DETERMINATION OF ROUGHNESS COEFFICIENTS FOR STREAMS IN WEST-CENTRAL FLORIDA

By Denis F. Gillen

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
inch (in.)	25.40	millimeter
foot (ft)	0.3048	meter
foot per foot (ft/ft)	0.3048	meter per meter
foot per second (ft/s)	0.3048	meter per second
square foot (ft^2)	0.0929	square meter
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot-pounds per second (ft-lbs/s) second	0.1383	kilogram-meters per

Sea Level : In this report, "sea level' refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929) -- a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

ABBREVIATIONS

α	Energy-head coefficient
A	Cross-section area (ft^2)
D	Hydraulic depth or mean depth (ft)
d_{50}	Particle diameter that equals or exceeds that of 50 percent of the particles (mm)
d_{84}	Particle diameter that equals or exceeds that of 84 percent of the particles (mm)
g	Gravitational acceleration (ft/s^2)
h	Water-surface elevation (ft)
h_f	Energy loss due to boundary friction
h_v	Velocity head (ft)
K	Conveyance (ft^3/s)
k	Expansion or contraction loss coefficient
L	Length of channel reach (ft)
L_m	Meander length (ft)
L_s	Straight length of a reach, (ft)
m	Correction factor for meandering of channel or flood plain
n	Manning's roughness coefficient
P	Wetted perimeter (ft)

ABBREVIATIONS –Continued

Q	Discharge (ft^3/s)
R	Hydraulic radius of channel cross-section (ft)
S_f	Friction slope (ft/ft)
S_w	Slope of the water-surface profile (ft/ft)
SP	Stream power [(ft-lb/s)/ft^2]
T	Top width of stream channel (ft)
V	Mean velocity (ft/s)

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ABSTRACT

Physical and hydraulic characteristics are presented for 10 west-central Florida stream reaches. These may be used as reference reaches for estimating Manning's roughness coefficient, *n,* in similar rivers and channels. Discharge in these reaches ranged from 1.8 to 3,010 cubic feet per second and water-surface slope ranged from 0.00002 to 0.00476 foot per foot. Sites were selected at or near U.S. Geological Survey streamflow gaging stations at which the stage-discharge relations were relatively stable. Crest-stage gages were installed at appropriate locations in each study reach in order to obtain water-surface elevations.

Water-surface profiles were collected over a range of discharges at each of the 10 sites and the roughness coefficient was computed for each discharge. For the 104 recorded streamflow events used in this report, the computed roughness coefficients ranged from 0.021 to 0.218 and the mean was 0.072. The median *n* value was 0.060; 70 percent of the time the *n* value was greater than 0.047 and 80 percent of the time the computed *n* was greater than 0.043. Bed material is so uniform at sites throughout west-central Florida that there is negligible variation in roughness as a result of variation in bed material. Streambank vegetation appears to be the major contributor to variations in roughness values for streams in west-central Florida.

Channel roughness can be estimated quantitatively by evaluating the interaction of all roughness factors. Photographs of sites where *n* values have been computed can be used for comparison to estimate values at similar sites. Using a base *n* value of 0.040 and increasing *n* for factors of vegetation, channel obstructions, and other factors provides the best determination of *n* values for streams in west-central Florida.

INTRODUCTION

Hydraulic calculations to determine flow in open channels require an evaluation of all characteristics that affect the roughness of the main channel. The Manning's roughness coefficient, *n*, is used to describe the flow resistance or relative roughness of a channel and is a function of the bed material, depth of flow, cross-section geometry, channel variations, obstructions to flow, type and density of vegetation, and degree of channel meandering. Term *n* appears in the general Manning equation for open-channel flow. The Manning equation, along with energy and continuity equations, can be used for the indirect computations of streamflow and has applications in flood-engineering studies, bridge and highway design, or other hydraulic computations.

Extensive guidelines for the selection of roughness characteristics are available (Cowan, 1956; Chow, 1959; Aldridge and Garrett, 1973; Arcement and Schneider, 1989; Jarrett, 1985; Coon, 1995). However, these studies for the field verification of roughness coefficients have not included the low-gradient channels and densely vegetated overbank areas that are characteristic of west-central Florida. The selection of roughness coefficients for stream channels and the overbank areas common to west-central Florida has been a subjective art rather than a quantitative science. The ability to determine roughness coefficients for natural channels representing a wide range of conditions needs to be developed through experience. Experience can be obtained in several ways, namely (1) understanding the factors that affect the value of the roughness coefficient, and thus acquiring a basic knowledge of the problem, (2) consulting and using a table of typical roughness coefficients for channels, and (3) examining and becoming acquainted with the appearance of some typical channels whose roughness coefficients are known.

Photographs of channels with known *n*-values are useful in estimating the roughness coefficients of similar channels. The photographs and data presented in this report cover a wide range of conditions. Familiarity with channel geometry, appearance, and roughness coefficients of these channels will improve the ability to select roughness coefficients for other similar channels.

ACKNOWLEDGMENTS

The author gratefully acknowledges the assistance of Jim Mann and Tom Harrison of the Southwest Florida Water Management District for help with project planning and data collection reviews. The assistance of Kathleen Hammett, John Coffin, William Kaehrle, and William Coon, hydrologists with the U.S. Geological Survey, in designing and conducting data collection activities and providing technical guidance is greatly appreciated.

DESCRIPTION OF STUDY AREA

The study area covers approximately 10,000 mi^2 and includes all or part of 16 counties of west-central Florida (fig. 1). Included are all basins draining into the Gulf of Mexico from the Withlacoochee River on the north to the Peace River on the south.

The west-central Florida area lies within two of the five natural topographic regions of Florida -- the Coastal Lowlands and the Central Highlands. Land-surface elevations in the study area range from sea level in the Coastal Lowlands to just over 300 ft above sea level in the Central Highlands. The two regions consist of low, nearly level plains and gently undulating to rolling areas with many ponds, swamps, and marshes as well as numerous lakes and perennial streams. A topographic high, which contains the headwaters of several major rivers, exists in the central part of the study area.

The climate is characterized by warm, humid summers and mild, moderately dry winters. Variation in land-surface elevations has little effect on the overall climate of the study area. The proximity to the sea and numerous wetland areas contributes to the humid, temperate climate.

For most streams in west-central Florida, roughness characteristics are significantly affected by streambank vegetation. At the study sites, streambank vegetation ranged from grasses along the banks at Delaney Creek near Tampa to dense ground cover and vines along with very prominent cypress trees and knees at Anclote River near Elfers. Two sites, South Creek near Vamo and Withlacoochee River at Wysong Dam at Carlson, had considerable in-stream vegetation during the study period.

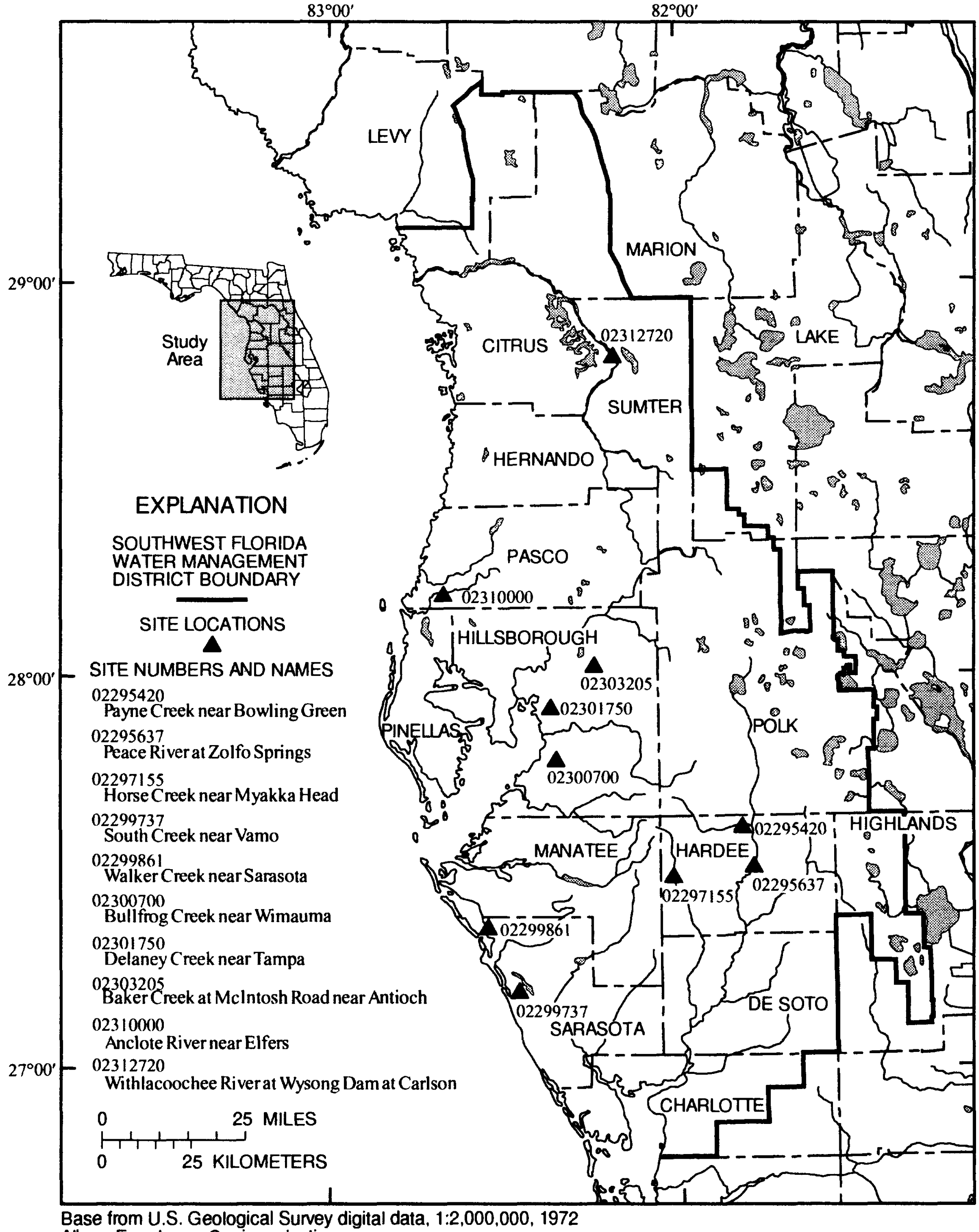

Figure 1. Location of the study area and study sites.

