Verification of Step-Backwater Computations On Ephemeral Streams in Northeastern Wyoming

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By Stanley A. Druse

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Abstract

Step-backwater computations were verified by subsequent discharge measurements at three ephemeral streamflow stations in northeastern Wyoming. The standard step-backwater method for gradually varied, subcritical flow was used in computing the water-surface profiles and stage-discharge ratings. Step-backwater computations were made at selected intervals from 1 through 1,000 cubic feet per second on Lodgepole Creek, through 150 cubic feet per second on Raven Creek, and through 600 cubic feet per second on Sand Creek. Stage-discharge rating curves and discharge measurements are illustrated for the three sites, with lines of 15-percent departure from the rating curves drawn to measure accuracy of the results. All discharge measurements showed departures of less than 15 percent at the high end of the rating curves.

INTRODUCTION

Streamgaging stations were installed during August and September 1977 at 11 sites in northeastern Wyoming in a project area for measuring streamflow in basins where there is active or potential strip mining of coal (fig. 1). Objectives of the project are to determine the characteristics of the regional water-resource system and to detect and document changes in the system that may be associated with coal mining. To accomplish these objectives, a few gaging stations had to be located at remote sites. Many of the stations are on ephemeral streams where flood flows of short duration make timely access to the sites during high flow very difficult. Roads are poor and sometimes impassable during wet weather. These access problems seemed particularly acute at three sites, and it was anticipated that few, if any, high-flow current-meter measurements would be made. Timely definition of the high ends of the stage-discharge curves was considered to be of high priority, so step-backwater methods were used to aid in developing stage-discharge relations.

During widespread flooding in March and May 1978, high-flow current-meter measurements were made at most streamgaging stations, including two where previous step-water computations had been made. At a third site, two slope-area measurements of peak flow were made at reaches independent of each other and independent of the step-backwater reach. The purpose of this report is to document the favorable results of the step-backwater computations at the three project stations and to substantiate the validity of using the method.

Methods of Investigation

The standard step-backwater method for gradually varied, subcritical flow was used in computing the water-surface profiles. Computations were made using the current U.S. Geological Survey step-backwater computer program and method (Shearman, 1976).

The step-backwater method allows the user to compute theoretical water-surface profiles, for any selected discharge, along a reach of a stream that has channel control. Basically, the theory implements the principle of the conservation of energy between two cross sections. A series of cross sections is surveyed downstream from a point where a stage-discharge relation is needed. Cross-section properties and energy components are computed for a selected discharge at an estimated water-surface elevation for the cross section farthest downstream. Cross-section properties and energy components are computed for higher water-surface elevations at the next cross section upstream until an energy balance is achieved between the upstream and the downstream cross sections. These computations are made for each successive cross section upstream. The computation is then repeated for different starting elevations and discharges.

Values of cross-section elevations and Manning's roughness coefficients obtained by field surveys were used in the computations without adjustment, except for straight-line extrapolation of the end of one cross section. Cross sections of the channel were surveyed at visually selected locations, beginning downstream and ending at the gage cross section. The roughness coefficients were selected in the field to represent average spring and summer conditions. The roughness coefficients were assigned to vary with hydraulic depth as described by Shearman (1976, p. 22). Cross sections were subdivided on the basis of shape, and roughness coefficients were assigned to each subsection.

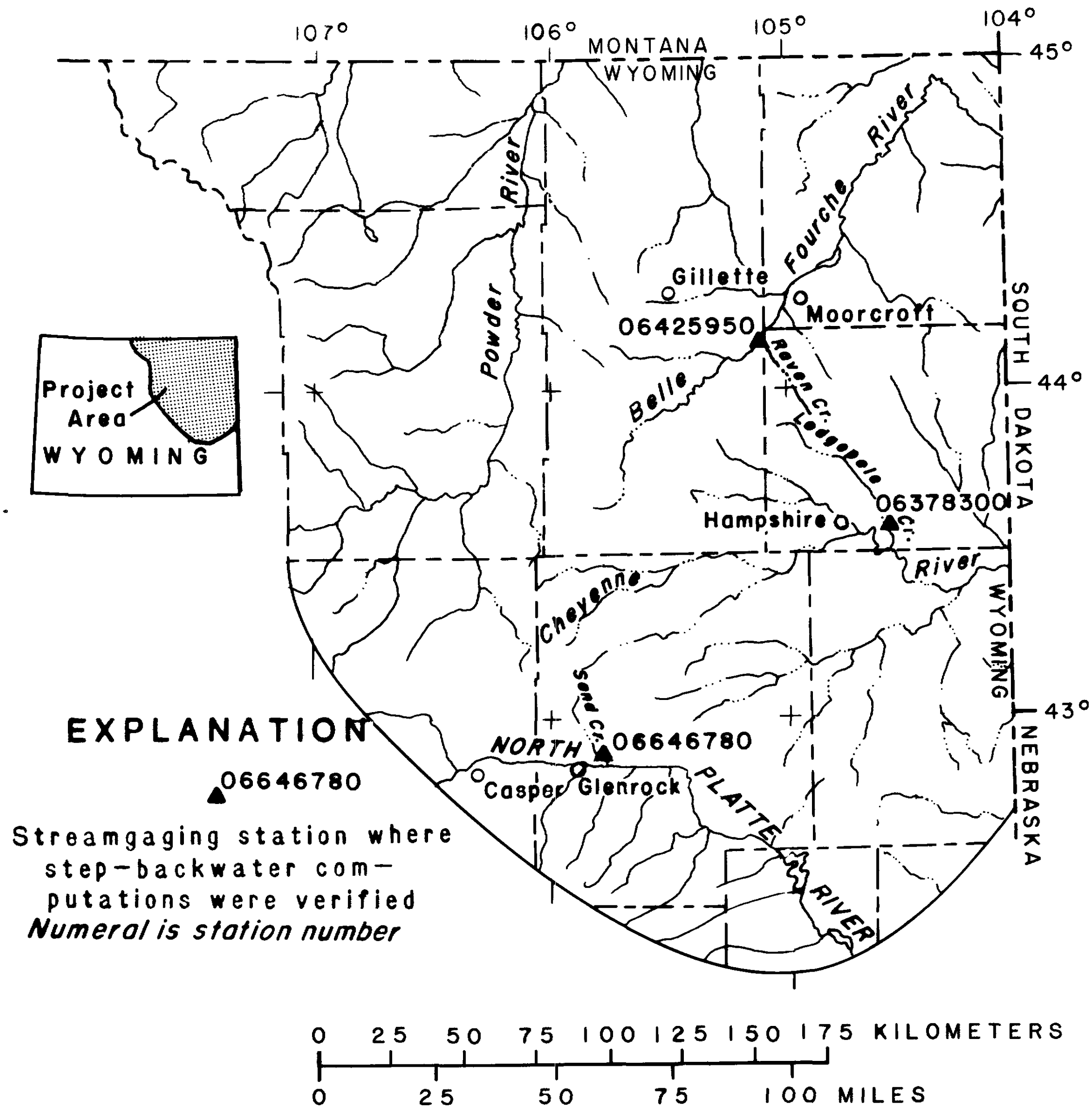

Figure 1. Locations of project area for measuring streamflow in areas of strip mining of coal in northeastern Wyoming and streamgaging stations where step-backwater computations were verified.

