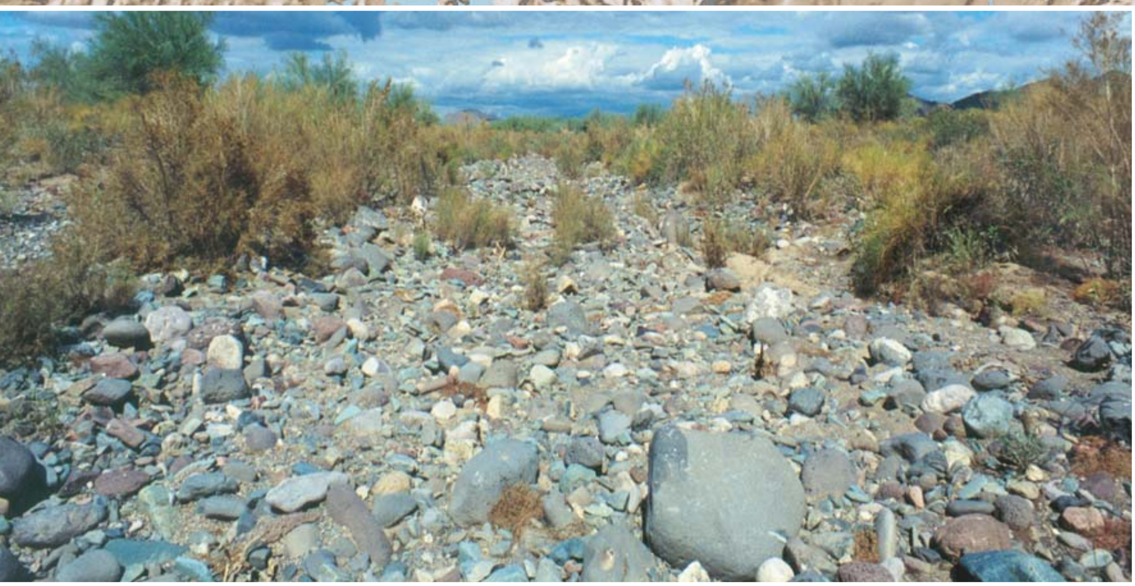

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Computed Roughness Coefficients for Skunk Creek above Interstate 17, Maricopa County, Arizona

Water-Resources Investigations Report 99–4248

Prepared in cooperation with the
FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

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By C.M. O'Day *and* J.V. Phillips

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Tucson, Arizona
2000

U.S. DEPARTMENT OF THE INTERIOR
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Cover: Toenleshushe Canyon, Arizona, northern part of study area. Photograph by Don Bills.

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CONVERSION FACTORS

Multiply	By	To obtain
inch (in)	25.4	millimeter
foot (ft)	0.3048	meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

Computed Roughness Coefficients for Skunk Creek above Interstate 17, Maricopa County, Arizona

By C.M. O'Day *and* J.V. Phillips

Abstract

In the winter of 1997–98, the U.S. Geological Survey, in cooperation with the Flood Control District of Maricopa County, made six verification measurements for Manning's roughness coefficient at Skunk Creek above Interstate 17. Data from four floodflows were recorded and analyzed, three of these flows occurred in February 1998 when Arizona received precipitation from the El Niño weather phenomenon. Discharges ranged from 187 to 760 cubic feet per second and resultant verified values for Manning's roughness coefficient, *n*, ranged from 0.056 to 0.039. Skunk Creek above Interstate 17—an ephemeral wash within a flood-control structure—is overgrown with desert brush throughout the main channel and the presence of the vegetation has a significant effect on *n* values throughout the reach. The results of this study are verified roughness coefficients that can be transferred to similarly vegetated channels in Maricopa County and other arid and semiarid environments where roughness factors must be assessed for flood management or other purposes.

INTRODUCTION

This report presents verified roughness coefficients for a vegetated ephemeral channel, Skunk Creek above Interstate 17, that should be useful to engineers and others who need to assess the hydraulic effects of low flows in streams in arid or semiarid environments for open-channel flow computations. The Flood Control District of Maricopa County (FCDMC) has the responsibility of delineating flood profiles on drainage channels within Maricopa County, Arizona. Flood profiles are computed using water-surface profile computer models that require an evaluation of channel and roughness characteristics. Manning's roughness coefficient, *n*, commonly is used to represent flow resistance for hydraulic computations of flow in open channels. This report has been prepared by the U.S. Geological Survey (USGS) in cooperation with the FCDMC in order to further define these hydraulic characteristics, specifically Manning's *n*, to aid in flood management.

The procedure for selecting *n* values is subjective and requires judgment and skill developed primarily through experience. The expertise necessary for proper selection of *n* values can be obtained, in part, by examining characteristics of channels that have known or verified roughness coefficients. Derived empirical relations between channel characteristics and hydraulic parameters and the verified roughness coefficients also can be used to estimate roughness coefficients for similar channel types.

Several investigators have indicated that vegetation can be the primary factor in determining frictional resistance for ephemeral streams in the southwestern United States (Burkham, 1970; Phillips and Ingersoll, 1998; Phillips and others, 1998). The vegetation, which commonly grows in dense amounts throughout the main channels of these streams, can significantly impede flow and therefore affect total energy losses. Further study of the effects of vegetation on open-channel flow computations is required because vegetation substantially influences total energy losses in these stream types and guidelines for assessing the frictional resistance associated with the vegetation are currently based on few data.

BACKGROUND

In cooperation with the FCDMC, the USGS has been conducting a two-phase investigation for the purpose of assessing Manning's *n* values for stream channels in central Arizona. Thomsen and Hjalmarson (1991) concluded the first phase by publishing guidelines for determining *n* values and presented estimated *n* values for 16 stream channels in central Arizona. Phase two included the presentation of verified roughness coefficients for a variety of channel conditions in central Arizona and included initial work at the Skunk Creek study area by Phillips and Ingersoll (1998) and a study on methods for estimating flow-induced changes in main-channel vegetation conditions and the resultant effect on computed conveyance and water-surface elevations (Phillips and others, 1998). This report is an extension of those studies.

PURPOSE AND SCOPE

The purpose of this report is to present verified roughness coefficients for Skunk Creek above Interstate 17. Flows from four storms provided data needed to verify six roughness coefficients for this vegetated channel. Three of the four storms occurred in February 1998 when Arizona received El Niño induced precipitation. The verification information was used to further define already developed relations between Manning's *n* and hydraulic radius as defined by Phillips and Ingersoll (1998). This relation can be utilized by engineers who must assess *n* values for similarly vegetated stream channels in arid and semiarid environments.

DESCRIPTION OF STUDY AREA

The Skunk Creek above Interstate 17 site was established by previous investigators (Phillips and Ingersoll, 1998). The reach is 677 ft in length and begins about 1,000 ft upstream from streamflow-gaging station, 09513860, Skunk Creek near Phoenix (**fig. 1**) within the bounds of the Skunk Creek flood-control structure. The study reach is divided into six cross sections that are spaced roughly 110 to 150 ft apart. The constructed channel is fairly uniform, and bed material is predominately cobble- to pebble-size gravel with some sand.

Vegetation consists of low brush that is 2 to 3 ft in height, of moderate spatial density, and grows randomly throughout the channel. Triangle leaf bursage, brittle bush, and turpentine bush are the most common plants in addition to a few immature paloverdes. The stream is ephemeral and flow is unregulated. The channel flows from the New River Mountains north of Phoenix to the southwest through the northwestern part of the metropolitan area before joining the New River. The drainage area is 64.4 mi^2 and runoff usually produces a sharp spike-like hydrograph.

