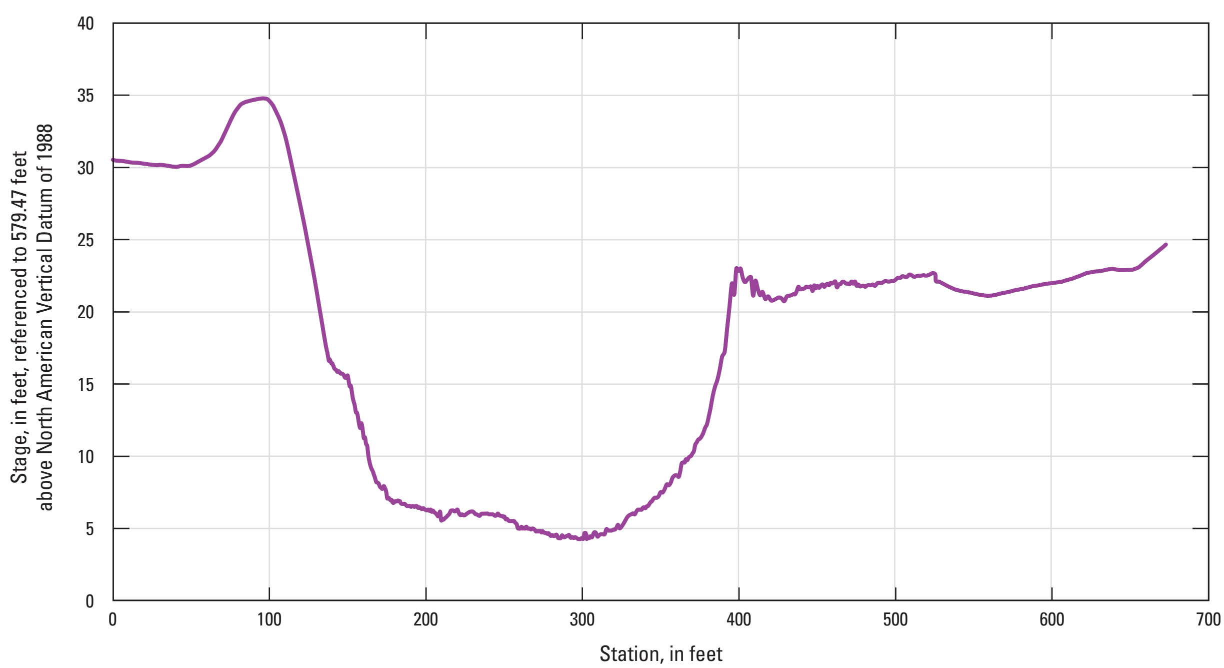


Figure 18. Graph showing combined cross section at Tittabawassee River at Midland, Michigan (U.S. Geological Survey streamgage 04156000). ft, foot.

For all sites, an event was chosen to compute the value of r (ratio of S_0 to S_W); the event was typically an isolated flood wave with a moderate peak stage and discharge. The stage at the time immediately before the onset of the flood was inserted into equation 20 as h_0. The peak stage of the flood is h_p in equation 20. The time of peak stage minus the time of occurrence of h_0 is τ in equation 20.

Subsections were added to the cross section of each site based on the need to (1) develop a smooth conveyance and stage relation, (2) add regions where transitions in roughness occur in the floodplain, (3) remove those areas of the cross section that do not contribute to the momentum of the flow (in other words, sections of the floodplain that were not inundated or sections of the channel higher in elevation than the peak stage during a high flow event), and (4) allow for computation of the non-uniform velocity distribution coefficient. To determine the smoothness of the stage-conveyance relation, conveyance was plotted against stage and visually analyzed. If an abrupt change in the slope of the relation was observed, the cross section was analyzed for sudden changes in geometry. Existing subsections that contained sudden changes in geometry were split into two subsections by inserting a split where the changes take place.

If there was a sudden change in the slope of the relation with no obvious change in channel geometry, the n-values of the cross section were modified according to the stage value at which the flow pattern shifted. The change was assumed to be because of unknown phenomena such as varying bed material or vegetation, obstruction, or channel meandering (Davidian, 1984; Arcement and Schneider, 1989).

A full water year of stage and discharge time series was used to calibrate the method at each site. A water year is defined as the 12-month period, October 1 through September 30, and is designated by the calendar year in which it ends. Typically, at least 5 field measurements were used to calibrate each of the 10 streamgages for which results are discussed. Cross sections were also subsectioned so the DYNPOUND-computed measurement would match the field measurement. The S_0, value of r, and cross-section geometry were considered fixed values for the calibration.

After the site was calibrated, a different period in the record was selected to evaluate the method. For each site, the evaluation period typically follows the calibration period and contains at least five field measurements, and a wide range of WSC-computed discharge and WSC-measured stage time-series values. Discharge field measurements were then compared to DYNPOUND-computed discharge at the same times and vice versa for stage field measurements. Sometimes, WSC-computed discharge or WSC-measured stage data were missing from the time series, in which case the missing discharge or stage values of the DYNPOUND-computed time series were estimated through linear interpolation (Domanski and others, 2022b). If the period of missing data was longer than a few hours, a different period was chosen for calibration.

Meherrin River near Bryants Corner, Virginia

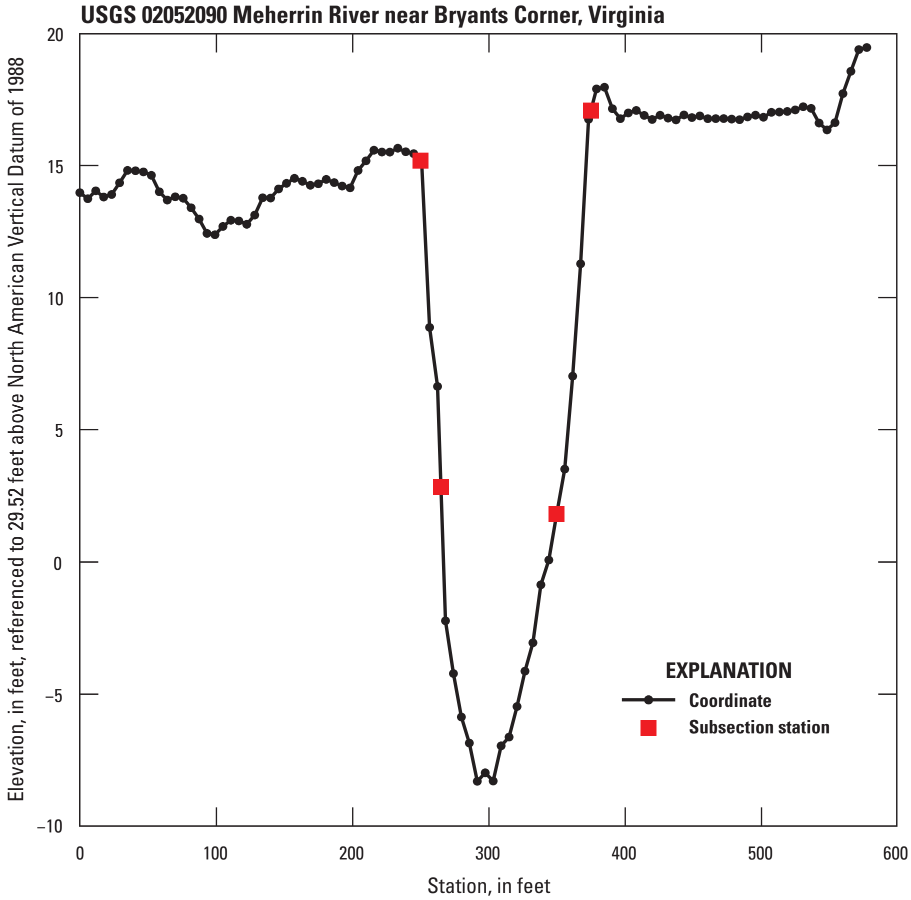
The USGS streamgage at Meherrin River near Bryants Corner, Virginia (USGS streamgage 02052090), encompasses 870 square miles (mi^2). The computed S_0 for the site is 0.00037809 (table 3). The value of r computed for the event with a peak stage of 16.82 ft at 6:15 (coordinated universal time [UTC]) on December 28, 2015 (U.S. Geological Survey, 2020), is 80.63. The cross section used to compute the time series for this streamgage is shown in figure 19. The n-values chosen for the DYNPOUND computations vary from 0.045 to 0.45 (table 4). The cross section was split into five subsections; subsection stations are 250, 265, 350, and 375 ft from left bank.

Twenty field measurements of stage and discharge from the 2017 water year were used for calibration (table 5 and table 6). The WSC-measured stage time series for the 2017 water year was used to compute discharge, and the WSC-computed discharge time series for the same water year was used to compute stage using the DYNPOUND method. (U.S. Geological Survey, 2020). The MSLE for the DYNPOUND discharge calibration was 1.30×10^{-2}, and the mean percent error was 2.36 percent (table 5). The MSLE for the DYNPOUND stage calibration was 9.97×10^{-3}, and the mean percent error was 0.37 (table 6).

To evaluate the stage-discharge relation for the USGS streamgage at Meherrin River near Bryants Corner, Virginia, time series of stage and discharge were computed for the period between May 17 and 31, 2018, which included four field measurements used for error assessment (fig. 20 and fig. 21). A comparison of field measurement discharge and DYNPOUND-computed discharge for the period indicates the DYNPOUND values were biased high when compared to the field measurements and had a mean error of 6.25 percent (fig. 20). The MSLE was 6.40×10^{-3} (table 7). The mean error for the DYNPOUND-computed stage was −0.84 percent, and the MSLE was 2.48×10^{-3} (table 8). DYNPOUND captured hysteresis in the stage-discharge relation for the computed event, whereas the USGS-computed discharge is monotonic and did not capture hysteresis (fig. 22).

Tug Fork at Kermit, West Virginia

The USGS streamgage Tug Fork at Kermit, West Virginia (USGS streamgage 03214500), encompasses 1,277 mi^2. The computed S_0 for the site is 0.000352 (table 3). The r value, computed from the event with the peak stage of 24.35 ft at 01:15 (coordinated universal time [UTC]) on April 25, 2017 (U.S. Geological Survey, 2020), is 37.19. The cross section used to compute the time series is shown in figure 23. However, it does not meet the criteria for subdivision (Dalrymple and Benson, 1967; Davidian, 1984). The n-values were chosen for the full cross section based on a plot of n-values, calculated with Manning's equation and field



USGS, U.S. Geological Survey.

Figure 19. Graph showing the cross section used to compute the stage and discharge time series at Meherrin River near Bryants Corner, Virginia (U.S. Geological Survey streamgage 02052090; U.S. Geological Survey, 2020).

Table 4. Stage and roughness coefficient values used to calibrate the DYNPOUND method at Meherrin River near Bryants Corner, Virginia (U.S. Geological Survey streamgage 02052090).

[Data from Domanski and others, 2025. ft, foot]

Stage (ft)	Roughness coefficient (*n*-value)
3.00	0.45
4.00	0.3
7.00	0.2
11.00	0.18
17.00	0.045

Table 5. Discharge calibration results for the DYNPOUND ratings at Meherrin River near Bryants Corner, Virginia (U.S. Geological Survey streamgage 02052090).

[Field measurement discharge data from U.S. Geological Survey, 2020. DYNPOUND is the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft³/s, cubic foot per second; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM discharge (ft³/s)	DYNPOUND discharge (ft³/s)	DYNPOUND discharge error (percent)	DYNPOUND discharge SLE
10/13/2016	17:43	6,550	6,946	6.06	0.00345
11/15/2016	15:08	183	198	8.61	0.00621
11/15/2016	15:42	171	198	16.2	0.02149
01/10/2017	15:12	360	374	4.12	0.00146
02/24/2017	15:20	291	299	2.93	0.00074
04/25/2017	15:18	1,130	989	−12.40	0.01776
04/25/2017	16:30	1,130	1,003	−11.20	0.01421
04/26/2017	13:59	1,970	1,750	−11.10	0.01402
04/26/2017	15:51	1,990	1,799	−9.56	0.01018
04/28/2017	13:16	2,650	2,949	11.30	0.01143
04/29/2017	14:51	2,850	3,485	22.30	0.04046
04/29/2017	16:05	2,790	3,438	23.20	0.04362
05/01/2017	14:32	898	1,035	15.30	0.02016
05/01/2017	15:13	895	992	10.90	0.01059
05/02/2017	13:45	562	603	7.43	0.00496
05/02/2017	14:42	600	575	−4.07	0.00181
05/03/2017	13:49	513	453	−11.60	0.01547
05/03/2017	15:02	510	450	−11.70	0.01567
07/12/2017	15:27	185	180	−2.36	0.00075
09/07/2017	15:09	228	211	−7.10	0.00600
Mean	NA	NA	NA	**2.36**	**1.30×10^{-2}**

measurements, versus stage (table 9). To review software functionality and documentation regarding these plots, refer to the software release by Knight and others (2024).

Six field measurements of stage and discharge from the 2016 water year were used to calibrate the method at this site. (table 10 and table 11). The WSC-measured stage time series for the 2016 water year was used to compute discharge, and the WSC-computed discharge time series for the same water year was used to compute stage using the DYNPOUND method (U.S. Geological Survey, 2020). The MSLE for the DYNPOUND discharge calibration was 7.84×10^{-3}, and the mean percent error was −6.69 percent (table 10). The MSLE for the DYNPOUND stage calibration was 3.17×10^{-2}, and the mean percent error was 3.27 percent (table 11).

To evaluate the stage-discharge relation for the USGS streamgage Tug Fork at Kermit, West Virginia, time series of stage and discharge were computed for the period between February 5 and March 1, 2018, which included five field measurements used for error assessment (fig. 24 and fig. 25). The DYNPOUND-computed discharge values had a mean percent error of 3.47 percent, and the MSLE was 1.38×10^{-2} (table 12). The mean percent error for the DYNPOUND-computed stage was −4.71 percent, and the MSLE was 1.05×10^{-2} (table 13). DYNPOUND captured hysteresis in the stage-discharge relation for the computed event, whereas the USGS-computed discharge is monotonic (fig. 26). The DYNPOUND computation has some inaccuracy because two of the field measurements are outside the loop: one was collected during the rising limb, and one was collected during the falling limb (fig. 26). Natural conditions, such as varying vegetation, debris, obstructions, or meandering of the channel, may be the cause of this inaccuracy, but are unknown to the authors. Tug Fork forms a section of the boundary between Kentucky and West Virginia, a mountainous region where torrential flows are common (McClellan, 2018), therefore requiring further calibration by those familiar with its hydrologic characteristics.

Table 6. Stage calibration results for the DYNPOUND ratings at Meherrin River near Bryants Corner, Virginia (U.S. Geological Survey streamgage 02052090).

[Field measurement stage data from U.S. Geological Survey, 2020. DYNPOUND is the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft, foot; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM stage (ft)	DYNPOUND stage (ft)	DYNPOUND stage error (percent)	DYNPOUND stage SLE
10/13/2016	17:43	16.26	16	−0.76	0.00026
11/15/2016	15:08	3.40	3	−2.58	0.01567
11/15/2016	15:42	3.40	3	−2.54	0.01567
01/10/2017	15:12	4.88	4	−0.62	0.03954
02/24/2017	15:20	4.09	4	−1.93	0.00050
04/25/2017	15:18	8.62	9	7.42	0.00186
04/25/2017	16:30	8.79	9	8.23	0.00056
04/26/2017	13:59	12.05	12	3.37	0.00002
04/26/2017	15:51	12.17	12	2.82	0.00020
04/28/2017	13:16	14.00	13	−3.85	0.00549
04/29/2017	14:51	14.53	13	−5.47	0.01238
04/29/2017	16:05	14.47	13	−5.51	0.01148
05/01/2017	14:32	9.29	8	−4.81	0.02235
05/01/2017	15:13	9.20	8	−5.22	0.01953
05/02/2017	13:45	6.44	6	−1.02	0.00501
05/02/2017	14:42	6.36	6	−0.88	0.00340
05/03/2017	13:49	5.48	5	5.86	0.00840
05/03/2017	15:02	5.45	5	6.09	0.00743
07/12/2017	15:27	3.24	3	3.56	0.00592
09/07/2017	15:09	3.50	3	5.23	0.02376
Mean	NA	NA	NA	**0.37**	**$9.97{\times}10^{-3}$**

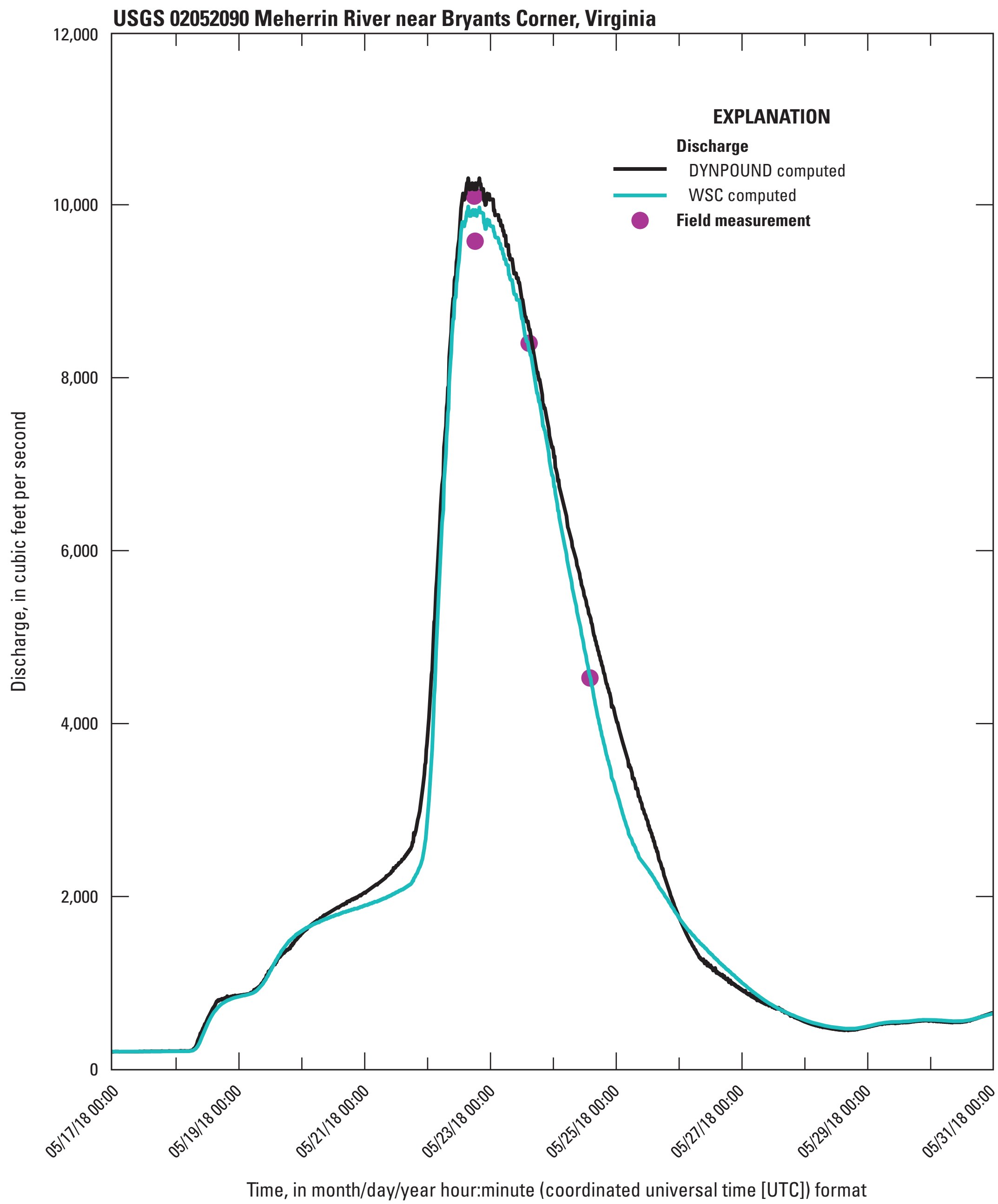
Tittabawassee River at Midland, Michigan

The USGS streamgage Tittabawassee River at Midland, Michigan (USGS streamgage 04156000) encompasses 2,400 mi^2. The computed S_0 for the site is 0.000139 (table 3). The value of r was computed as 18.08 by using the event with a peak stage of 22.16 ft at 12:30 UTC on April 11, 2015 (U.S. Geological Survey, 2020). The cross section used to compute the time series is shown in figure 27. Subsection stations are at 90 and 401 ft. The leftmost subsection of the cross section becomes inundated at stages above 35 ft. Based on the channel geometry and corresponding stage, an n-value of 0.0285 was chosen. An n-value of 0.0315 was used when stages rose above 22 ft on the flood-plain area of the right bank (fig. 27 and table 14). The middle subsection, which contains the same geometry as the main channel and assigned an n-value of 0.033, is always used when computing hydraulic properties (fig. 27 and table 14).

Nine field measurements of stage and discharge collected during the 2017 water year were used for calibration (table 15 and table 16). The WSC-measured stage time series from the 2017 water year was used to compute discharge, and the WSC-computed discharge time series for the same water year was used to compute stage using the DYNPOUND method (U.S. Geological Survey, 2020). The calibration results for the DYNPOUND discharge computation indicate the MSLE was $2.88{\times}10^{-2}$, and the mean percent error was 1.93 percent (table 15). The MSLE for the DYNPOUND stage calibration was 0.24, and the mean error was $4.22{\times}10^{-3}$ percent (table 16).

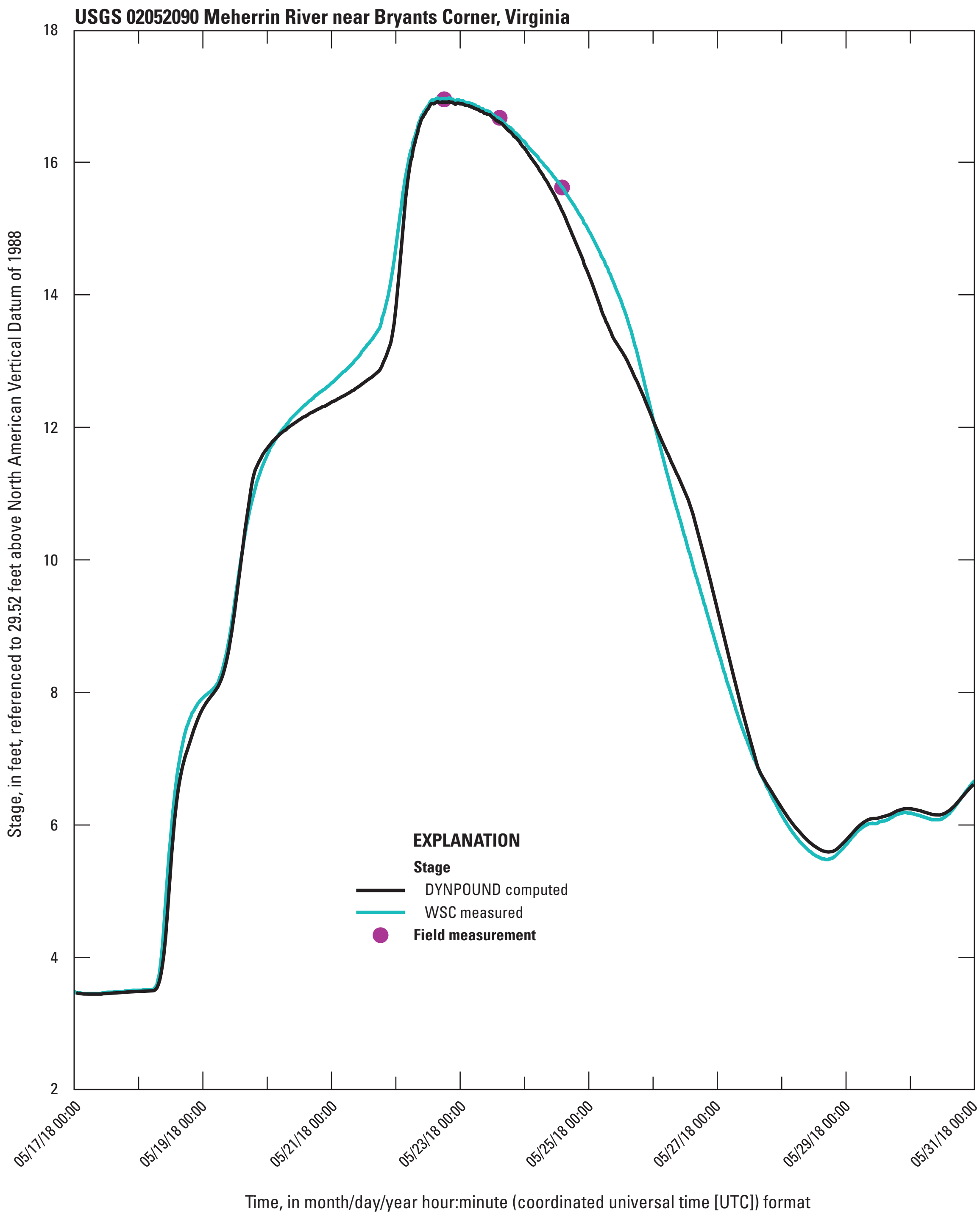
Field measurements of stage and discharge, DYNPOUND-computed stage and discharge time series, and WSC-computed stage and discharge time series were evaluated for the period between May 1 and June 30, 2020 (fig. 28 and fig. 29). The peak of the period is an extreme event for the site due to a dam break upstream. The stage hydrograph reached 35.13 ft (fig. 29), which was above the stage values defined by the cross-section geometry on the right overbank (fig. 27).

The DYNPOUND-computed stage and discharge values were compared to three field measurements (table 17 and table 18). The DYNPOUND discharge time series had a mean percent error of −0.57 percent and a MSLE of $1.71{\times}10^{-3}$



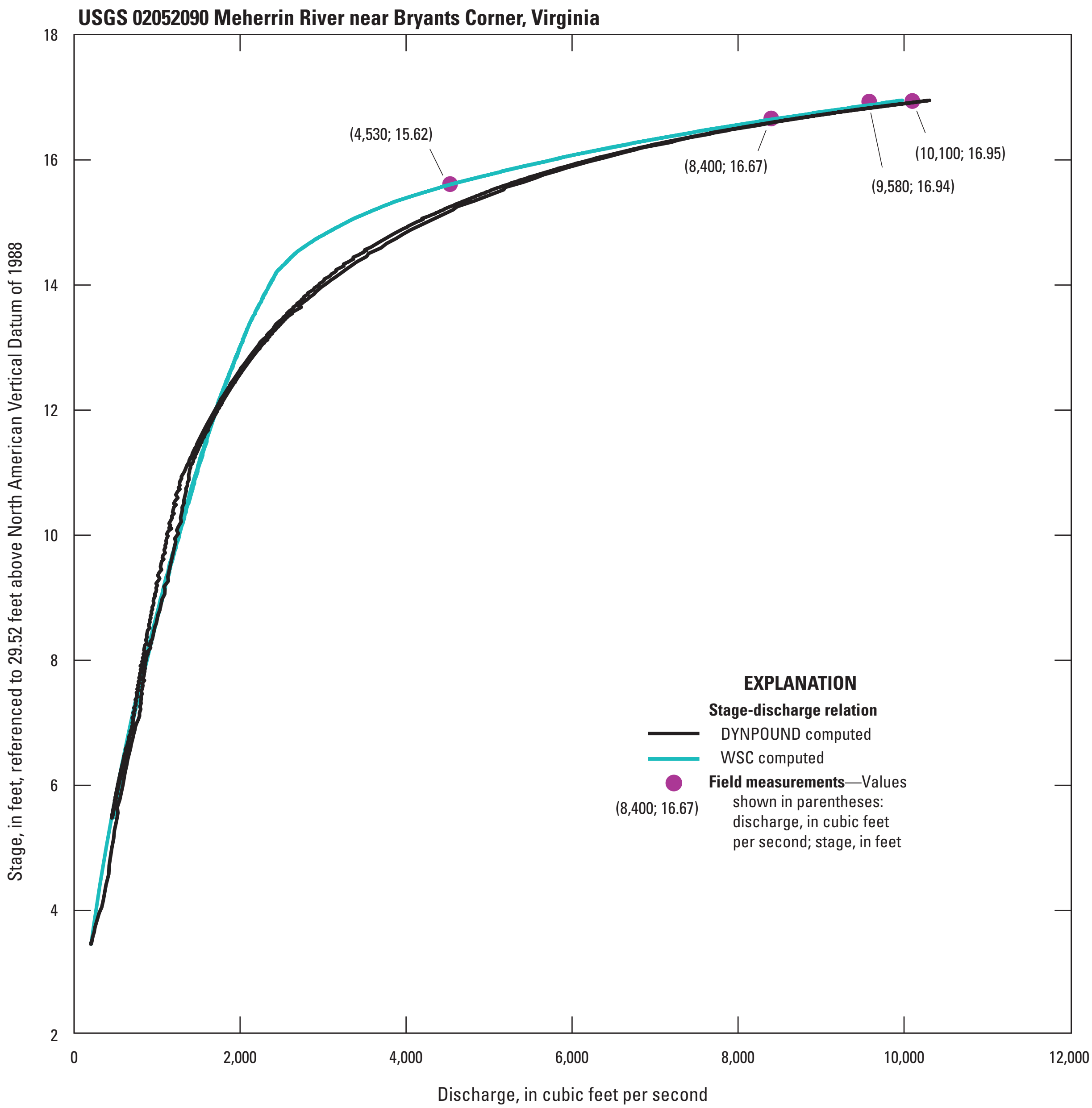
USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 20. Graph showing the discharge time series computed with the DYNPOUND method shown with the time series of WSC-computed discharge and field measurements made at Meherrin River near Bryants Corner, Virginia (U.S. Geological Survey streamgage 02052090; U.S. Geological Survey, 2020).



USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 21. Graph showing the stage time series computed with the DYNPOUND method shown with the time series of WSC-measured stage and field measurements made at Meherrin River near Bryants Corner, Virginia (U.S. Geological Survey streamgage 02052090; U.S. Geological Survey, 2020).



USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 22. Graph showing the stage-discharge relation at Meherrin River near Bryants Corner, Virginia (U.S. Geological Survey streamgage 02052090; U.S. Geological Survey, 2020), using discharge computed with the DYNPOUND method, WSC-computed discharge, and field measurements.

(table 17). The DYNPOUND stage time series had a mean percent error of 0.40 percent and a MSLE of 6.19×10^{-4} (table 18). The DYNPOUND method captured hysteresis in the stage-discharge relation, whereas the USGS-computed method was not capable of representing hysteresis (fig. 30). The stage-discharge relation computed with DYNPOUND shows fluctuating discharges near the peak stage of the time series, which may be because of the poor definition of the cross-section geometry under the extreme flow conditions. Discharge might be better computed for this site by including a more precise definition of the channel geometry at high stages.

Table 7. Discharge computed for an event-based time series at Meherrin River near Bryants Corner, Virginia (U.S. Geological Survey streamgage 02052090), with the DYNPOUND methods and the associated error.

[Field measurement discharge data from U.S. Geological Survey, 2020. DYNPOUND is the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft^3/s, cubic foot per second; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM discharge (ft^3/s)	DYNPOUND discharge (ft^3/s)	DYNPOUND discharge error (percent)	DYNPOUND discharge SLE
05/22/2018	17:51	10,100	10,179	0.78	0.00006
05/22/2018	18:06	9,580	10,212	6.60	0.00408
05/23/2018	14:39	8,400	8,567	2.00	0.00039
05/24/2018	13:59	4,530	5,238	15.60	0.02109
Mean	NA	NA	NA	**6.25**	**6.40×10^{-3}**

Table 8. Stage computed for an event-based time series at Meherrin River near Bryants Corner, Virginia (U.S. Geological Survey streamgage 02052090), with the DYNPOUND methods and the associated error.

[Field measurement stage data from U.S. Geological Survey, 2020. DYNPOUND is the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft, foot; SLE, squared logarithmic error; NA, not applicable]

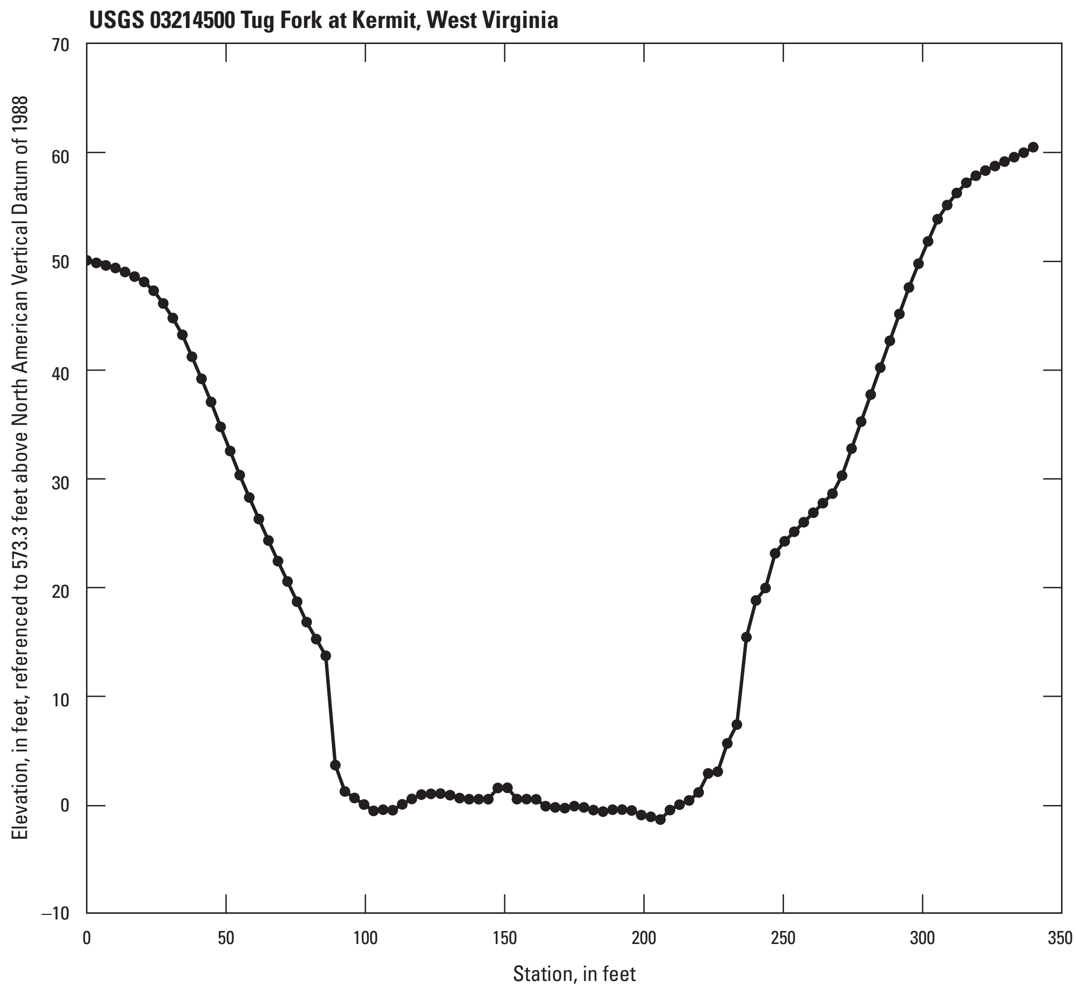
Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM stage (ft)	DYNPOUND stage (ft)	DYNPOUND stage error (percent)	DYNPOUND stage SLE
05/22/2018	17:51	16.95	16	−0.353	0.00333
05/22/2018	18:06	16.94	16	−0.273	0.00326
05/23/2018	14:39	16.67	16	−0.474	0.00168
05/24/2018	13:59	15.62	15	−2.27	0.00164
Mean	NA	NA	NA	**−0.84**	**2.48×10^{-3}**

Red River of the North at Fargo, North Dakota

The USGS streamgage Red River of the North at Fargo, North Dakota (U.S. Geological Survey streamgage 05054000) encompasses 6,800 mi^2. The Red River of the North flows north through South Dakota, North Dakota, and Minnesota before entering Canada. Discharge at this site is affected by climactic variability and human alteration of the surrounding landscape, such as dam construction and agriculture (Nustad and Vecchia, 2020). The computed S_0 for the site is 0.000145 (table 3). The *r* value, computed from the event with a peak stage of 27.85 ft at 23:30 UTC on June 23, 2014 (U.S. Geological Survey, 2020), is 27.4. The cross section used to compute the time series was split into four subsections for the DYNPOUND computation (fig. 31). Subsection stations are 625, 875, and 1,060 ft. The *n*-values used to calibrate the DYNPOUND computations vary from 0.067 to 0.224 (table 19).

Twelve field measurements of stage and discharge collected during the 2019 water year were used for calibration (table 20 and table 21). The WSC-measured stage time series from the 2019 water year was used to compute discharge, and the WSC-computed discharge time series for the same water year was used to compute stage using the DYNPOUND method (U.S. Geological Survey, 2020). The MSLE for the DYNPOUND discharge calibration was 9.62×10^{-3}, and the mean percent error was 3.48 percent (table 20). The MSLE for the DYNPOUND stage calibration was 1.30×10^{-3}, and the mean percent error was 1.53 percent (table 21).

A discharge time series was computed with DYNPOUND for the period between March 16 and May 5, 2020, and was used to evaluate the generated rating in comparison to six field measurements collected during this period (fig. 32). The stage-discharge relation for the computed event is shown in figure 33. DYNPOUND shows that there is hysteresis with significant oscillation at stages of 19 ft and above. The channel begins to widen considerably at 19 ft, which may account for some of the oscillation. Other possible causes of the oscillation may be attributed to the hydroclimatic variability of the site, such as rising groundwater, surface-water runoff, increased soil moisture, and surface-water storage of the surrounding basin (Nustad and Vecchia, 2020). The WSC-computed discharge failed to capture hysteresis. The mean percent error of the DYNPOUND computed discharge was 0.21 percent and the MSLE was 6.37×10^{-3} (table 22). The DYNPOUND method was unable to compute stage for this event, which may relate to errors in the channel geometry.



USGS, U.S. Geological Survey.

Figure 23. Graph showing the cross section used to compute the stage and discharge time series at Tug Fork at Kermit, West Virginia (U.S. Geological Survey streamgage 03214500; U.S. Geological Survey, 2020).

Table 9. Stage and roughness coefficient values used to calibrate the DYNPOUND method at Tug Fork at Kermit, West Virginia (U.S. Geological Survey streamgage 03214500).

[Data from Domanski and others, 2025; ft, foot]

Stage (ft)	Roughness coefficient (*n*-value)
0.00	0.041
30.00	0.045
35.00	0.047
40.00	0.050

Table 10. Calibration results for the DYNPOUND discharge ratings at Tug Fork at Kermit, West Virginia (U.S. Geological Survey streamgage 03214500).

[Field measurement discharge data from U.S. Geological Survey, 2020. DYNPOUND is the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft^3/s, cubic foot per second; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM discharge (ft^3/s)	DYNPOUND discharge (ft^3/s)	DYNPOUND discharge error (percent)	DYNPOUND discharge SLE
11/03/2015	19:48	344	358	4.14	0.00159
01/13/2016	19:22	641	587	−8.41	0.00774
03/22/2016	17:48	1,090	965	−11.4	0.01484
05/12/2016	19:11	7,540	7,016	−6.94	0.00519
07/21/2016	18:53	805	746	−7.21	0.00579
09/19/2016	17:40	688	617	−10.30	0.01186
Mean	NA	NA	NA	**−6.69**	**7.84×10^{-3}**

Table 11. Calibration results for the DYNPOUND stage ratings at Tug Fork at Kermit, West Virginia (U.S. Geological Survey streamgage 03214500).

[Field measurement stage data from U.S. Geological Survey, 2020. DYNPOUND is the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft, foot; SLE, squared logarithmic error; NA, not applicable]

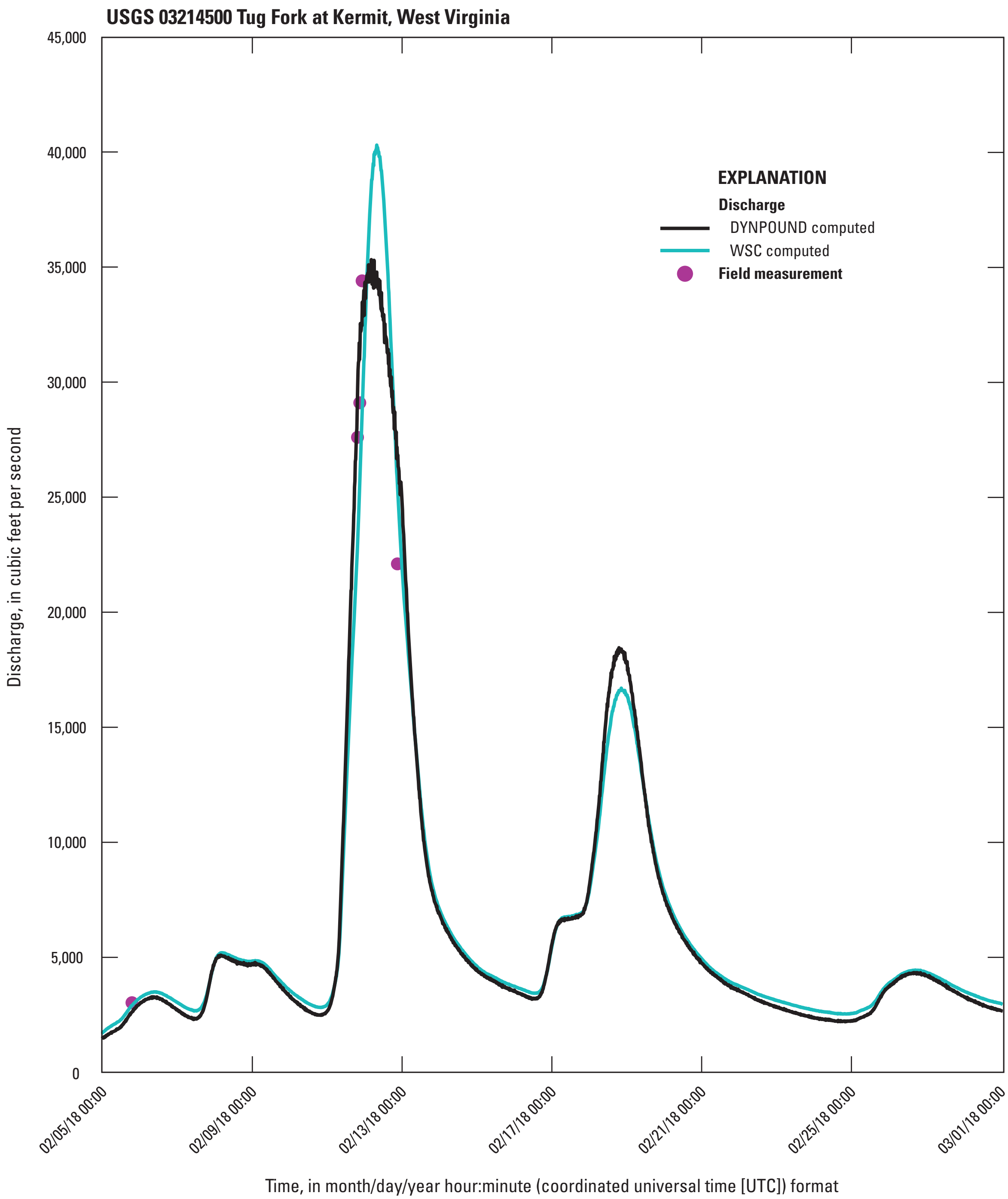
Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM stage (ft)	DYNPOUND stage (ft)	DYNPOUND stage error (percent)	DYNPOUND stage SLE
11/03/2015	19:48	2.74	2	−3.20	0.09911
01/13/2016	19:22	3.66	3	3.62	0.03954
03/22/2016	17:48	4.79	5	7.79	0.00184
05/12/2016	19:11	15.11	15	2.14	0.00005
07/21/2016	18:53	4.18	4	5.57	0.00194
09/19/2016	17:40	3.73	3	3.72	0.04744
Mean	NA	NA	NA	**3.27**	**3.17×10^{-2}**

Papillion Creek at Fort Crook, Nebraska

The USGS streamgage Papillion Creek at Fort Crook, Nebraska (USGS streamgage 06610795) encompasses 946 mi^2. The computed S_0 for the site is 0.00025438 (table 3). The value of r, computed from the event with a peak stage of 21.76 ft at 5:15 (coordinated universal time [UTC]) on June 17, 2017 (U.S. Geological Survey, 2020), is 2.7. The cross section used to compute the time series was split into four subsections for the DYNPOUND computation, with subsection stations at 105, 245, and 325 ft (fig. 34). Manning's n-values selected to calibrate the DYNPOUND computations varied from 0.022 to 0.015 (table 23).

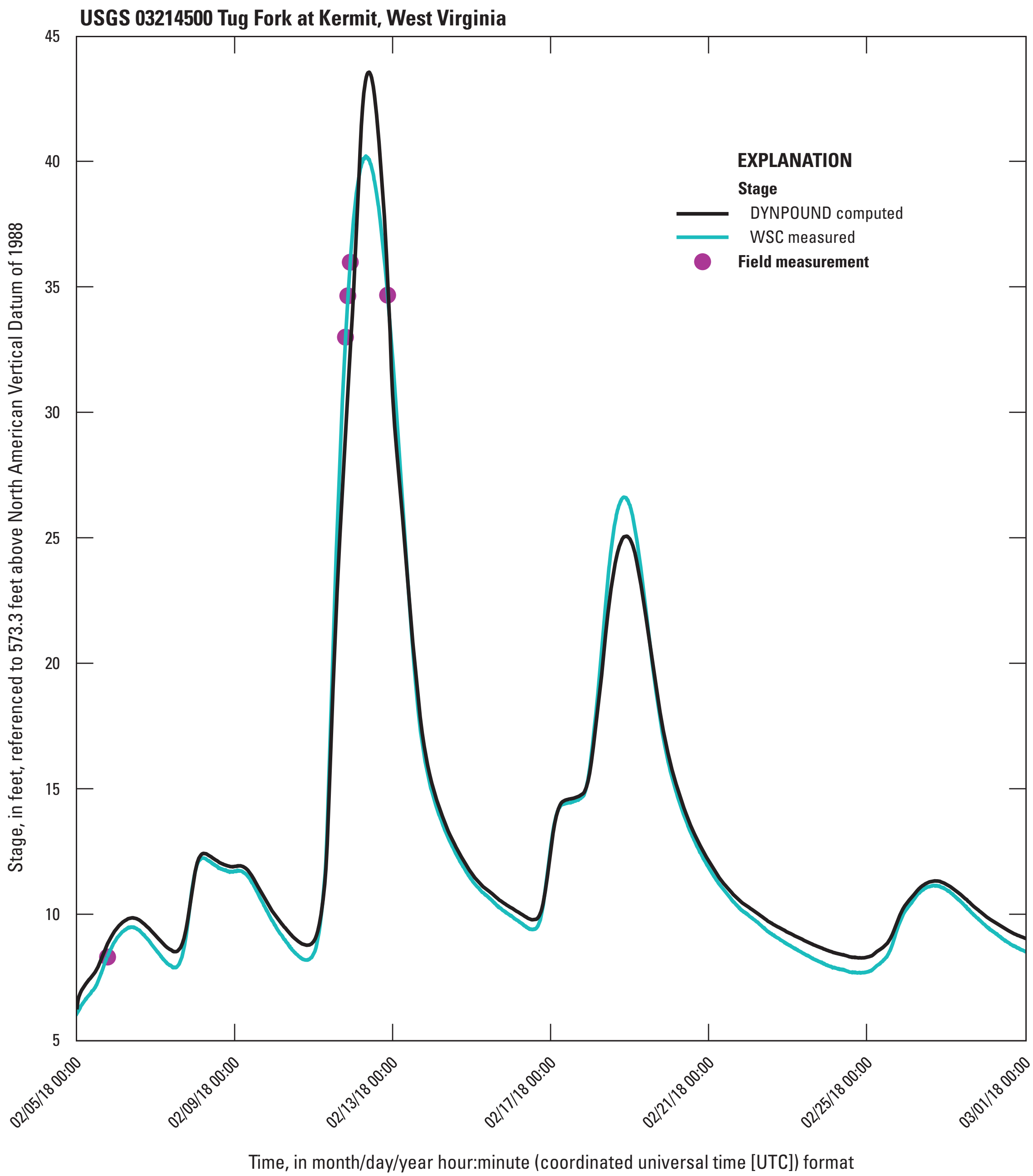
Eight field measurements of stage and discharge from the 2016 water year were used for calibration (table 24 and table 25). The WSC-measured stage time series for the 2016 water year was used to compute discharge, and the WSC-computed discharge time series for the same water year was used to compute stage using the DYNPOUND method. (U.S. Geological Survey, 2020). The MSLE for the DYNPOUND discharge calibration was 3.04×10^{-2}, and the mean percent error was 13.40 percent (table 24). The MSLE for the DYNPOUND stage calibration was 6.62×10^{-3}, and the mean percent error was −1.90 percent (table 25).

To evaluate the stage-discharge relation for the USGS streamgage Papillion Creek at Fort Crook, Nebraska, time series of stage and discharge were computed for the period between August 22 and 24, 2014, which included three field measurements used for error assessment (fig. 35 and fig. 36). DYNPOUND captured hysteresis for two peaks in the stage-discharge relation for the computed event (fig. 37). A comparison between the WSC-computed and DYNPOUND-computed discharge for the period resulted in a mean percent error of 14.26 percent and a MSLE of 2.30×10^{-2} (table 26). Results of the comparison between WSC-measured and DYNPOUND-computed stage for this event showed a mean percent error of −3.01 percent and a MSLE of 6.72×10^{-3} (table 27).



USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 24. Graph showing the discharge time series computed with the DYNPOUND method shown with the time series of WSC-computed discharge and field measurements made at Tug Fork at Kermit, West Virginia (U.S. Geological Survey streamgage 03214500; U.S. Geological Survey, 2020).

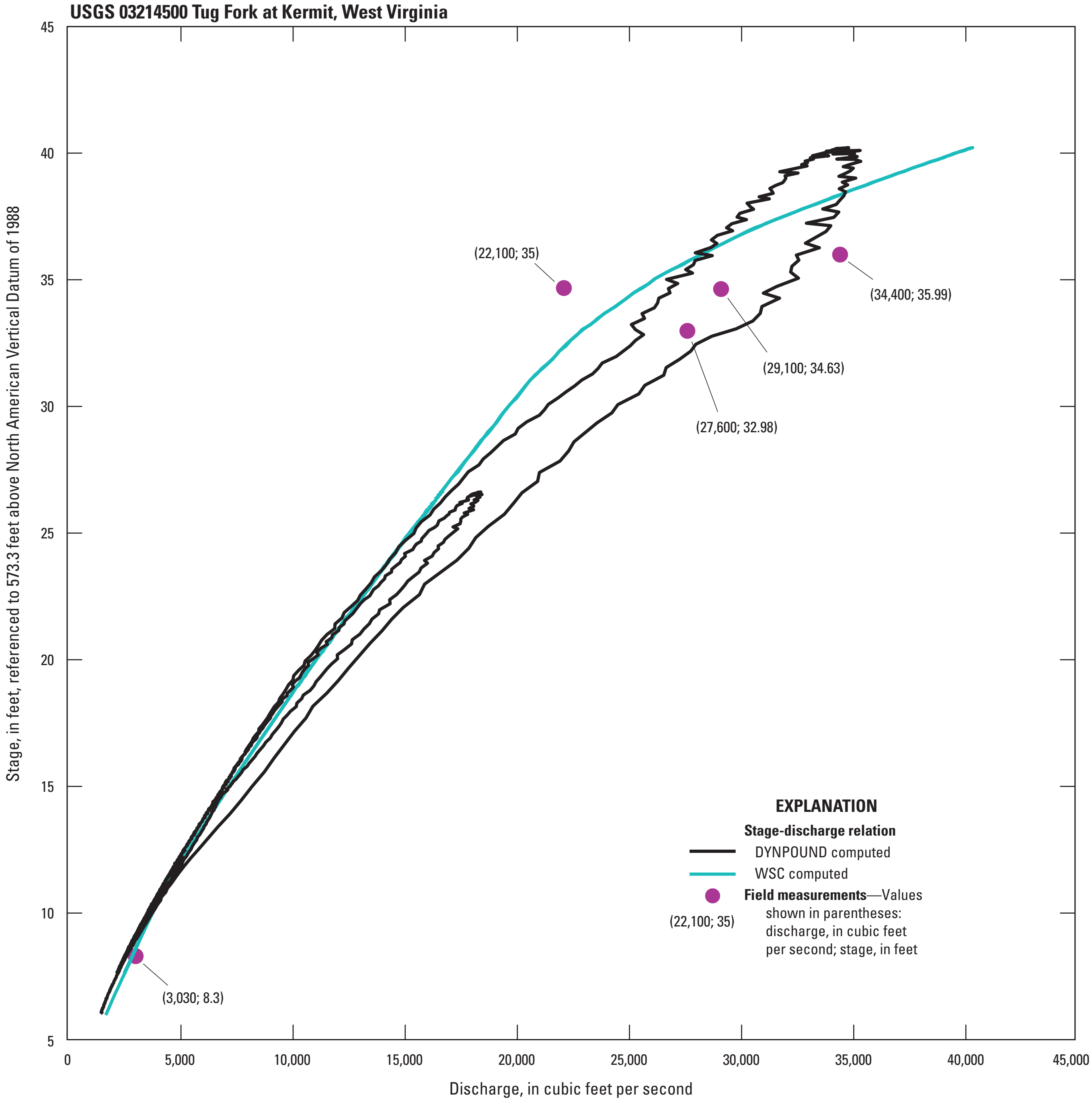


USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 25. Graph showing the stage time series computed with the DYNPOUND method shown with the time series of WSC-measured stage and field measurements made at Tug Fork at Kermit, West Virginia (U.S. Geological Survey streamgage 03214500; U.S. Geological Survey, 2020).

Gasconade River at Jerome, Missouri

The USGS streamgage at Gasconade River at Jerome, Missouri (USGS streamgage 06933500) encompasses 2,840 mi². The computed S_0 for the site is 0.00040953 (table 3). The value of *r*, computed from the event with a peak stage of 20 ft at 9:00 (coordinated universal time [UTC]) on February 26, 2018 (U.S. Geological Survey, 2020), is 30.02. The cross section used to compute the time series was split into four subsections for the DYNPOUND computation, with subsection stations at 525, 725, and 1,275 ft (fig. 38). The *n*-values used to calibrate the DYNPOUND computations varied from 0.026 to 0.19 (table 28).



USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 26. Graph showing the stage-discharge relation at Tug Fork at Kermit, West Virginia (U.S. Geological Survey streamgage 03214500; U.S. Geological Survey, 2020), using discharge computed with the DYNPOUND method, WSC-computed discharge, and field measurements.

Table 12. Discharge computed for an event-based time series at Tug Fork at Kermit, West Virginia (U.S. Geological Survey streamgage 03214500), with the DYNPOUND methods and the associated error.

[Field measurement discharge data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft^3/s, cubic foot per second; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM discharge (ft^3/s)	DYNPOUND discharge (ft^3/s)	DYNPOUND discharge error (percent)	DYNPOUND discharge SLE
02/05/2018	18:51	3,030	2,623	−13.40	0.02081
02/11/2018	19:24	27,600	29,389	6.49	0.00394
02/11/2018	20:52	29,100	31,268	7.45	0.00516
02/11/2018	22:21	34,400	32,896	−4.37	0.00200
02/12/2018	20:59	22,100	26,781	21.20	0.03691
Mean	NA	NA	NA	**3.47**	**$1.38×10^{-2}$**

Table 13. Stage computed for an event-based time at the streamgage at Tug Fork at Kermit, West Virginia (U.S. Geological Survey streamgage 03214500), with the DYNPOUND methods and the associated error.