METHODS OF STUDY

Values of the Manning's roughness coefficient may be assigned for conditions that exist at the time of a specific flow event, for average conditions over a range in stage, or for anticipated conditions at the time of a future event. The *n*-values presented in this report are intended primarily for use in one-dimensional, open-channel flow applications, such as slope-area computations of discharge or step-backwater computations of water-surface elevation.

Roughness coefficients apply to a longitudinal reach of channel. A hypothetical channel, reaches, and cross sections are shown in figure 2. Subreaches of the channel should reflect representative conditions in that subreach rather than conditions just at the cross section. Cross sections were located as nearly as possible at right angles to the direction of flow and were established at locations where the conveyance appeared to vary uniformly between cross sections. The cross sections of the reach may be of regular geometric shape (such as triangular, trapezoidal, or semi-circular) or of an irregular shape typical of many natural channels. The flow may be confined to one or more channels, and, especially during floods, the flow may occur both in the channel and in the flood plain. Such cross sections are typically divided into sub-sections at points where major roughness or shape changes occur, such as at the juncture of dense vegetation and grassy areas or flood plain and main channel. During the period of study for this project, only two sites had overbank flow. As a result of insufficient overbank data, only within-bank flows were used to compute roughness coefficients in this study.

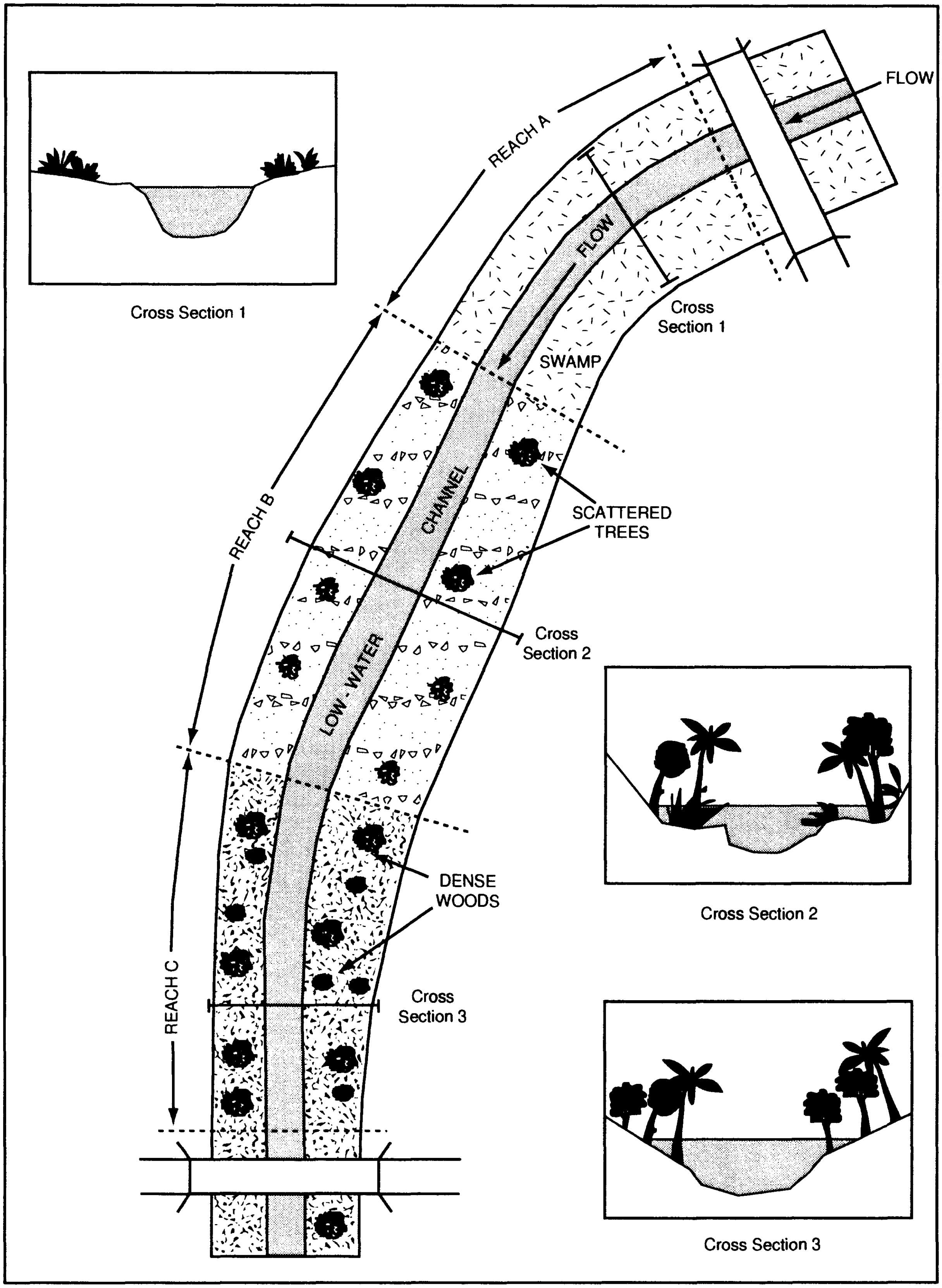

Figure 2. Plan view of a hypothetical channel and flood plain.

Hydraulic Principles

The Manning equation (Chow, 1959) is used for computing the reach properties and computed n values for this report. The roughness coefficient term appears in the general Manning equation for velocity of open-channel flow:

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

where

V = mean cross-section velocity, in feet per second;

R = hydraulic radius, in feet;

S_f = friction slope, in feet per foot; and

n = roughness coefficient, dimensionless.

The continuity equation may be written as:

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

where

Q = discharge, in cubic feet per second;

V = mean velocity, in feet per second; and

A = cross-section area, in square feet.

Substituting equation 1 for V in equation 2 yields a variation of the Manning equation for computation of discharge.

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

Equations 1 and 3 were developed for conditions of uniform flow in which the water-surface profile and energy gradient are parallel to the streambed, and the area, depth, and velocity are constant throughout the reach. The equation is assumed to be valid for nonuniform flow reaches if the energy gradient is modified to reflect only the losses resulting from boundary friction (Barnes, 1967). The Manning equation has been used extensively as a method for computing discharges or water-surface elevations in natural channels.

The energy equation for a nonuniform open-channel reach between cross sections 1 and 2 as shown on figure 3 is

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

where

h = elevation of the water surface at the respective section, in feet above a common datum;

h_v = velocity head at the respective section, in feet;

h_f = energy loss due to boundary friction in the reach, in feet;

Δh_v = upstream velocity head minus the downstream velocity head, in feet;

k = a coefficient equal to 0 for contracting reaches and 0.5 for expanding reaches.

$k(\Delta h_v)$ = energy loss due to increases in velocity in an contracting reach or decreases in velocity in an expanding reach, in feet.

Subscript numerals 1 and 2 refer to the upstream and downstream sections, respectively.

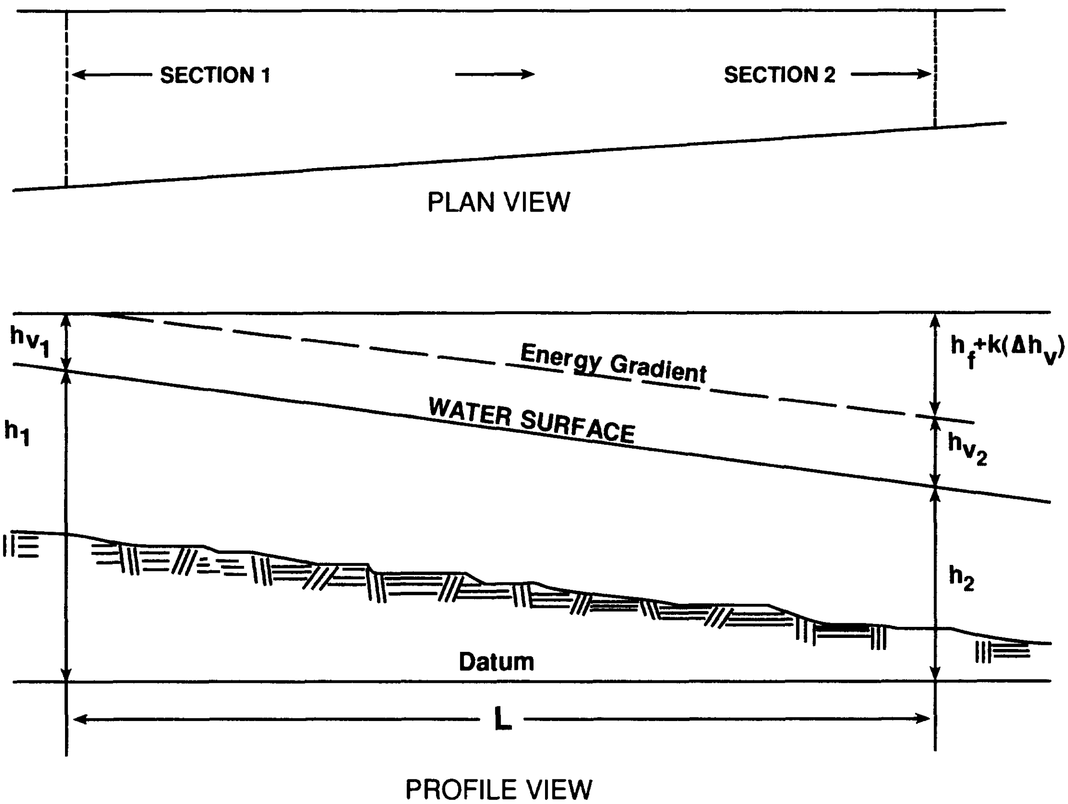

Figure 3. Definition sketch of an open-channel flow reach. (Modified from Barnes, 1967.)