DATA COLLECTION AND ANALYSIS

Methods of Data Collection

Discharges used for each *n*-verification measurement were obtained by the current-meter method when possible, but were more frequently determined from a well-defined stage-discharge relation (Rantz and others, 1982) from the Skunk Creek streamflow-gaging station. Direct measurements of discharge are difficult to obtain for small drainage basins in arid environments such as Skunk Creek owing to the very brief period of runoff generated from most storms (**fig. 2**). When direct discharge measurements were possible, flagging was used to mark the water surface associated with that measurement. These points were then surveyed with a transit stadia to define the water-surface elevation at each cross section.

A series of six crest-stage gages are located along the right bank at each of the cross sections (**fig. 3**). These gages are used to capture accurate peak water-surface elevations at times of flow and have proved exceptionally useful because of the flashy nature of Skunk Creek. The water-surface elevations derived from the crest-stage gages when combined with the stage-discharge relation from the Skunk Creek streamflow-gaging station are used to calculate the channel properties.

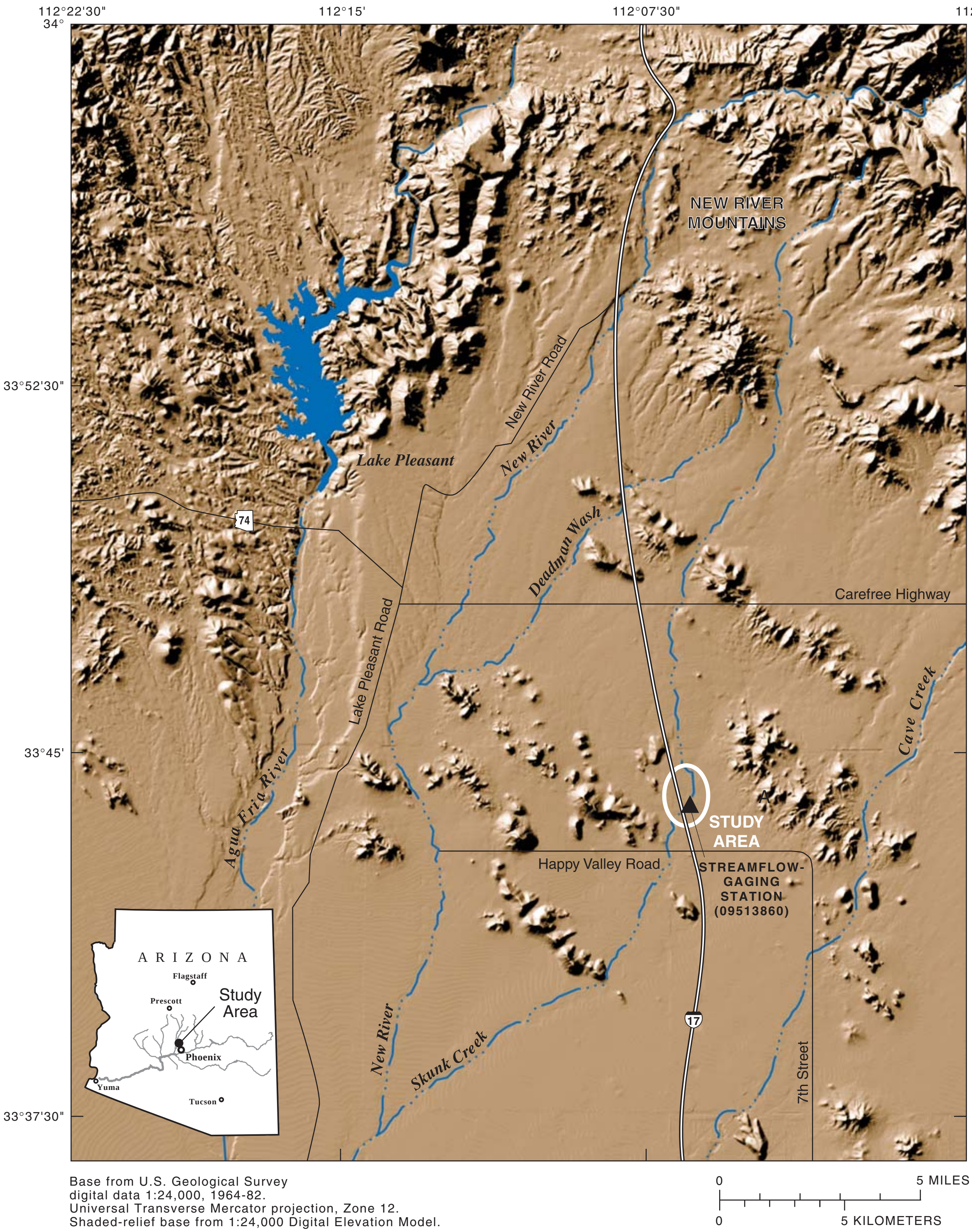

Figure 1. Skunk Creek above Interstate 17, Manning's n-verification study area.

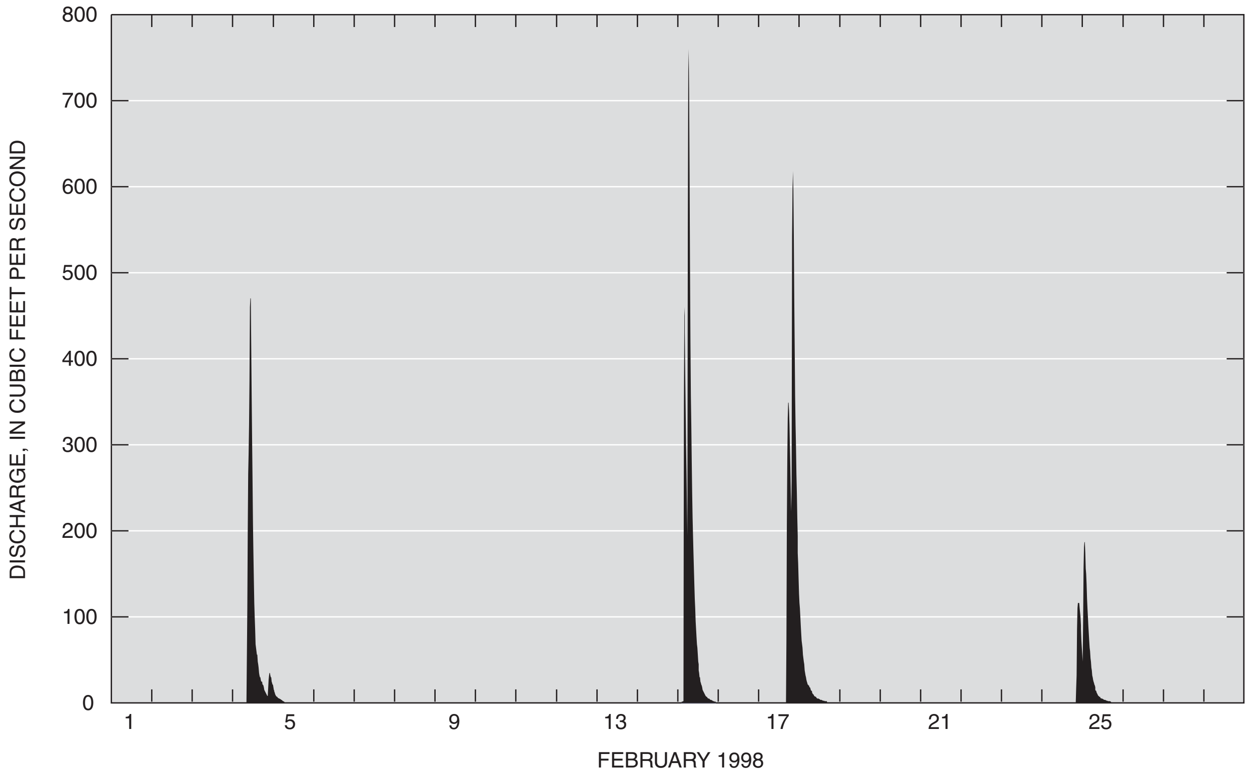

Figure 2. Recorded flows for February 1998 at streamflow-gaging station Skunk Creek near Phoenix (09513860).