Location Numbering System

The eight-digit station number, which precedes the station name, was assigned using the U.S. Geological Survey's downstream numbering convention. The first two digits denote the drainage basin ("06" is assigned the Missouri River drainage). The last six digits, which increase in downstream order, are unique to a specific site.

STEP-BACKWATER SURVEYS AND RATING DEVELOPMENT

Site Descriptions

Stations selected for rating development by the step-backwater method were:

06378300, Lodgepole Creek near Hampshire, Wyo.;

06425950, Raven Creek near Moorcroft, Wyo.; and

06646780, Sand Creek near Glenrock, Wyo.

(Locations are shown in fig. 1) Drainage areas at the stations in square miles are 354 for Lodgepole Creek, 76 for Raven Creek, and 80 for Sand Creek. The streams are ephemeral with moderately sinuous channels. A plan view of the step-backwater reach, referencing cross-section locations, and graphs of the cross sections with assigned roughness coefficients are shown for each site in figures 2–4.

Lodgepole Creek

Lodgepole Creek has a shallow low-water channel,

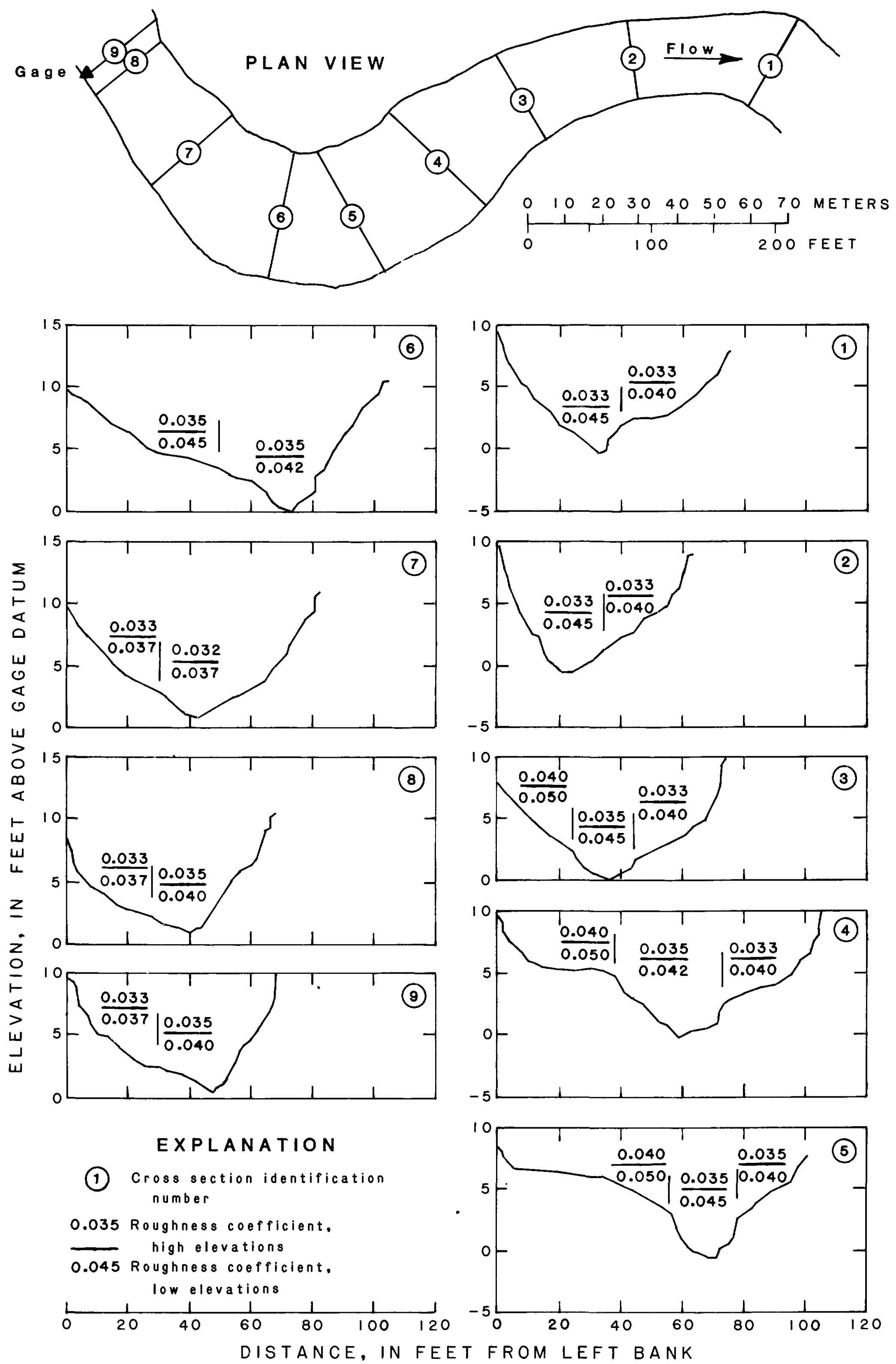

Figure 2. Plan view, channel cross sections, and subsection roughness coefficients for station 06378300, Lodgepole Creek near Hampshire, Wyo.