Velocity head, h_v, can be affected by non-uniform distribution of velocities in the cross section. Irregular cross-section geometry or changes in the distribution of vegetation across the cross section are two factors that can cause non-uniform distribution of velocity. Multiplying velocity head, h_v, by a coefficient α that takes into consideration variations in velocity in subsections of the cross section can improve the accuracy of the h_v term. Although cross sections used for this study were not subdivided on the basis of channel geometry or distribution of vegetation, a basic understanding of the velocity-head coefficient is necessary for general application of the Manning equation. The velocity head coefficient, α, is computed as:

$$\alpha = \frac{\Sigma v^3 \Delta A}{V^3 A} \qquad (5)$$

where

v = the measured velocity in a subarea of the cross section, in feet per second;

ΔA = subarea of the cross section, in square feet;

V = mean velocity in the cross section, in feet per second; and

A = area of cross section, in square feet.

For a practically straight channel with a cross section of uniform shape, the effect of nonuniform velocity distribution on the computed velocity head is small and in the absence of a more suitable method, the coefficient is assumed to be unity (Chow, 1959).

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

$$S_f = \frac{h_f}{L} = \frac{\Delta h + \Delta h_v - k(\Delta h_v)}{L} \qquad (6)$$

where

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

L = the length of the reach, in feet.

Other variables are as previously defined.

The average value of the Manning roughness coefficient was computed for each reach from the known discharge, the water-surface profile, and the hydraulic properties of the reach as defined by the cross sections. The equation applicable to a multisection reach of M cross sections which are designated 1, 2, 3,...M-1, M is:

$$n = \frac{1.486}{Q}\sqrt{\frac{(h+h_v)_1 - (h+h_v)_M - (k\Delta h_v)_{1,2} + (k\Delta h_v)_{2,3} + \ldots + (k\Delta h_v)_{(M-1),M}}{\frac{L_{1,2}}{Z_1 Z_2} + \frac{L_{2,3}}{Z_2 Z_3} + \ldots + \frac{L_{(M-1),M}}{Z_{(M-1)} Z_M}}} \quad (7)$$

where

$Z = AR^{2/3}$

Other variables are as previously defined.

Manning's n was computed for each subreach or combination of cross sections within the reach. A friction-head weighted average of the n values of the subreaches was computed to represent the n value for the site. The weighting procedure is described in Jarrett and Petsch (1985).

The concepts of flow regime and stream power are also important in the estimation of roughness coefficients. Flow regime is governed by the size of the bed materials and stream power is a measure of energy transfer. Flows are classified as lower, transition, and upper regime (Simons and Richardson, 1966) depending on the bed forms that are produced. Stream power (*SP*) is computed by the formula:

$$SP = 62 R S_w V \quad (8)$$

where

62 = specific weight of water, in pounds per cubic foot,

R = hydraulic radius, in feet

S_w = water-surface slope, in feet per foot, and

V = mean velocity, in feet per second.

The relation of stream power and median grain size to flow regime (modified from Benson and Dalrymple, 1967) is shown in figure 4. If the value $62R\,S_wV$ plots above the upper line, it may be assumed the upper-regime flow occurs. The roughness coefficients for lower and transition regimes depend on grain size and bed-form roughness at a particular time and are difficult to assess. Generally, as flow increases, dune formation greatly increases and the roughness is much greater than the upper-regime flow roughness.

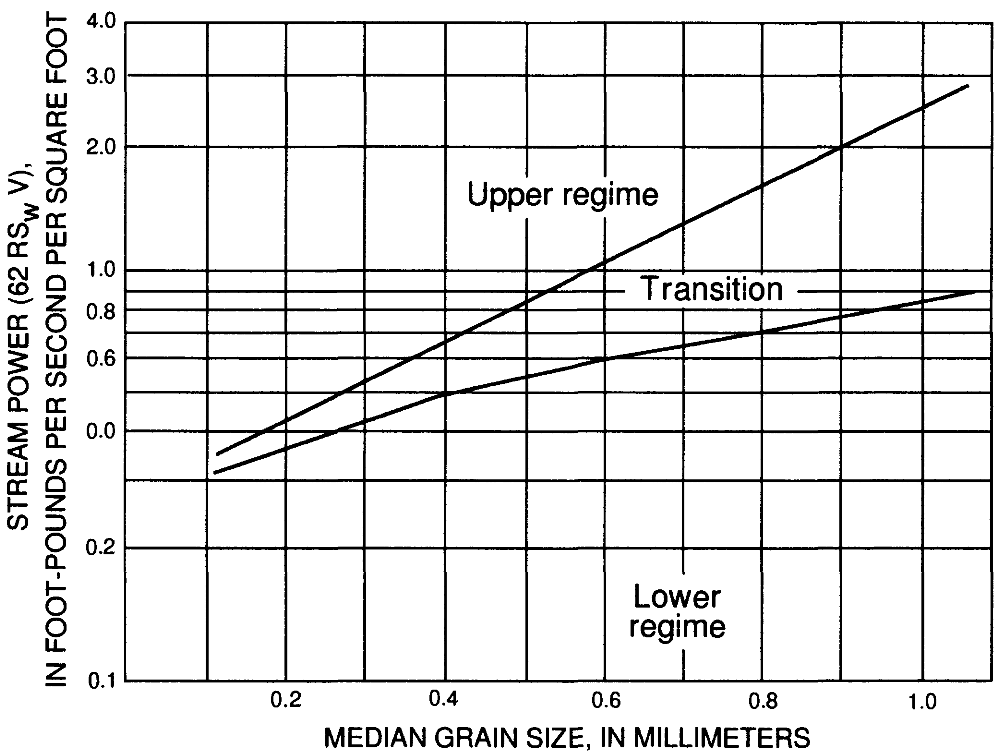

Figure 4. Relation of stream power and median grain size to flow regime. (Modified from Benson and Dalrymple, 1967.)

Site Selection

The sites used in this study were selected to meet the following criteria: (1) a U.S. Geological Survey streamflow-gaging station with a relatively stable stage-discharge relation was nearby; (2) the study reaches were relatively uniform in shape. The sites selected represent a wide range of channel types, flow widths and depths, channel slopes, vegetative characteristics, and roughness conditions and are representative of streams in west-central Florida. Although most sites had straight channels, there were three -- Bullfrog Creek, Anclote River, and Horse Creek with varying degrees of meander, and one -- Peace River, that curved gently throughout the reach. It is desireable to avoid sites with expanding reaches so that energy losses due to decreases in velocity (Eq. 4) can be avoided, but the Bullfrog Creek and South Creek sites each had some expansion in one subreach. Because velocities in west-central Florida streams tend to be relatively low, any energy losses due to decreases in velocity in expanding reaches would be small and were not taken into account in the computations for this report.

Data Collection

Multiple water-surface profiles and stream discharges were obtained at each of the study sites during 1992-94. A total of 104 measured events were included for analysis in this report. Channel geometry was surveyed at the beginning of the study and resurveyed if fill or scour within the reach occurred. Streambed particle size was measured, streambank vegetation identified, and various perspectives of each reach were photographed. Stream-gaging stations and water-level (crest-stage) gages were inspected and serviced on a regular basis.