[Field measurement stage data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft, foot; SLE, squared logarithmic error; NA, not applicable]

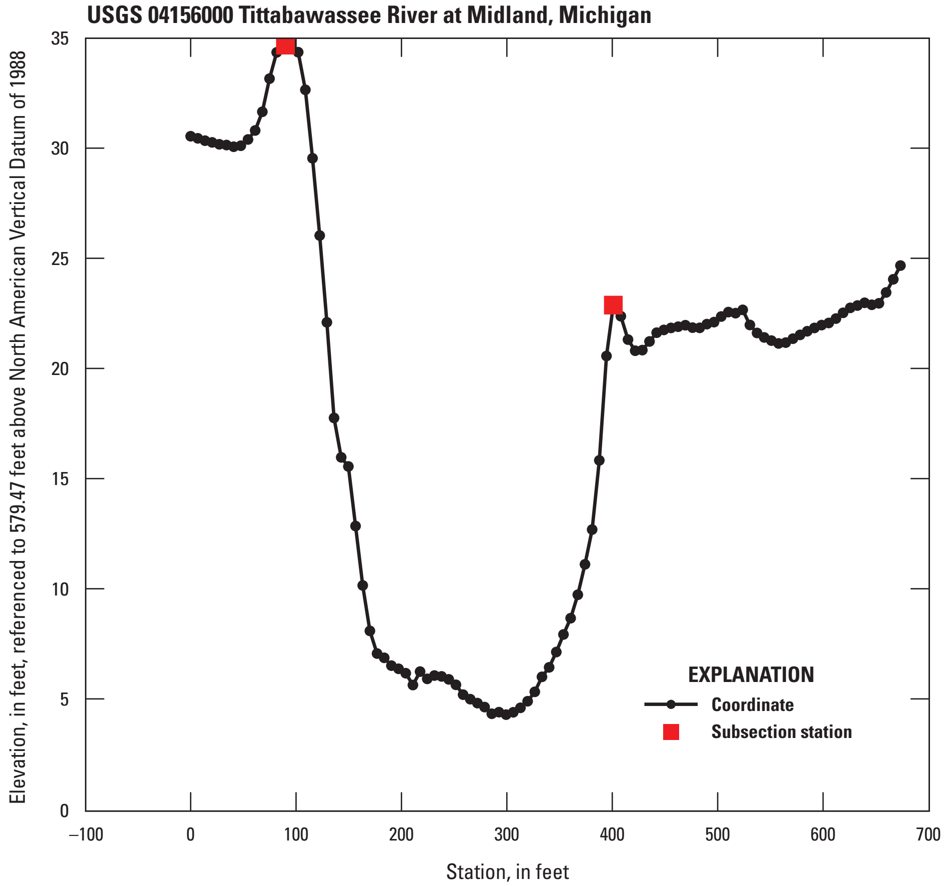
Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM stage (ft)	DYNPOUND stage (ft)	DYNPOUND stage error (percent)	DYNPOUND stage SLE
02/05/2018	18:51	8.30	8.00	6.51	0.00136
02/11/2018	19:24	32.98	29.00	−11.70	0.01654
02/11/2018	20:52	34.63	30.00	−10.90	0.02060
02/11/2018	22:21	35.99	32.00	−9.27	0.01381
02/12/2018	20:59	34.67	35.00	1.79	0.00009
Mean	NA	NA	NA	**−4.71**	**$1.05×10^{-2}$**

Seven stage and discharge field measurements from the 2016 water year were used for calibration (table 29 and table 30). The WSC-measured stage time series for the 2016 water year was used to compute discharge, and the WSC-computed discharge time series for the same water year was used to compute stage using the DYNPOUND method (U.S. Geological Survey, 2020). The MSLE for the DYNPOUND discharge calibration was $1.36×10^{-1}$, and the mean percent error was 33.79 percent (table 29). The MSLE for the DYNPOUND stage calibration was $9.12×10^{-2}$, and the mean percent error was −44.26 percent (table 30).

To evaluate the stage-discharge relation for the USGS streamgage Gasconade River at Jerome, Missouri, time series of stage and discharge were computed for the period between March 15 and June 23, 2017, which included four field measurements used for error assessment (fig. 39 and fig. 40). DYNPOUND captured minor hysteresis in the stage-discharge relation for the computed event, whereas the USGS-computed discharge is monotonic (fig. 41). A comparison between the observed and computed discharge for the period resulted in a mean percent error of 4.73 percent for DYNPOUND. The MSLE was $9.43×10^{-3}$ (table 31). Results of the stage computation in comparison to field measurements for this event showed a mean percent error of −2.30 percent and a MSLE of $1.23×10^{-2}$ (table 32).

Mississippi River at St. Louis, Missouri

The USGS streamgage on the Mississippi River at St. Louis, Missouri (USGS streamgage 07010000), encompasses 697,000 mi^2. The S_0 for the site is 0.000110 (table 3). A value of 13.5 for *r* was computed using the event with a peak stage of 24.8 ft at 14:00 (UTC) on March 13, 2013 (U.S. Geological Survey, 2020). The cross section used to compute the discharge time series is shown in figure 42. No subdivision of the cross section for this site was made to compute stage and discharge with the DYNPOUND method. The *n*-values chosen to calibrate the DYNPOUND computations varied from 0.029 to 0.058 (table 33).



USGS, U.S. Geological Survey.

Figure 27. Graph showing the cross section used to compute the stage and discharge time series for the Tittabawassee River at Midland, Michigan (U.S. Geological Survey streamgage 04156000; U.S. Geological Survey, 2020).

Table 14. Stage and roughness coefficient values used to calibrate the DYNPOUND method at Tittabawassee River at Midland, Michigan (U.S. Geological Survey streamgage 04156000).

[Data from Domanski and others, 2025. ft, foot]

Stage (ft)	Roughness coefficient (*n*-value)
4.00	0.033
22.00	0.0315
35.00	0.0285

Eleven field measurements of stage and discharge collected during the 2014 water year were used to calibrate the dynamic ratings for the Mississippi River at St. Louis, Missouri, streamgage (table 34 and table 35). The WSC-measured stage time series from the 2014 water year was used to compute discharge, and the WSC-computed discharge time series for the same water year was used to compute stage using the DYNPOUND method (U.S. Geological Survey, 2020). For the DYNPOUND discharge calibration, the MSLE was 2.30×10^{-3}, and the mean percent

Table 15. Discharge calibration results for the DYNPOUND ratings at Tittabawassee River at Midland, Michigan (U.S. Geological Survey streamgage 04156000).

[Field measurement discharge data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft^3/s, cubic foot per second; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM discharge (ft^3/s)	DYNPOUND discharge (ft^3/s)	DYNPOUND error (percent)	DYNPOUND SLE
10/12/2016	15:22	905	1,183	30.8	0.07176
12/01/2016	18:14	2,960	2,487	−16	0.03032
01/27/2017	19:03	6,020	4,929	−18.1	0.03998
03/16/2017	17:15	2,290	1,979	−13.5	0.02130
05/10/2017	15:51	2,040	1,911	−6.3	0.00427
06/24/2017	15:12	37,700	38,191	1.3	0.00017
06/24/2017	16:58	38,800	38,186	−1.58	0.00025
06/26/2017	15:31	19,100	20,287	6.22	0.00364
08/25/2017	11:40	765	1,028	34.5	0.08732
Mean	NA	NA	NA	**1.93**	**2.88×10^{-2}**

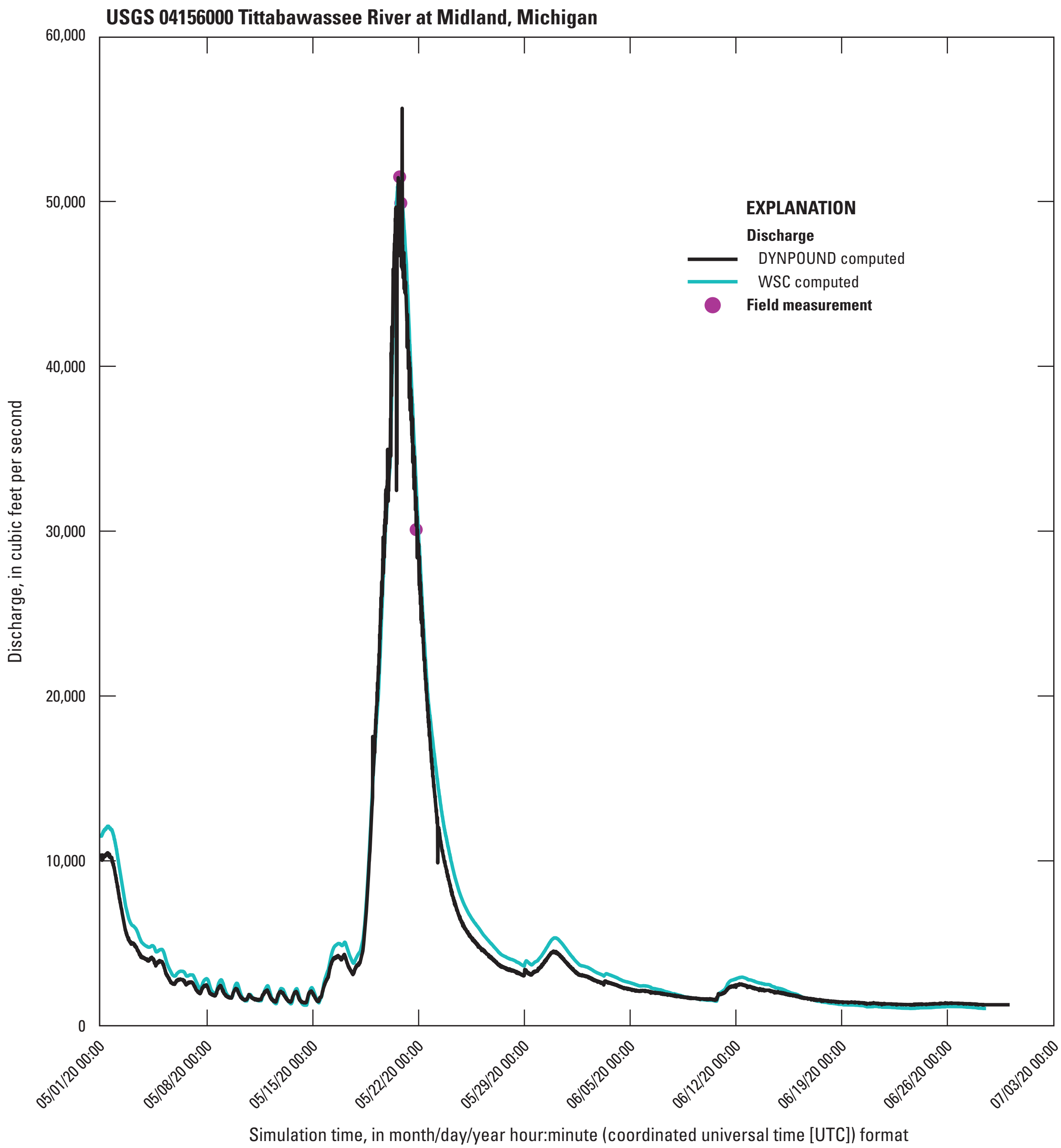
Table 16. Stage calibration results for the DYNPOUND ratings at Tittabawassee River at Midland, Michigan (U.S. Geological Survey streamgage 04156000).

[Field measurement discharge data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft, feet; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM stage (ft)	DYNPOUND stage (ft)	DYNPOUND error (percent)	DYNPOUND SLE
10/12/2016	15:22	10.26	9.00	−7.46	0.01717
12/01/2016	18:14	12.65	13.00	6.08	0.00074
01/27/2017	19:03	15.99	17.00	7.35	0.00375
03/16/2017	17:15	11.66	11.00	−0.727	0.00340
05/10/2017	15:51	11.60	11.00	1.39	0.00282
06/24/2017	15:12	31.83	31.00	−1.03	0.00070
06/24/2017	16:58	31.96	31.00	−0.337	0.00093
06/26/2017	15:31	26.35	26.00	1.93	0.00018
08/25/2017	11:40	9.86	9.00	−5.08	0.00833
Mean	NA	NA	NA	**0.24**	**4.22×10^{-3}**

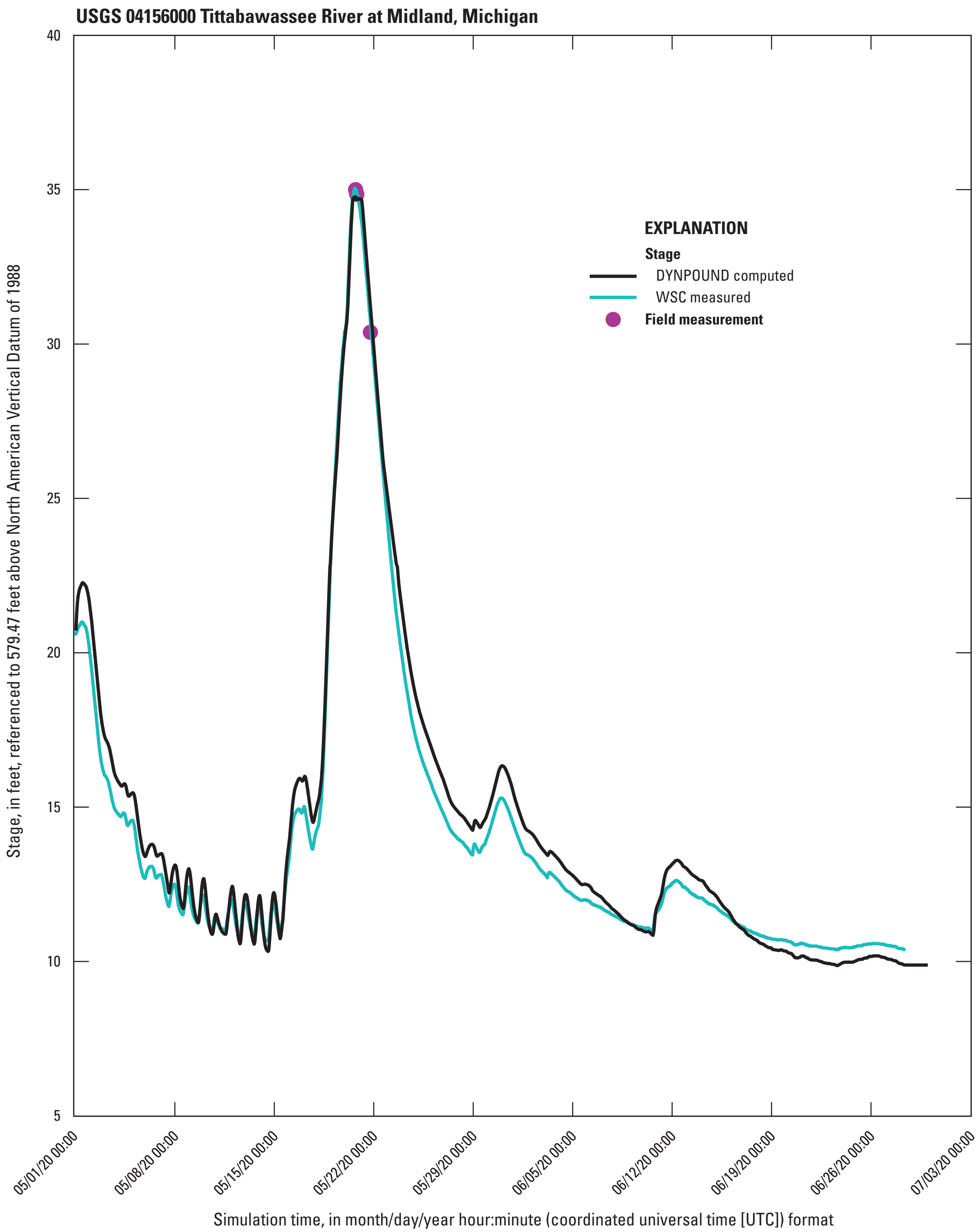
error was −2.75 percent (table 34). The DYNPOUND stage calibration resulted in a MSLE of 1.17×10^{-1} and a mean percent error of 20.64 percent (table 35).

To evaluate the dynamic rating methods for this site, stage and discharge for the period between June 1 and August 15, 2015, were computed and compared to the 68 field stage and discharge measurements made at this site (fig. 43 and fig. 44). The mean percent error for the DYNPOUND-computed discharge was 0.37 percent, and the MSLE was 1.75×10^{-3} (table 36). For the DYNPOUND-computed stage, the mean percent error was −0.90 percent, and the MSLE was 7.08×10^{-4} (table 37). DYNPOUND captured hysteresis in the stage-discharge relation for the computed event, whereas the USGS-computed discharge is single-valued. The WSC- and DYNPOUND-computed stage-discharge relations were biased to the right compared to the field measurements. Further adjustment of the *n*-values, based on first-hand knowledge of channel conditions, may improve the DYNPOUND-computed relation (fig. 45).



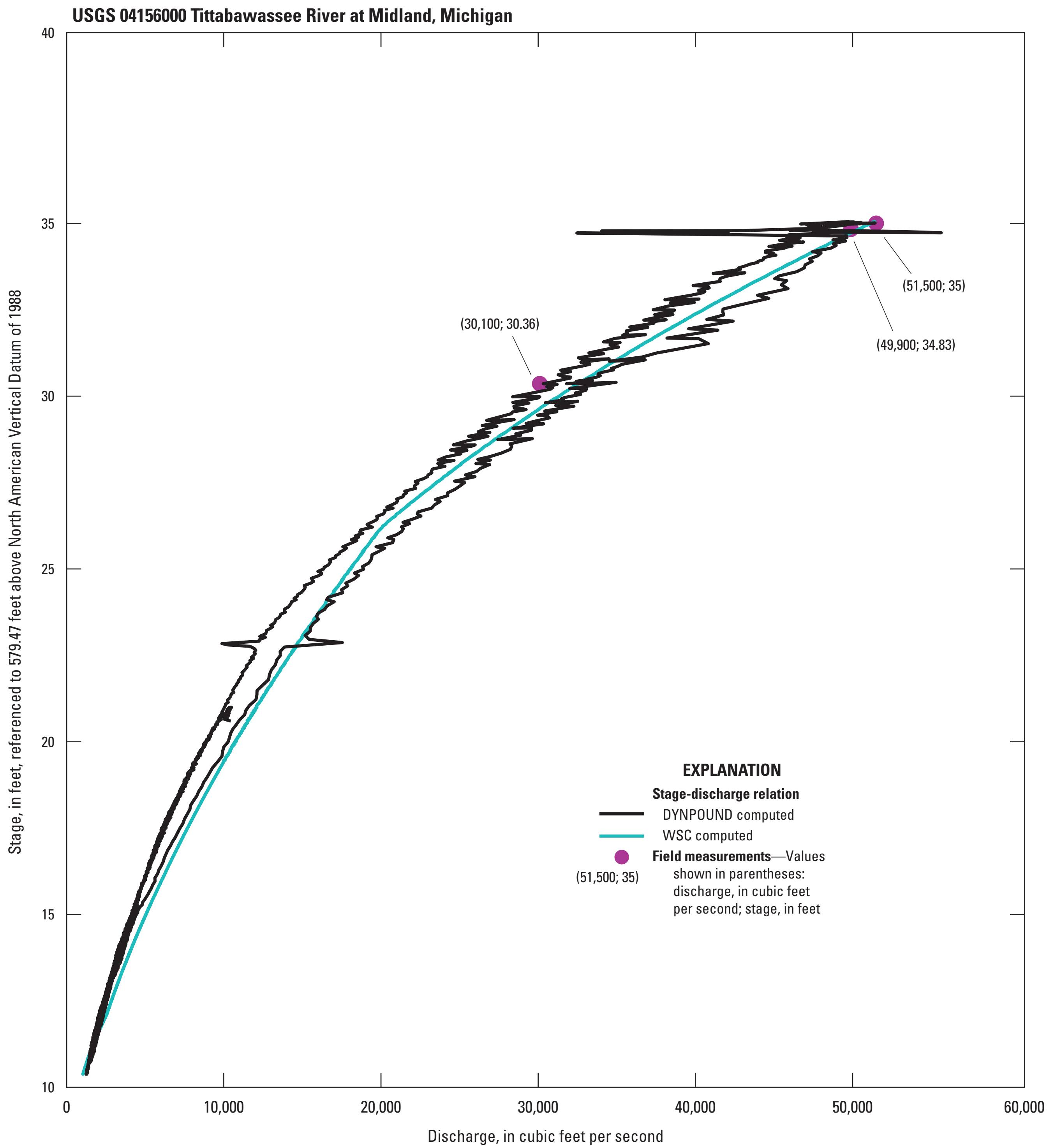
USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 28. Graph showing the discharge time series computed with the DYNPOUND method shown with the time series of WSC-computed discharge and field measurements made at Tittabawassee River at Midland, Michigan (U.S. Geological Survey streamgage 04156000; U.S. Geological Survey, 2020).



USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 29. Graph showing the stage time series computed with the DYNPOUND method shown with the time series of WSC-measured and field measurements made at Tittabawassee River at Midland, Michigan (U.S. Geological Survey streamgage 04156000; U.S. Geological Survey, 2020).



USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 30. Graph showing the stage-discharge relation at Tittabawassee River at Midland, Michigan (U.S. Geological Survey streamgage 04156000; U.S. Geological Survey, 2020), using discharge computed with the DYNPOUND method, WSC-computed discharge, and field measurements.

Table 17. Discharge computed with the DYNPOUND method and associated error for an event-based time series at Tittabawassee River at Midland, Michigan (U.S. Geological Survey streamgage 04156000).

[Field measurement discharge data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft^3/s, cubic foot per second; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM discharge (ft^3/s)	DYNPOUND discharge (ft^3/s)	DYNPOUND error (percent)	DYNPOUND SLE
05/20/2020	17:48	51,500	50,020	−2.87	0.00085
05/20/2020	19:31	49,900	47,883	−4.04	0.00170
05/21/2020	19:18	30,100	31,664	5.2	0.00257
Mean	NA	NA	NA	**−0.57**	**1.71×10^{-3}**

Table 18. Stage computed with the DYNPOUND method and associated error for an event-based time series at Tittabawassee River at Midland, Michigan (U.S. Geological Survey streamgage 04156000).

[Field measurement discharge data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft, feet; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM stage (ft)	DYNPOUND stage (ft)	DYNPOUND error (percent)	DYNPOUND SLE
05/20/2020	17:48	35.00	34.00	−0.842	0.00084
05/20/2020	19:31	34.83	34.00	−0.356	0.00058
05/21/2020	19:18	30.36	31.00	2.41	0.00044
Mean	NA	NA	NA	**0.40**	**6.19×10^{-4}**

Calcasieu River near Kinder, Louisiana

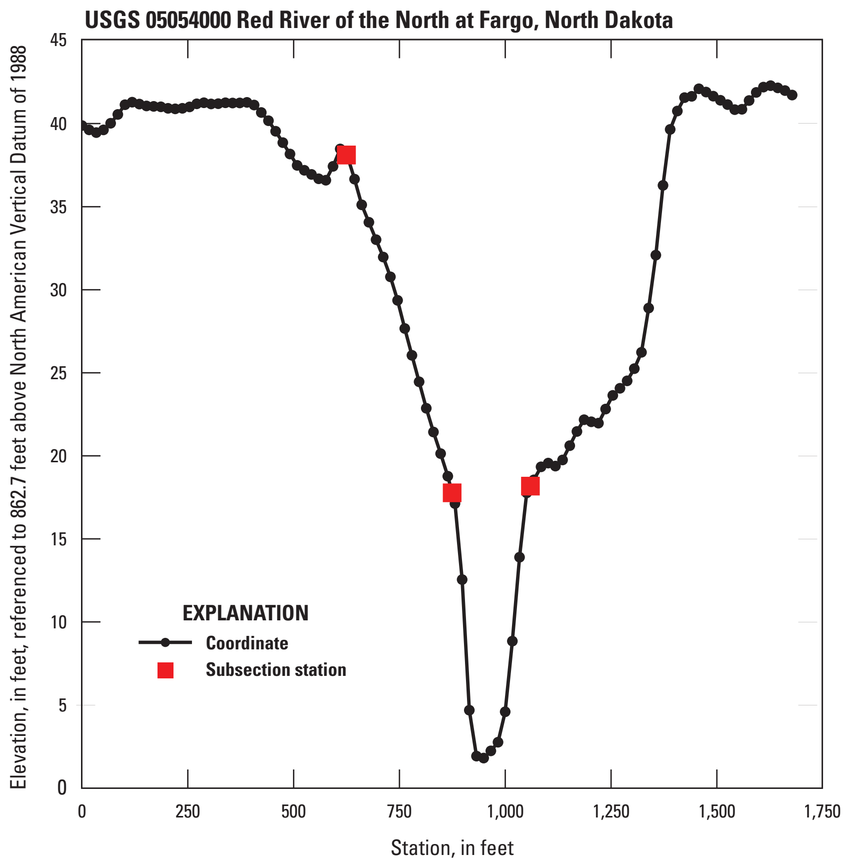
The USGS streamgage Calcasieu River near Kinder, Louisiana (USGS streamgage 08015500), represents an area of 1,700 mi^2. At this location, the river is surrounded by a coastal plain consisting of pine forests, agriculture, and urban areas (Forbes, 1988). The computed S_0 for the site is 0.00018992 (table 3). The value of r is 9.79 and was computed from the event with a peak stage of 19.44 ft at 23:30 (coordinated universal time [UTC]) on July 16, 2019 (U.S. Geological Survey, 2020). The cross section used to compute the time series is shown in figure 46. The channel cross section was split into three subsections for the DYNPOUND computation; subsection stations were at 2,051.52 and 2,366 ft (fig. 46). Manning's n–values, used to calibrate the DYNPOUND computations, varied from 0.064 to 0.15 (table 38).

Five discharge and four stage field measurements from the 2019 water year were used for calibration (table 39 and table 40). The WSC–measured stage time series for the 2019 water year was used to compute discharge, and the WSC–computed discharge time series for the same water year was used to compute stage using the DYNPOUND method (U.S. Geological Survey, 2020). The MSLE for the DYNPOUND discharge calibration was 1.15×10^{-1}, and the mean percent error was 37.80 percent (table 39). The MSLE for the DYNPOUND stage calibration was 6.08×10^{-2}, and the mean percent error was −12.18 percent (table 40).

To evaluate the ratings for the USGS streamgage 08015500 Calcasieu River near Kinder, Louisiana, time series of stage and discharge were computed for the period between January 30 and April 16, 2018, which included one field measurement used for error assessment (fig. 47 and fig. 48). DYNPOUND captured hysteresis for each of the three peaks in the stage-discharge relation for the computed period, whereas the WSC-computed discharge is monotonic (fig. 49). A comparison of the field measurement and DYNPOUND-computed discharge for the period resulted in a percent error of 2.21 percent (table 41). For the DYNPOUND-computed stage, the percent error was −1.89 percent (table 42).

Rio Grande Near Cerro, New Mexico

The USGS streamgage Rio Grande near Cerro, New Mexico (USGS streamgage 08263500) encompasses 8,440 mi^2. The Rio Grande meanders through an 800-ft-deep canyon (Bureau of Land Management, 2024), in which 50–75 percent of peak flows are the result of snowmelt runoff in late spring to early summer (Elias and others, 2015). The S_0



USGS, U.S. Geological Survey.

Figure 31. Graph showing the cross section used to compute the discharge time series at Red River of the North at Fargo, North Dakota (U.S. Geological Survey streamgage 05054000; U.S. Geological Survey, 2020).

Table 19. Stage and roughness coefficient values used to calibrate the DYNPOUND method at Red River of the North at Fargo, North Dakota (U.S. Geological Survey streamgage 05054000).

[Data from Domanski and others, 2025. ft, foot]

Stage (ft)	Roughness coefficient (*n*-value)
14.00	0.224
16.50	0.0474
20.00	0.04
27.50	0.056
36.00	0.067

Table 20. Discharge calibration results for the DYNPOUND ratings at Red River of the North at Fargo, North Dakota (U.S. Geological Survey streamgage 05054000).

[Field measurement discharge data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft^3/s, cubic foot per second; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM discharge (ft^3/s)	DYNPOUND discharge (ft^3/s)	DYNPOUND error (percent)	DYNPOUND SLE
11/02/2018	11:13	434	474	9.44	0.00777
01/23/2019	18:00	442	512	15.90	0.02161
03/05/2019	23:15	432	508	17.70	0.02626
04/02/2019	22:28	7,340	6,414	−12.60	0.01819
04/05/2019	17:42	15,500	15,122	−2.44	0.00061
04/06/2019	18:23	17,200	17,689	2.84	0.00079
04/07/2019	18:50	19,500	18,866	−3.25	0.00109
04/08/2019	19:49	19,200	19,161	−0.201	0.00000
04/15/2019	23:04	11,400	12,517	9.80	0.00874
04/23/2019	21:32	13,000	13,660	5.08	0.00245
06/11/2019	17:27	3,390	3,067	−9.51	0.01003
07/23/2019	15:34	2,450	2,791	13.90	0.01698
Mean	NA	NA	NA	**3.89**	**9.54×10^{-3}**

Table 21. Stage calibration results for the DYNPOUND ratings at Red River of the North at Fargo, North Dakota (U.S. Geological Survey streamgage 05054000).