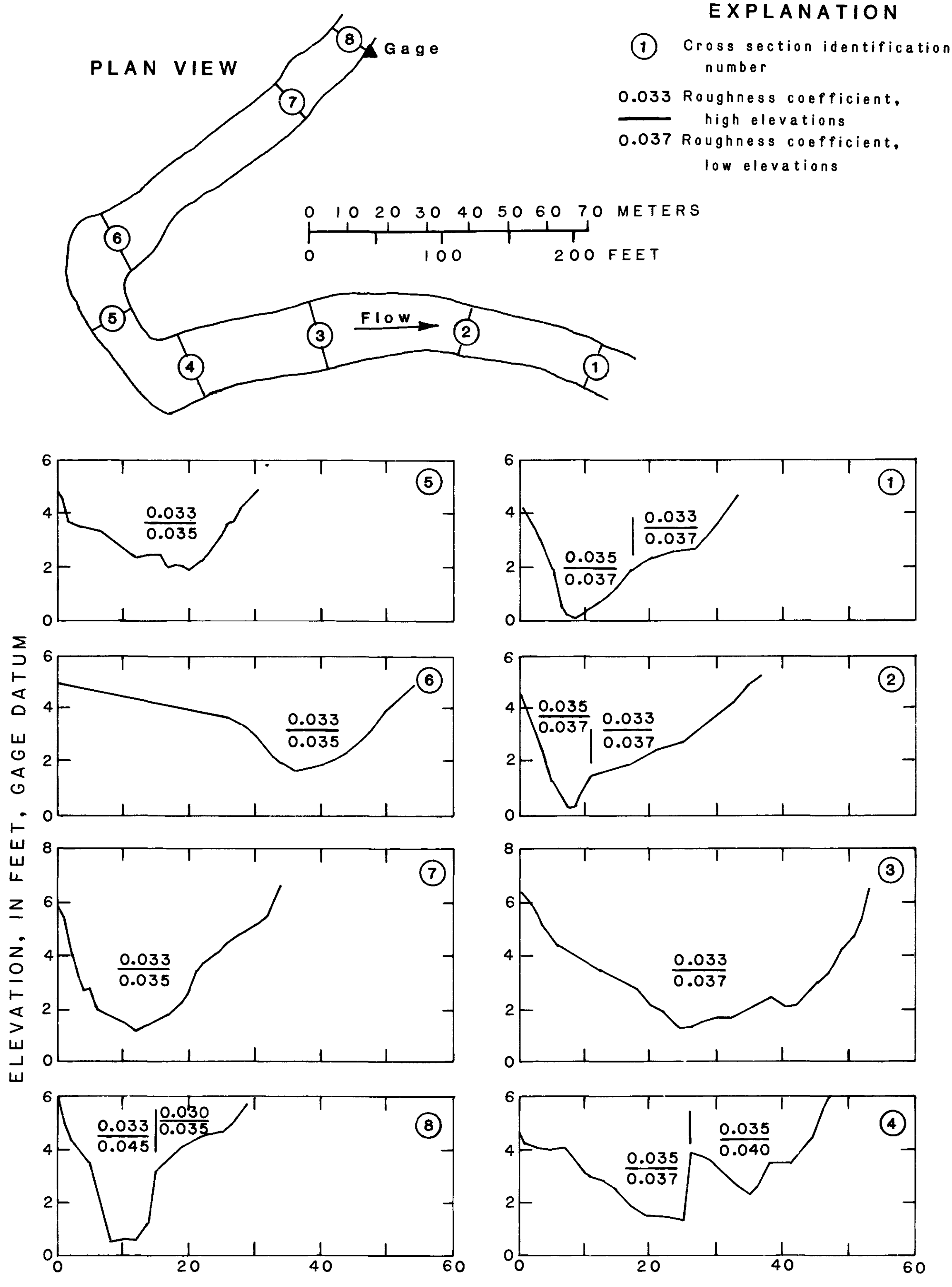

Figure 3. Plan view, channel cross sections, and subsection roughness coefficients for station 06425950, Raven Creek near Moorcroft, Wyo.

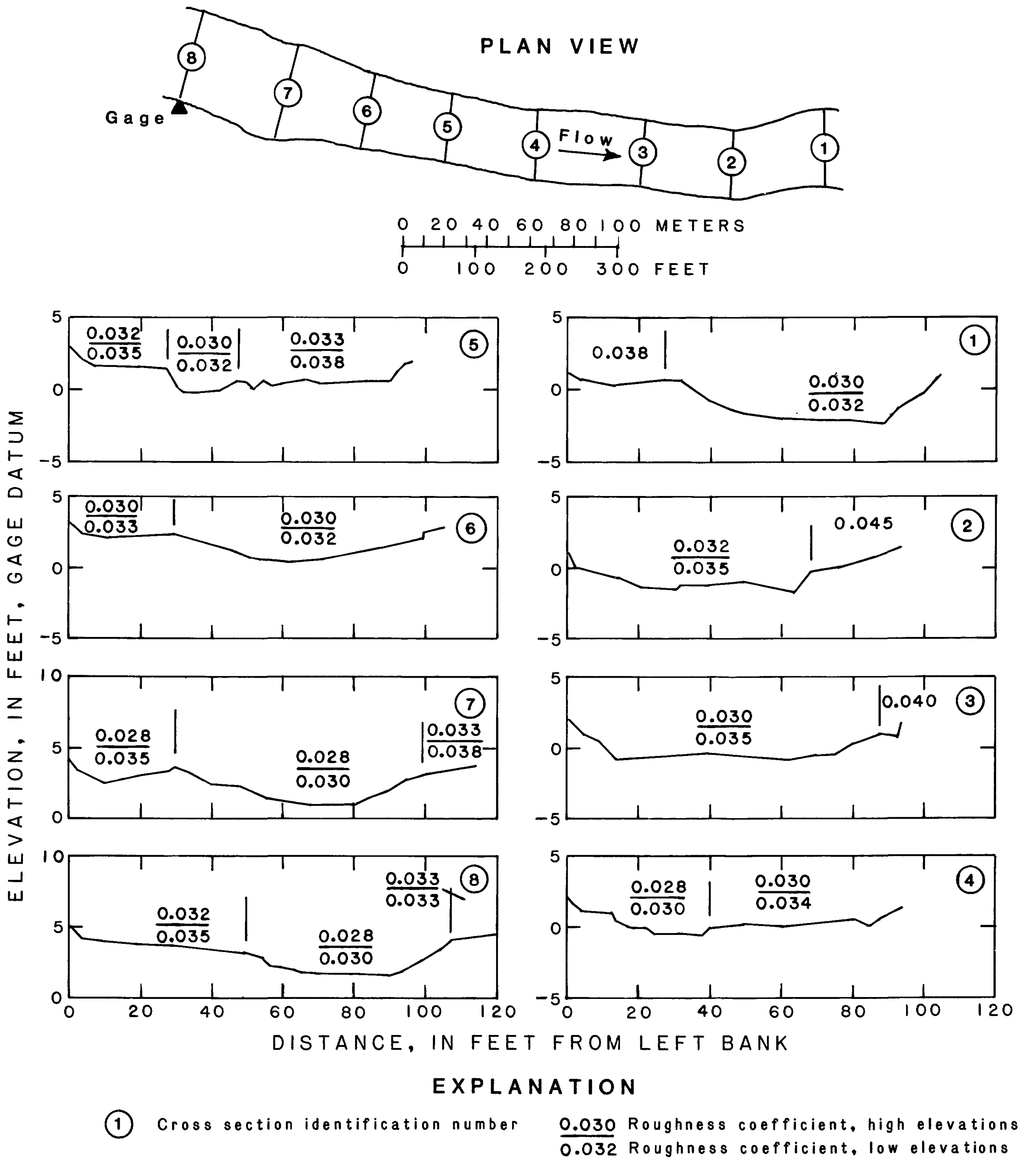

Figure 4. Plan view, channel cross sections, and subsection roughness coefficients for station 06646780, Sand Creek near Glenrock, Wyo.

gradually sloping to steep banks which can confine most flows. The channel is silt and sand covered with grass and scattered sage. Values selected for roughness coefficients ranged from 0.032 to 0.045 in the main channel and from 0.033 to 0.050 in the overflow plains. The profile of the channel bottom indicated a subtle pool-riffle sequence; the average channel slope through the step-backwater reach is 0.0014 ft/ft. The nine cross sections through the 700-foot reach are detailed in figure 2. Photographs of the reach are shown in figure 5.