Water-Surface Profiles

Water-surface profiles were computed using both recorded stages from stream-gaging stations and recorded peaks from standard U.S. Geological Survey crest-stage gages (fig. 5). A crest-stage gage records the peak water-surface elevation during an event by means of a

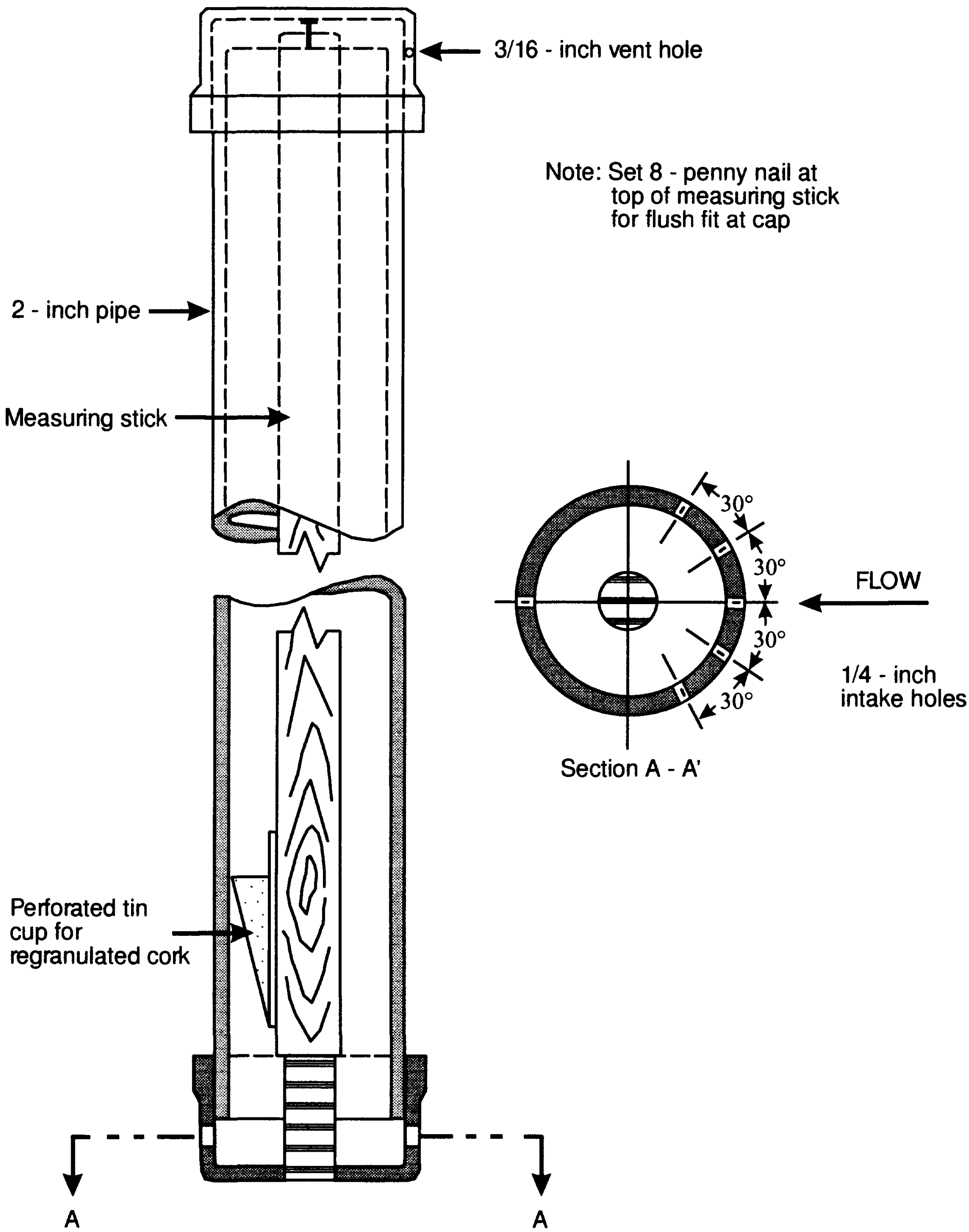

Figure 5. Crest-stage gage. (Modified from Buchanan and Somers, 1968.)

"corkline" that adheres to a wooden stick inside a 2-in. diameter pipe that has been secured to a tree or post on the river bank. Granulated cork within the pipe floats on the surface of the water, which enters the gage through holes in the bottom of the crest-stage gage and rises inside the pipe. A line of cork granules is left on the wooden stick at a height equal to the peak water-surface elevation of the stream. The peak stage is obtained by measuring the interval on the staff between the reference point and the floodmark. The datum of each crest-stage gage was checked by levels run from a reference mark at a nearby U.S. Geological Survey stream-gaging station. At most locations, the nearby U.S. Geological Survey stream-gaging station was used to measure water-surface elevation at one end of the selected reach and a crest-stage gage was used to measure the water-surface elevation at the opposite boundary of the reach. At Bullfrog Creek and Anclote River, both the upstream and downstream water-surface elevations of the reach were measured using crest-stage gages. Some sites had additional crest-stage gages located at intermediate cross sections to help define the water-surface profile. The water-surface elevation at intermediate cross sections was determined using a straight line interpolation of the recorded water surfaces from the upstream and the downstream gages. Water-surface elevations were also obtained from surveys of high-water marks and by direct measurements of the water-surface elevation from reference points.

Stream Discharge

The discharge for each recorded water-surface profile was obtained from discharge records of the nearby U. S. Geological streamflow-gaging station. The stability of the stage-discharge relation at each site was checked routinely by discharge measurements. Discharges used in the study ranged from 1.8 ft^3/s to 3,010 ft^3/s.

Channel Geometry

Channel geometry was surveyed at the beginning of the study and surveys were repeated at those sites where scour or fill changes were observed in the channel during the study. The cross sections were chosen to represent typical conditions within each reach. Each site had a minimum of two cross sections; most sites had three or more cross sections. Cross section 3 at Payne Creek near Bowling Green (02295420) and cross section 1 at Peace River at Zolfo Springs (02295637) were computed using data from numerous bridge measurements and boat measurements made at those locations. Examinations of graphic plots for those cross sections showed little, if any, variation with time. Historical photographs of those same cross sections did not show any major changes in the vegetation and historical conditions were felt to be similar to current conditions.

Streambed Particle Size

Streambed particle size was measured in accordance with the methods of Wolman (1954), and Benson and Dalrymple (1967). Random grab samples of bed material were taken at equal spacing across each cross section within the reach and composited into one sample. Sieve analyses were conducted by the University of South Florida. All of the study sites had bed material that was predominantly sand or finer particles. The percentage of sand that comprised the bed material at each site was 92 or greater with the exception of Peace River at Zolfo Springs, where the percentage of sand was 84. Results of the sieve analysis are shown in table 1.

Table 1.-- Summary of bed material particle size data for study sites in west-central Florida. (Locations are shown in figure 1)

	Diameter, in millimeters		
Site	d_{50}	d_{84}	Percent sand
02295420 Payne Creek near Bowling Green	0.20	0.36	99.0
02295637 Peace River at Zolfo Springs	0.33	1.96	84.0
02297155 Horse Creek near Myakka Head	0.27	0.39	98.5
02299737 South Creek near Vamo	0.23	0.41	98.2
02299861 Walker Creek near Sarasota	0.29	0.71	92.4
02300700 Bullfrog Creek near Wimauma	0.29	0.42	100.0
02301750 Delaney Creek near Tampa	0.28	0.41	99.6
02303205 Baker Creek at McIntosh Road near Antioch	0.25	0.40	97.8
02310000 Anclote River near Elfers	0.17	0.24	99.6
02312720 Withlacoochee River at Wysong Dam at Carlson	0.19	0.31	95.1

A sand-channel stream is defined as a stream which has an unlimited supply of sand in the channel bed. Sand, by definition, has a size range from 0.062 to 2 mm. Since the bed material at each site in this study is predominately sand, the d_{50} and d_{84} values used in this report represent those corresponding percentiles from the sieve analysis. The smallest sand for which reliable laboratory tests are available is 0.2 mm. Sand of this size has a Manning's coefficient of 0.012 for upper regime flow. Aldridge and Garrett (1973) extrapolated the laboratory data and concluded that 0.1 mm sand has a base Manning's *n* value of 0.010.

While most studies of Manning's *n* use bed material size as one of the major contributors to roughness determinations, bed material in west-central Florida streams is so similar from site to site that the effect of variations in streambed particle size on differences in roughness coefficients is negligible. A comparison of the bed material analyses from other studies is shown in table 2. The data illustrate the uniqueness of streams in west-central Florida as compared to other regions. A study of 21 Colorado streams (Jarrett, 1985) included statistical size distribution of the intermediate diameter of bed material. The range of the d_{50} percentile was 62 to 427 mm (0.2 to 1.4 ft). For the 10 west-central Florida streams used in this study, the range of the d_{50} percentile was 0.17 to 0.33 mm (0.0006 to 0.0011 ft). Using the d_{84} percentile the range for the 21 Colorado streams was from 91 to 792 mm (0.3 to 2.6 ft), while the west-central Florida streams had a range for the d_{84} percentile of 0.24 to 1.96 mm (0.0008 to 0.0064 ft). Measurements of streambed particle size for 78 New Zealand streams (Hicks and Mason, 1991) indicated only eight of the streams had a d_{50} of less than 2 mm. Six of those eight streams had particle-size-analysis data; particle sizes for two were estimated. The average d_{50} for the six streams where data were available was 0.82 mm (0.0064 ft); the d_{50} ranged from 0.33 to 1.18 mm (0.0011 to 0.0039 ft).

Table 2.-- Comparison of bed material particle size data from previous studies.

	Statistical size distribution of intermediate diameter of bed material, in millimeters, shown in the following percentiles					
	d_{50}			d_{84}		
Locations	Minimum	Maximum	Average	Minimum	Maximum	Average
Florida[1]	0.17	0.33	0.25	0.24	1.96	0.56
New Zealand[2]	0.33	397	61	1.18	800	109
Colorado[3]	62	427	155	91	792	354

[1]10 west-central Florida rivers.

[2]78 New Zealand rivers (Hicks and Mason, 1991).

[3]21 Colorado rivers (Jarrett, 1985).

Photographs

Photographs were taken during routine field trips to provide a guide in evaluating the Manning's roughness coefficient. Photographs were taken from a variety of perspectives, depending on the field of view and accessibility afforded by bank vegetation. The plan view for each study site shows the camera location and the view direction for each photograph used in this report. The photographs are intended to illustrate representative conditions throughout the reach. For most sites, photographs showing both the bed material and the streambank vegetation are used.