Figure 3. One of the series of six crest-stage gages along the right bank of Skunk Creek used to record accurate peak water-surface elevations.

Accurate water-surface elevations and channel-geometry data were obtained from transit-stadia surveys of the reach after each flow had subsided. Standard surveying techniques were used throughout the study as described in detail by Benson and Dalrymple (1967). The information obtained from the surveys was used to plot the channel geometry and to determine the required channel-geometry components for computation of Manning's *n* (fig. 4). When possible, photographs of the sites were taken during and after the flow.

A particle-size distribution of the bed material was measured because energy losses can be influenced by the size of the bed material (Chow, 1959). For the cobbles that make up most of the bed material in the Skunk Creek reach, frequency distributions were obtained by measuring the intermediate axis of

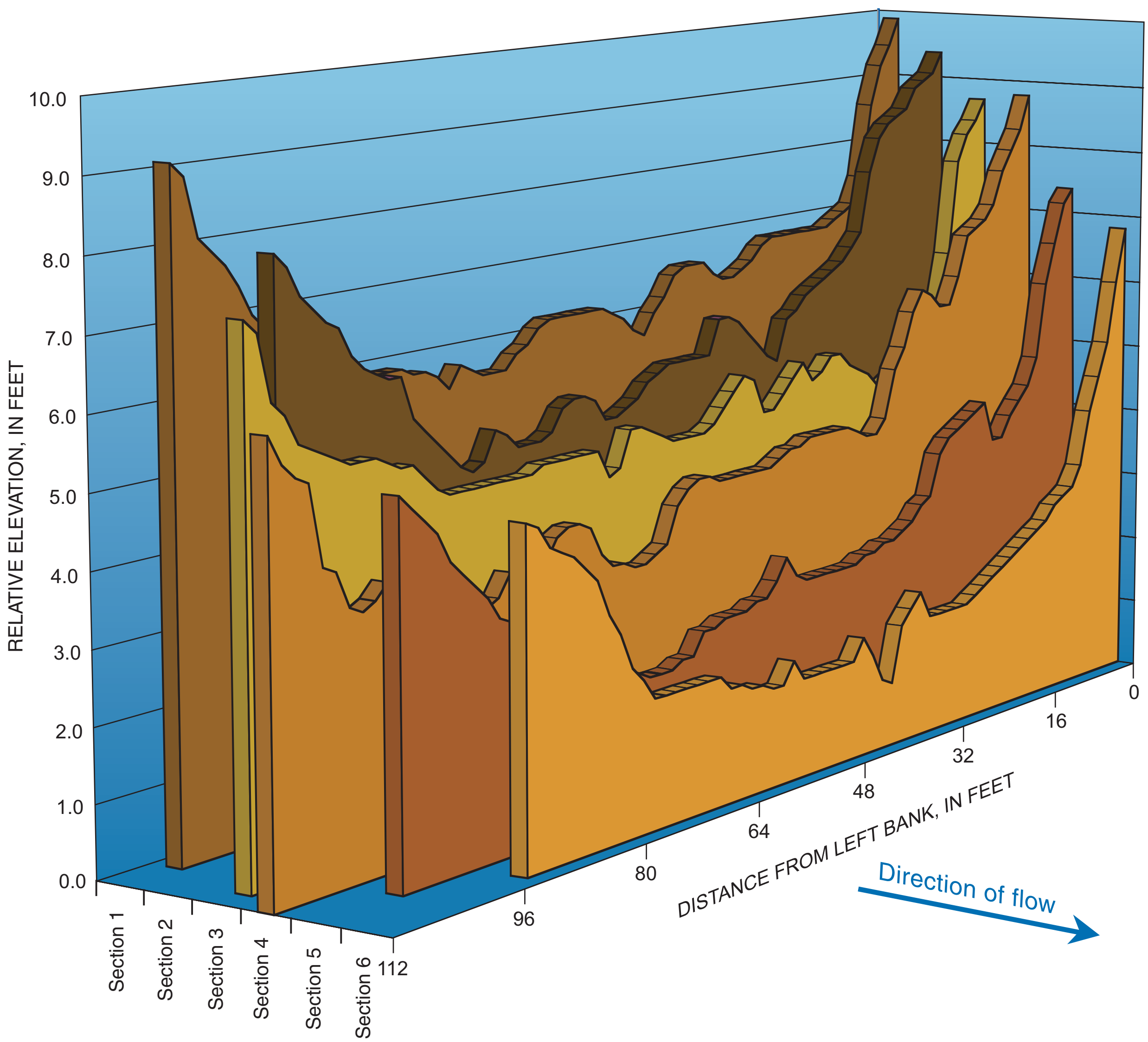

Figure 4. Cross-section geometry for Skunk Creek above Interstate 17, sections 1 through 6.

100 particles selected at random from the study reach (Wolman, 1954; Benson and Dalrymple, 1967). The small sand fraction in the channel was analyzed using frequency distributions of bed-material size determined by sieve analysis. These data were used to determine the median grain-size diameter expressed as d_{50}.

Methods of Computations

The fundamental equations on which many open-channel hydraulic computations are based include the Manning's equation, the continuity equation, and the energy equation. The computer program NCALC, developed by Jarrett and Petsch (1985), is based primarily on these equations and was used to compute the values of Manning's *n* in this report. These equations remain unchanged from those in previously published *n*-verification reports. Manning's equation is defined as:

$$V = \frac{1.486}{n} R^{2/3} S_f^{\ 1/2} , \qquad (1)$$

where

- V = mean velocity of flow, in feet per second;
- R = hydraulic radius, in feet;
- S_f = energy gradient or friction slope, in feet per foot; and
- n = Manning's roughness coefficient.

The hydraulic radius is defined as the ratio of a stream channel's cross-sectional area to its wetted perimeter in a plane normal to the direction of flow. A common substitution for hydraulic radius is the mean depth of flow.

The continuity equation is expressed as:

$$Q = AV, \qquad (2)$$

where

- Q = discharge, in cubic feet per second;
- A = cross-sectional area of channel, in square feet; and
- V = mean velocity of flow, in feet per second.

Substitution of equation 1 for V in equation 2 yields a variation of Manning's equation often used to compute discharge in open channels:

$$Q = \frac{1.486}{n} A R^{2/3} S_f^{\ 1/2} . \qquad (3)$$

Equation 3 was developed for conditions of uniform flow in which the water-surface slope and energy gradient are parallel to the streambed, and the area, depth, and velocity are constant throughout the reach. Equation 3 is assumed for nonuniform reaches if the energy gradient is modified to reflect only the losses resulting from boundary friction (Barnes, 1967). The energy equation for a nonuniform stream- channel reach between sections 1 and 2 according to Barnes is:

$$(h + h_v)_1 = (h + h_v)_2 + (h_f)_{1-2} + k(\Delta h_v)_{1-2} , \qquad (4)$$

where

- h = elevation of the water surface at the respective section above a common datum, in feet;
- h_v = velocity head at the respective section equals $\alpha V^2/2g$, in feet;
- h_f = energy loss due to boundary friction in reach, in feet;
- Δh_v = upstream velocity head minus the down-stream velocity head, in feet;
- $k(\Delta h_v)$ = energy loss due to acceleration of velocity in a contracting reach, or deceleration of velocity in an expanding reach, in feet; and
- k = coefficient assumed to be equal to 0 for contracting reaches, and 0.5 for expanding reaches (Barnes, 1967);

and where

- α = velocity-head coefficient; and
- g = acceleration due to gravity, in feet per second per second.