Raven Creek

Raven Creek's low-water channel is nearly V-shaped at the initial cross sections, broadening to a trapezoidal shape at the intermediate cross sections, and ending in a more confined, trapezoidal shape with cut banks at the gage. The left bank slopes upward steeply from the low-water channel in the starting and ending cross sections. A small left-bank overflow plain occurs in the intermediate cross sections. A right-bank overflow plain is apparent in the initial and final cross sections. The channel is mostly firm sand and silt in the upper reach and gradually becomes grass covered in the lower reach. A few trees and large sandstone boulders are scattered throughout the channel. The banks and overflow plains are covered with grass, scattered trees, and sage. Values selected for roughness coefficients ranged from 0.033 to 0.045 in the main channel and 0.030 to 0.040 in the overflow plains. The profile of the channel bottom indicates a pronounced riffle in the middle of the reach with a moderating slope just downstream from the riffle. The average channel slope is about 0.0017 ft/ft. A plan view and eight cross sections are shown in figure 3; photographs of the reach are shown in figure 6.

Sand Creek

Sand Creek has a shallow, trapezoidal low-water channel with overflow plains on both banks. Steep, high banks at the overflow boundaries confine high flows. The alluvial low-water channel is subject to shifting, while the overflow plains are stabilized with grass, scattered bush, and trees. Main-channel roughness coefficients ranged from 0.028 to 0.035, and overflow- section coefficients ranged from 0.028 to 0.045. The channel is fairly straight throughout the 900-foot step-backwater reach, and the average channel slope is about 0.0043 ft/ft. The eight cross sections used are shown in figure 4; photographs of the reach are shown in figure 7.

The theoretical water-surface profiles for each of the stations are shown in figures 8–10. Step-backwater computations were made at selected discharge intervals from 1 through 1,000 ft^3/s on Lodgepole creek, through 150 ft^3/s on Raven Creek, and through 600 ft^3/s on Sand Creek. At least two different starting elevations were assigned at cross section 1 for each discharge to determine if unique solutions for gage height would be computed at the gage section. The terms gage height and stage both refer to the elevation (gage datum) of the water surface at the gage for a specific discharge rate. The convergence of the profiles to a unique solution is one criterion used in analyzing the validity of the computations. The unique solution for gage height at the gage and the corresponding discharge were used to develop the theoretical stage-discharge rating curves.

Stage-Discharge Relation Development

Rating curves developed on the basis of step-backwater computations are shown in figures 11–13. Flood peaks of several hundred cubic feet per second occurred at all three sites during March and May 1978. Current-meter or slope-area discharge measurements were obtained throughout most of the range of stage. The step-backwater computation points, current-meter measurements, and slope-area measurements are identified separately in figures 11–13 for comparison purposes. Lines of 15-percent departure in discharge from the rating curve are shown to indicate accuracy of the results.

SUMMARY

Stage-discharge ratings developed by the step-backwater method were substantiated within reasonable limits by subsequent discharge measurements. Satisfactory definition of the high end of each rating curve was achieved; high-flow discharge measurements were within 15 percent of the rating discharge at all three sites. A few low-flow discharge measurements on Lodgepole Creek and Sand Creek indicate a departure slightly greater than 15 percent. The measurements on Raven Creek show a departure of less than 15 percent throughout.

The slope-area measurements on Sand Creek do not provide conclusive verification of the step-backwater computations because both the methods are theoretical. However, the results are highly consistent and deserve mention, in view of the fact that the two slope-area measurements were made at sites independent of each other and independent of the step-backwater reach.

REFERENCES CITED

Shearman, J. O., 1976, Computer applications for step-backwater and floodway analyses: U.S. Geological Survey Open-File Report 76–499, 103 p.

METRIC CONVERSION

Metric equivalents of inch-pound units used in this report may be determined by the following conversion factors:

Multiply	*By*	*To obtain*
foot (ft)	0.3048	meter (m)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

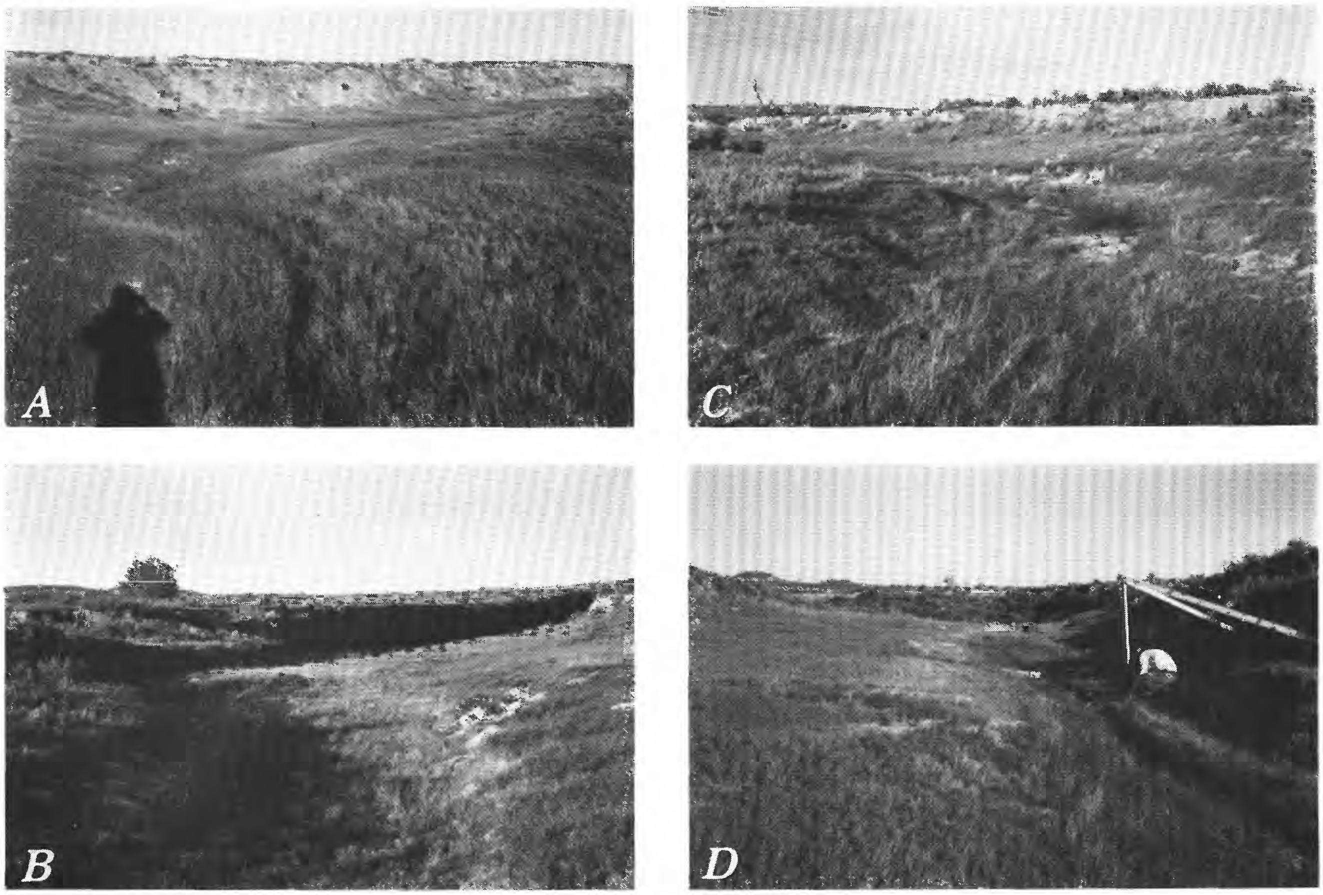

Figure 5. Views of step-backwater reach, station 06378300, Lodgepole Creek near Hampshire, Wyo. Location of cross sections shown in figure 2. *A*, view downstream from cross section 2; *B*, view downstream from cross section 4; *C*, view downstream from midway between cross sections 6 and 7; *D*, view downstream at gage cross section.