Streambank Vegetation

Using field notes and photographs, along with the cross-section plots, the stage below which there was no vegetation in each cross section was determined. Using that stage value in the NCALC program, the wetted perimeter for the non-vegetated portion of each cross section was computed. The vegetated wetted perimeter was computed by subtracting the value of the non-vegetated wetted perimeter from the total wetted perimeter for each cross section. The percentage of vegetated wetted perimeter used for each site represents the average of all the cross sections at that site.

Data Computation Procedure

In this study, Manning's equation was used to compute *n* based on a known discharge. Cross-section elevations, water-surface elevations and their associated discharges were input to NCALC; the *n* calculation computer program developed by Jarrett and Petsch (1985). For each water-surface profile and discharge, the roughness coefficient for every combination of cross sections and for the entire reach, along with the hydraulic properties for each cross section were computed. Hydraulic data as well as the resulting computed roughness coefficient for each discharge and water-surface profile, are presented with the site information. The tabulated values for area, top width, hydraulic radius, and velocity are averages of values computed for each cross section within a reach. In addition, Manning's *n* was computed for each individual subreach and combinations of cross sections within the reach. A friction-head weighted average value of *n* was used to represent the average conditions at each site.

Caution must be exercised when using the NCALC software to compute the *n* value. Just as the computational process for calculating discharge using the slope-area method (Dalrymple and Benson, 1967) is subject to assumptions and limitations, so too is the NCALC procedure. One assumption of the method is that there is uniform (or near uniform) flow distribution and conveyance with uniform energy losses across the section. When this is not found in nature, the method requires calculation of a composite *n* value to account for within-bank variations in roughness. Davidian (1984) discusses subdivision of cross sections. For overbank areas, cross sections are subdivided into unit shapes that have complete or nearly complete wetted perimeters (or into areas of consistent "roughness," such as an area of denser, more resistive vegetation). A channel with overbank flow would be subdivided at the top of the bank (regardless of whether a change in vegetative "roughness" was evident). If a panhandle section is not properly subdivided, the computed *n* value will be erroneously low, which results from an erroneously low hydraulic radius value. For higher stage calculations made on unsubdivided cross sections, the computed *n* value will be lower than it otherwise would be and reflects not a decrease in energy losses, but a limitation of the NCALC procedure.

ANALYSIS OF ROUGHNESS COEFFICIENT DATA

One hundred and four data sets (water-surface profiles and discharges) were obtained from 10 study sites in the west-central Florida area. Manning's roughness coefficients were computed for each individual event. The hydraulic data and computed roughness coefficients were used (1) to evaluate the change in the *n* value with discharge, hydraulic radius, slope, and vegetation; (2) and to compare the differences in the relation of *n* value to hydraulic radius at individual sites.

Hydraulic Radius

The relation of Manning's *n* to the hydraulic radius of all streams used in this study is shown in figure 6. Streams were grouped according to hydraulic characteristics of drainage area and stream alignment. There was little variation in roughness values at each of the study sites when the hydraulic radius exceeded 2.5. The exceptions were Withlacoochee River and Payne Creek. Both of these sites have considerable vegetation. The increase in *n* values at Payne Creek when the hydraulic radius increases is the result of dense vegetation at higher stages, whereas at the Withlacoochee River, variances in *n* values with hydraulic radius are attributable to extensive in-stream vegetation.

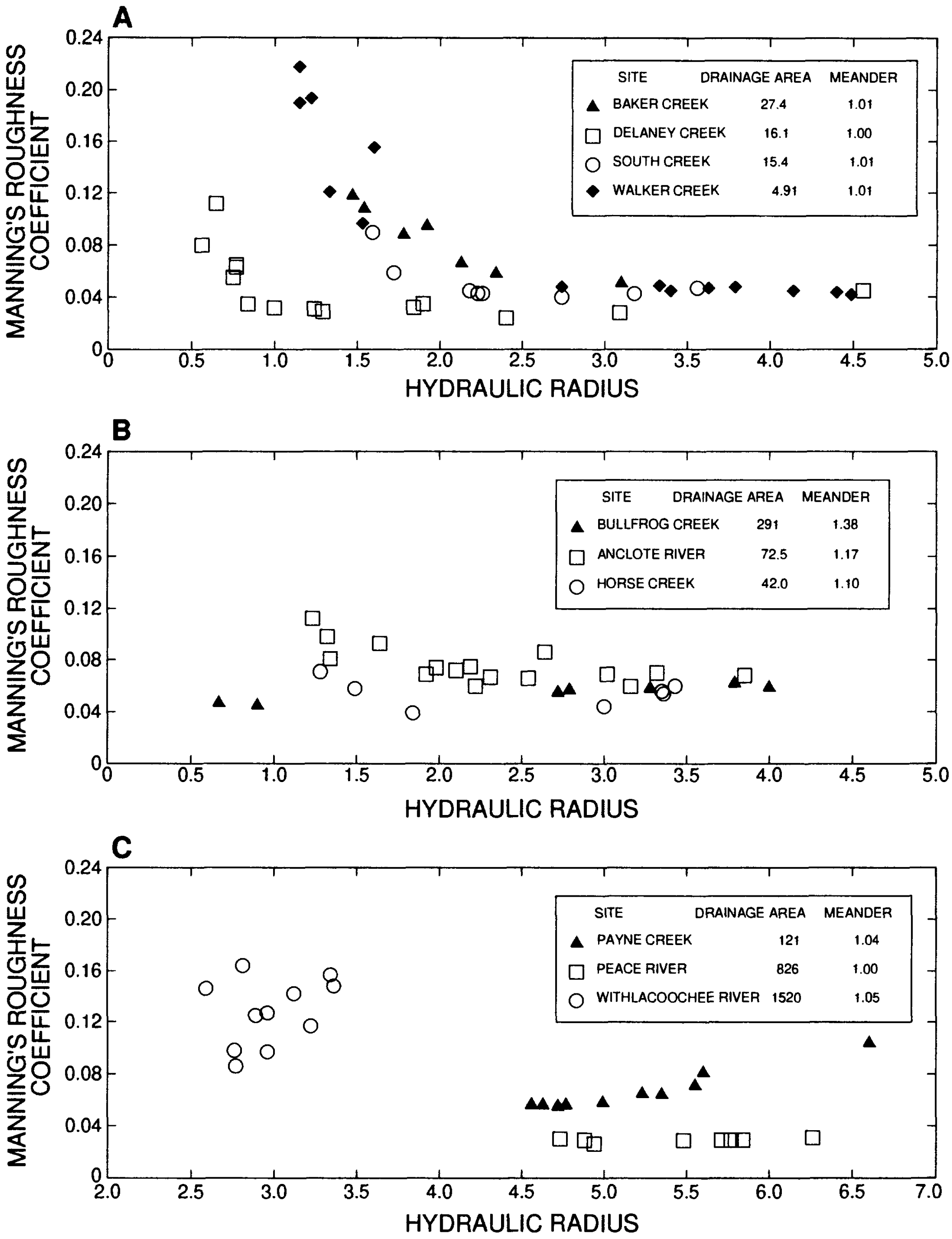

Figure 6. Relation between hydraulic radius and Manning's roughness coefficient for streams with similar hydraulic characteristics. (A) small drainage area straight stream channels, (B) small drainage area meandering stream channels, (C) large drainage area straight stream channels.

Water-Surface Slope

In a study of high-gradient streams in Colorado, Jarrett (1984) reported that, for similar bed-material size, channels with low-gradients have lower *n* values than channels with high gradients. Data for streams in west-central Florida also indicate that roughness increases with slope. There is considerable scatter in the relation of Manning's roughness coefficient to water-surface slope (fig. 7), but the general increase in *n* as slope increases is apparent. While friction slope is the term used in the Manning, equation there was a perfect correlation (r=1.0) between water-surface slope and friction slope for the data collected for this study. Water-surface slope is presented because it is easily measured in the field.

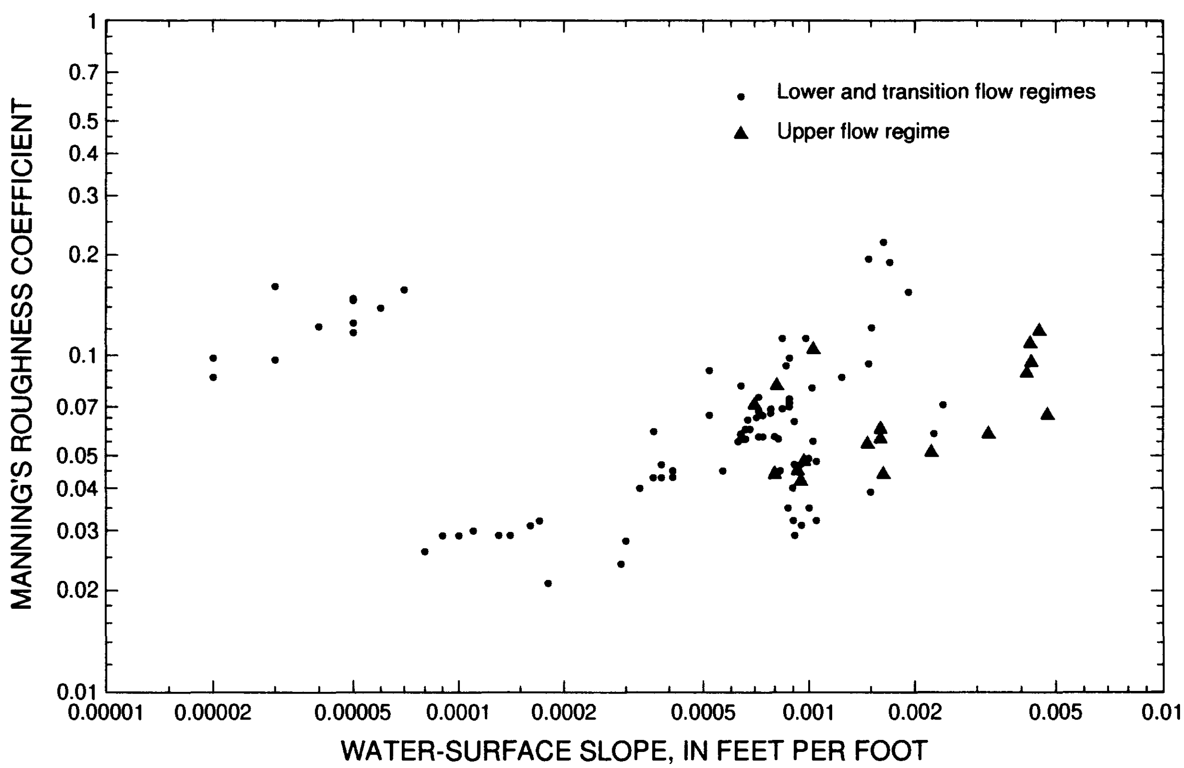

Figure 7. Relation between Manning's roughness coefficient and water-surface slope.