In computing the values of *n* using this method, the value of α is always considered to be 1.00. This requirement limits verification computations to unit channels that do not require segmenting or subdividing (Jarrett and Petsch, 1985). Although α can be much larger than 1.00 in natural channels (Jarrett, 1985), any resulting error in the computation of *n* is assumed to be minimal because the effect of α actually depends on the relative difference between the velocity-head coefficients from upstream and downstream cross sections rather than their actual magnitudes (Coon, 1995).

The friction slope, S_f, to be used in Manning's equation is defined as:

$$S_f = \frac{h_f}{L} = \frac{\Delta h + \Delta h_v - k(\Delta h_v)}{L} , \quad (5)$$

where

Δh = difference in water-surface elevation at the two sections, in feet; and

L = length of the reach, in feet (Dalrymple and Benson, 1967; Barnes, 1967).

In Manning's equation, the quantity $(1.486/n)\,AR^{2/3}$ is called conveyance, K, and is computed for each cross section. The mean conveyance in the reach between any two sections is computed as the geometric mean of the conveyance of the two sections. The discharge equation in terms of conveyance is expressed as:

$$Q = (K_1 K_2 S_f)^{1/2} . \quad (6)$$

In this investigation, *n* is computed for each reach of known discharge, the water-surface profile, and the hydraulic properties of the reach as defined by the cross sections. The following equation was used to compute *n* for this study and is applicable to a multisection reach of M cross sections, designated 1, 2, 3, ... $M - 1$, M:

$$n = \frac{1.486}{Q}\sqrt{\frac{\beta - [(k\Delta h_v)_{1-2} + (k\Delta h_v)_{2-3} + \ldots + (k\Delta h_v)_{(M-1)-M}]}{\frac{L_{1-2}}{Z_1 Z_2} + \frac{L_{2-3}}{Z_2 Z_3} + \ldots + \frac{L_{(M-1)-M}}{Z_{(M-1)} Z_M}}} , \quad (7)$$

where

β = $(h + h_v)_1 - (h + h_v)_M$, and

Z = $AR^{2/3}$ (Barnes, 1967).

Components of Manning's *n*

Manning's roughness coefficient, *n*, is made up of five different components as listed in equation 8 and *m*, a correction factor related to the meandering of a channel (Cowan, 1956). Of these five, only the base value and the vegetation component are applicable at Skunk Creek because of the uniformity of the reach and cross sections. Because the channel has been engineered for low sinuosity, the meander factor is also considered negligible at this site and *m* is assumed to equal 1.000. The channel has a moderate amount of randomly spaced vegetation that directly influences the roughness coefficients as shown by Phillips and Ingersoll (1998). Few verification measurements in previous studies have defined and isolated the vegetation parameter, which is particularly important for studies of streams in arid and semiarid environments (Phillips and others, 1998). The following equation, first introduced by Cowan (1956), is used to calculate the total composite *n* for a channel:

$$n = (n_b + n_1 + n_2 + n_3 + n_4)m , \quad (8)$$

where

n_b = base *n* value for a straight uniform channel,

n_1 = surface irregularities,

n_2 = variations in shape and size of the channel,

n_3 = obstructions,

n_4 = vegetation, and

m = correction factor for meandering of sinuosity of the channel.

The general approach for estimating flow resistance in stream channels in the field is to first select a base value of Manning's *n* for the bed material, n_b (Thomsen and Hjalmarson, 1991). The base *n* value represents the bed-material grain size and shape along the wetted perimeter. Cross-section irregularities, channel alignment, vegetation, obstructions, and other factors that increase roughness then are added to n_b.

Phillips and Ingersoll (1998) were able to isolate n_4 by surveying and collecting runoff data after the FCDMC graded the Skunk Creek channel and removed all vegetation in the spring of 1994. The reach was surveyed and analyzed throughout the regrowth period. When the vegetation had matured in 1996, it was found that n_4 accounted for about 30 percent of the total *n* value for the measured flows (fig. 5).

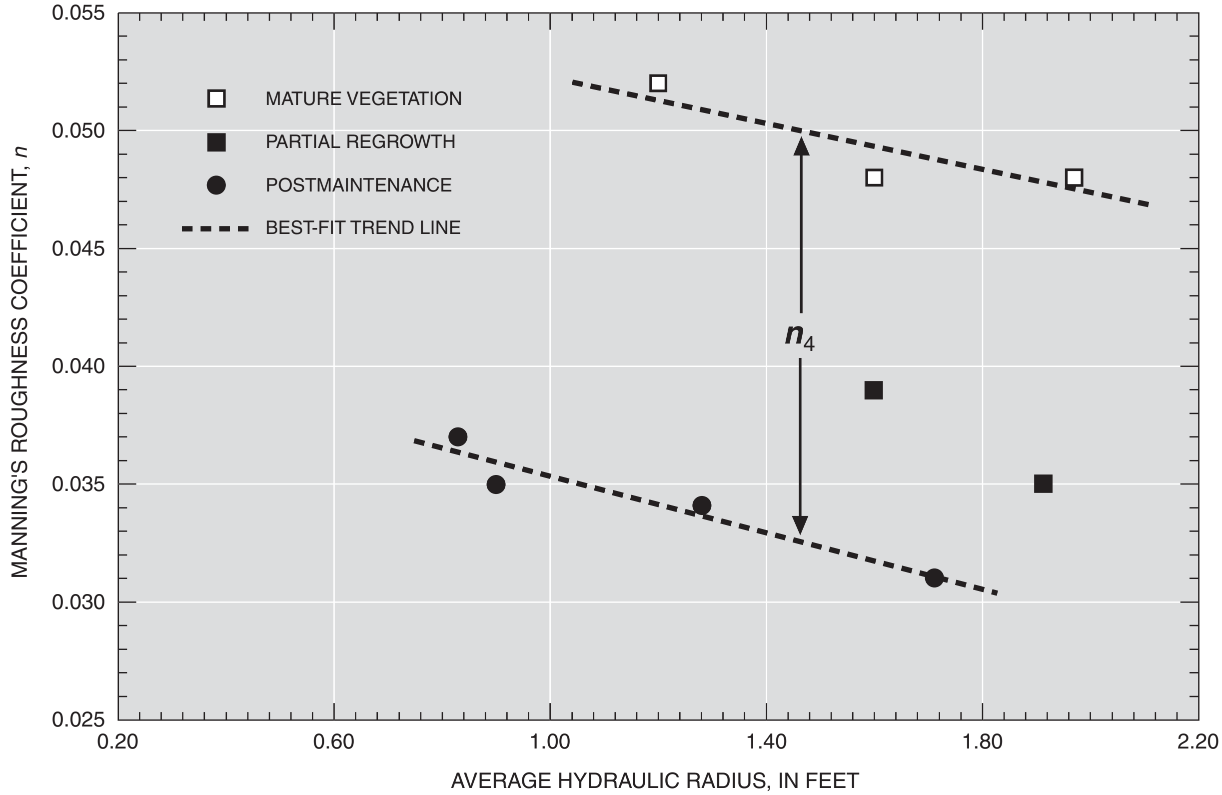

Figure 5. Relation of Manning's n and hydraulic radius showing n_4 for Skunk Creek above Interstate 17 (modified from Phillips and Ingersoll, 1998).

Uncertainties of Measurements

Although efforts were made to strictly follow the data-collection criteria, assumptions were required for some of the verification measurements as channel and hydraulic conditions were not always ideal. The main sources of potential errors in calculations of roughness coefficients for channels in arid and semiarid environments include changing boundary and vegetation conditions, discharge measurement uncertainties, and changing bedforms (Phillips and Ingersoll, 1998). At the Skunk Creek site, changing boundary conditions and bedforms are considered unlikely because the study area is a flood-control structure that has a predominately gravel bed with only a minor sand component.