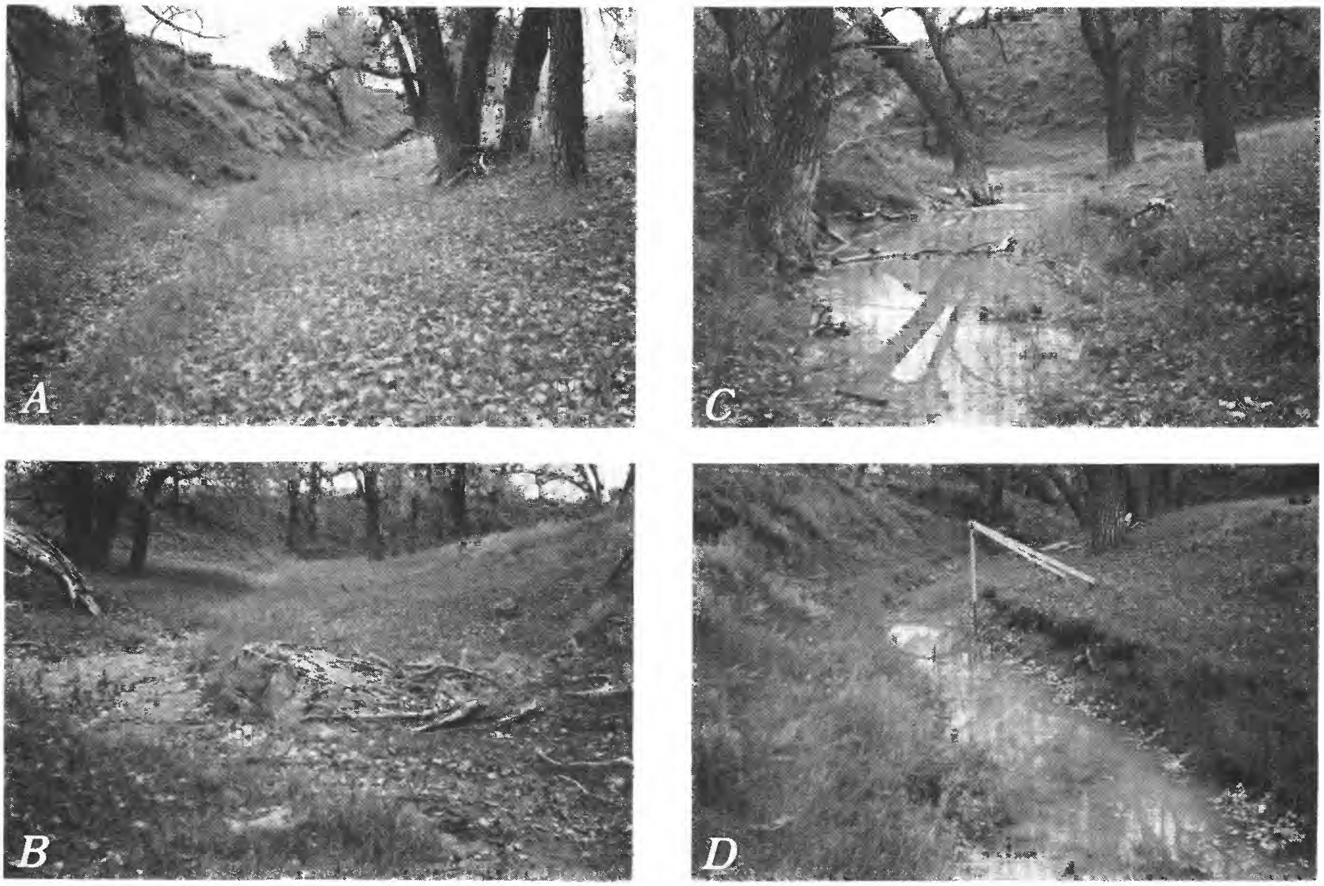

Figure 6. Views of step-backwater reach, station 06425950, Raven Creek near Moorcroft, Wyo. Location of cross sections shown in figure 3. *A*, view downstream from cross section 2; *B*, view downstream from cross section 4; *C*, view downstream from cross section 6; *D*, view downstream at gage cross section.