Streambank Vegetation

Flow resistance within a vegetated area is a function of different variables, including velocity, distribution of vegetation, roughness of the channel boundary, and the structural and hydrodynamic properties associated with various plants, leaves and trees. In west-central Florida streams, velocities are very low in comparison with other regions; vegetation is quite dense with minimal seasonal variation; and a variety of vegetation types is present along most streams. Typical reaches will include various hardwoods such as the live oak and sweetgum, bald cypress with numerous cypress knees, sabal palms, palmetto palms, along with considerable short stemmed grasses, ferns, and vines. In-stream aquatic vegetation such as water hyacinths or hydrilla, which can extend throughout the water column, is also common in the streams of west-central Florida. In this study, South Creek, Delaney Creek, and Withlacoochee River had various amounts of in-stream vegetation in addition to streambank vegetation.

The relation between Manning's roughness coefficient and the hydraulic radius at Baker Creek (fig. 6A) is typical of streams with little or no streambank vegetation. However, at most streams in west-central Florida when flows increase, the effects of streambank vegetation increase and this result in an increase in n values. The effect that dense brush along the streambank has on Manning's roughness coefficient for Delaney Creek, Anclote River, and Payne Creek is illustrated in figure 8. Figure 8 indicates that dense vegetation can have a marked effect on total flow resistance for streams in west-central Florida and must be evaluated properly.

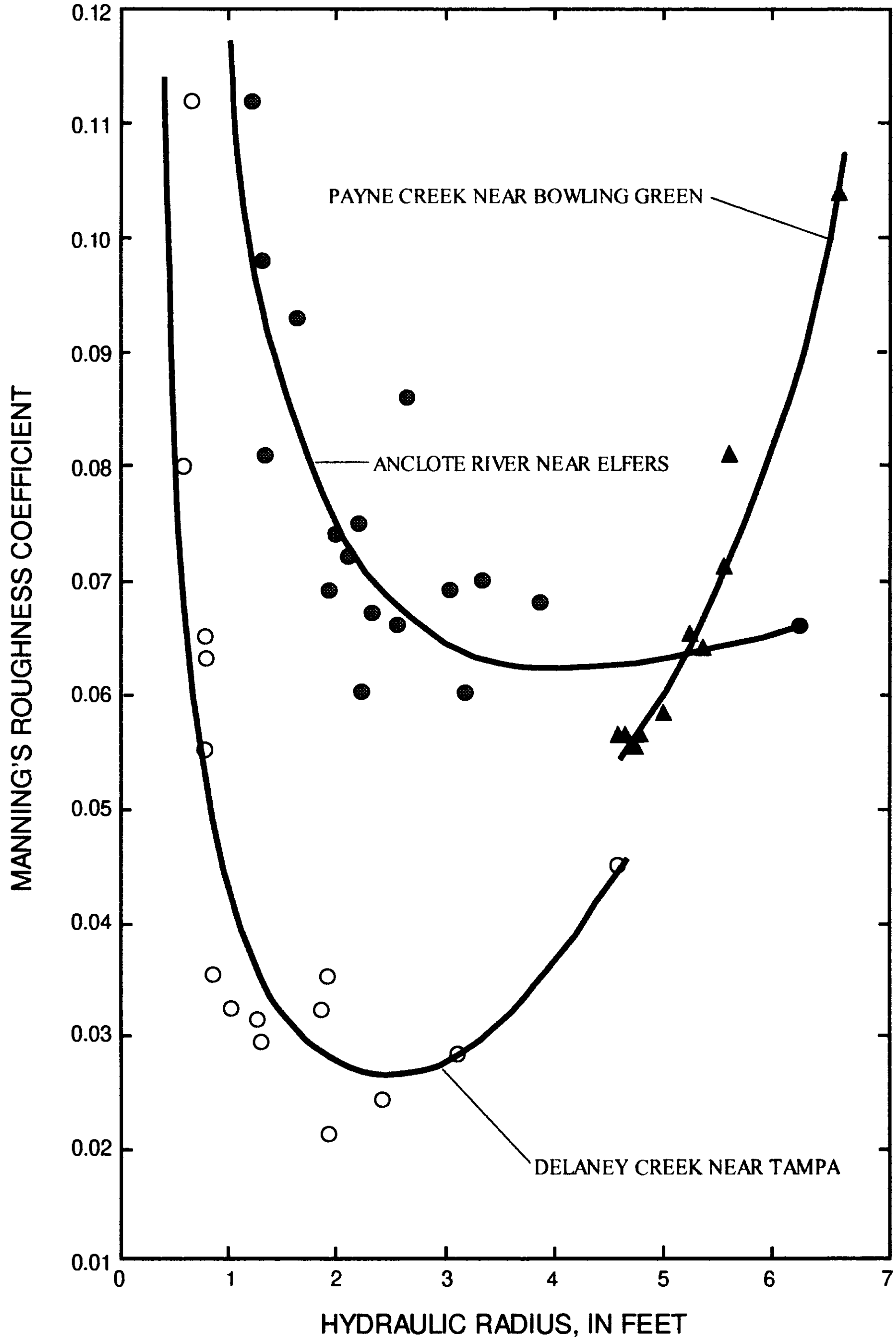

Figure 8. Relation between Manning's roughness coefficient and hydraulic radius showing the effect of streambank vegetation

Assessment of Published Equations

Eleven equations that have previously been developed to estimate *n* values from field parameters were used to estimate *n* for the 104 data sets in this study (table 3). These equations were developed under constraints of geographic parameters unique to their respective areas. None of these equations were developed using data from the low-gradient, low-velocity, highly-vegetated streams common to west-central Florida. Application of these equations to conditions other than those from which they were developed is questionable. The equations are presented to inform users of the potential errors associated with their application to west-central Florida streams.

Table 3.-- Published *n*-value equations

Investigator	Equation[1]	Equation number	Range of differences	Mean absolute error
Bray (1979)[2]	$n=0.104\ S_w^{0.177}$	9	-0.001 to 0.185	0.043
	$n=0.048\ d_{50}^{0.179}$	10	-0.014 to 0.180	0.037
	$n=\frac{0.0927\ R^{1/6}}{0.248+2.36\log(R/d_{50})}$	11	-0.031 to 0.161	0.034
Strickler (1923)[3]	$n=0.034\ d_{50}^{1/6}$	12	-0.004 to 0.190	0.044
Limerinos (1970)	$n=\frac{0.0926\ R^{1/6}}{1.16+2.0\log(R/d_{84})}$	13	-0.036 to 0.158	0.036
	$n=\frac{0.0926\ R^{1/6}}{0.35+2.0\log(R/d_{50})}$	14	-0.034 to 0.157	0.032
Froehlich (1978)[2]	$n=0.245\ R^{0.14}(R/d_{50})^{-0.44}(R/T)^{0.30}$	15	-0.030 to 0.153	0.034
Griffiths (1981)[2]	$n=\frac{0.0927\ R^{1/6}}{0.760+1.98\log(R/d_{50})}$	16	-0.018 to 0.169	0.035
	$n=0.104\ R^{1/6}(R/d_{50})^{-0.297}(R/P)^{0.103}$	17	-0.026 to 0.162	0.032
Sauer (1990)[4]	$n=0.11\ S_w^{0.18}\ R^{0.08}$	18	-0.003 to 0.183	0.040
Jarrett (1984)	$n=0.39\ S_f^{0.38}\ R^{-0.16}$	19	0.003 to 0.185	0.049 0.038[5]

[1] All length dimensions are in feet. S_w = slope of water surface. T = top width of stream. P = wetted perimeter. Other variables are as previously defined.

[2] As published in Jobson and Froehlich (1988).

[3] As published in Henderson (1966).

[4] V. B. Sauer (U.S. Geological Survey, written commun., (1990), as published in Coon (1995).

[5] Based on 9 n-value computations from channels with friction slope greater than 0.002.

Bray (Eq. 9, 10, and 11) presents equations that relate *n* to water-surface slope, intermediate bed material size, d_{50}, and hydraulic radius. The equations were based on high within-bank flow data from 67 gravel-bed river reaches in Alberta, Canada. The intermediate bed material size (d_{50}) ranged from 0.06 to 0.48 ft. Sites were selected that had minimal bed transport, no significant vegetation in the channel, and no dominant bedform features.