The accuracy of the verification measurements for Manning's *n* presented in this report is rated as either good or fair with corresponding potential errors of less than 10 or 15 percent, respectively (**table 1**).The accuracy depends primarily on the precision of the measured discharge. As mentioned previously, discharge was determined by a current-meter measurement or from a well-defined stage-discharge relation. Current-meter measurements made by the USGS are rated as excellent, good, fair, or poor depending on factors that include the number of subsections in the measurement, stability of the channel, and accuracy of the equipment (Rantz and others, 1982). These ratings correspond to possible errors of less than 2, 5, 8, or greater than 8 percent of the actual discharge, respectively. Errors for discharges determined from a well-defined and stable stage-discharge relation are assumed to be less than 10 percent.

COMPUTED ROUGHNESS COEFFICIENTS

Reach Properties

When all the field data were collected and tabulated, the NCALC computer program computed the hydraulic properties of the reach including Manning's *n*. Six verifications were made from the data collected from the runoff of four storms, the first in September 1997 and the rest in February 1998 (table 1). The *n* values and hydraulic radius values were plotted together with the data series from Phillips and Ingersoll (1998; fig. 5 this report) as shown in **figure 6**.

Table 1. Selected flow data and computed roughness coefficients, Skunk Creek above Interstate 17

Date of flow	Discharge, in cubic feet per second	Manning's roughness coefficient, *n*	Hydraulic radius, in feet	Rating of verification measurement
9–11–97	521	0.051	1.87	Fair
2–04–98	282	.054	1.45	Good
2–04–98	371	.051	1.67	Good
2–04–98	470	.049	1.77	Good
2–15–98	760	.039	2.04	Good
2–25–98	187	.056	1.20	Good

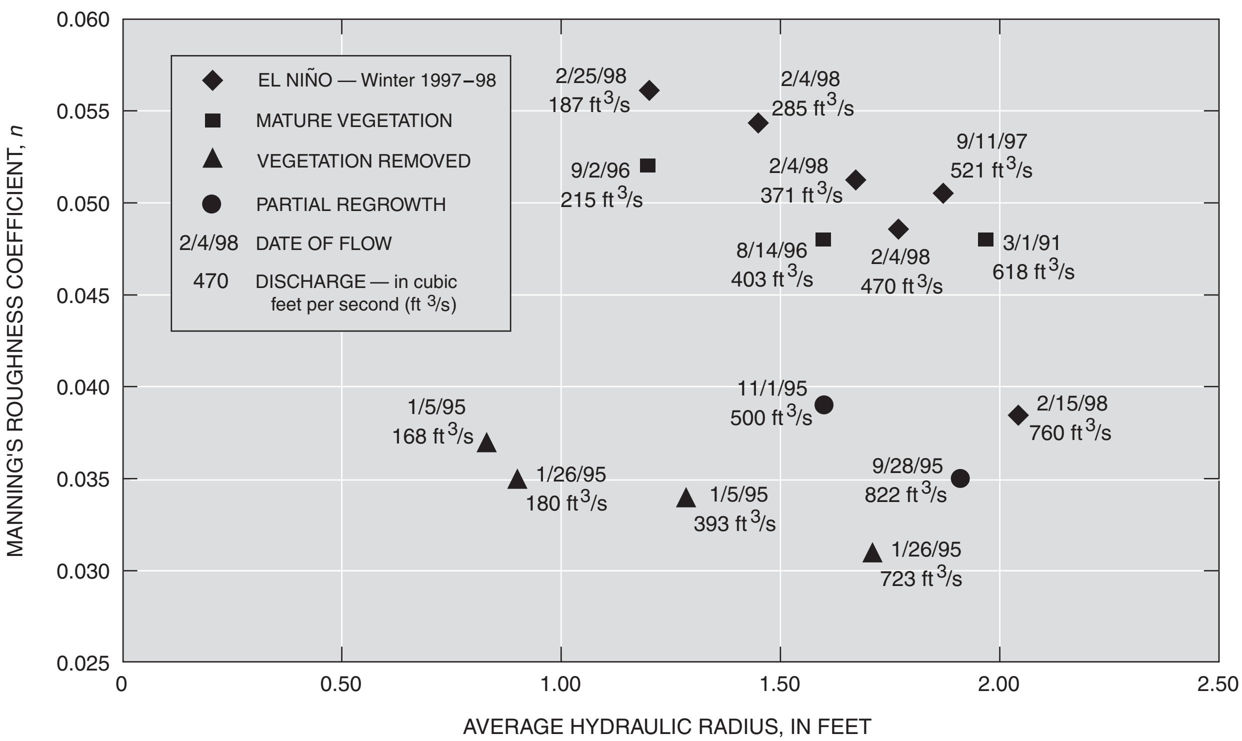

Figure 6. Relation of Manning's *n* and average hydraulic radius for Skunk Creek above Interstate 17.

The hydraulic radius approximates mean flow depth of the channel for shallow streams (Leopold and others, 1964) and relation of *n* to hydraulic radius demonstrates the changes of roughness with depth (Phillips and Ingersoll, 1998). These comparison points show the channel through stages of revegetation from January 1995, after the bed was completely denuded, to August and September 1996, when the vegetation had fully regrown. Select reach properties, also determined by the NCALC program, were averaged across the six cross sections and are given in table 2.

In 1998, the channel vegetation was considered fully regrown and the new data points correlate well with the data from 1996 (**fig. 6**). The only outlier point is from a flow of 760 ft^3/s in which the vegetation may have been laid down by the force of the flow and thus reduced Manning's *n*.

Another possibility is that the sand, now present in the channel, could have been washed in by the high flow and reduced the base *n* value. The other five verification measurements presented in this report display increased roughness-coefficient values in response to a mature, vegetated channel. This supports findings from previous USGS studies for discharges less than 940 ft^3/s, which is the magnitude of the 2-year return flow (Pope and others, 1998). The measurement of 760 ft^3/s indicates that the vegetative component of resistance could diminish near the 2-year return flow. Further studies are needed to extend verification for higher flows and define the effect of vegetation on channel resistance for flows above the 2-year return flow.

One interesting observation was that the sand and gravel fraction of bed material had increased significantly since the analysis by Phillips and Ingersoll (1998; **figs. 7a,b** this report). The origin of the finer-grained sediment is unclear, but the sand pulse, in conjunction with the higher-velocity flow on February 15, 1998, probably only had a marginal effect on lowering the base value of *n*. The channel bed is predominately cobble- to pebble-size gravel (90 to 95 percent) and has a small component of sand. Particle-size distribution data are expressed in **figure 8** as d_{50}. The d_{50} for the gravel fraction was 94 mm and the d_{50} for the sand fraction was 1.1 mm.

Cross-Section Data

The Skunk Creek reach was divided into six cross sections (**fig. 9**) numbered in downstream order. Channel geometry was defined for each cross section from field surveys and hydraulic computations. These data include values for area, top width, wetted perimeter, hydraulic radius, discharge, mean velocity, velocity head, and Froude numbers (tables 3–8). Individual cross-section profiles depicting the water-surface elevations for the high and low discharge are shown in conjunction with associated photographs of each section (figs. 10–21).

Table 2. Average reach properties, Skunk Creek above Interstate 17

Date	Area, in square feet	Top width, in feet	Hydraulic radius, in feet	Mean velocity, in feet per second	Froude number	Total reach length, in feet	Total fall, in feet	Water-surface slope, in feet per foot
09–11–97	156.9	83.4	1.87	3.36	0.43	677	3.52	0.0052
02–04–98	113.1	77.9	1.45	2.56	.38	677	3.53	.0053
02–04–98	134.2	79.9	1.67	2.81	.39	568	2.78	.0050
02–04–98	146.9	82.3	1.77	3.25	.43	677	3.35	.0050
02–15–98	176.2	86.4	2.04	4.38	.55	677	3.26	.0049
02–25–98	88.0	74.7	1.20	2.17	.36	677	3.63	.0054

A. 1996

B. March 1998

Figure 7. Increase of sand and gravel in the channel of Skunk Creek between 1996 and March 1998.