[Field measurement stage data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft, feet; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM stage (ft)	DYNPOUND stage (ft)	DYNPOUND error (percent)	DYNPOUND SLE
11/02/2018	11:13	14.33	14.00	−0.747	0.00054
01/23/2019	18:00	14.50	14.00	1.73	0.00123
03/05/2019	23:15	14.47	16.00	13.90	0.01010
04/02/2019	22:28	22.64	22.00	1.10	0.00082
04/05/2019	17:42	31.09	31.00	0.277	0.00001
04/06/2019	18:23	33.41	33.00	0.52	0.00015
04/07/2019	18:50	34.54	34.00	0.476	0.00025
04/08/2019	19:49	34.98	35.00	0.756	0.00000
04/15/2019	23:04	29.74	29.00	−1.81	0.00063
04/23/2019	21:32	30.69	30.00	−0.658	0.00052
06/11/2019	17:27	17.13	17.00	3.76	0.00006
07/23/2019	15:34	16.57	16.00	−0.896	0.00123
Mean	NA	NA	NA	**1.53**	**1.30×10^{-3}**

Table 22. Discharge computed with the DYNPOUND method and associated error for an event-based time series at Red River of the North at Fargo, North Dakota (U.S. Geological Survey streamgage 05054000).

[Field measurement discharge data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft^3/s, cubic foot per second; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM discharge (ft^3/s)	DYNPOUND discharge (ft^3/s)	DYNPOUND error (percent)	DYNPOUND SLE
03/26/2020	17:32	4,250	4,476	5.34	0.00268
03/31/2020	18:03	11,700	10,664	−7.27	0.00860
04/04/2020	17:36	7,750	8,866	14.40	0.01810
04/09/2020	14:51	10,300	10,202	−0.944	0.00009
04/15/2020	16:58	5,990	5,903	−1.45	0.00021
05/01/2020	15:44	3,400	3,100	−8.82	0.00853
Mean	NA	NA	NA	**0.21**	**6.37×10^{-3}**

for the site is computed as 0.00360 (table 3). A value for *r* of 697 was computed using the event with a peak stage of 5.57 ft at 03:00 (UTC) on June 3, 2021 (U.S. Geological Survey, 2020). Values of *r* are anticipated to fall within a range of approximately 10 to 100 (Fread, 1973). The computed value of *r* for this site is substantially larger than the largest expected value. Further investigation could help determine the cause of the high value of *r* for this site.

Seven field measurements of stage and discharge collected during the 2015 water year were used for calibration. The WSC-measured stage time series from the 2015 water year was used to compute discharge, and the WSC-computed discharge time series for the same water year was used to compute stage using the DYNPOUND method (U.S. Geological Survey, 2020). No subdivision of the cross section (fig. 50) was warranted based upon subdivision criteria in the computation of the hydraulic properties for the DYNPOUND method. The *n*-value used to calibrate the DYNPOUND computations varied from 0.064 to 0.128 (table 43). The calibrated Manning's *n* values were much larger than anticipated, and the large *n*-values may be mitigating for phenomena not adequately captured in the rating. The MSLE and mean percent error for the DYNPOUND discharge calibration were 8.51×10^{-4} and 0.35 percent, respectively (table 44). The MSLE and mean percent error for the DYNPOUND stage calibration were 2.02×10^{-2} and −0.40 percent, respectively (table 45).

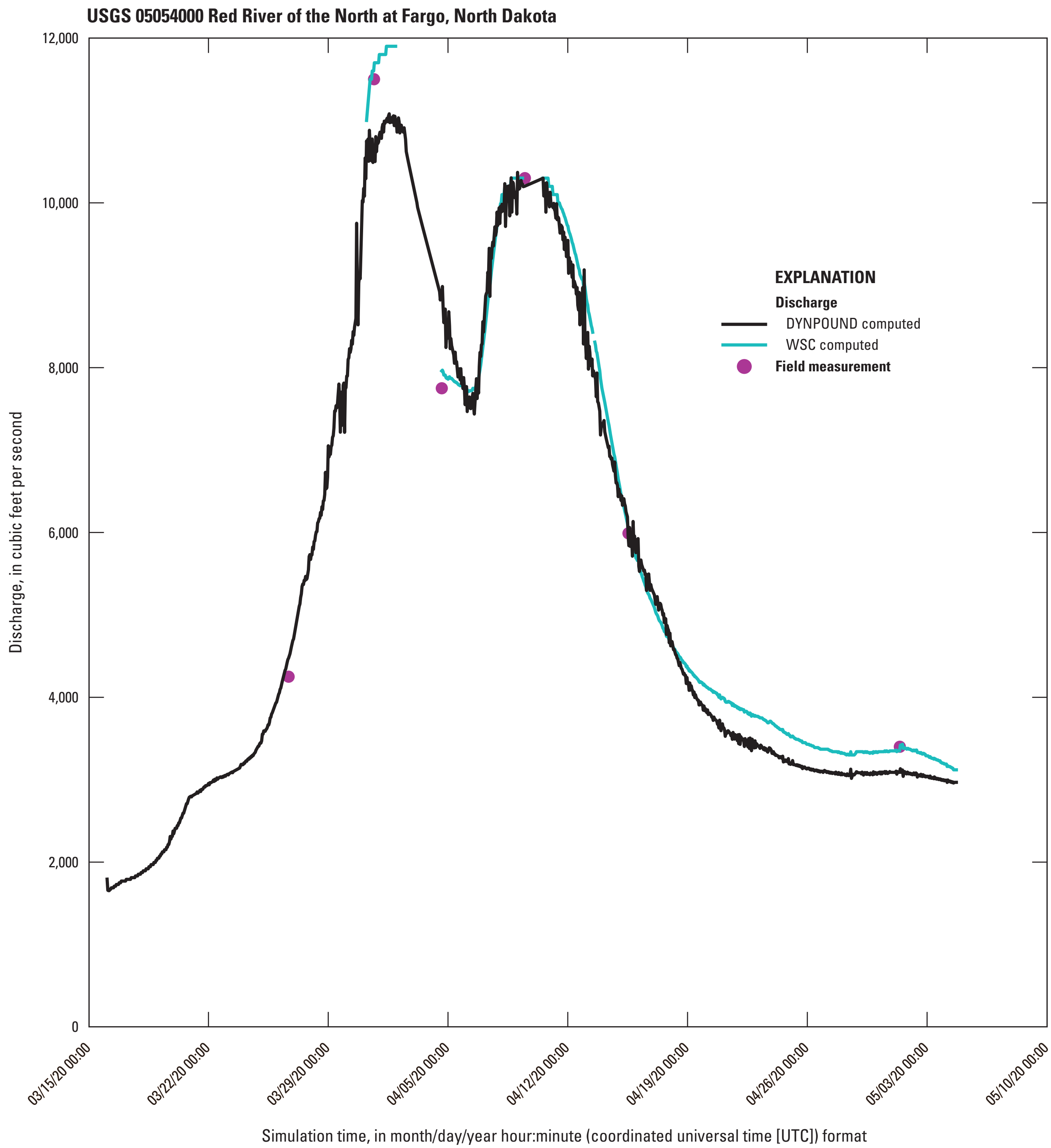
The stage and discharge values computed during the period between April 1 and August 5, 2019, were used to evaluate the DYNPOUND method for this site; the two field measurements made during this period were used for comparison. The DYNPOUND-computed discharge was lower at the peaks above 2,000 ft^3/s, and the DYNPOUND-computed stage was higher at the peaks over 9 ft (fig. 51, fig. 52, and fig. 53). The mean percent error of the DYNPOUND-computed discharge is 3.84 percent, and the MSLE is 1.39×10^{-3} (table 46). The mean percent error of the DYNPOUND-computed stage is −2.32 percent, and the MSLE is 1.82×10^{-2} (table 47).

San Joaquin River Near Mendota, California

The USGS streamgage San Joaquin River near Mendota, California (U.S. Geological Survey streamgage 11254000) encompasses 3,940 mi^2. The meandering San Joaquin River is characterized by low-gradient flows and a sandy bottom (Marineau and others, 2017). The computed S_0 for the site is 0.000248 (table 3). A high value of 159.5 for *r* was computed from the event with a peak stage of 5.46 ft at 12:30 (UTC) on February 22, 2015 (U.S. Geological Survey, 2020). The cross section used to compute the time series is shown in figure 54.

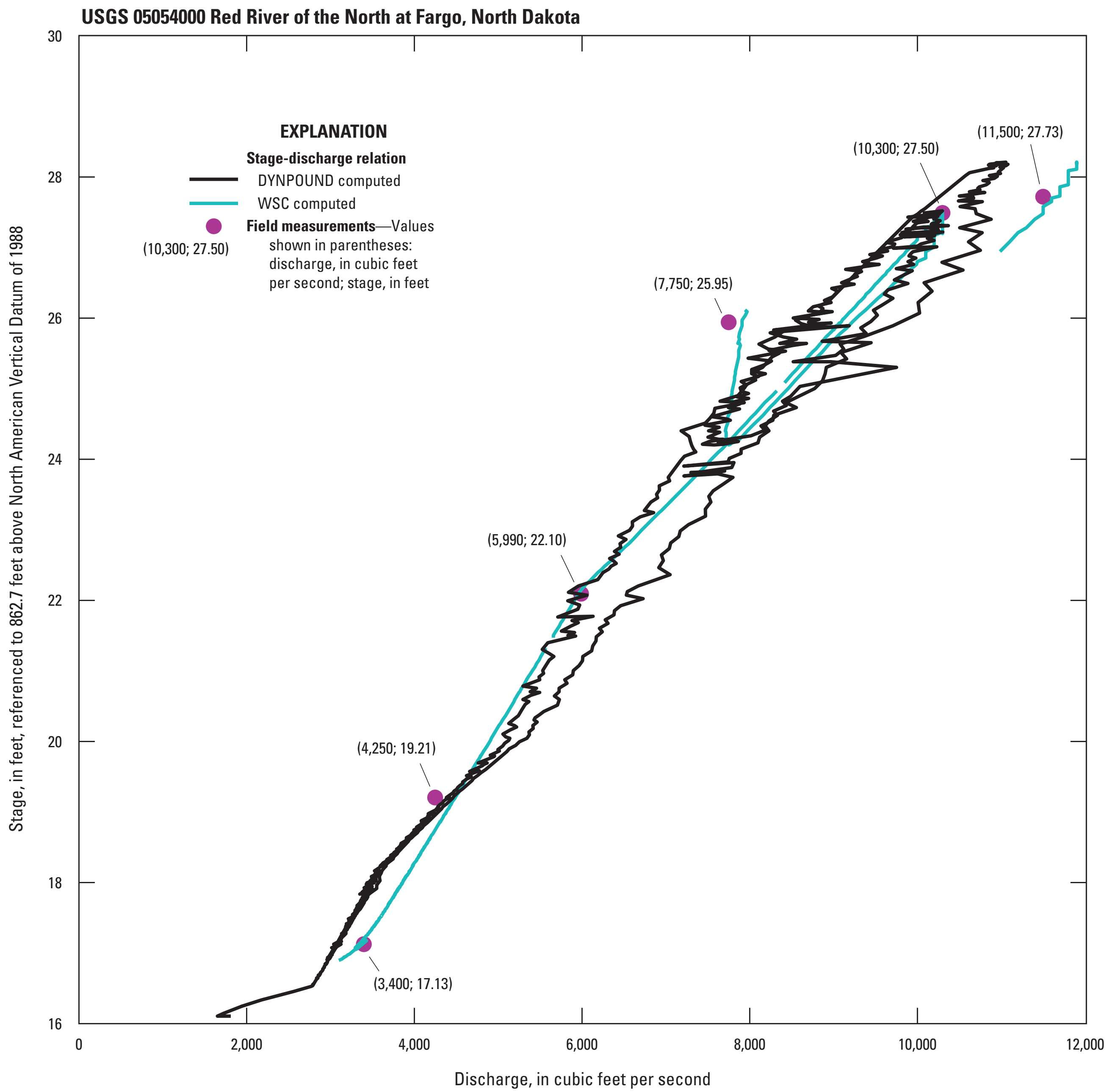
Nine field measurements of stage and discharge collected during the 2015 water year were used for calibration. The WSC-measured stage time series from the 2015 water year was used to compute discharge, and the WSC-computed discharge time series for the same water year was used to compute stage using the DYNPOUND method (U.S. Geological Survey, 2020). The cross section for the DYNPOUND analyses was subdivided into three subsections for the DYNPOUND computations; subsection stations were at 540 and 700 ft (fig. 54). The *n*-values used to calibrate the DYNPOUND computations varied from 0.031 to 0.08 (table 48). The MSLE for the DYNPOUND discharge calibration was 7.88×10^{-3}, and the mean percent error was −4.89 percent (table 49). The MSLE for the DYNPOUND stage calibration was 3.89×10^{-2}, and the mean percent error was 2.03 percent (table 50).

Time series of stage and discharge were computed for the period between May 20 and July 10, 2019, to evaluate the DYNPOUND method at San Joaquin River near Mendota, California (fig. 55 and fig. 56). Two field measurements are available for comparison during this



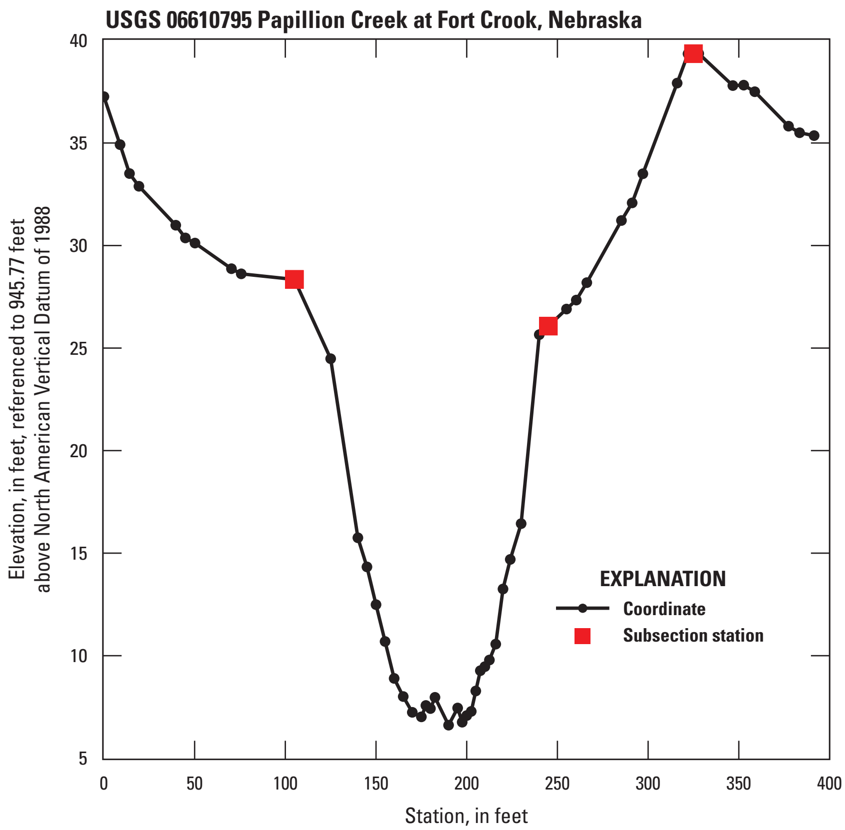
USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 32. Graph showing the discharge time series computed with the DYNPOUND method shown with the time series of WSC-computed discharge and field measurements made at Red River of the North at Fargo, North Dakota (U.S. Geological Survey streamgage 05054000; U.S. Geological Survey, 2020).



USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 33. Graph showing the stage-discharge relation at Red River of the North at Fargo, North Dakota (U.S. Geological Survey streamgage 05054000; U.S. Geological Survey, 2020), using discharge computed with the DYNPOUND method, WSC-computed discharge, and field measurements.



USGS, U.S. Geological Survey.

Figure 34. Graph showing the cross section used to compute the stage and discharge time series at Papillion Creek at Fort Crook, Nebraska (U.S. Geological Survey streamgage 06610795; U.S. Geological Survey, 2020).

Table 23. Stage and roughness coefficient values used to calibrate the DYNPOUND method at Papillion Creek at Fort Crook, Nebraska (U.S. Geological Survey streamgage 06610795).

[Data from Domanski and others, 2025. ft, foot]

Stage (ft)	Roughness coefficient (*n*-value)
6.00	0.022
12.00	0.018
17.00	0.016
20.00	0.015
28.00	0.0187
36.00	0.017

Table 24. Discharge calibration results for the DYNPOUND ratings at Papillion Creek at Fort Crook, Nebraska (U.S. Geological Survey streamgage 06610795).

[Field measurement discharge data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels; MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft^3/s, cubic foot per second; SLE, squared logarithmic error; NA, not applicable]

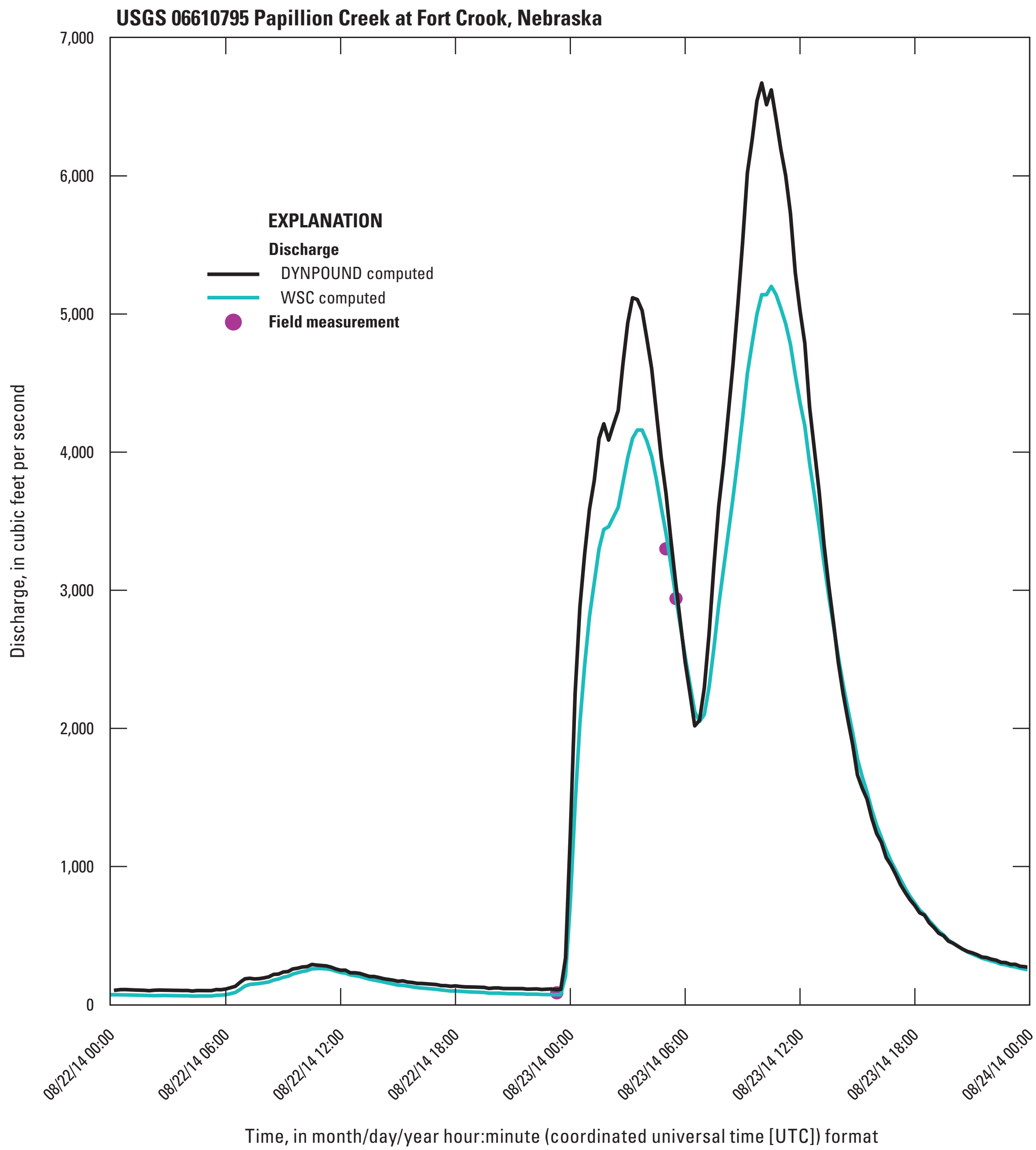
Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM discharge (ft^3/s)	DYNPOUND discharge (ft^3/s)	DYNPOUND error (percent)	DYNPOUND SLE
11/17/2015	18:10	1,770	1,546	−12.60	0.01831
03/11/2016	17:44	191	229	20.00	0.03292
04/20/2016	19:42	7,320	7,869	7.50	0.00523
06/15/2016	16:32	213	253	19.00	0.02962
07/15/2016	18:40	241	273	13.30	0.01554
08/23/2016	16:19	161	214	33.20	0.08098
Mean	NA	NA	NA	**13.40**	**3.04×10^{-2}**

Table 25. Stage calibration results for the DYNPOUND ratings at Papillion Creek at Fort Crook, Nebraska (U.S. Geological Survey streamgage 06610795).

[Field measurement stage data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels; MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft^3/s, cubic foot per second; SLE, squared logarithmic error; NA, not applicable]

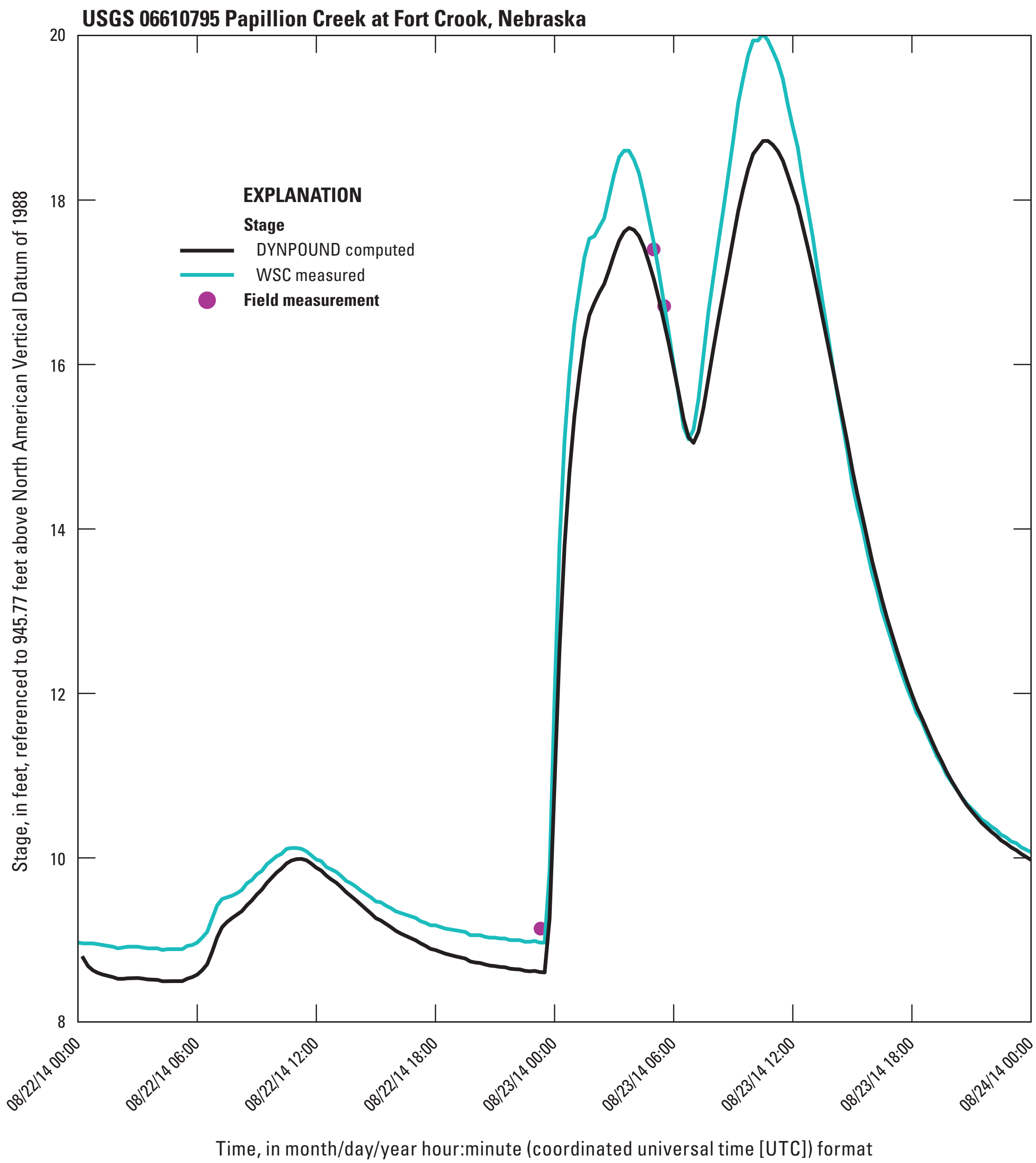
Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM stage (ft^3/s)	DYNPOUND stage (ft^3/s)	DYNPOUND error (percent)	DYNPOUND SLE
11/17/2015	18:10	13.93	14.00	1.11	0.00003
03/11/2016	17:44	9.74	9.00	−1.24	0.00624
04/20/2016	19:42	22.48	21.00	−4.22	0.00464
06/15/2016	16:32	9.96	9.00	−2.34	0.01027
07/15/2016	18:40	10.07	9.00	−1.82	0.01262
08/23/2016	16:19	9.72	9.00	−2.87	0.00592
Mean	NA	NA	NA	**−1.90**	**6.62×10^{-3}**

period. The MSLE for the DYNPOUND computed discharge is 1.72×10^{-2} with a mean percent error of −4.27 percent (table 51). Stage computed with the DYNPOUND method resulted in a MSLE of 9.11×10^{-3} and a mean percent error of 3.91 percent (table 52). DYNPOUND captures hysteresis in the stage-discharge relation for the computed event and shows intensifying oscillation as stage rises above 8 ft. This intensifying oscillation might be attributed to flow inundating the floodplain on the left channel bank. By comparison, the WSC-computed discharge is singled-valued (fig. 57). Compared to the discharge observed on June 9, 2019, at 18:32 UTC, the DYNPOUND computed discharge is 7.26 percent higher.



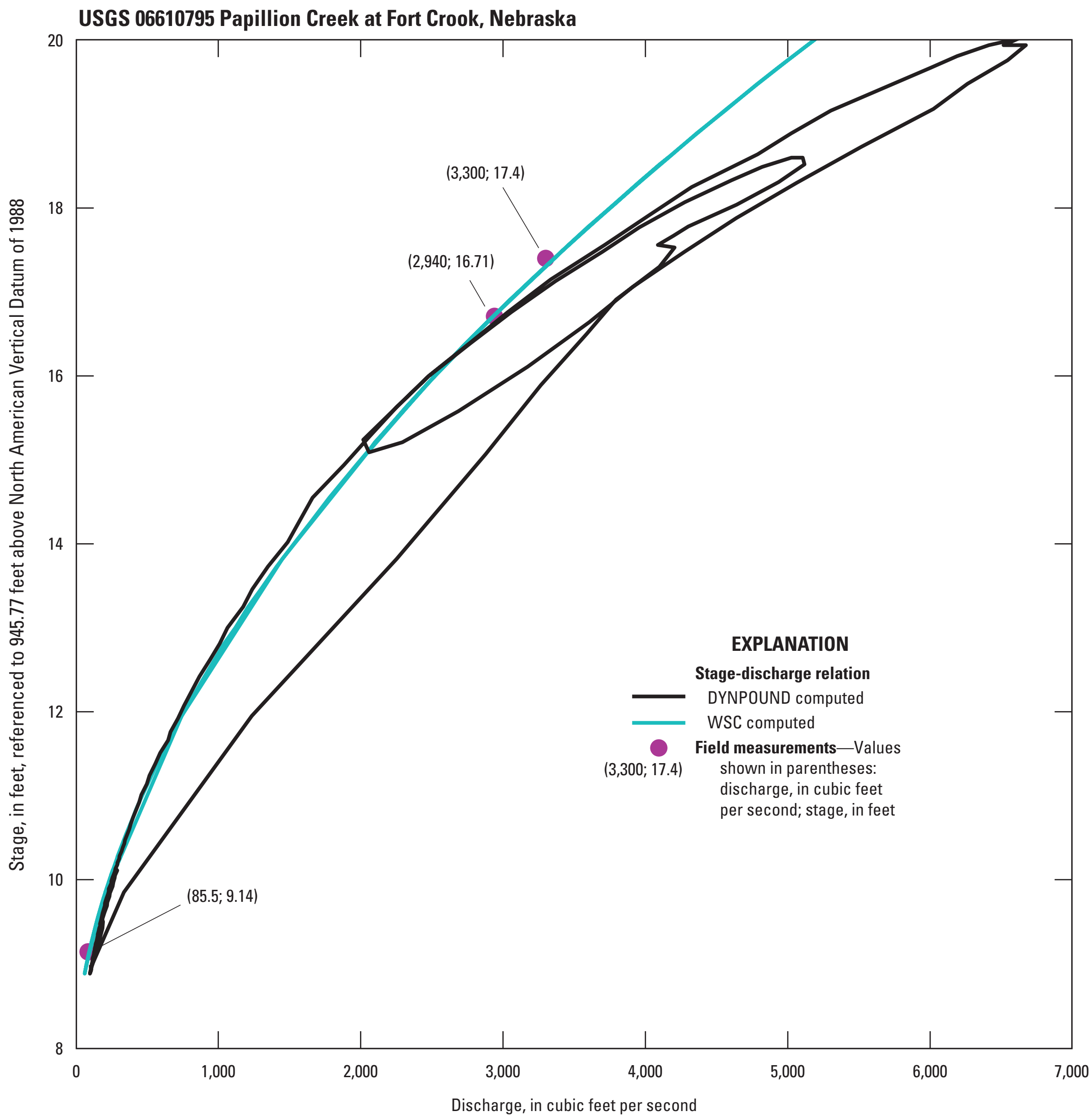
USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 35. Graph showing the discharge time series computed with the DYNPOUND method shown with the time series of WSC-computed discharge and field measurements made at Papillion Creek at Fort Crook, Nebraska (U.S. Geological Survey streamgage 06610795; U.S. Geological Survey, 2020).



USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 36. Graph showing the stage time series computed with the DYNPOUND method shown with the time series of WSC-measured stage and field measurements made at Papillion Creek at Fort Crook, Nebraska (U.S. Geological Survey streamgage 06610795; U.S. Geological Survey, 2020).



USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 37. Graph showing the stage-discharge relation at Papillion Creek at Fort Crook, Nebraska (U.S. Geological Survey streamgage 06610795; U.S. Geological Survey, 2020), using discharge computed with the DYNPOUND method, WSC-computed discharge, and field measurements.

Table 26. Discharge computed for an event-based time series at Papillion Creek at Fort Crook, Nebraska (U.S. Geological Survey streamgage 06610795), with the DYNPOUND methods and the associated error.

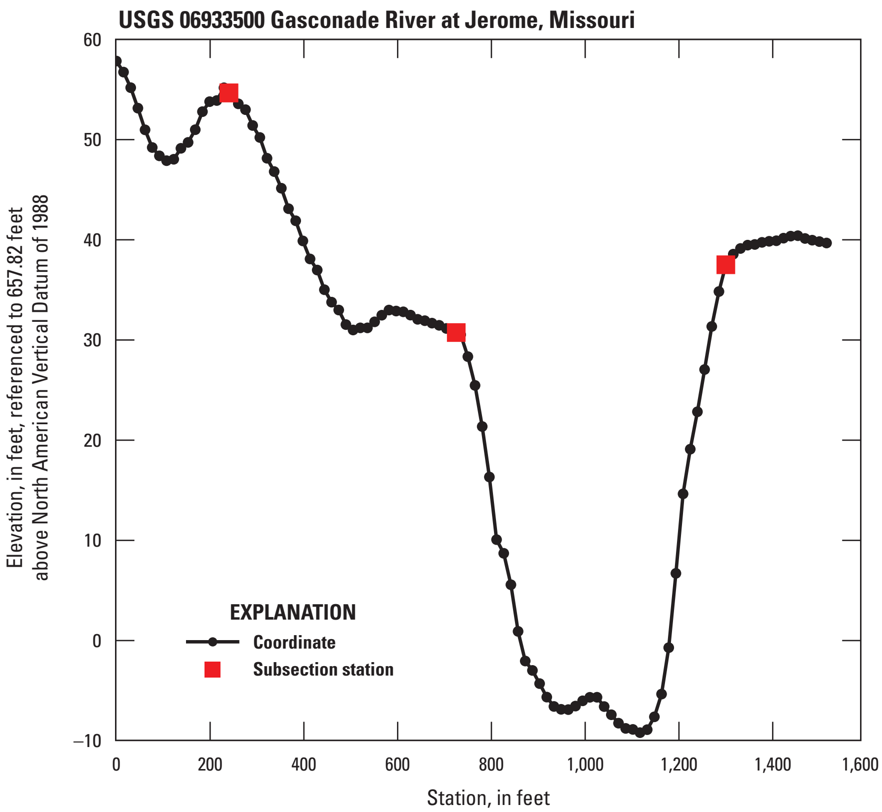
[Field measurement discharge data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft^3/s, cubic foot per second; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM discharge (ft^3/s)	DYNPOUND discharge (ft^3/s)	DYNPOUND error (percent)	DYNPOUND SLE
08/22/2014	23:17	85.5	108	27.2	0.05458
08/23/2014	4:59	3,300	3,707	12.4	0.01353
08/23/2014	5:31	2,940	3,033	3.19	0.00097
Mean	NA	NA	NA	**14.26**	**2.30×10^{-2}**

Table 27. Stage computed for an event-based time series at Papillion Creek at Fort Crook, Nebraska (U.S. Geological Survey streamgage 06610795), with the DYNPOUND methods and the associated error.

[Field measurement stage data from U.S. Geological Survey, 2020; DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels; MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft^3/s, cubic foot per second; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM stage (ft^3/s)	DYNPOUND stage (ft^3/s)	DYNPOUND error (percent)	DYNPOUND SLE
08/22/2014	23:17	9.14	8.00	−5.79	0.01775
08/23/2014	4:59	17.40	17.00	−2.04	0.00054
08/23/2014	5:31	16.71	16.00	−1.2	0.00189
Mean	NA	NA	NA	**−3.01**	**6.72×10^{-3}**



USGS, U.S. Geological Survey.

Figure 38. Graph showing the cross section used to compute the discharge time series at Gasconade River at Jerome, Missouri (U.S. Geological Survey streamgage 06933500; U.S. Geological Survey, 2020).

Table 28. Stage and roughness coefficient values used to calibrate the DYNPOUND method at Gasconade River at Jerome, Missouri (U.S. Geological Survey streamgage 06933500).

[Data from Domanski and others, 2025. ft, foot]

Stage (ft)	Roughness coefficient (*n*-value)
2.00	0.19
5.00	0.099
10.00	0.06
20.00	0.0565
30.00	0.0398
40.00	0.026

Table 29. Discharge calibration results for the DYNPOUND ratings at Gasconade River at Jerome, Missouri (U.S. Geological Survey streamgage 06933500).

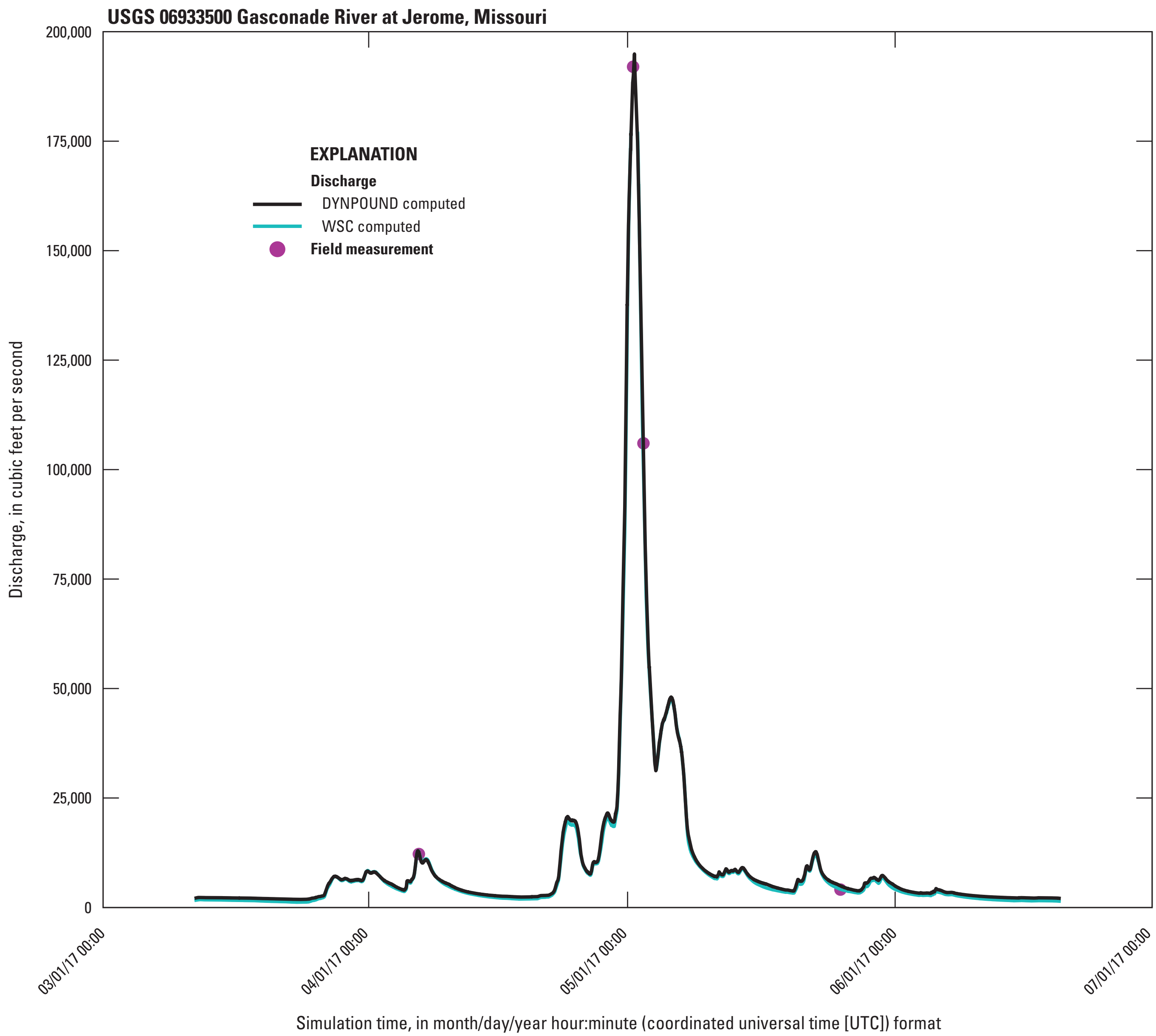
[Field measurement discharge data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft^3/s, cubic foot per second; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM discharge (ft^3/s)	DYNPOUND discharge (ft^3/s)	DYNPOUND error (percent)	DYNPOUND SLE
10/09/2015	15:31	631	1,528	142.00	0.78218
12/08/2015	19:18	2,830	3,023	6.84	0.00435
12/29/2015	22:05	146,000	148,590	1.77	0.00031
02/01/2016	15:32	1,770	2,242	26.70	0.05588
03/28/2016	14:54	1,810	2,326	28.50	0.06291
06/02/2016	21:03	3,620	3,975	9.82	0.00875
08/01/2016	21:33	2,180	2,635	20.90	0.03593
Mean	NA	NA	NA	**33.79**	**1.36×10^{-1}**

Table 30. Stage calibration results for the DYNPOUND ratings at Gasconade River at Jerome, Missouri (U.S. Geological Survey streamgage 06933500).

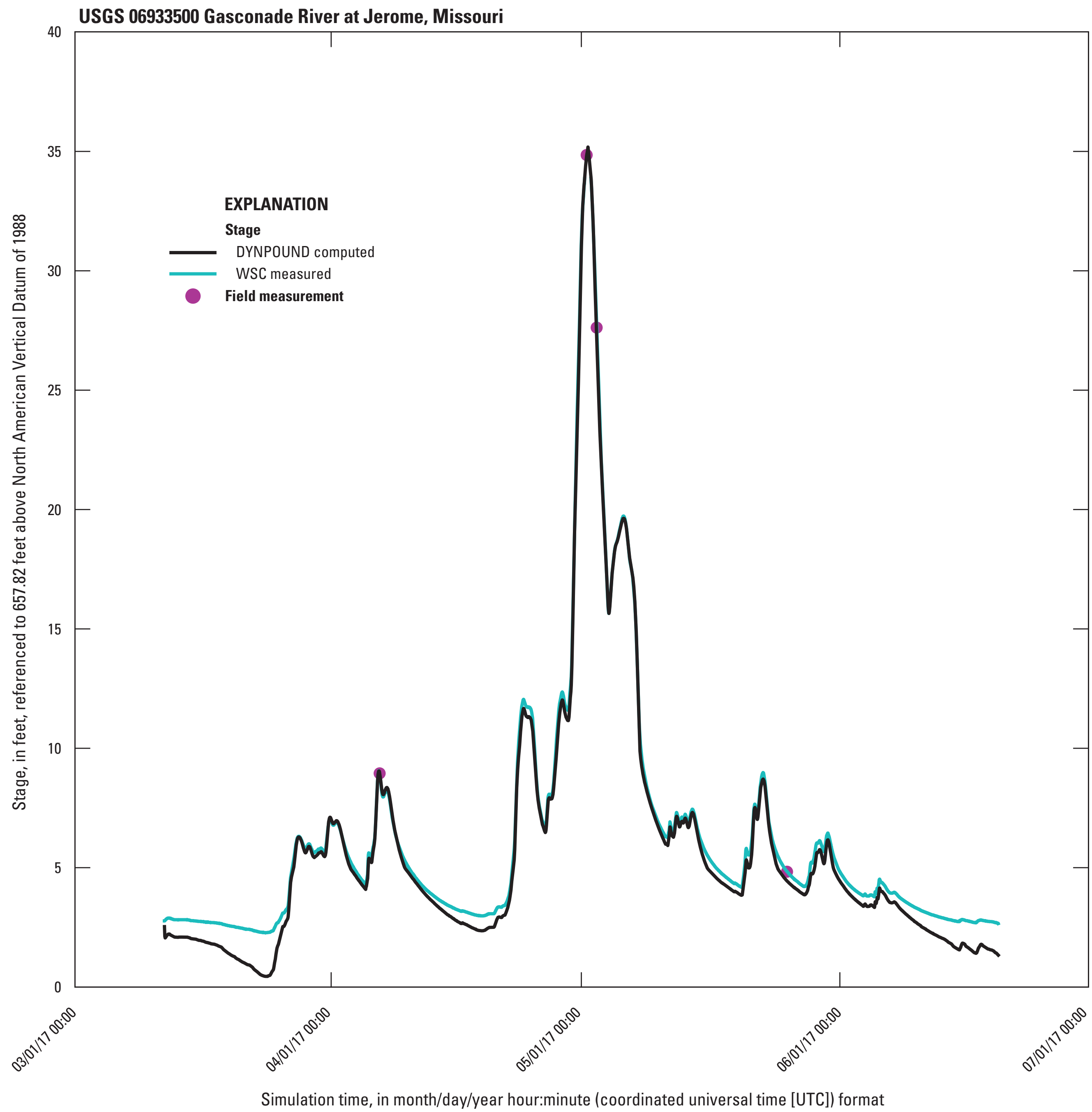
[Field measurement stage data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft, feet; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM stage (ft)	DYNPOUND stage (ft)	DYNPOUND error (percent)	DYNPOUND SLE
10/09/2015	15:31	1.52	−1.00	−228.00	
12/08/2015	19:18	3.65	3.00	−9.22	0.03846
12/29/2015	22:05	31.83	30.00	−2.73	0.00351
02/01/2016	15:32	2.83	2.00	−24.40	0.12050
03/28/2016	14:54	2.93	2.00	−21.60	0.14581
06/02/2016	21:03	4.33	4.00	−4.76	0.00628
08/01/2016	21:33	3.24	2.00	−19.10	0.23273
Mean	NA	NA	NA	**−44.26**	**9.12×10^{-2}**



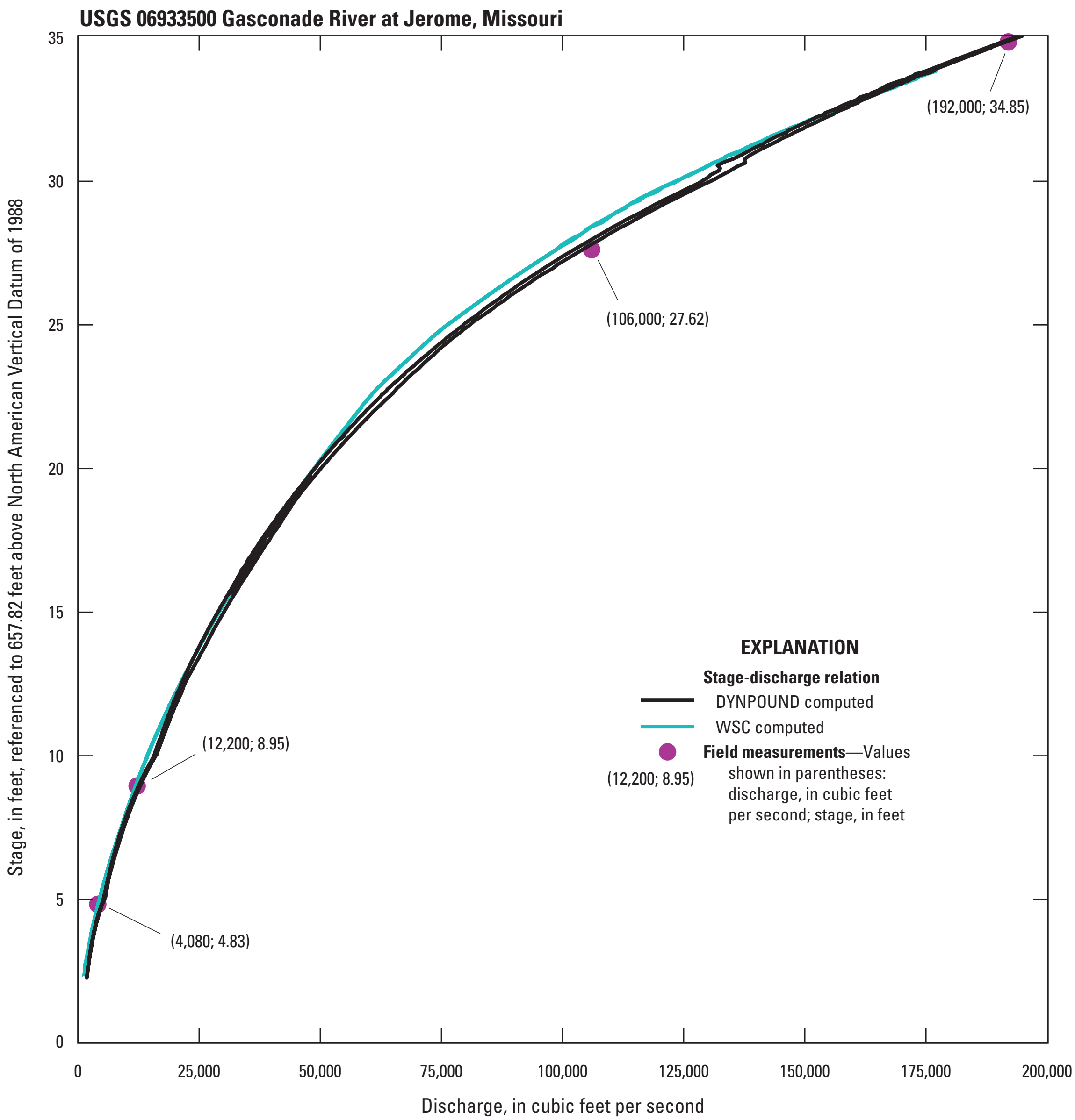
USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 39. Graph showing the discharge time series computed with the DYNPOUND method shown with the time series of WSC-computed discharge and field measurements made at Gasconade River at Jerome, Missouri (U.S. Geological Survey streamgage 06933500; U.S. Geological Survey, 2020).



USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 40. Graph showing the stage time series computed with the DYNPOUND method shown with the time series of WSC-measured stage and field measurements made at Gasconade River at Jerome, Missouri (U.S. Geological Survey streamgage 06933500; U.S. Geological Survey, 2020).



USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 41. Graph showing stage-discharge relation at Gasconade River at Jerome, Missouri (U.S. Geological Survey streamgage 06933500; U.S. Geological Survey, 2020), using discharge computed with the DYNPOUND method, WSC-computed discharge, and field measurements.

Table 31. Discharge computed for an event-based time series at Gasconade River at Jerome, Missouri (U.S. Geological Survey streamgage 06933500), with the DYNPOUND methods and the associated error.

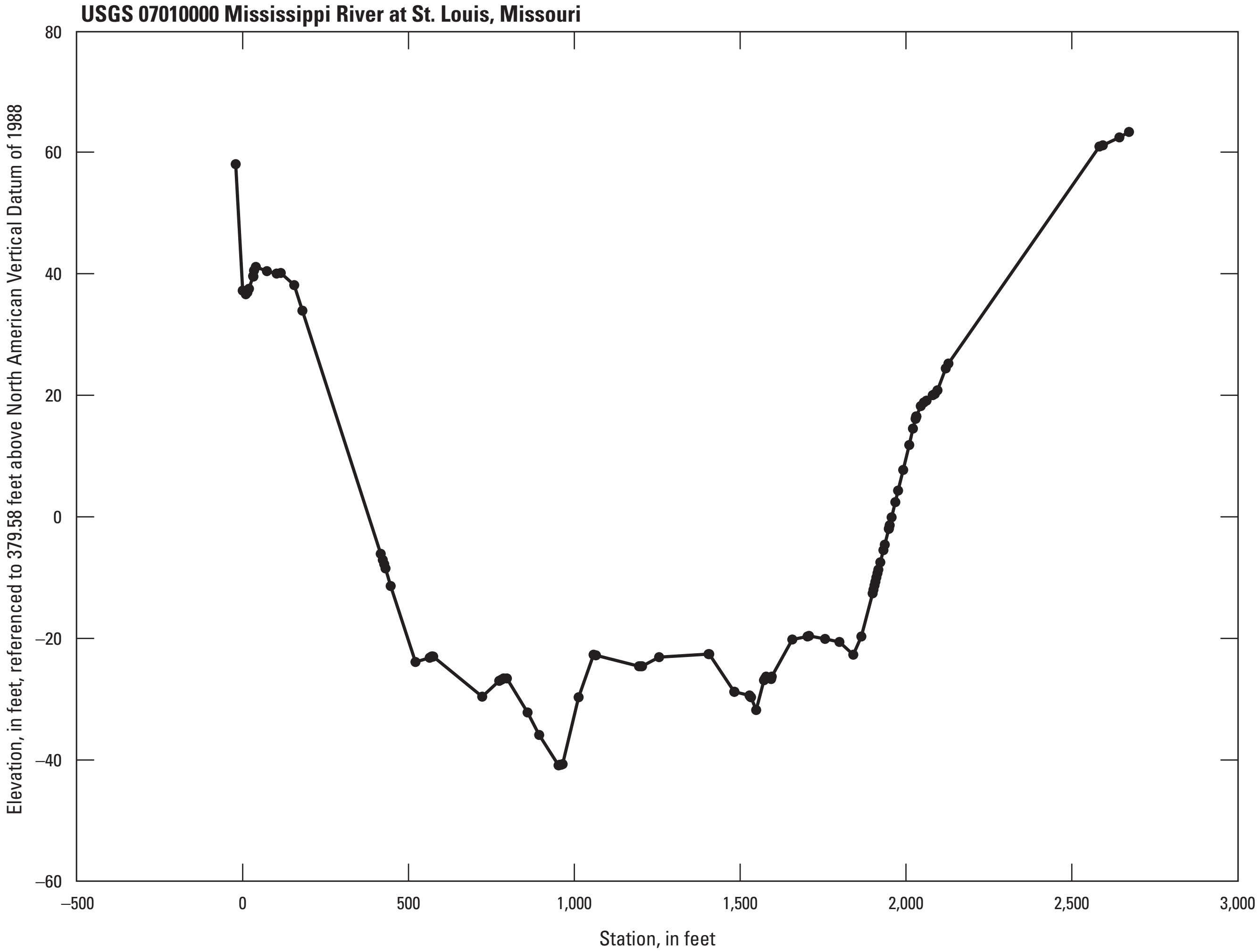
[Field measurement discharge data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft^3/s, cubic foot per second; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM discharge (ft^3/s)	DYNPOUND discharge (ft^3/s)	DYNPOUND error (percent)	DYNPOUND SLE
04/06/2017	19:29	12,200	12,620	3.45	0.00115
05/01/2017	15:17	192,000	189,222	−1.45	0.00021
05/02/2017	20:03	106,000	102,105	−3.67	0.00140
05/25/2017	15:57	4,080	4,919	20.60	0.03497
Mean	NA	NA	NA	**4.73**	**9.43×10^{-3}**

Table 32. Stage computed for an event-based time series at Gasconade River at Jerome, Missouri (U.S. Geological Survey streamgage 06933500), with the DYNPOUND methods and the associated error.

[Field measurement stage data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft, feet; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM stage (ft)	DYNPOUND stage (ft)	DYNPOUND error (percent)	DYNPOUND SLE
04/06/2017	19:29	8.95	8.00	0.379	0.01259
05/01/2017	15:17	34.85	34.00	−0.0467	0.00061
05/02/2017	20:03	27.62	27.00	−1.45	0.00052
05/25/2017	15:57	4.83	4.00	−8.09	0.03555
Mean	NA	NA	NA	**−2.30**	**1.23×10^{-2}**



USGS, U.S. Geological Survey.

Figure 42. Graph showing the cross section used to compute the discharge time series at Mississippi River at St. Louis, Missouri (U.S. Geological Survey streamgage 07010000; U.S. Geological Survey, 2020).

Table 33. Stage and roughness coefficient values used to calibrate the DYNPOUND method at Mississippi River at St. Louis, Missouri (U.S. Geological Survey streamgage 07010000).

[Data from Domanski and others, 2025. ft, foot]

Stage (ft)	Roughness coefficient (*n*-value)
−4.58	0.058
10.00	0.045
20.00	0.039
30.00	0.035
50.42	0.029

Table 34. Discharge calibration results for the DYNPOUND ratings at Mississippi River at St. Louis, Missouri (U.S. Geological Survey streamgage 07010000).