Strickler's equation (Eq. 12) was devloped from mostly Swiss and French data of gravel-bed streams and fixed bed-channels. Strickler is probably the first investigator who attempted to relate a resistance coefficient explicitly to the sediment property of alluvial channels. Strickler's equation yields poor results when the bedform effect is predominant because of the limitations of the data that were used. The equation estimates the *n* value independently of stage and is appropriate only for high within-bank flows.

Limerinos (Eq. 13 and 14) related *n* to hydraulic radius and bed particle size using data from 11 stream channels having bed material ranging from small gravel to medium size boulders. He related *n* to both the intermediate diameter, d_{50}, and the minimum diameter, d_{84}. Limerinos selected reaches having a minimum amount of roughness other than that caused by bed material.

Froehlich (Eq. 15) developed an equation that relates *n* to hydraulic radius, relative smoothness, and a depth-to-width factor. Froehlich used data from 15 sites described in Barnes (1967) for which bed-material particle sizes were included. This equation is presented in Jobson and Froehlich (1988).

Griffiths (Eq. 16 and 17) studied the hydraulic resistance in coarse gravel-bed rivers. He proposed relations for gravel rivers with rigid and movable beds using 136 field data sets from 72 reaches on 46 New Zealand gravel-bed rivers.

Sauer's (Eq. 18) equation is based on data from Barnes (1967) and is applicable to channels with water-surface slopes between 0.0003 and 0.018 and with hydraulic radii up to 19 ft. This equation includes the roughness effects of not only the bed and bank material, but other flow-resisting factors such as cross-sectional irregularities, variations in channel size and shape, along with vegetated bank conditions. Roughness coefficients estimated by this equation would be composite values. This equation would likely give reasonable estimates for stream channels whose *n* values are significantly affected by multiple factors.

Jarrett (Eq. 19) relates *n* to hydraulic radius and friction slope using data from 21 high-gradient (friction slope greater than 0.002) cobble and boulder streams in Colorado .

A comparison of the errors resulting from applying these equations to west-central Florida streams is presented in table 3; for each event, the two best results from these equations are given in tables 4 and 5. Only high within-bank flows for each site were used in an attempt to standardize the equations. Results for lower flows in the same channels may be quite different from the high flows listed. These flows were also separated into upper, transition, and lower regime flows. Table 4 lists the best estimates of *n* values by the published equations with less than 70 percent of the cross-section area vegetated, whereas table 5 lists the same results for streams with more than 70 percent of the cross-section area vegetated.

None of the equations accurately estimated *n* values for streams in west-central Florida, although results were generally better for events where the wetted perimeter was less than 70 percent vegetated. The average mean absolute error from using each equation for every event was 0.039 and ranged from -0.036 to 0.190. This range demonstrates the errors that can result if published equations are used to estimate *n* values for streams in west-central Florida.

Table 4.-- Best estimates of *n* values computed from study-site data for high within bank flows with less than 70 percent of cross-section area vegetated. (Locations are shown in figure 1. ft^3/s = cubic foot per second. Equation numbers are defined in table 3)

				Best estimates of computed *n* values			
Site name	Discharge (ft^3/s)	Computed *n* value	Wetted perimeter % vegetated	*n* value	Equation number	n value	Equation number
UPPER REGIME FLOWS							
Walker Creek near Sarasota	971	0.042	61	0.043	13	0.044	14
	438	0.045	32	0.044	13	0.044	14
	398	0.044	27	0.044	14	0.043	13
	312	0.048	19	0.049	15	0.049	17
	278	0.047	18	0.045	13	0.045	14
Baker Creek at McIntosh Road	310	0.051	50	0.047	17	0.046	15
near Antioch	151	0.058	28	0.051	15	0.049	17
	128	0.066	23	0.056	15	0.049	17
	81	0.095	18	0.053	15	0.050	17
	78	0.088	15	0.054	15	0.050	17
	51	0.108	9	0.055	15	0.052	14
	43	0.118	7	0.055	15	0.052	14
TRANSITION REGIME FLOWS							
Walker Creek near Sarasota	242	0.045	12	0.045	13	0.046	14
	217	0.049	11	0.050	17	0.051	15
LOWER REGIME FLOWS							
Peace River at Zolfo Springs	3,010	0.032	55	0.032	15	0.028	12
	2,300	0.030	52	0.032	15	0.028	12
Horse Creek near Myakka Head	211	0.044	37	0.046	14	0.041	11
South Creek near Vamo	166	0.047	58	0.046	17	0.045	15
	130	0.043	54	0.043	14	0.046	15
Bullfrog Creek near Wimauma	356	0.059	63	0.047	17	0.044	14
	254	0.062	54	0.048	17	0.046	15
Delaney Creek near Tampa	222	0.028	66	0.028	12	0.028	18

Table 5.-- Best estimates of *n* values computed from study-site data for high within bank flows with more than 70 percent of cross-section area vegetated. (Locations are shown in figure 1. ft^3/s = cubic foot per second. Equation numbers are defined in table 3)

Site name	Discharge (ft^3/s)	Computed *n* value	Wetted perimeter % vegetated	Best estimates of computed n values: *n* value	Equation number	n value	Equation number
UPPER REGIME FLOWS							
Payne Creek near Bowling Green	1,500	0.104	83	0.037	17	0.037	14,18
	915	0.081	76	0.039	17	0.038	14
Horse Creek near Myakka Head	529	0.060	76	0.045	17	0.044	14
	495	0.054	74	0.045	17	0.045	14
	488	0.056	73	0.045	17	0.045	14
LOWER REGIME FLOWS							
Payne Creek near Bowling Green	852	0.071	74	0.039	17	0.038	14
	728	0.064	70	0.040	17	0.038	14
Delaney Creek near Tampa	496	0.045	75	0.046	17	0.044	14
Anclote River near Elfers	782	0.066	84	0.038	17	0.036	14
	274	0.068	77	0.040	17	0.038	14
	209	0.070	75	0.041	17	0.039	14
	173	0.060	72	0.041	17	0.039	14
	152	0.069	71	0.041	17	0.039	14
Withlacoochee River at Wysong	352	0.117	81	0.040	14	0.036	10,11
Dam at Carlson	332	0.157	81	0.040	14	0.036	10,11

PROCEDURE FOR ESTIMATING ROUGHNESS COEFFICIENTS FOR WEST-CENTRAL FLORIDA STREAMS

Quantitative Methods

A general quantitative approach for determining roughness coefficients is to select a base n value for a straight, uniform, smooth channel in the natural materials of the streambed and banks and to add modifying values for channel-surface irregularity, channel-shape variation, obstructions, type and density of vegetation, and a degree of meandering. Cowan (1956) developed a procedure for estimating the effects of these factors to determine the value of n for a channel. The value may be computed by

$$n = (n_b + n_1 + n_2 + n_3 + n_4)\, m \qquad (9)$$

where

n_b = a base value of n for a straight, uniform, smooth channel with natural materials,

n_1 = a correction factor for the effect of surface irregularities,

n_2 = a value for variations in shape and size of the channel cross section,

n_3 = a value for obstructions,

n_4 = a value for the amount of vegetation and flow conditions, and

m = a correction factor for meandering of the channel.

The use of a field form for evaluating roughness factors (fig. 9) can be helpful in applying this type of quantitative approach.

ROUGHNESS COEFFICIENT EVALUATION

Stream and location: ______________________________ **Date:** ______________

____

____

Reach length: ____

Reach description: ____

____

____

Width: __________ **Hydraulic radius:** __________ **Water-surface slope:** __________

Bed material: ____

____

Vegetation description: ______________________________________

____

____

Percentage of wetted perimeter that is vegetated: ____________________

Channel computation of n-value:

Factor	Value	Remarks/Reference
Base value (n_b)		
Cross-section irregularity (n_1)		
Channel variation (n_2)		
Effects of obstructions (n_3)		
Channel vegetation (n_4)		
Degree of meandering (m)		L_m/L_s =
$n = (n_b + n_1 + n_2 + n_3 + n_4)\ m$ =		

____

Overbank n-values:

Subarea	Value	Remarks

Calculation of composite n value: weighted by wetted perimeter or area.

____

Figure 9. Roughness evaluation form. (Modified from Jarrett, 1985.)

Base *n* values (n_b) for channels

In the selection of a base *n* value, the channel must be classified as a stable channel or as a sand channel. A stable channel is defined as a channel in which the bed is composed of firm soil, gravel, cobbles, boulders, or bedrock and the channel remains relatively unchanged throughout most of the range in flow. A sand channel is defined as a channel in which the bed has an unlimited supply of sand. By definition, sand ranges in grain size from 0.062 to 2 mm.

As noted in the discussion of streambed particle size, all of the sites studied in west-central Florida had sand channels with fine-grained sands. Benson and Dalrymple (1967, p.22) provide a list of base *n* values for sand channels. These range from 0.012 to 0.026 (table 6) and are for upper regime flow only. Of the 104 events from the sites used for this study, only 17 were for upper regime flow, 6 events were classified as transition regime, and the remaining 81 were classified as lower regime flow.