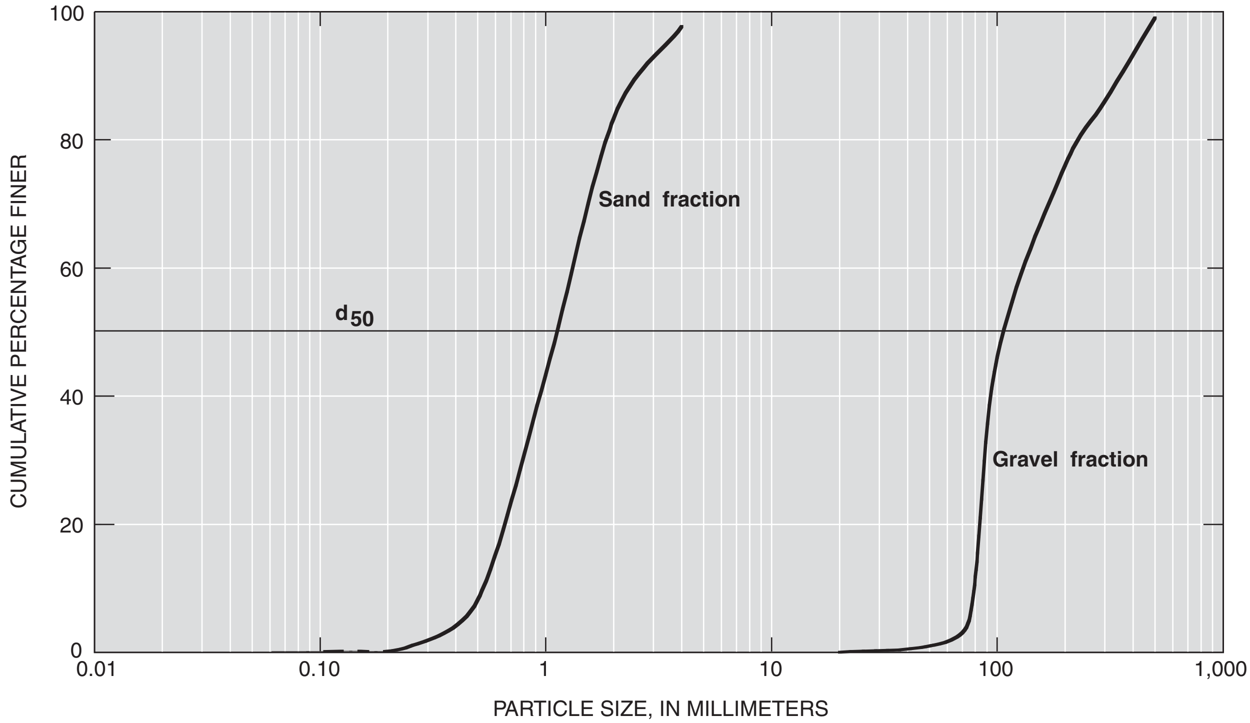

Figure 8. Graph showing particle-size distribution for bed material, Skunk Creek above Interstate 17.

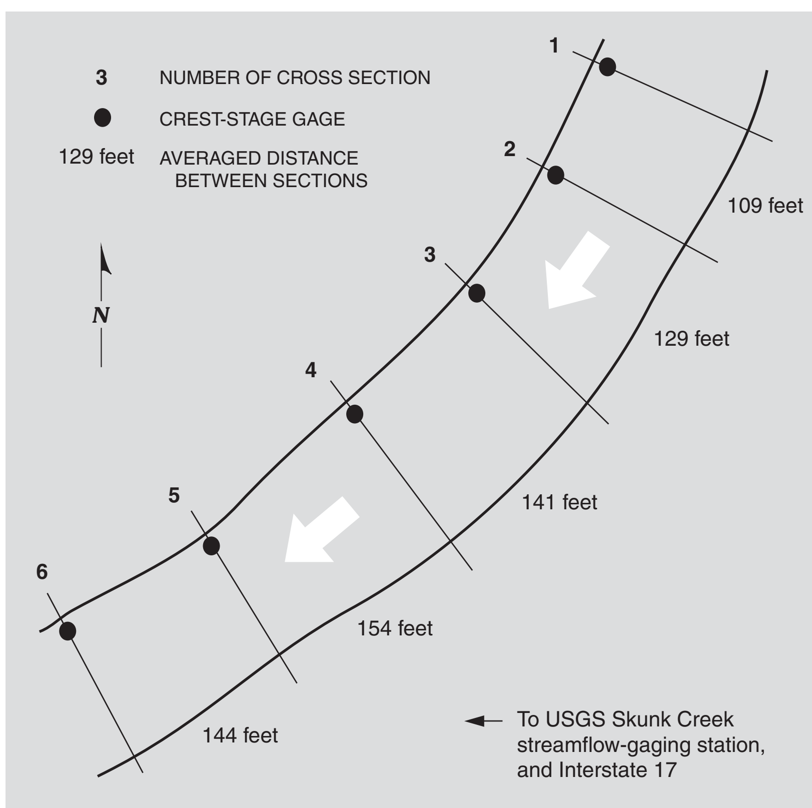

Figure 9. Schematic plan view of Skunk Creek above Interstate 17.

Table 3. Channel geometry and hydraulic properties for cross-section 1, Skunk Creek above Interstate 17

[Note: Only two measurements were made on February 4, 1998, at this section]

Date	Area, in square feet	Top width, in feet	Wetted perimeter, in feet	Hydraulic radius, in feet	Discharge, in cubic feet per second	Mean velocity, in feet per second	Velocity head, in feet	Froude number
09–11–97	136.6	84.7	85.1	1.6	521	3.81	0.23	0.53
02–04–98	95.5	79.8	80.2	1.2	285	2.98	.14	.48
02–04–98	123.2	83.1	83.5	1.5	470	3.82	.23	.55
02–15–98	152.9	86.5	87.0	1.8	760	4.97	.38	.66
02–25–98	74.3	77.2	77.5	1.0	187	2.52	.10	.45

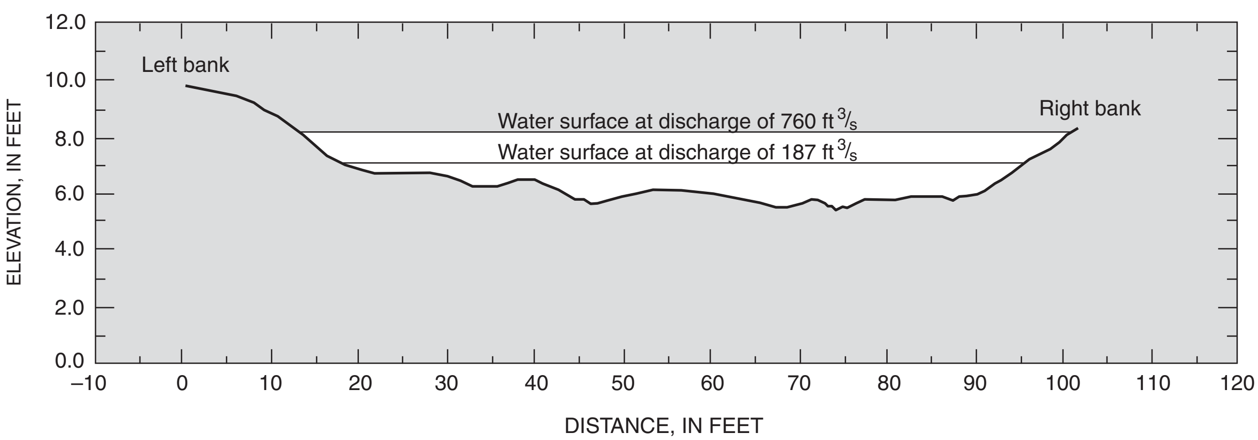

Figure 10. Cross-section 1, Skunk Creek above Interstate 17.