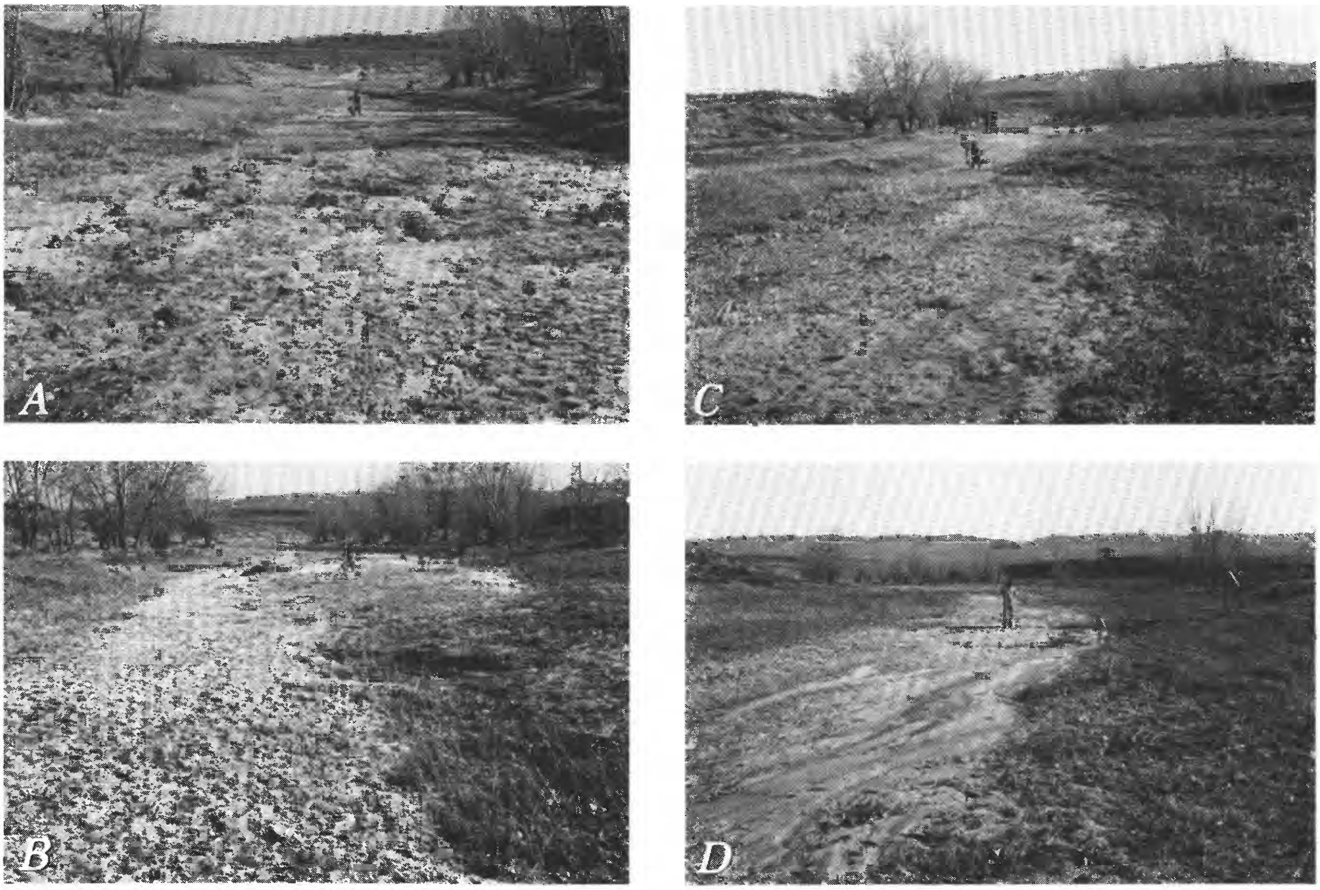

Figure 7. Views of step-backwater reach, station 06646780, Sand Creek near Glenrock, Wyo. Location of cross sections shown in figure 4. *A*, view downstream from cross section 2; *B*, view downstream from cross section 4; *C*, view downstream from cross section 6; *D*, view downstream at gage cross section.

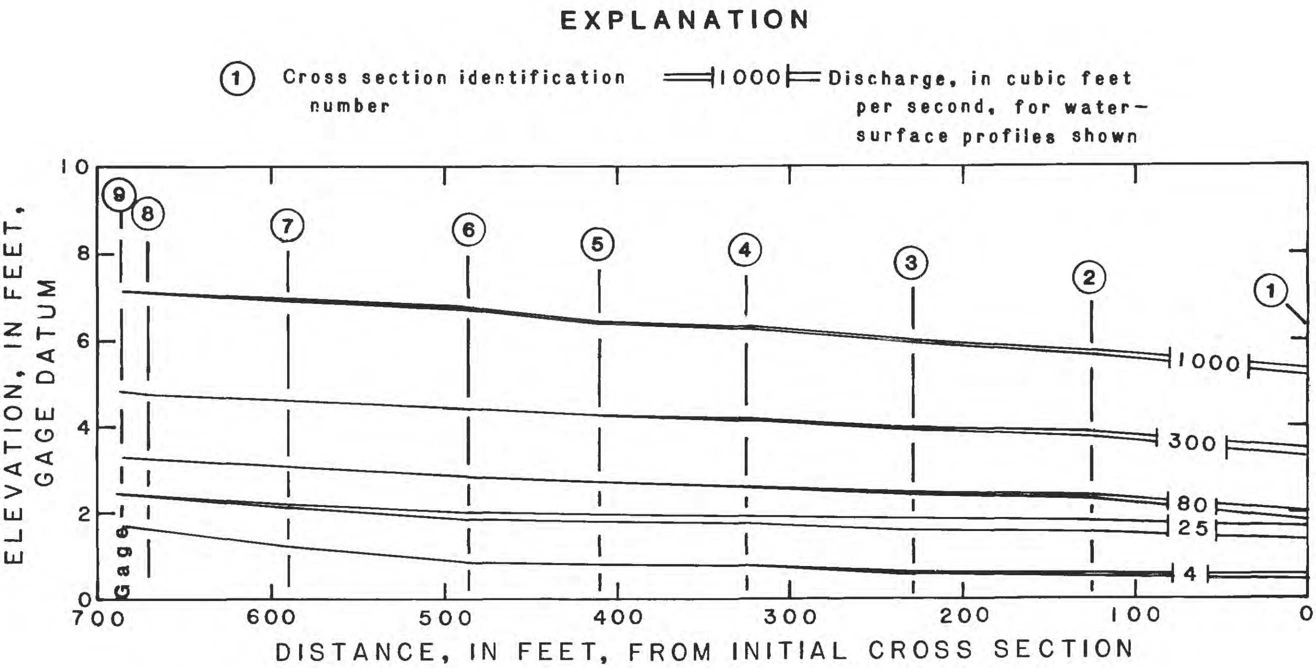

Figure 8. Computed water-surface profiles, through step-backwater reach, for selected discharges for station 06378300, Lodgepole Creek near Hampshire, Wyo.