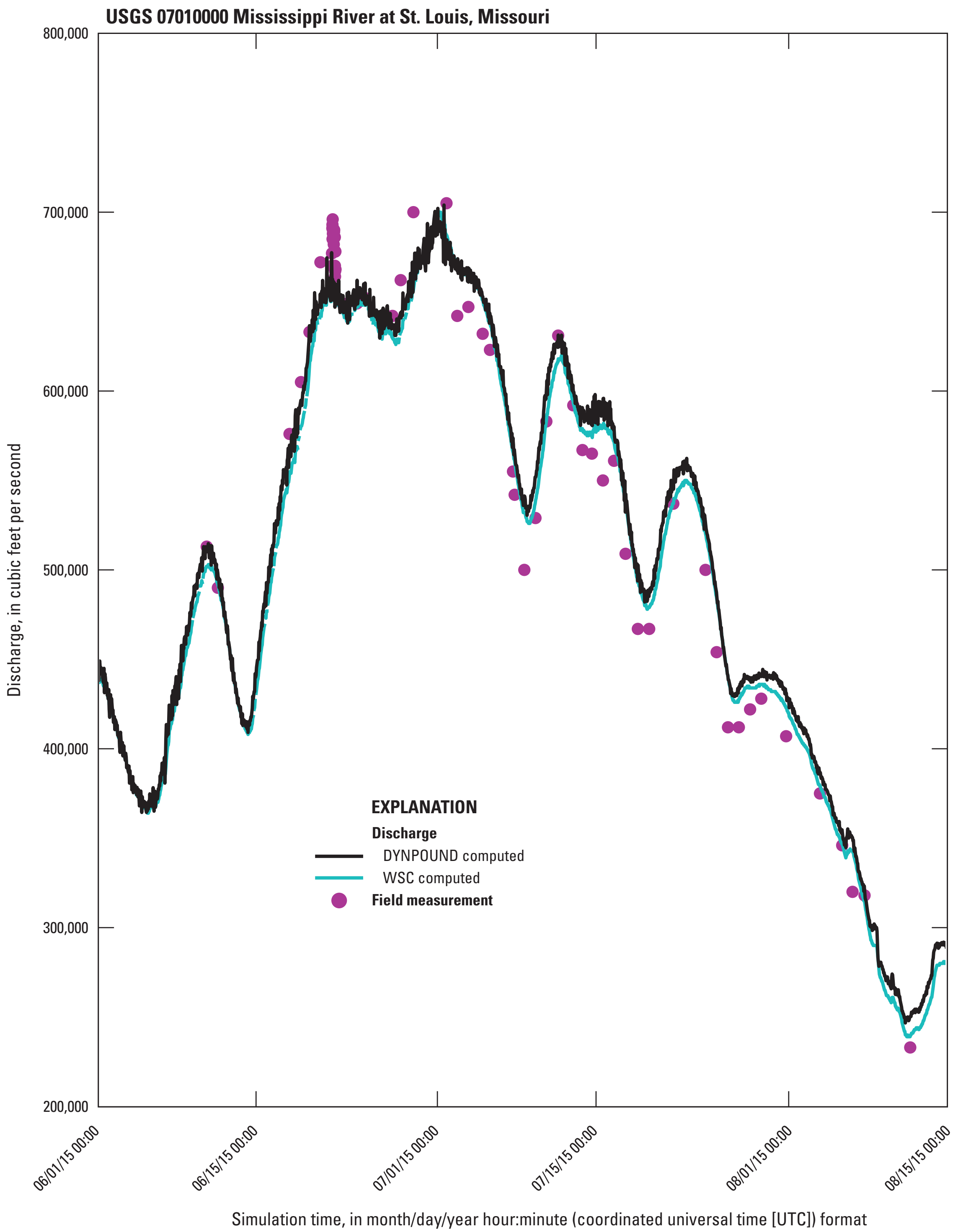
[Field measurement discharge data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft^3/s, cubic foot per second; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM discharge (ft^3/s)	DYNPOUND discharge (ft^3/s)	DYNPOUND error (percent)	DYNPOUND SLE
10/31/2013	18:05	98,500	103,824	5.41	0.00277
11/21/2013	17:57	106,000	102,814	−3.01	0.00093
01/15/2014	19:24	99,100	93,852	−5.3	0.00296
02/20/2014	16:50	92,500	92,749	0.27	0.00001
03/13/2014	16:34	167,000	158,409	−5.14	0.00279
04/10/2014	18:13	245,000	234,495	−4.29	0.00192
05/21/2014	14:54	331,000	309,916	−6.37	0.00433
06/05/2014	17:19	291,000	274,636	−5.62	0.00335
07/10/2014	18:19	555,000	518,176	−6.63	0.00471
08/14/2014	18:37	137,000	141,025	2.94	0.00084
09/18/2014	15:09	400,000	389,887	−2.53	0.00066
Mean	NA	NA	NA	**−2.75**	**2.30×10^{-3}**

Table 35. Stage calibration results for the DYNPOUND ratings at Mississippi River at St. Louis, Missouri (U.S. Geological Survey streamgage 07010000).

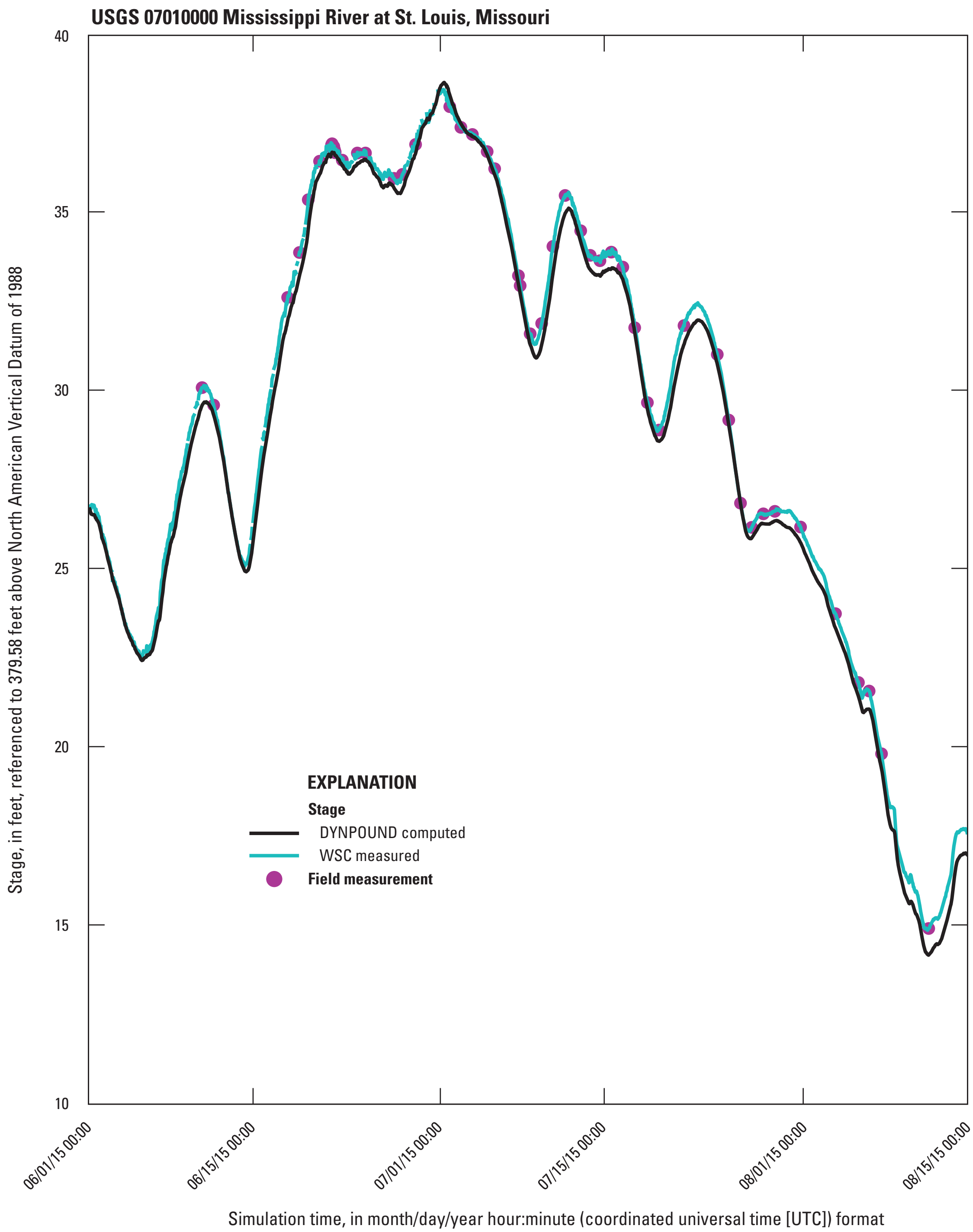
[Field measurement stage data from U.S. Geological Survey, 2020; DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft^3/s, cubic foot per second; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM stage (ft^3/s)	DYNPOUND stage (ft^3/s)	DYNPOUND error (percent)	DYNPOUND SLE
10/31/2013	18:05	1.68	1.00	−12.3	0.26915
11/21/2013	17:57	1.81	1.00	−1.36	0.35204
01/15/2014	19:24	0.48	1.00	144	0.53871
02/20/2014	16:50	−0.41	0.00	69.1	NA
03/13/2014	16:34	7.53	8.00	6.58	0.00367
04/10/2014	18:13	13.90	14.00	5.16	0.00005
05/21/2014	14:54	19.15	20.00	5.08	0.00189
06/05/2014	17:19	16.51	17.00	3.67	0.00086
07/10/2014	18:19	30.28	30.00	−0.365	0.00009
08/14/2014	18:37	6.22	6.00	6.19	0.00130
09/18/2014	15:09	24.09	24.00	1.27	0.00001
Mean	NA	NA	NA	**20.64**	**1.17×10^{-1}**



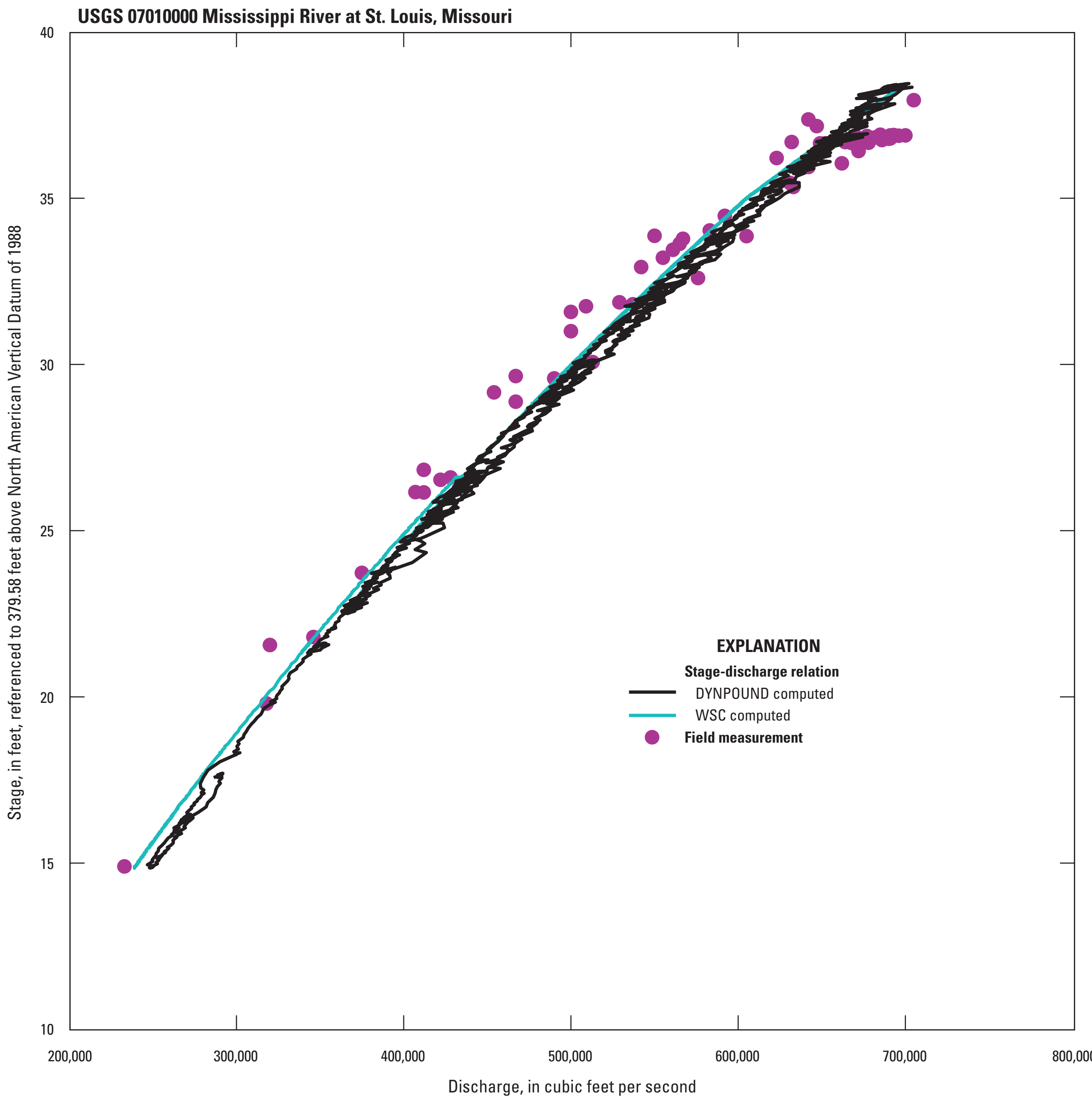
USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 43. Graph showing the discharge time series computed with the DYNPOUND method shown with the WSC-computed discharge time series and field measurements made at Mississippi River at St. Louis, Missouri (U.S. Geological Survey streamgage 07010000; U.S. Geological Survey, 2020).



USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 44. Graph showing the stage time series computed with the DYNPOUND method shown with the time series of WSC-measured stage and field measurements made at Mississippi River at St. Louis, Missouri (U.S. Geological Survey streamgage 07010000; U.S. Geological Survey, 2020).



USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 45. Graph showing the stage-discharge relation at Mississippi River at St. Louis, Missouri (U.S. Geological Survey streamgage 07010000; U.S. Geological Survey, 2020), using discharge computed with the DYNPOUND method, WSC-computed discharge, and field measurements.

Table 36. Discharge computed for an event-based time series at Mississippi River at St. Louis, Missouri (U.S. Geological Survey streamgage 07010000), with the DYNPOUND method and the associated error.

[Field measurement discharge data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft^3/s, cubic foot per second; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM discharge (ft^3/s)	DYNPOUND discharge (ft^3/s)	DYNPOUND error (percent)	DYNPOUND SLE
06/10/2015	15:29	513,000	511,938	−0.207	0.00000
06/11/2015	15:09	490,000	497,769	1.59	0.00025
06/17/2015	22:52	576,000	569,071	−1.2	0.00015
06/18/2015	23:06	605,000	594,573	−1.72	0.00030
06/19/2015	17:09	633,000	636,515	0.555	0.00003
06/20/2015	16:19	672,000	652,340	−2.93	0.00088
06/21/2015	16:49	677,000	661,514	−2.29	0.00054
06/21/2015	17:12	670,000	659,106	−1.63	0.00027
06/21/2015	17:32	691,000	660,573	−4.4	0.00203
06/21/2015	17:48	693,000	661,672	−4.52	0.00214
06/21/2015	18:02	685,000	662,107	−3.34	0.00116
06/21/2015	18:15	696,000	659,500	−5.24	0.00290
06/21/2015	18:29	685,000	656,824	−4.11	0.00176
06/21/2015	18:43	688,000	654,025	−4.94	0.00256
06/21/2015	18:57	690,000	651,434	−5.59	0.00331
06/21/2015	19:10	691,000	652,637	−5.55	0.00326
06/21/2015	20:05	690,000	660,857	−4.22	0.00186
06/21/2015	20:18	687,000	659,859	−3.95	0.00162
06/21/2015	20:32	682,000	658,803	−3.4	0.00120
06/21/2015	20:46	690,000	657,760	−4.67	0.00229
06/21/2015	21:00	690,000	656,821	−4.81	0.00243
06/21/2015	21:13	689,000	657,626	−4.55	0.00217
06/21/2015	21:27	690,000	658,431	−4.58	0.00219
06/21/2015	22:47	686,000	649,689	−5.29	0.00296
06/21/2015	23:00	670,000	646,911	−3.45	0.00123
06/21/2015	23:14	664,000	647,701	−2.45	0.00062
06/21/2015	23:27	667,000	648,488	−2.78	0.00079
06/21/2015	23:43	668,000	649,448	−2.78	0.00079
06/22/2015	0:02	678,000	650,747	−4.02	0.00168
06/22/2015	0:18	668,000	652,853	−2.27	0.00053
06/22/2015	14:56	649,000	648,360	−0.0985	0.00000
06/23/2015	21:48	649,000	659,695	1.65	0.00027
06/24/2015	14:27	652,000	654,102	0.322	0.00001
06/27/2015	0:52	642,000	637,112	−0.761	0.00006
06/27/2015	18:16	662,000	642,937	−2.88	0.00085
06/28/2015	21:13	700,000	662,892	−5.3	0.00297
07/01/2015	19:17	705,000	679,881	−3.56	0.00132
07/02/2015	18:04	642,000	667,719	4.01	0.00154
07/03/2015	17:40	647,000	663,509	2.55	0.00063

Table 36. Discharge computed for an event-based time series at Mississippi River at St. Louis, Missouri (U.S. Geological Survey streamgage 07010000), with the DYNPOUND method and the associated error.—Continued

[Field measurement discharge data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft^3/s, cubic foot per second; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM discharge (ft^3/s)	DYNPOUND discharge (ft^3/s)	DYNPOUND error (percent)	DYNPOUND SLE
07/04/2015	23:57	632,000	652,874	3.3	0.00106
07/05/2015	15:22	623,000	642,516	3.13	0.00095
07/07/2015	16:07	555,000	573,325	3.3	0.00106
07/07/2015	19:37	542,000	565,195	4.28	0.00176
07/08/2015	16:07	500,000	541,323	8.26	0.00631
07/09/2015	15:44	529,000	551,805	4.31	0.00178
07/10/2015	14:47	583,000	599,233	2.78	0.00075
07/11/2015	15:47	631,000	629,878	−0.178	0.00000
07/12/2015	23:45	592,000	600,151	1.38	0.00019
07/13/2015	19:15	567,000	589,702	4	0.00154
07/14/2015	15:14	565,000	584,450	3.44	0.00115
07/15/2015	14:34	550,000	593,655	7.94	0.00583
07/16/2015	14:08	561,000	579,357	3.27	0.00104
07/17/2015	14:30	509,000	537,348	5.57	0.00294
07/18/2015	16:31	467,000	498,457	6.74	0.00425
07/19/2015	16:31	467,000	486,799	4.24	0.00172
07/21/2015	19:36	537,000	546,536	1.78	0.00031
07/24/2015	15:48	500,000	525,869	5.17	0.00254
07/25/2015	15:21	454,000	486,259	7.11	0.00471
07/26/2015	15:25	412,000	440,043	6.81	0.00434
07/27/2015	14:24	412,000	434,158	5.38	0.00274
07/28/2015	14:14	422,000	439,498	4.15	0.00165
07/29/2015	13:53	428,000	440,489	2.92	0.00083
07/31/2015	18:33	407,000	430,950	5.88	0.00327
08/03/2015	18:11	375,000	386,880	3.17	0.00097
08/05/2015	17:14	346,000	354,051	2.33	0.00053
08/06/2015	15:09	320,000	350,144	9.42	0.00810
08/07/2015	16:36	318,000	321,111	0.979	0.00009
08/11/2015	17:21	233,000	250,299	7.42	0.00513
Mean	NA	NA	NA	**0.37**	**$1.75x10^{-3}$**

Table 37. Stage computed for an event-based time series at Mississippi River at St. Louis, Missouri (U.S. Geological Survey streamgage 07010000), with the DYNPOUND method and the associated error.

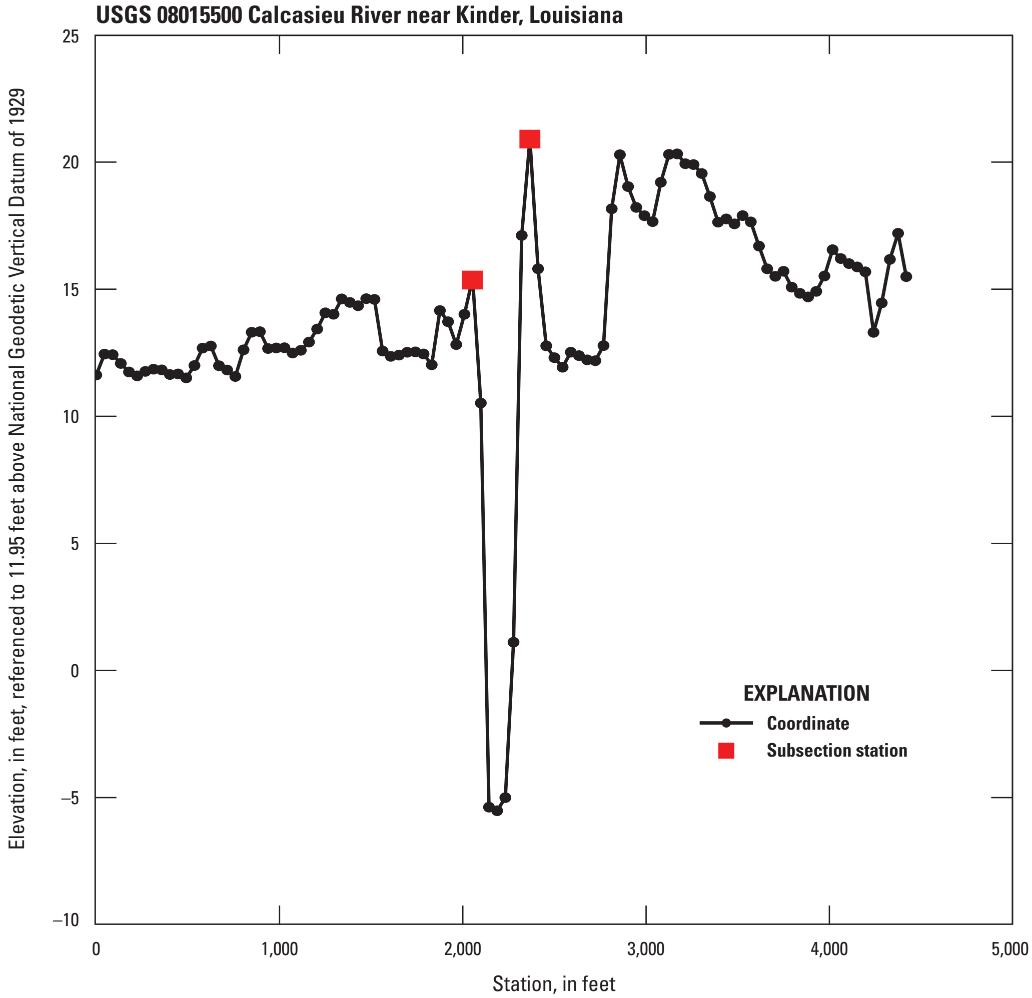
[Field measurement stage data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft, feet; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM stage (ft)	DYNPOUND stage (ft)	DYNPOUND error (percent)	DYNPOUND SLE
06/10/2015	15:29	30.07	29.00	−1.65	0.00131
06/11/2015	15:09	29.58	29.00	−0.943	0.00039
06/17/2015	22:52	32.60	31.00	−2.01	0.00253
06/18/2015	23:06	33.86	33.00	−1.91	0.00066
06/19/2015	17:09	35.34	34.00	−2.29	0.00149
06/20/2015	16:19	36.42	36.00	−1	0.00013
06/21/2015	16:49	36.87	36.00	−0.632	0.00057
06/21/2015	17:12	36.88	36.00	−0.631	0.00058
06/21/2015	17:32	36.89	36.00	−0.629	0.00060
06/21/2015	17:48	36.90	36.00	−0.634	0.00061
06/21/2015	18:02	36.91	36.00	−0.646	0.00062
06/21/2015	18:15	36.88	36.00	−0.581	0.00058
06/21/2015	18:29	36.84	36.00	−0.49	0.00053
06/21/2015	18:43	36.82	36.00	−0.453	0.00051
06/21/2015	18:57	36.79	36.00	−0.388	0.00047
06/21/2015	19:10	36.80	36.00	−0.412	0.00048
06/21/2015	20:05	36.85	36.00	−0.518	0.00054
06/21/2015	20:18	36.84	36.00	−0.495	0.00053
06/21/2015	20:32	36.83	36.00	−0.472	0.00052
06/21/2015	20:46	36.82	36.00	−0.45	0.00051
06/21/2015	21:00	36.82	36.00	−0.453	0.00051
06/21/2015	21:13	36.83	36.00	−0.474	0.00052
06/21/2015	21:27	36.83	36.00	−0.469	0.00052
06/21/2015	22:47	36.75	36.00	−0.332	0.00043
06/21/2015	23:00	36.70	36.00	−0.222	0.00037
06/21/2015	23:14	36.69	36.00	−0.217	0.00036
06/21/2015	23:27	36.68	36.00	−0.212	0.00035
06/21/2015	23:43	36.66	36.00	−0.185	0.00033
06/22/2015	0:02	36.67	36.00	−0.24	0.00034
06/22/2015	0:18	36.68	36.00	−0.277	0.00035
06/22/2015	14:56	36.45	36.00	−0.433	0.00015
06/23/2015	21:48	36.65	36.00	−0.804	0.00032
06/24/2015	14:27	36.65	36.00	−0.528	0.00032
06/27/2015	0:52	35.94	35.00	−0.736	0.00070
06/27/2015	18:16	36.05	35.00	−1.14	0.00087
06/28/2015	21:13	36.89	36.00	−0.675	0.00060
07/01/2015	19:17	37.95	38.00	0.842	0.00000
07/02/2015	18:04	37.37	37.00	0.276	0.00010
07/03/2015	17:40	37.17	37.00	−0.145	0.00002
07/04/2015	23:57	36.69	36.00	−0.237	0.00036

Table 37. Stage computed for an event-based time series at Mississippi River at St. Louis, Missouri (U.S. Geological Survey streamgage 07010000), with the DYNPOUND method and the associated error.—Continued

[Field measurement stage data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft, feet; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM stage (ft)	DYNPOUND stage (ft)	DYNPOUND error (percent)	DYNPOUND SLE
07/05/2015	15:22	36.21	36.00	−0.449	0.00003
07/07/2015	16:07	33.21	32.00	−0.733	0.00138
07/07/2015	19:37	32.93	32.00	−0.63	0.00082
07/08/2015	16:07	31.58	31.00	−0.96	0.00034
07/09/2015	15:44	31.87	31.00	−1.89	0.00077
07/10/2015	14:47	34.03	33.00	−2.23	0.00094
07/11/2015	15:47	35.46	34.00	−1.43	0.00177
07/12/2015	23:45	34.47	34.00	−0.892	0.00019
07/13/2015	19:15	33.78	33.00	−1.17	0.00055
07/14/2015	15:14	33.63	33.00	−1.23	0.00036
07/15/2015	14:34	33.87	33.00	−1.39	0.00068
07/16/2015	14:08	33.45	33.00	−1.03	0.00018
07/17/2015	14:30	31.75	31.00	−0.426	0.00057
07/18/2015	16:31	29.65	29.00	−0.699	0.00049
07/19/2015	16:31	28.88	28.00	−1.09	0.00096
07/21/2015	19:36	31.81	31.00	−1.66	0.00067
07/24/2015	15:48	31.00	30.00	−0.866	0.00108
07/25/2015	15:21	29.16	29.00	−0.43	0.00003
07/26/2015	15:25	26.83	26.00	−0.033	0.00099
07/27/2015	14:24	26.15	25.00	−1.14	0.00202
07/28/2015	14:14	26.53	26.00	−1.05	0.00041
07/29/2015	13:53	26.6	26.00	−1.01	0.00052
07/31/2015	18:33	26.16	25.00	−1.67	0.00206
08/03/2015	18:11	23.73	23.00	−1.73	0.00098
08/05/2015	17:14	21.80	21.00	−1.78	0.00140
08/06/2015	15:09	21.56	21.00	−2.36	0.00069
08/07/2015	16:36	19.80	19.00	−2.11	0.00170
08/11/2015	17:21	14.90	14.00	−4.98	0.00388
Mean	NA	NA	NA	**−0.90**	**7.08×10^{-4}**



USGS, U.S. Geological Survey.

Figure 46. Graph showing the cross section used to compute the stage and discharge time series at Calcasieu River near Kinder, Louisiana (U.S. Geological Survey streamgage 08015500; U.S. Geological Survey, 2020).

Table 38. Stage and roughness coefficient values used to calibrate the DYNPOUND method at Calcasieu River near Kinder, Louisiana (U.S. Geological Survey streamgage 08015500).

[Data from Domanski and others, 2025. ft, foot]

Stage (ft)	Roughness coefficient (*n*-value)
2.00	0.15
4.00	0.09
11.00	0.07
15.00	0.064
20.00	0.087

Table 39. Discharge calibration results for the DYNPOUND ratings at Calcasieu River near Kinder, Louisiana (U.S. Geological Survey streamgage 08015500).