Figure 11. View upstream to cross-section 1, March 1998.

Table 4. Channel geometry and hydraulic properties for cross-section 2, Skunk Creek above Interstate 17

Date	Area, in square feet	Top width, in feet	Wetted perimeter, in feet	Hydraulic radius, in feet	Discharge, in cubic feet per second	Mean velocity, in feet per second	Velocity head, in feet	Froude number
09–11–97	136.4	72.5	73.3	1.9	521	3.82	0.23	0.49
02–04–98	103.9	69.1	69.7	1.5	285	2.74	.12	.39
02–04–98	112.9	70.0	70.8	1.6	371	3.28	.17	.46
02–04–98	128.5	71.6	72.4	1.8	470	3.66	.21	.48
02–15–98	151.8	74.0	74.9	2.0	760	5.01	.39	.62
02–25–98	81.5	66.5	67.1	1.2	187	2.29	.08	.36

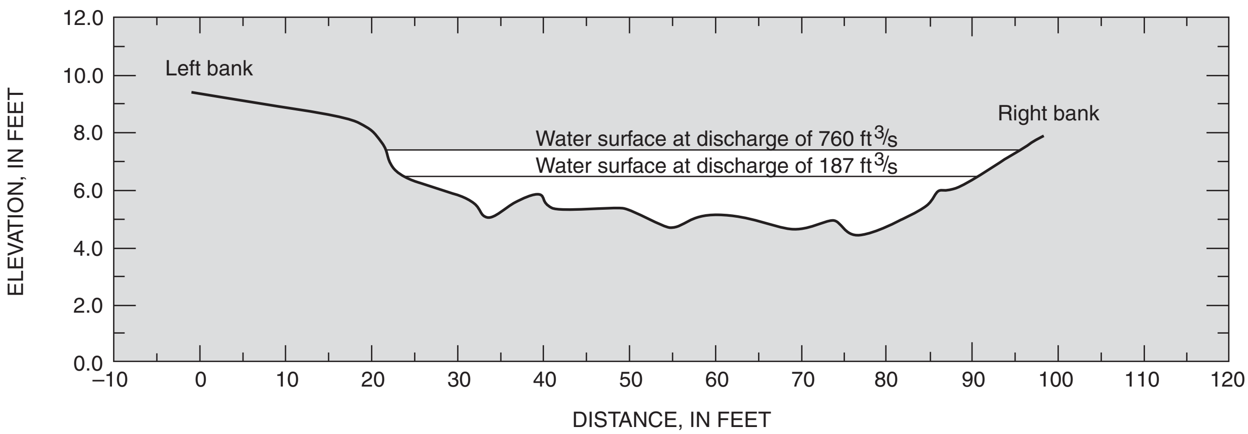

Figure 12. Cross-section 2, Skunk Creek above Interstate 17.

Figure 13. View upstream to cross-section 2, March 1998.

Table 5. Channel geometry and hydraulic properties for cross-section 3, Skunk Creek above Interstate 17

[Note: Only two measurements were made on February 4, 1998, at this section]

Date	Area, in square feet	Top width, in feet	Wetted perimeter, in feet	Hydraulic radius, in feet	Discharge, in cubic feet per second	Mean velocity, in feet per second	Velocity head, in feet	Froude number
09–11–97	171.7	93.1	93.9	1.8	521	3.03	0.14	0.39
02–04–98	119.2	87.8	88.4	1.4	285	2.39	.09	.36
02–04–98	132.5	89.1	89.8	1.5	371	2.80	.12	.40
02–04–98	154.2	91.3	92.1	1.7	470	3.05	.14	.41
02–15–98	182.9	94.2	95.0	1.9	760	4.16	.27	.53
02–25–98	94.2	85.1	85.6	1.1	187	1.99	.06	.33

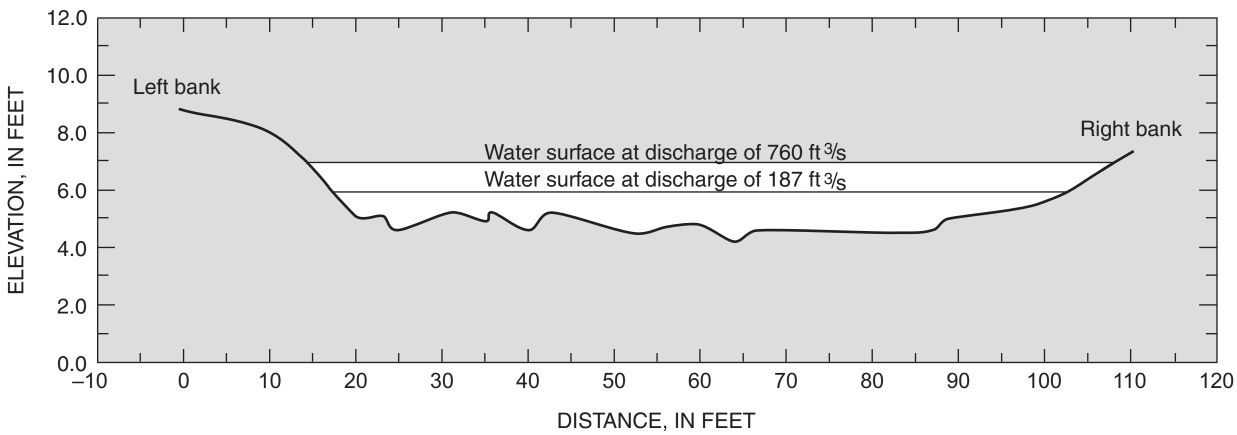

Figure 14. Cross-section 3, Skunk Creek above Interstate 17.

Figure 15. View upstream to cross-section 3, March 1998.

Table 6. Channel geometry and hydraulic properties for cross-section 4, Skunk Creek above Interstate 17

[Note: Only two measurements were made on February 4, 1998, at this section]

Date	Area, in square feet	Top width, in feet	Wetted perimeter, in feet	Hydraulic radius, in feet	Discharge, in cubic feet per second	Mean velocity, in feet per second	Velocity head, in feet	Froude number
09–11–97	160.2	86.7	87.4	1.8	521	3.25	0.16	0.42
02–04–98	105.4	79.6	80.2	1.3	285	2.70	.11	.41
02–04–98	123.1	81.6	82.2	1.5	371	3.01	.14	.43
02–04–98	143.9	84.7	85.4	1.7	470	3.27	.17	.44
02–15–98	167.0	91.0	8.1	1.9	760	4.55	.32	.59
02–25–98	79.6	76.9	77.4	1.0	187	2.35	.09	.41

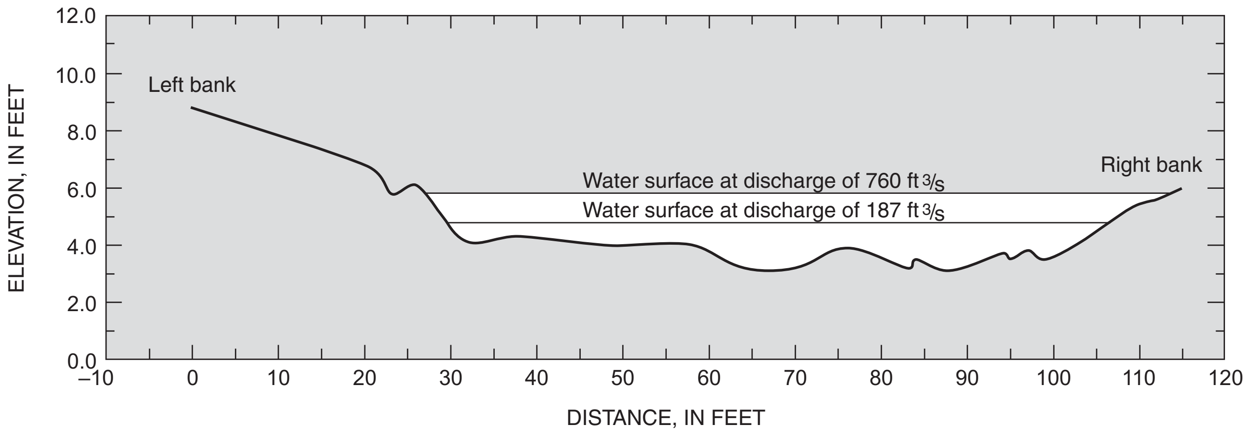

Figure 16. Cross-section 4, Skunk Creek above Interstate 17.