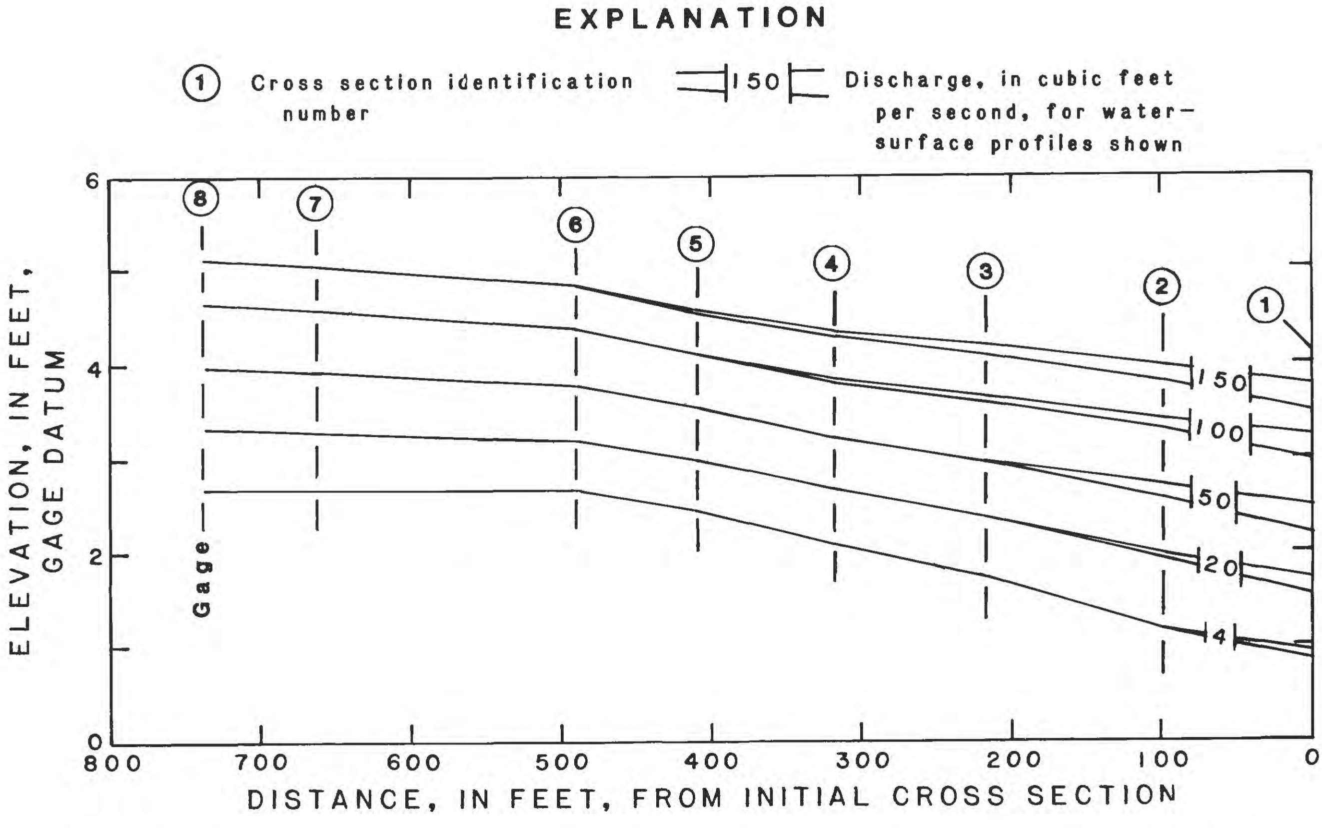

Figure 9. Computed water-surface profiles, through step-backwater reach, for selected discharges for station 6425950, Raven Creek near Moorcroft, Wyo.

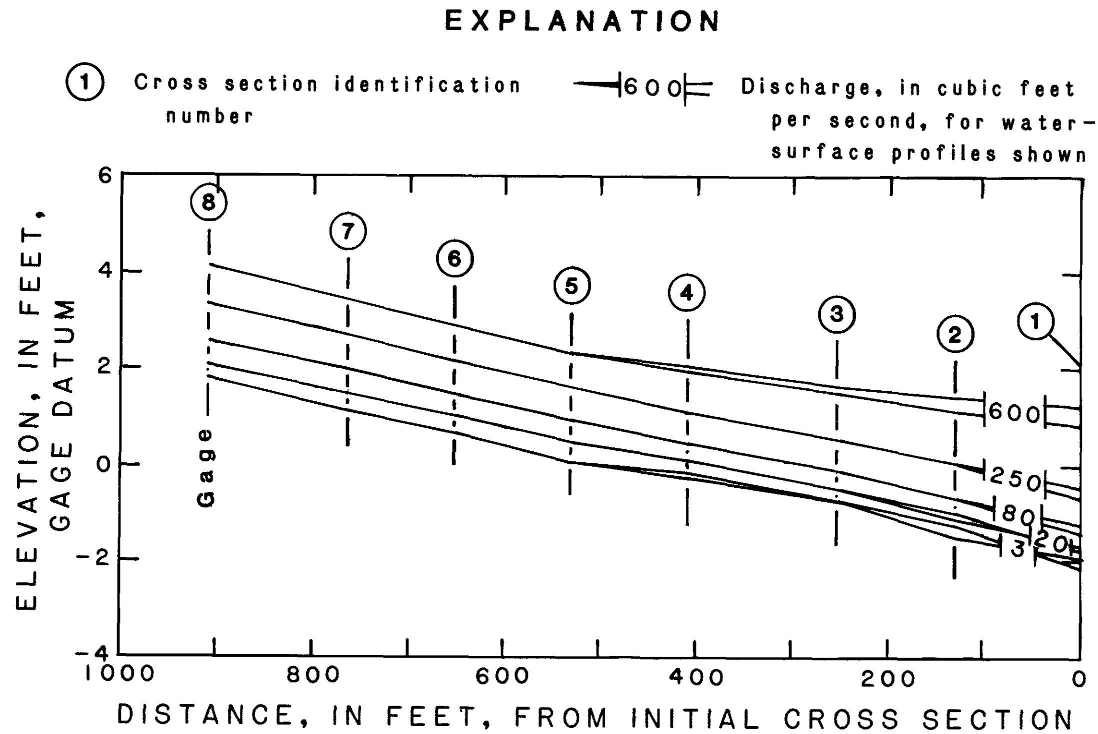

Figure 10. Computed water-surface profiles, through step-backwater reach, for selected discharges for station 06646780, Sand Creek near Glenrock, Wyo.

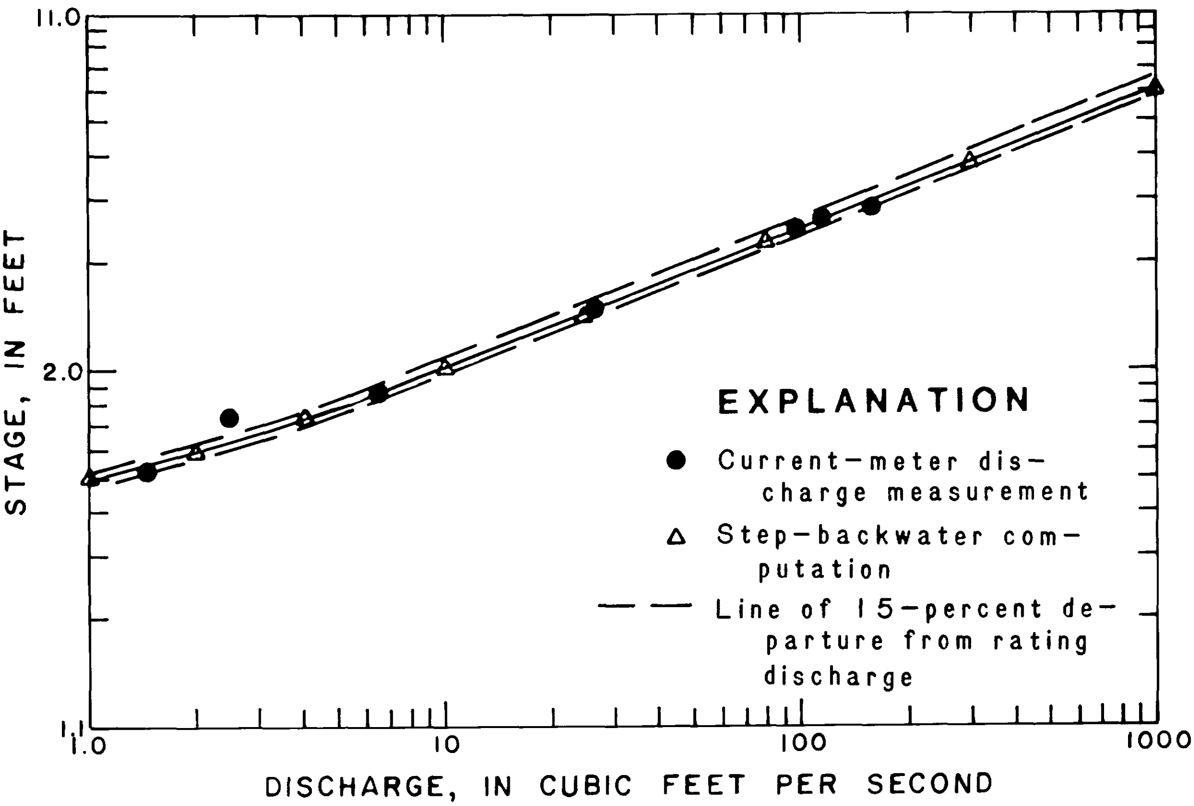

Figure 11. Stage-discharge rating curve for station 06378300, Lodgepole Creek near Hampshire, Wyo.