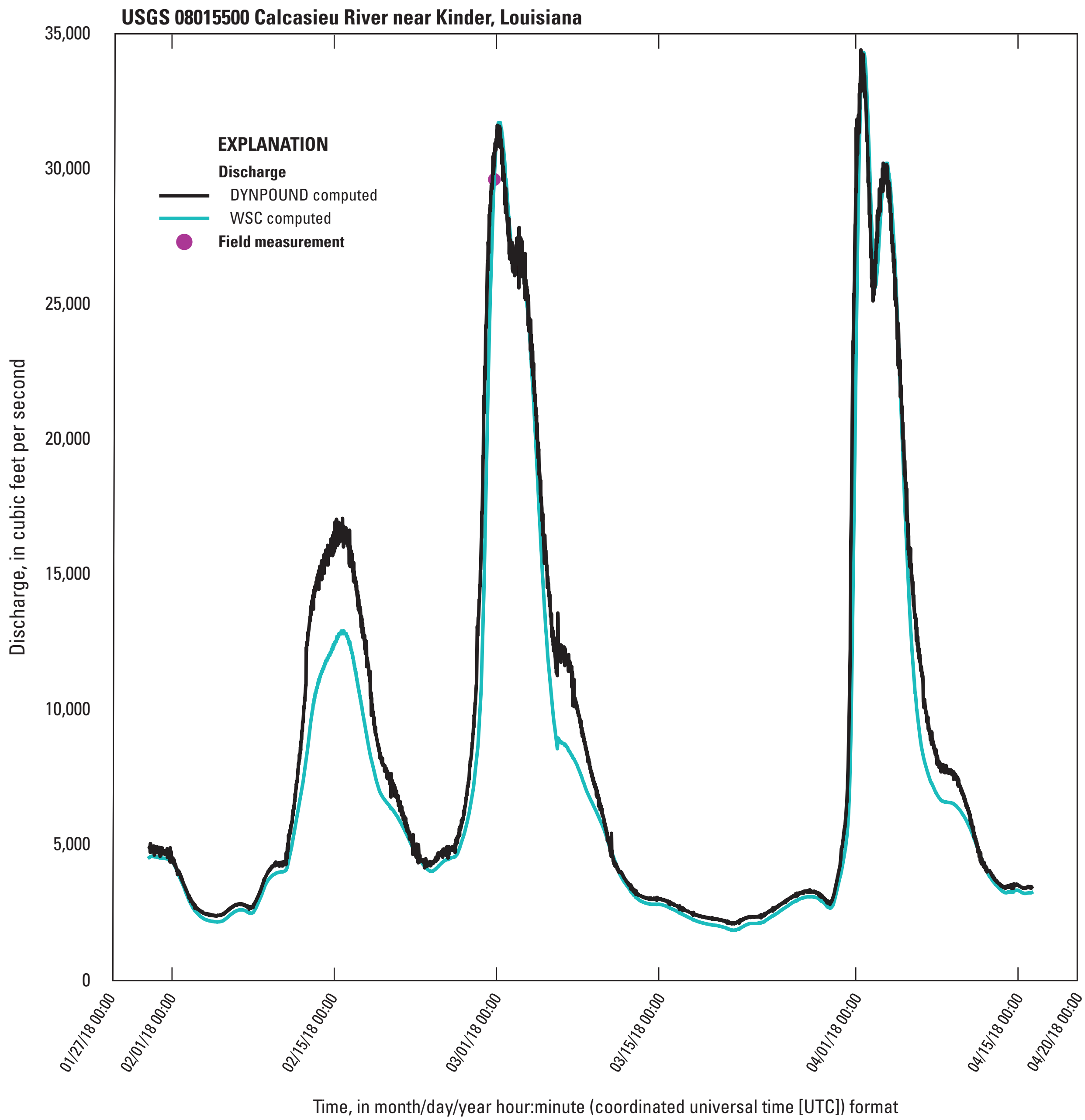
[Field measurement discharge data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft^3/s, cubic foot per second; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM discharge (ft^3/s)	DYNPOUND discharge (ft^3/s)	DYNPOUND error (percent)	DYNPOUND SLE
10/2/2018	16:38	889	1,283	44.40	0.13459
02/26/2019	18:31	2,860	3,178	11.10	0.01112
05/7/2019	19:43	1,960	2,423	23.60	0.04497
07/9/2019	16:19	734	1,200	63.60	0.24164
09/10/2019	14:08	454	664	46.30	0.14454
Mean	NA	NA	NA	**37.80**	**1.15×10^{-1}**

Table 40. Stage calibration results for the DYNPOUND ratings at Calcasieu River near Kinder, Louisiana (U.S. Geological Survey streamgage 08015500).

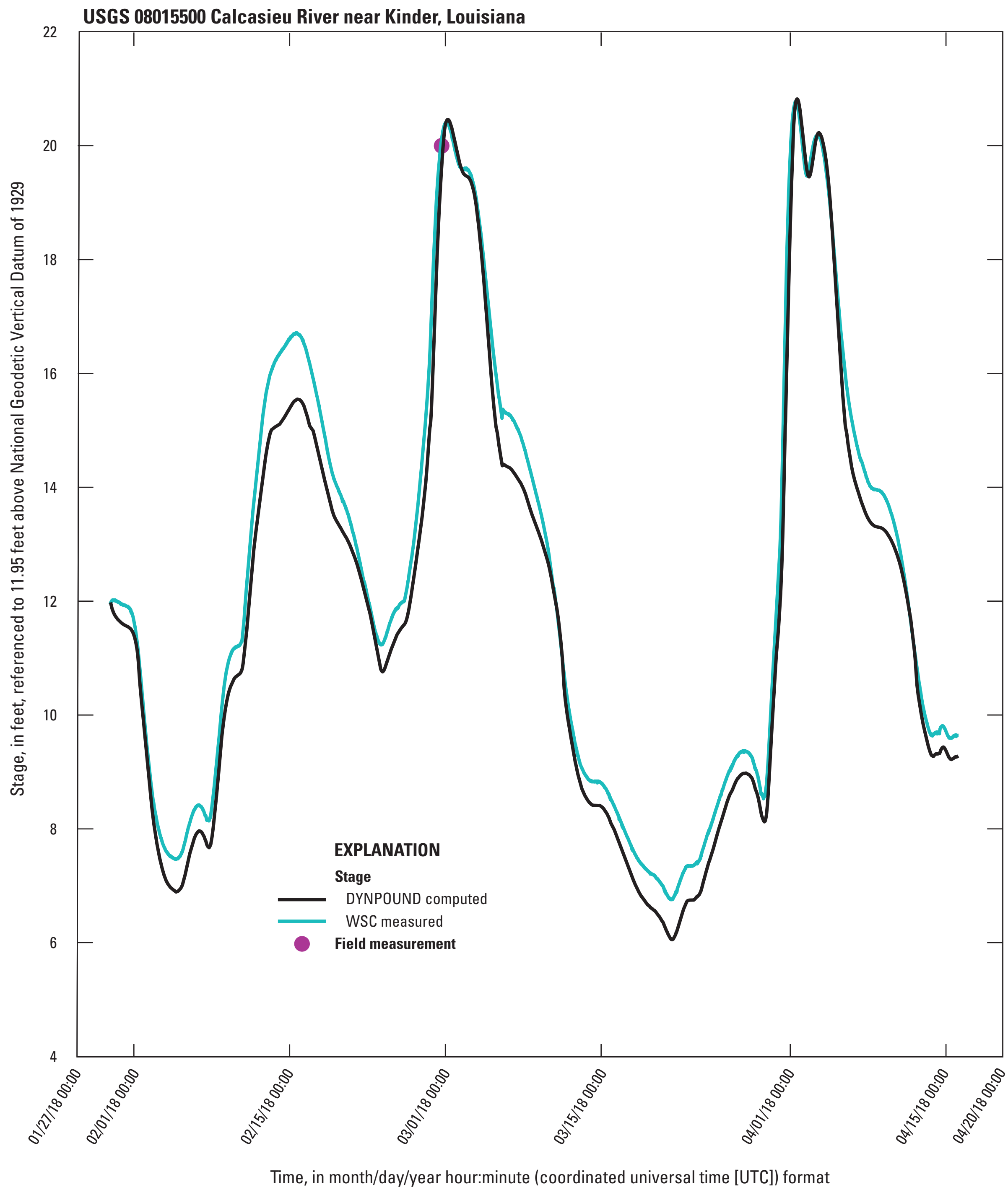
[Field measurement stage data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft, feet; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM stage (ft)	DYNPOUND stage (ft)	DYNPOUND error (percent)	DYNPOUND SLE
10/2/2018	16:38	4.22	3.00	−18.00	0.11643
02/26/2019	18:31	9.14	8.00	−3.76	0.01775
05/7/2019	19:43	7.63	7.00	−6.16	0.00743
09/10/2019	14:08	2.75	2.00	−20.80	0.10141
Mean	NA	NA	NA	**−12.18**	**6.08×10^{-2}**



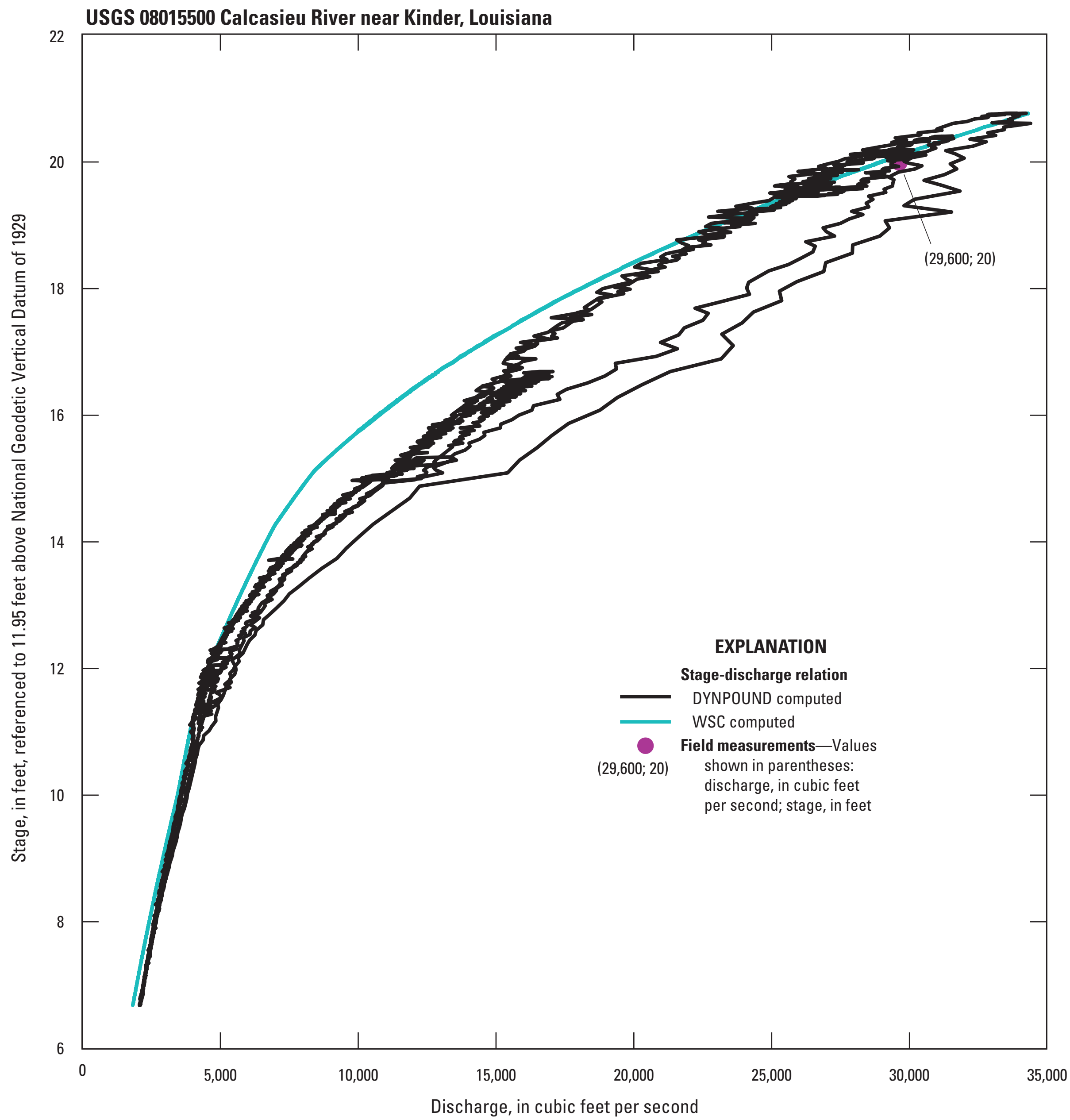
USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 47. Graph showing the discharge time series computed with the DYNPOUND method shown with the time series of WSC-computed discharge and field measurements made at Calcasieu River near Kinder, Louisiana (U.S. Geological Survey streamgage 08015500; U.S. Geological Survey, 2020).



USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 48. Graph showing the stage time series computed with the DYNPOUND method shown with the time series of WSC-measured stage and field measurements made at Calcasieu River near Kinder, Louisiana (U.S. Geological Survey streamgage 08015500; U.S. Geological Survey, 2020).



USGS, U.S.Geological Survey
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 49. Graph showing the stage-discharge relation at Calcasieu River near Kinder, Louisiana (U.S. Geological Survey streamgage 08015500; U.S. Geological Survey, 2020), using discharge computed with the DYNPOUND method, WCS-computed discharge, and field measurements.

Table 41. Discharge computed for an event-based time series at Calcasieu River near Kinder, Louisiana (U.S. Geological Survey streamgage 08015500), with the DYNPOUND methods and the associated error.

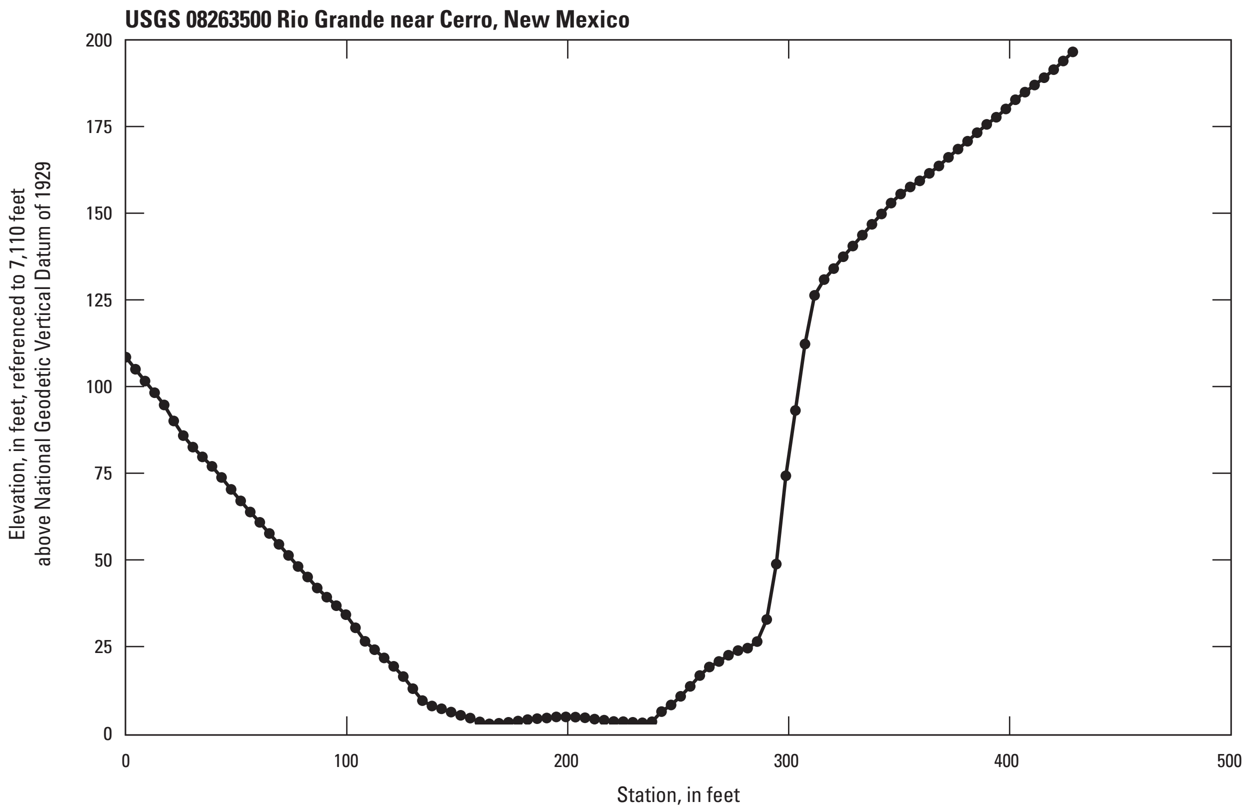
[Field measurement discharge data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft^3/s, cubic foot per second; SLE, squared logarithmic error]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM discharge (ft^3/s)	DYNPOUND discharge (ft^3/s)	DYNPOUND error (percent)	DYNPOUND SLE
02/28/2018	17:22	29,600	30,255	2.21	0.00048

Table 42. Stage computed for an event-based time series at Calcasieu River near Kinder, Louisiana (U.S. Geological Survey streamgage 08015500), with the DYNPOUND methods and the associated error.

[Field measurement stage data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft, foot; SLE, squared logarithmic error]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM stage (ft)	DYNPOUND stage (ft)	DYNPOUND error (percent)	DYNPOUND SLE
02/28/2018	17:22	20.00	19.00	−1.89	0.00263



USGS, U.S. Geological Survey.

Figure 50. Graph showing the cross section used to compute the stage and discharge time series at Rio Grande near Cerro, New Mexico (U.S. Geological Survey streamgage 08263500; U.S. Geological Survey, 2020).

Table 43. Stage and roughness coefficient values used to calibrate the DYNPOUND method at Rio Grande near Cerro, New Mexico (U.S. Geological Survey streamgage 08263500).

[Data from Domanski and others, 2025, ft, foot]

Stage (ft)	Roughness coefficient (*n*-value)
0.00	0.064
4.00	0.128
6.00	0.127
10.00	0.122

Table 44. Discharge calibration results for the DYNPOUND ratings at Rio Grande near Cerro, New Mexico (U.S. Geological Survey streamgage 08263500).

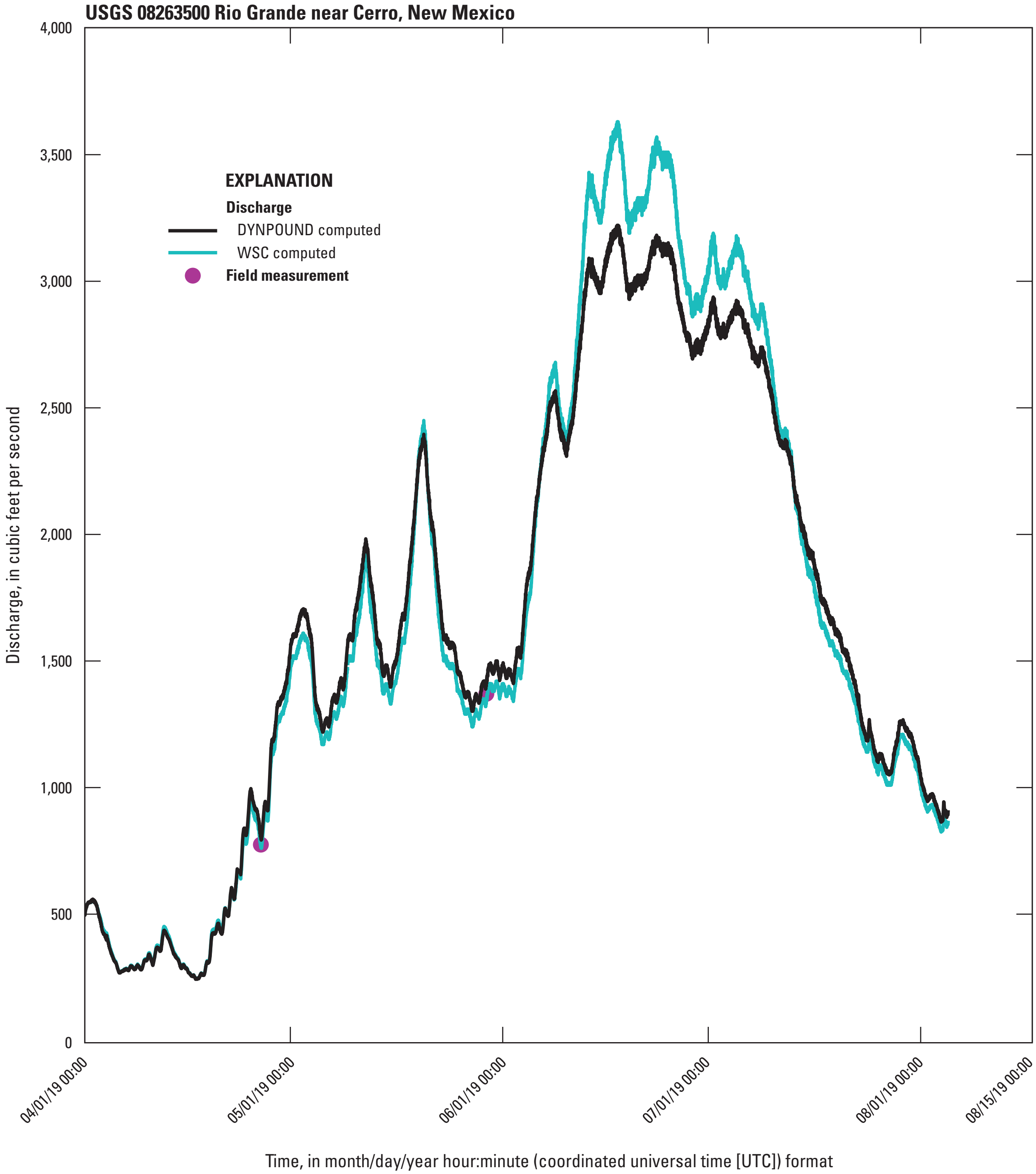
[Field measurement discharge data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft^3/s, cubic foot per second; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM discharge (ft^3/s)	DYNPOUND discharge (ft^3/s)	DYNPOUND error (percent)	DYNPOUND SLE
10/09/2014	15:02	306	307	0.624	0.00001
12/04/2014	17:25	451	433	−3.92	0.00166
01/206/2015	17:16	273	286	5.03	0.00216
02/26/2015	16:16	349	349	0.261	0.00000
04/14/2015	17:59	189	191	1.33	0.00011
07/30/2015	16:18	381	391	2.66	0.00067
08/20/2015	14:50	167	161	−3.57	0.00134
Mean	NA	NA	NA	**0.35**	**8.51×10^{-4}**

Table 45. Stage calibration results for the DYNPOUND ratings at Rio Grande near Cerro, New Mexico (U.S. Geological Survey streamgage 08263500).

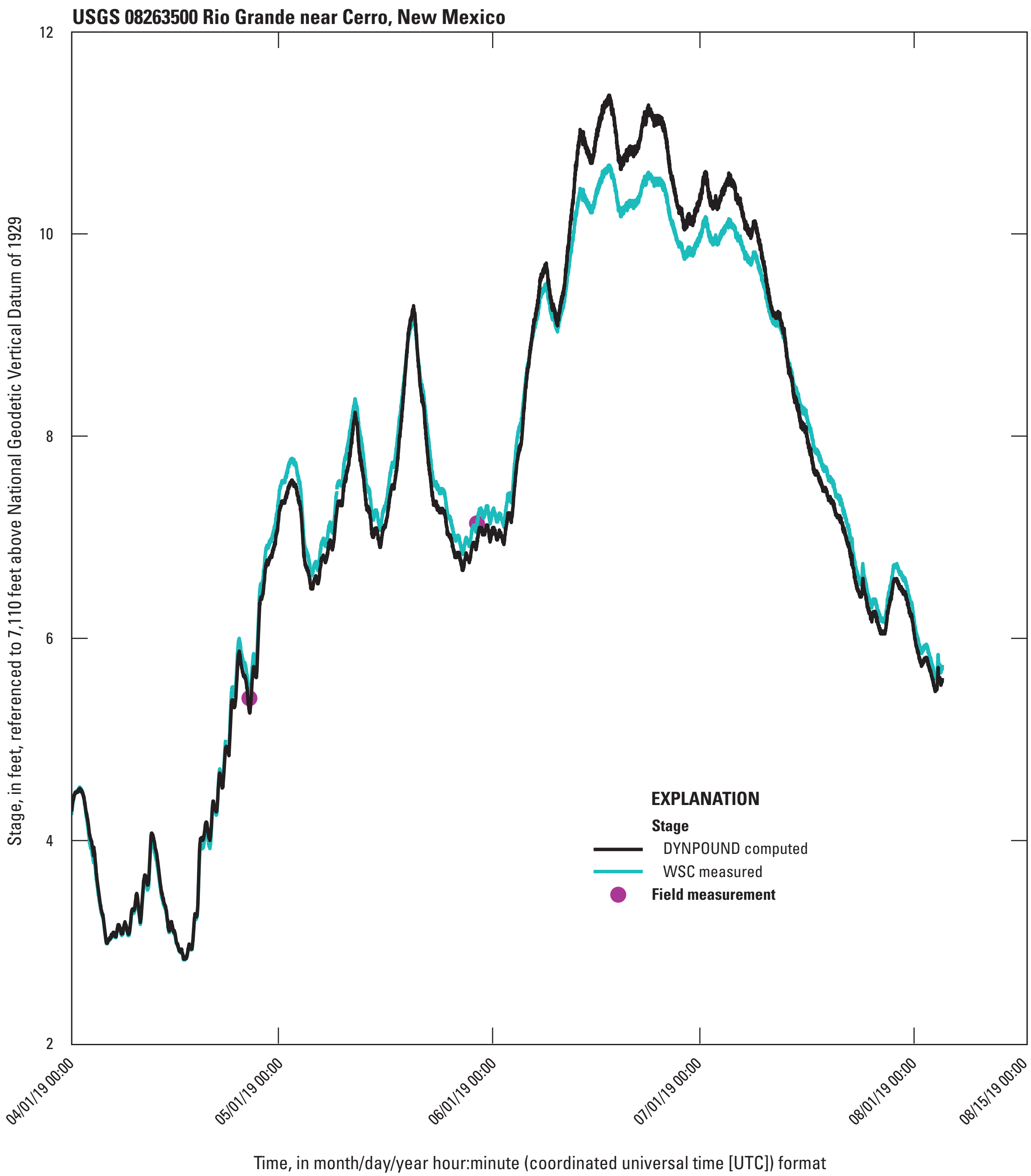
[Field measurement stage data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft, foot; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM stage (ft)	DYNPOUND stage (ft)	DYNPOUND error (percent)	DYNPOUND SLE
10/09/2014	15:02	3.23	3.00	−0.782	0.00546
12/04/2014	17:25	4.00	4.00	1.41	0.00000
01/26/2015	17:16	3.09	3.00	−2.16	0.00087
02/26/2015	16:16	3.49	3.00	−0.503	0.02289
04/14/2015	17:59	2.48	2.00	−0.661	0.04627
07/30/2015	16:18	3.75	3.00	−1.63	0.04979
08/20/2015	14:50	2.27	2.00	1.53	0.01604
Mean	NA	NA	NA	**−0.40**	**2.02×10^{-2}**



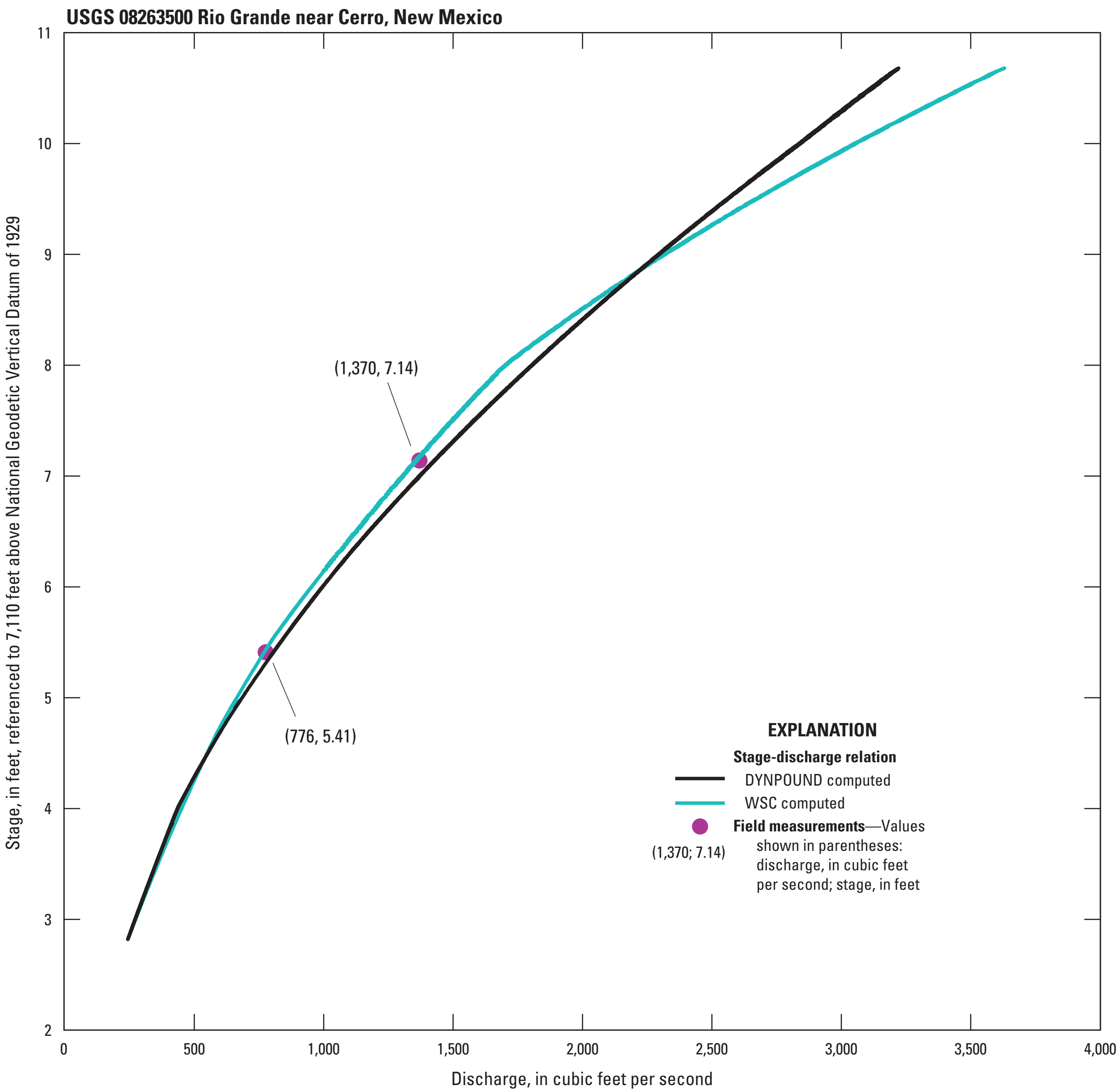
USGS, U.S.Geological Survey
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 51. Graph showing the discharge time series computed with the DYNPOUND method shown with the time series of WSC-computed discharge and field measurements made at Rio Grande near Cerro, New Mexico (U.S. Geological Survey streamgage 08263500; U.S. Geological Survey, 2020).



USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 52. Graph showing stage time series computed with the DYNPOUND method shown with the time series of WSC-measured stage and field measurements made at Rio Grande near Cerro, New Mexico (U.S. Geological Survey streamgage 08263500; U.S. Geological Survey, 2020).



USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 53. Graph showing the stage-discharge relation at Rio Grande near Cerro, New Mexico (U.S. Geological Survey streamgage 08263500; U.S. Geological Survey, 2020), using discharge computed with the DYNPOUND method, WSC-computed discharge, and field measurements.

Table 46. Discharge computed with the DYNPOUND method and associated error for an event-based time series at Rio Grande near Cerro, New Mexico (U.S. Geological Survey streamgage 08263500).

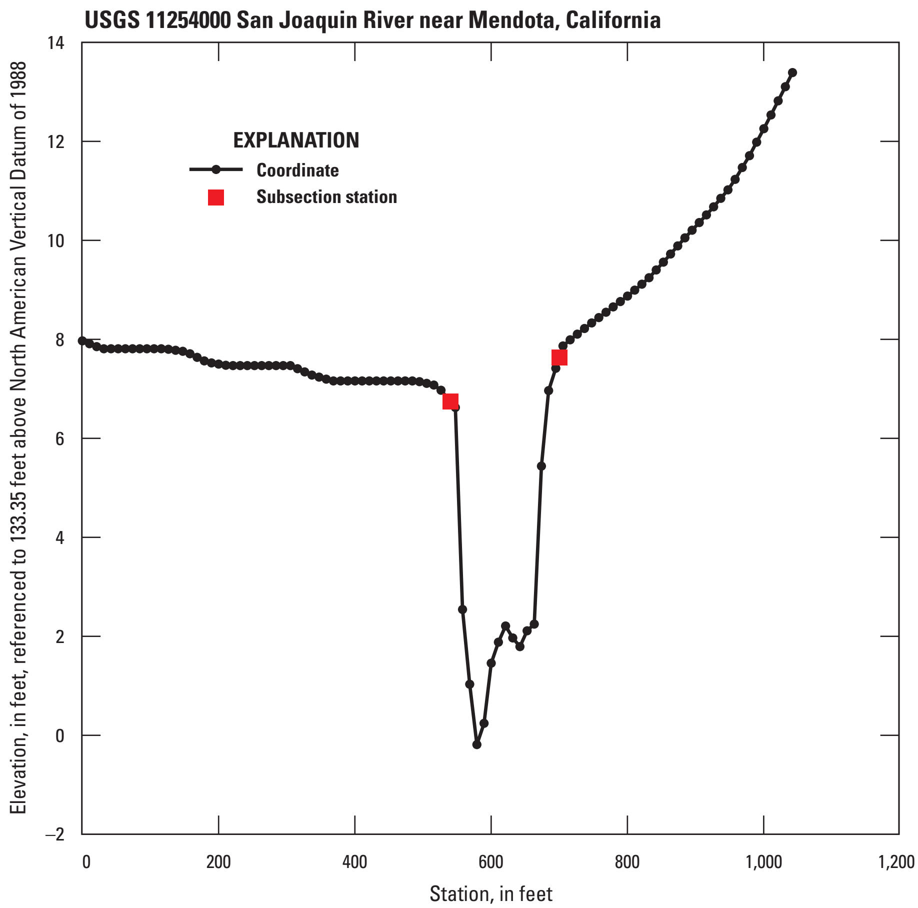
[Field measurement discharge data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft^3/s, cubic foot per second; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM discharge (ft^3/s)	DYNPOUND discharge (ft^3/s)	DYNPOUND error (percent)	DYNPOUND SLE
04/26/2019	16:20	776	801	3.34	0.00101
05/29/2019	16:00	1,370	1,429	4.34	0.00178
Mean	NA	NA	NA	**3.84**	**1.39×10^{-3}**

Table 47. Stage computed with the DYNPOUND method and associated error for an event-based time series at Rio Grande near Cerro, New Mexico (U.S. Geological Survey streamgage 08263500).

[Field measurement stage data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft, foot; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM stage (ft)	DYNPOUND stage (ft)	DYNPOUND error (percent)	DYNPOUND SLE
04/26/2019	16:20	5.41	5.00	−2.26	0.00621
05/29/2019	16:00	7.14	6.00	−2.38	0.03026
Mean	NA	NA	NA	**−2.32**	**1.82×10^{-2}**



USGS, U.S. Geological Survey.

Figure 54. Graph showing the cross section used to compute the stage and discharge time series at San Joaquin River Near Mendota, California (U.S. Geological Survey streamgage 11254000; U.S. Geological Survey, 2020).

Table 48. Stage and roughness coefficient values used to calibrate the DYNPOUND method at San Joaquin River near Mendota, California (U.S. Geological Survey streamgage 11254000).

[Data from Domanski and others, 2025. ft, foot]

Stage (ft)	Roughness coefficient (*n*-value)
0.00	0.031
4.00	0.041
8.00	0.048
10.00	0.07
15.00	0.08

Table 49. Discharge calibration results for the DYNPOUND ratings at San Joaquin River near Mendota, California (U.S. Geological Survey streamgage 11254000).

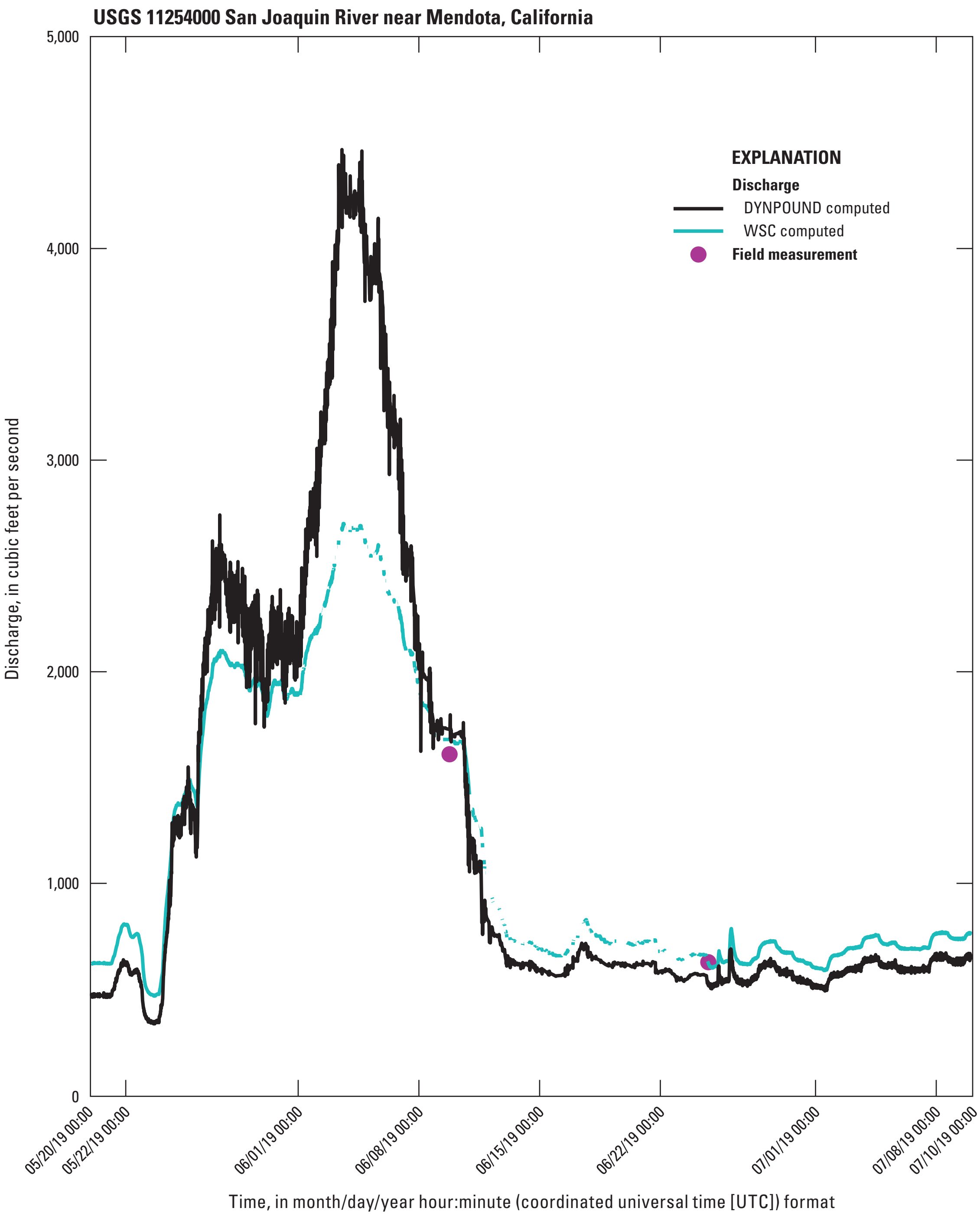
[Field measurement discharge data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft^3/s, cubic foot per second; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM discharge (ft^3/s)	DYNPOUND discharge (ft^3/s)	DYNPOUND error (percent)	DYNPOUND SLE
10/08/2014	16:51	312	257	−17.4	0.03761
11/03/2014	23:13	144	132	−7.66	0.00757
12/18/2014	19:43	103	97	−5.72	0.00360
01/27/2015	1:10	57	57	0.297	0.00000
03/17/2015	0:13	108	97	−10.1	0.01154
04/13/2015	22:49	131	119	−9	0.00923
05/29/2015	17:35	411	409	−0.373	0.00002
07/28/2015	22:56	431	459	6.57	0.00396
08/31/2015	18:23	263	266	1.37	0.00013
09/01/2015	18:17	274	255	−6.88	0.00516
Mean	NA	NA	NA	**−4.89**	**7.88×10^{-3}**

Table 50. Stage calibration results for the DYNPOUND ratings at San Joaquin River near Mendota, California (U.S. Geological Survey streamgage 11254000).

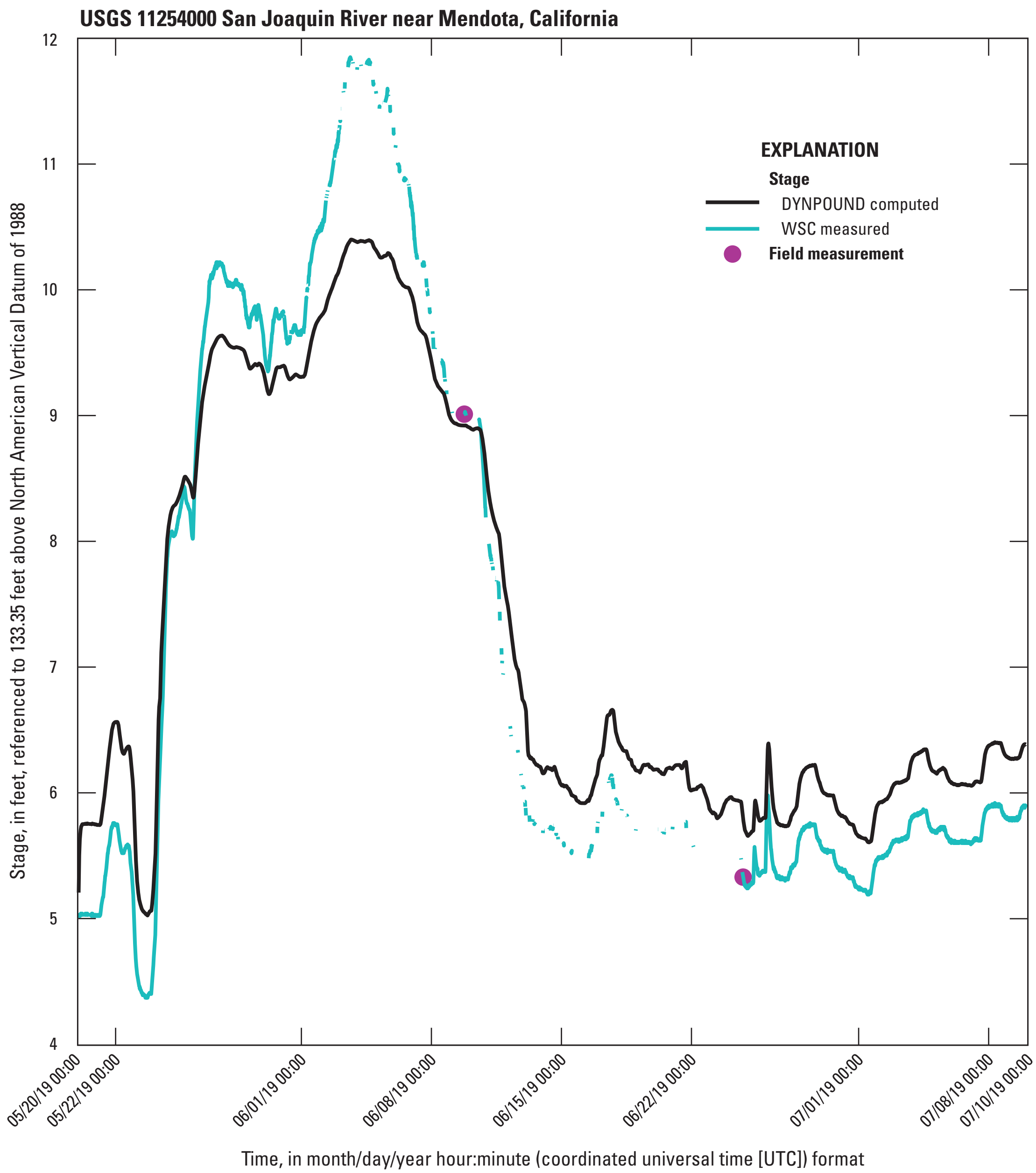
[Field measurement stage data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft, foot; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM stage (ft)	DYNPOUND stage (ft)	DYNPOUND error (percent)	DYNPOUND SLE
10/08/2014	16:51	3.91	4.00	6.99	0.00052
11/03/2014	23:13	3.08	3.00	2.48	0.00069
12/18/2014	19:43	2.77	2.00	2.09	0.10608
01/27/2015	1:10	2.40	2.00	0.196	0.03324
03/17/2015	0:13	2.77	2.00	2.08	0.10608
04/13/2015	22:49	2.95	3.00	2.59	0.00028
05/29/2015	17:35	4.73	4.00	2.32	0.02810
07/28/2015	22:56	4.98	4.00	−2.44	0.04802
08/31/2015	18:23	3.94	4.00	1.76	0.00023
09/01/2015	18:17	3.88	3.00	2.19	0.06616
Mean	NA	NA	NA	**2.03**	**3.89×10^{-2}**



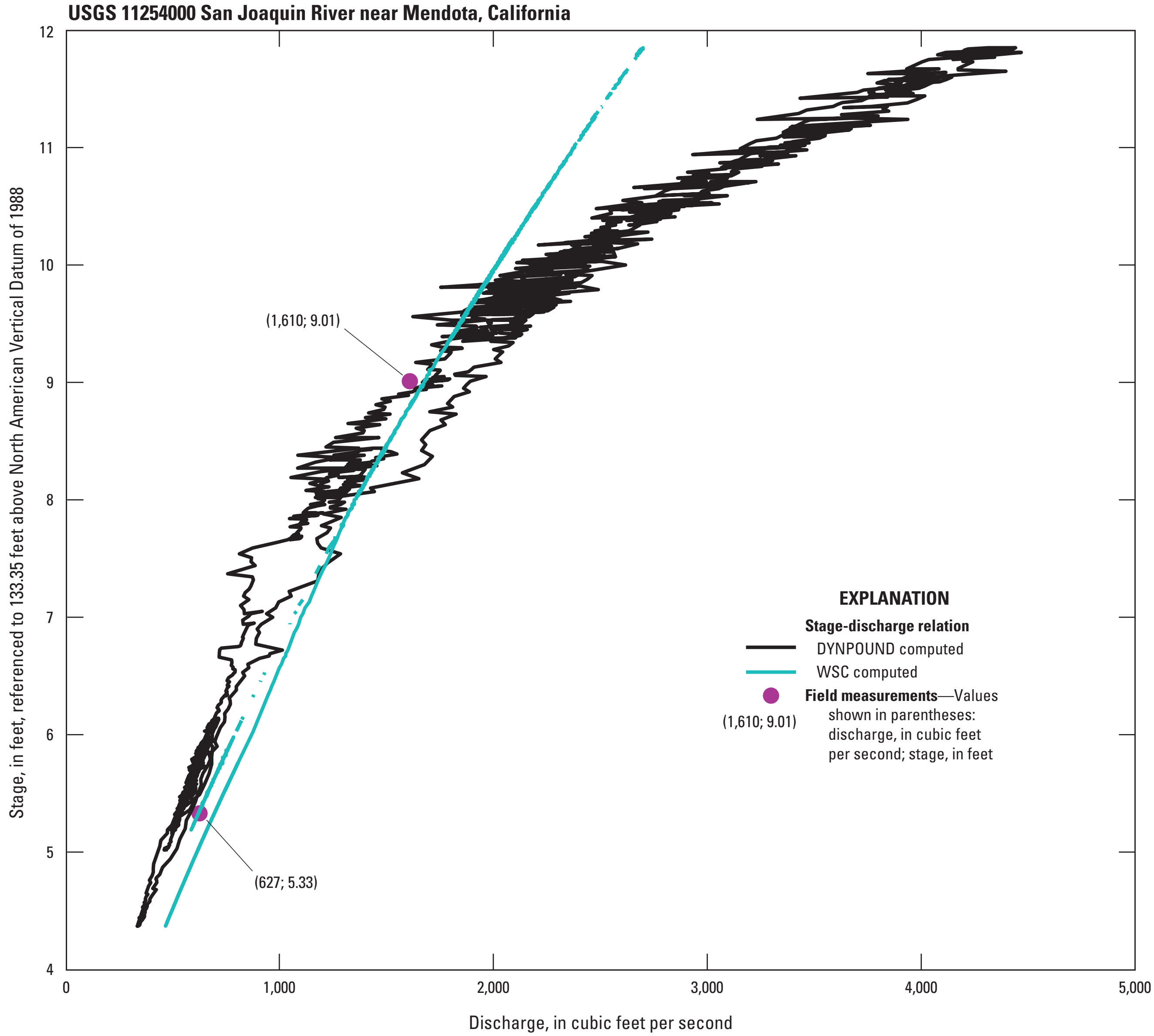
USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 55. Graph showing the discharge time series computed with the DYNPOUND method shown with the time series of WSC-computed discharge and field measurements made at San Joaquin River near Mendota, California (U.S. Geological Survey streamgage 11254000; U.S. Geological Survey, 2020).



USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 56. Graph showing the stage time series computed with the DYNPOUND method shown with the time series of WSC-measured stage and field measurements made at San Joaquin River near Mendota, California (U.S. Geological Survey streamgage 11254000; U.S. Geological Survey, 2020).



USGS, U.S. Geological Survey.
DYNPOUND, A dynamic rating method which accommodates compound and compact channel geometry.
WSC, U.S.Geological Survey Water Science Center.

Figure 57. Graph showing the stage-discharge relation at San Joaquin River near Mendota, California (U.S. Geological Survey streamgage 11254000; U.S. Geological Survey, 2020), using discharge computed with the DYNPOUND method, WSC-computed discharge, and field measurements.

Table 51. Discharge computed with the DYNPOUND method and associated error for an event-based time series at San Joaquin River near Mendota, California (U.S. Geological Survey streamgage 11254000).

[Field measurement discharge data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft^3/s, cubic foot per second; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM discharge (ft^3/s)	DYNPOUND discharge (ft^3/s)	DYNPOUND error (percent)	DYNPOUND SLE
06/09/2019	18:32	1,610	1,726	7.26	0.00484
06/24/2019	18:40	627	528	−15.8	0.02953
Mean	NA	NA	NA	**−4.27**	**1.72×10^{-2}**

Table 52. Stage computed with the DYNPOUND method and associated error for an event-based time series at San Joaquin River near Mendota, California (U.S. Geological Survey streamgage 11254000).

[Field measurement stage data from U.S. Geological Survey, 2020. DYNPOUND, the newly developed method that solves for stage and discharge in compact and compound channels. MM, month; DD, day; YYYY, year; UTC, coordinated universal time; FM, field measurement; ft, foot; SLE, squared logarithmic error; NA, not applicable]

Measurement date (MM/DD/YYYY)	Measurement time (UTC)	FM stage (ft)	DYNPOUND stage (ft)	DYNPOUND error (percent)	DYNPOUND SLE
06/09/2019	18:32	9.01	8.00	−0.994	0.01414
06/24/2019	18:40	5.33	5.00	8.81	0.00408
Mean	NA	NA	NA	**3.91**	**9.11×10^{-3}**

Dynamic Rating Application Guidelines

The DYNPOUND method may be improved by verifying the accuracy of and correcting the representation of the cross-section geometry and discharge conditions that affect rating development. The goal of developing this method is to provide a viable and cost-effective alternative for rating complex sites, therefore lowering usage of less accurate surrogate methods and the need for expensive index velocity equipment. Through the course of developing and testing the dynamic rating method, the following are suggested best practices for using this method.

- Select an appropriate cross section to characterize the channel geometry described as follows:
    - Select a reach where the flow is approximately one-dimensional (flow is orthogonal to the banks);
    - The flow direction should be well established in a one-dimensional nature. An ideal cross section would be one that is straight at least 100 times the bankfull depth upstream and 100 times the bankfull depth downstream; and
    - Within a river reach, avoid cross sections with abrupt changes in cross-sectional geometry.
- If possible, select multiple flood events to compute and assess the value of *r* in equation 20;
- Create the channel’s cross-section geometry properties and ensure that the stage/conveyance curve is smooth by subdividing the cross section;
- Choose a series of high-flow events to calibrate the values of Manning’s stage and roughness coefficients by the DYNPOUND method. Evaluate the method using a different set of high-flow events; and
- Although DYNPOUND was written for complex channels (those with floodplains), the method may perform well for compact channels (those without floodplains).

Summary

Ratings are used for a variety of reasons in water-resources investigations, but a predominant use of ratings is at streamgages, where autonomously measured stage is converted to discharge by use of a stage-discharge rating. Measuring discharge continuously is challenging and expensive and, therefore, discharge is typically determined through surrogate measures of one or more variables such as stage, water-surface slope, rate of change in stage, or index velocity collected at a streamgage. The discharge rating is developed and calibrated using discharge measurements made by field personnel. The simplest and most common rating relates discharge to stage of the river (simple rating).

For some sites, simple ratings work well. Simple ratings do not work for streamgages on low-gradient streams, streams with variable backwater, streams with large amounts of channel or overbank storage, streams with highly unsteady flow, or streams with highly mobile beds. Hydrologists and engineers have long recognized that hysteresis (loops) is in relations between stage and discharge. The hysteresis is sometimes small enough to be hidden within the error of the measurements. Likewise, when the discharge event period is large enough, the hysteresis averages out. In these cases, a dynamic rating is often needed. A dynamic rating relates discharge to stage and other variables because of the lack of a unique, univariate relation between stage and discharge at these sites. This type of rating accounts for a variable energy slope caused by unsteady flow accelerations. The newly improved dynamic rating method (DYNPOUND), which was developed for compact and compound channel geometry, is described in this report. This report explains the derivation of DYNPOUND's mathematical formulation and how its numerical solution method was developed. The improved DYNPOUND method includes the functionality to set pairs of stage and Manning's roughness coefficients (*n*-values) in cases where flow shifts dramatically, within cross sections or subsections, without notable changes in channel geometry.

Stage and discharge time series computed with the DYNPOUND rating method were compared to the simulated stage and discharge time series computed from the one-dimensional unsteady shallow water equations. These simulated time series were generated using one-dimensional hydraulic modeling software (HEC-RAS) and a prismatic channel created from a compound cross section. Four scenarios were designed for analysis using two different bed slopes and four different hydrographs that serve as the upstream boundary conditions. The hydrographs were created to capture the range of unsteadiness in the flow conditions. The mean squared logarithmic error (MSLE) between the DYNPOUND-computed discharge and HEC-RAS-computed discharge ranged from 2.747×10^{-7} to 2.02×10^{-4}. The MSLE between the DYNPOUND-computed stage and HEC-RAS-computed stage ranged from 7.24×10^{-8} to 2.60×10^{-5}.

Results computed with the DYNPOUND method were then compared to time series of WSC-computed discharge, WSC-measured stage, and field data previously collected at 10 USGS streamgage sites. A cross-section geometry for each streamgage site was created by combining "station, elevation" coordinates from ADCP discharge measurements with digital elevation data. Coordinate data were extracted from previously collected discharge measurements. Bed slopes for the sites were estimated from topographic maps due to a lack of existing data. The DYNPOUND computation is quite sensitive to bed slope input values, so more accurate values may improve results. WSC-measured stage and WSC-computed discharge time series, required for method computation, were obtained from the U.S. Geological Survey National Water Information System database (NWIS). Field measurements, which were used to calibrate and evaluate the performance of the DYNPOUND method, were also obtained from NWIS.

Dynamic ratings were developed and calibrated for each site. Calibration was done by adjusting *n*-values and adding subsections to the cross section to minimize the MSLE with respect to field measurements for the respective site. DYNPOUND successfully computed discharge and stage for each site. The DYNPOUND discharge calibration had a MSLE range of 8.51×10^{-4} to 1.36×10^{-1}, and the stage calibration had a MSLE range of 1.30×10^{-3} to 1.17×10^{-1}.

One event-based period was chosen for each site to evaluate the calibration of DYNPOUND; the calibrated rating was used, along with the stage time series from the period, to compute a discharge time series and vice versa. DYNPOUND successfully computed discharge and stage for the entire event at nine of the sites; it did not successfully compute a stage time series at one site. The range of MSLE for the DYNPOUND-computed event discharge was from 4.79×10^{-4} to 2.30×10^{-2}. For the DYNPOUND-computed event stage, the MSLE was from 6.19×10^{-4} to 1.82×10^{-2}.

Acknowledgments

The U.S. Geological Survey field offices of the California Water Science Center, Caribbean-Florida Water Science Center, Central Midwest Water Science Center, Dakota Water Science Center, Lower Mississippi-Gulf Water Science Center, Nebraska Water Science Center, New England Water Science Center, New Mexico Water Science Center, Ohio-Kentucky-Indiana Water Science Center, Oregon Water Science Center, Upper Midwest Water Science Center, Utah Water Science Center, Virginia and West Virginia Water Science Center, and Washington Water Science Center were instrumental in providing site data for this project.

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For more information about this publication, contact
Director, Lower Mississippi-Gulf Water Science Center
U.S. Geological Survey
640 Grassmere Park, Suite 100
Nashville, TN 37211
For additional information, visit https://www.usgs.gov/centers/lmg-water/
Publishing support provided by Lafayette Publishing Service Center

USGS

Domanski and others—**Dynamic Rating Method for Computing Discharge and Stage from Time-Series Data**—SIR 2024–5129

ISSN 2328-0328 (online)
https://doi.org/10.3133/sir20245129