Figure 17. View upstream to cross-section 4, March 1998.

Table 7. Channel geometry and hydraulic properties for cross-section 5, Skunk Creek above Interstate 17

[Note: Only two measurements were made on February 4, 1998, at this section]

Date	Area, in square feet	Top width, in feet	Wetted perimeter, in feet	Hydraulic radius, in feet	Discharge, in cubic feet per second	Mean velocity, in feet per second	Velocity head, in feet	Froude number
09–11–97	155.8	81.5	82.2	1.9	521	3.34	0.17	0.43
02–04–98	114.1	76.1	75.2	1.5	285	2.59	.10	.36
02–04–98	132.6	78.6	79.2	1.7	371	2.80	.12	.38
02–04–98	150.1	80.8	81.5	1.8	470	3.13	.15	.40
02–15–98	184.1	85.2	85.8	2.2	760	4.13	.26	.49
02–25–98	84.7	71.8	65.8	1.3	187	2.21	.08	.36

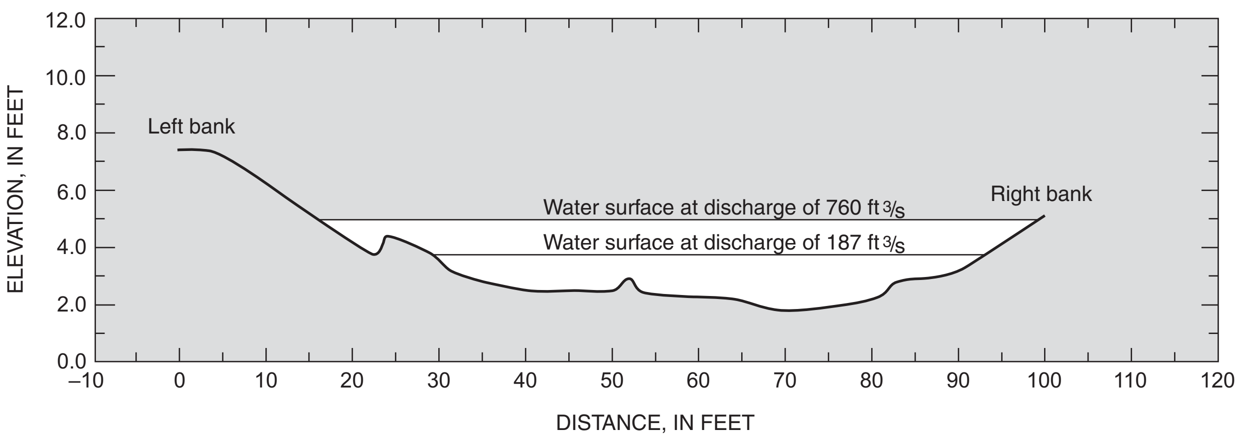

Figure 18. Cross-section 5, Skunk Creek above Interstate 17.

Figure 19. showing View upstream to cross-section 5, March 1998.

Table 8. Channel geometry and hydraulic properties for cross-section 6, Skunk Creek above Interstate 17

[Note: Only two measurements were made on February 4, 1998, at this section]

Date	Area, in square feet	Top width, in feet	Wetted perimeter, in feet	Hydraulic radius, in feet	Discharge, in cubic feet per second	Mean velocity, in feet per second	Velocity head, in feet	Froude number
09–11–97	80.6	82.0	82.8	2.2	521	2.89	0.13	0.34
02–04–98	140.5	75.1	75.9	1.8	285	2.03	.64	.26
02–04–98	170.0	80.2	81.1	2.1	371	2.18	.07	.26
02–04–98	181.4	82.1	83.0	2.2	470	2.59	.10	.31
02–15–98	218.8	87.7	88.6	2.5	760	3.47	.19	.32
02–25–98	113.5	71.1	71.8	1.6	187	1.65	.04	.23

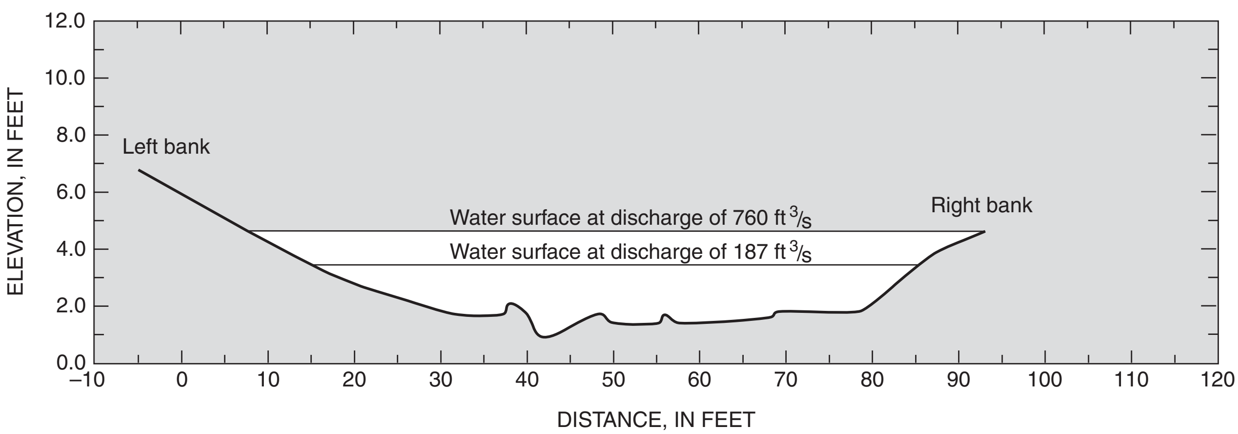

Figure 20. Cross-section 6, Skunk Creek above Interstate 17.

Figure 21. View upstream to cross-section 6, March 1998.

SUMMARY

In the winter of 1997–98, the USGS, in cooperation with the FCDMC, made six verification measurements for Manning's roughness coefficient at Skunk Creek above Interstate 17 from four floodflows. Skunk Creek is a moderately vegetated ephemeral channel and, according to results of this investigation, the vegetation present in the channel had a substantial effect on computed values of Manning's *n*. This study was a continuation of a previous investigation that verified Manning's *n* at this site for vegetated conditions, partially vegetated conditions, and conditions in which all of the vegetation was removed from the channel (Phillips and Ingersoll, 1998). The study confirms results obtained by Phillips and Ingersoll (1998) with the exception of one computed roughness coefficient. The lower *n* value of the measurement suggests that vegetation may have been laid over during peak flow, thus lowering total energy losses and the computed roughness coefficient. The information presented in this report can be utilized by engineers and hydrologists who must assess roughness coefficients for hydraulic studies of vegetated ephemeral channels in arid and semiarid environments.

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