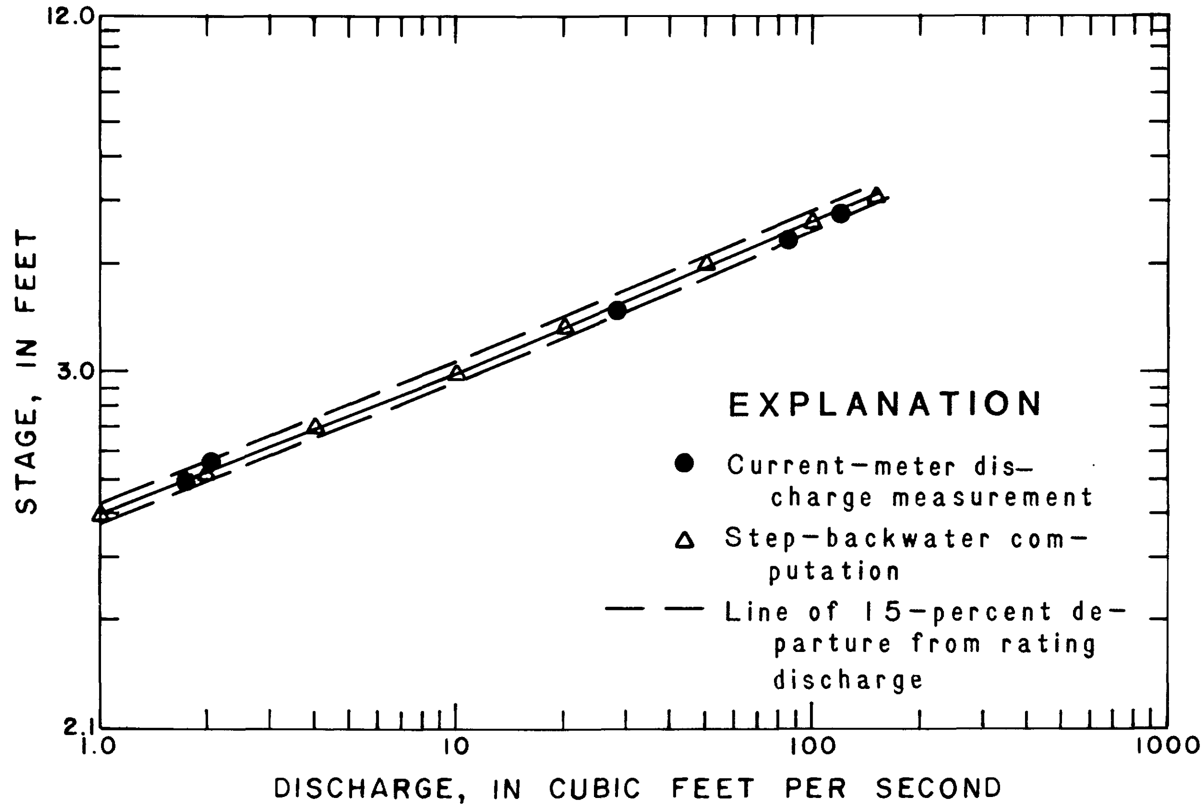

Figure 12. Stage-discharge rating curve for station 06425950, Raven Creek near Moorcroft, Wyo.

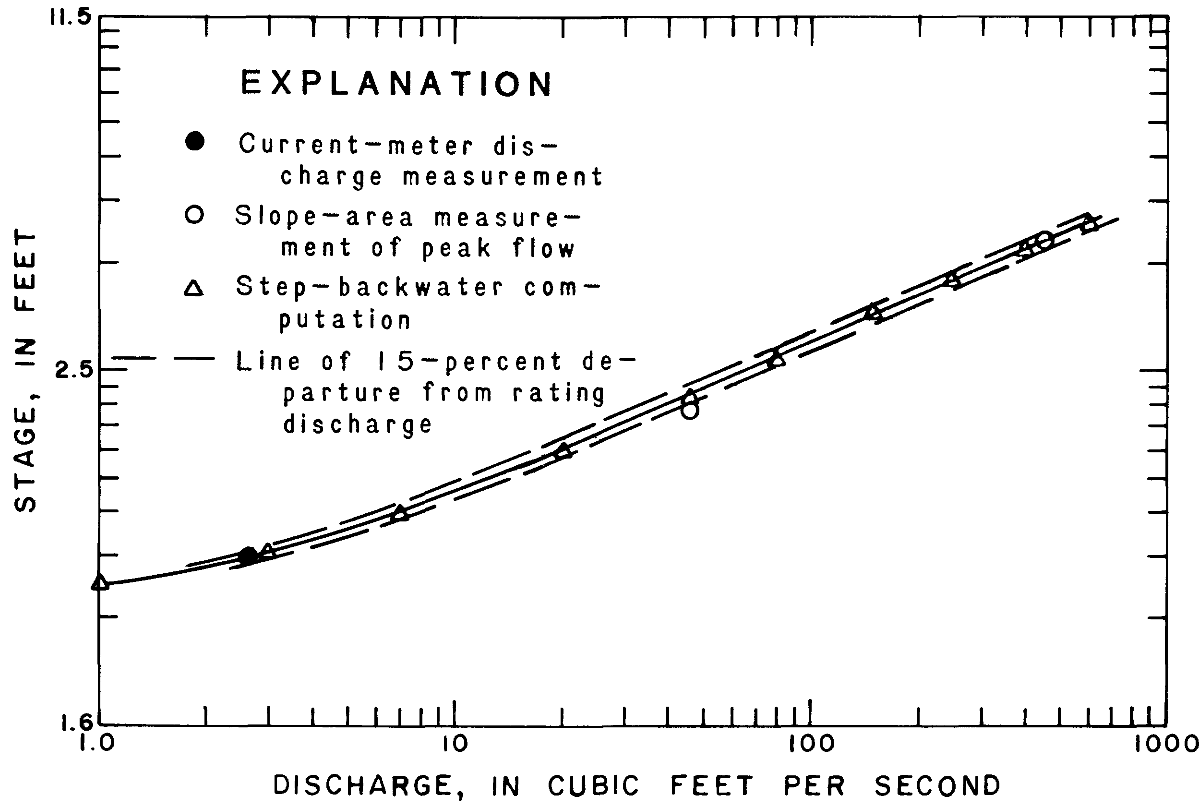

Figure 13. Stage-discharge rating curve for station 06646780, Sand Creek near Glenrock, Wyo.

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