Table 6.-- Base values of Manning's roughness coefficient, *n*, for sand channels (Modified from Benson and Dalrymple, 1967, p. 22)

	Base *n* value for upper regime flow
Median size of bed material (in millimeters)	Straight uniform channel
0.2	0.012
.3	.017
.4	.020
.5	.022
.6	.023
.8	.025
1.0	.026

Although table 6 provides a starting point for selecting a base n value for sand channels with upper regime flow, evaluation of the site information (Appendix) provides information that is more useful in estimating a base n value for streams in west-central Florida where lower regime flows predominate. The median n value for the events listed in the Appendix is 0.060; 80 percent of the computed n values were greater than 0.043. Therefore, it seems reasonable that except for the smoothest, non-vegetated sand channels, a base n value of 0.040 would be appropriate for streams in west-central Florida.

Once a base n value has been selected then cross-section irregularities, channel alignment, obstructions, vegetation, and other factors that contribute to the roughness are accounted for by adding increments of roughness to the base value of n. Table 7, modified from Aldridge and Garrett (1973), gives ranges of adjustments for the factors that affect channel roughness for the prevailing channel conditions.

Cross-section irregularities, n_1

Surface irregularities such as eroded and scalloped stream banks, exposed tree roots, and rock outcrops increase the wetted perimeter, create turbulence, and increase roughness. Generally the effect of these irregularities increases with depth of flow. Where the ratio of channel width to depth is small, larger adjustments are needed.

Channel variations, n_2

Changes in the size of cross sections and side-to-side shifting of the low-water channel in successive cross sections will increase energy losses. Gradual changes in channel dimensions do not increase turbulence; however, abrupt variations increase turbulence and need to be evaluated.

Table 7. -- Adjustment values for factors that affect the roughness of a channel[1] (Modified from Aldridge and Garret, 1973, table 2)

Channel conditions		*n* value adjustment[1]	Example
	Smooth	0.000	Compares to the smoothest channel attainable in a given bed material.
Degree of irregularity (n_1)	Minor	0.001-0.005	Compares to carefully dredged channels in good condition but having slightly eroded or scoured side slopes.
	Moderate	0.006-0.010	Compares to dredged channels having moderate to considerable bed roughness and moderately sloughed or eroded side slopes.
	Severe	0.011-0.020	Badly sloughed or scalloped banks of natural streams; badly eroded or sloughed sides of canals or drainage channels; unshaped, jagged, and irregular surfaces of channels in rock.
	Gradual	0.000	Size and shape of channel cross sections change gradually.
Variation in channel cross section (n_2)	Alternating occasionally	0.001-0.005	Large and small cross sections alternate occasionally, or the main flow occasionally shifts from side to side owing to changes in cross-sectional shape.
	Alternating frequently	0.010-0.015	Large and small cross sections alternate frequently, or the main flow frequently shifts from side to side owing to changes in cross-sectional shape.
	Negligible	0.000-0.004	A few scattered obstructions, which include debris deposits, stumps, exposed roots, logs, piers, or isolated boulders that occupy less than 5 percent of the cross-section area.
Effect of obstruction (n_3)	Minor	0.005-0.015	Obstructions occupy less than 15 percent of the cross-sectional area and the spacing between obstructions is such that the sphere of influence around one obstruction does not extend to the sphere of influence around another obstruction. Smaller adjustments are used for curved smooth-surfaced objects than are used for sharp-edged angular objects.
	Appreciable	0.020-0.030	Obstructions occupy more than 50 percent of the cross-section area or the space between obstructions is small enough to cause the effects of several obstructions to be additive, thereby block ing an equivalent part of a cross section.
	Severe	0.040-0.050	Obstructions occupy more than 50 percent of the cross-section area or the space between obstructions is small enough to cause turbulence across mostof the cross section.

Table 7.-- Adjustment values for factors that affect the roughness of a channel--(continued)[1]

Channel conditions		*n* value adjustment[2]	Example
	Negligible	0.000	Any type or density of vegetation growing on the banks of channels more than 100 ft wide with less than 25 percent of the wetted perimeter vegetated and no significant vegetation along channel bottoms. Mowed grass or vetch on banks of channels over 50 ft wide. (Could be applicable to narrower channels.)
	Small	0.002-0.010	Dense growth of flexible turf grass, such as Bermuda, or weeds growing where the average depth of flow is at least two times the height of the vegetation; supple tree seedlings such as willow, cottonwood, arrowweed,or salt cedar growing where the average depth of flow is at least three times the height of the vegetation. Dense woody brush, soft stemmed plants, a few mature trees, that cover 25 to 50 percent of the wetted perimeter on the banks of channels from 100 to about 250 ft wide.
Amount of vegetation (n_4)	Medium	0.010-0.025	Turf grass growing where the average depth of flow is from one to two times the height of the vegetation; moderately dense stemmy grass, weeds, or tree seedlings growing where the average depth of flow is from two to three times the height of the vegetation; brushy, moderately dense vegetation, similar to 1- to 2-year-old willow trees in the dormant season, growing along the banks and no significant vegetation along the channel bottoms where the hydraulic radius exceeds 2 ft.
	Large	0.025-0.050	Turf grass growing where the average depth of flow is about equal to the height of the vegetation; 8- to 10-year-old willow or cottonwood trees intergrown with some weeds and brush (none of the vegetation is in foliage) where the hydraulic radius exceeds 2 ft; bushy willows about 1 year old intergrown with some weeds along side slopes (all vegetation in full foliage) and no significant vegetation along channel bottoms where the hydraulic radius is greater than 2 ft.
	Very Large	0.050-0.100	Turf grass growing where the average depth of flow is less than half the height of the vegetation; bushy willow trees about 1 year old intergrown with weeds along side slopes (all vegetation in full foliage) or dense cattails growing along channel bottom; trees intergrown with weeds and brush (all vegetation in full foliage).
Degree of meandering[3] (m)	Minor	1.00	Ratio of the channel length to valley length is 1.0 to 1.2
	Appreciable	1.15	Ratio of the channel length to valley length is 1.2 to 1.5
	Severe	1.30	Ratio of the channel length to valley length is greater than 1.5

[1] The original source of data presented in this table is Cowan (1956). Modifications from Chow (1959), Aldridge and Garret (1973), Jarrett (1985), and Coon (1995) are included.

[2] Adjustments for degree of irregularity, variations in cross section, effect of obstructions, and vegetation are added to the base *n* value (table 6) before multiplying by the adjustment for meander.

[3] Adjustment values apply to flow confined in the channel and do not apply where downvalley flow crosses meanders.

Obstructions, n_3

Obstructions that disturb the flow pattern in the channel will increase the *n* value. Trees, stumps, large boulders, bridge piers, and debris deposits increase roughness and cause backwater upstream and eddy losses downstream. The amount of increased roughness can be evaluated in terms of the reduction in the cross-section area. This will depend on the type, size, shape, distribution, and number of the obstructions. The effect of obstructions on the roughness coefficient is also a function of velocity. When the velocity is high, an obstruction exerts a sphere of influence that is much larger than the obstruction. At the velocities that generally occur in channels with gentle to moderately steep slopes, the sphere of influence could be from 3 to 5 times the width of the obstruction (Aldridge and Garret, 1973). However, with the low-gradient streams and the low stream velocities found in west-central Florida, the sphere of influence of any single obstruction will rarely exceed two times its size. Several obstructions, closely spaced in a channel, can create overlapping spheres of influence and can cause a considerable increase in the roughness coefficient. In this study, an example of overlapping spheres of influence can be seen at the Anclote River site, where a substantial number of different-sized, closely-spaced, cypress knees cause a significant increase in the *n* value.

Channel vegetation, n_4

Streambank vegetation increases turbulence and roughness and reduces channel capacity. This is particularly true for narrow channels. The magnitude of this effect depends, largely, on the type of vegetation, the degree to which the vegetation is flattened by high water, the vegetation height in relation to the depth of flow, and the amount of vegetation that reduces channel capacity (the percentage of the wetted perimeter covered by vegetation). In some areas of the country, seasonal changes produce large variances in the effect vegetation has on roughness. While there is some measure of that same effect on streams in west-central Florida, because of the mild winter climate that normally occurs in west-central Florida, seasonal changes are not as important as the other vegetation factors. Streams in west-central Florida commonly have in excess of 70 percent of a cross section vegetated (table 5) throughout the year. In addition, stream velocities are low, so there is minimal bending of the vegetation. This is especially true when plant growth along the streambank includes palmettos, cypress knees, and densely matted underbrush commonly found along the streams in west-central Florida. Aldridge and Garret (1973) suggested *n* values for brush- and tree-covered channels, when the *n* value is assigned for the vegetation, would be the same as that for brush- and tree-covered flood plains.

Degree of meandering, *m*

The increase in channel roughness due to small curves and bends is considered to be insignificant. However, the effects of sharp bends may extend downstream for some distance. The degree of meandering is computed as the ratio of the channel length of the reach (L_m) divided by the valley length (L_s). The modified value for meandering is obtained by multiplying the total additive effects of the other factors for this reach by L_m/L_s.

Use of Photographs

Photographs of stream channels where *n* values have been determined can be used for comparison with field situations to help verify selected *n* values. Published reports that include photographs of channels for which *n* values have been computed include Chow (1959), Barnes (1967), Aldridge and Garrett (1973), Jarrett (1985), Hicks, and Mason, (1991), Thomsen and Hjalmarson, (1991) and Coon (1995). Barnes (1967) illustrates 50 channels in color photographs of streams from across the United States that represent a wide range of hydraulic characteristics. Hicks and Mason (1991) include color photographs for 78 New Zealand river and canal reaches. Thomsen and Hjalmarson, (1991) included color photographs for 16 sites representing desert channels in Maricopa County, Arizona.

Arcement and Schneider (1989) include color photographs of 15 densely vegetated flood plains in Mississippi, Alabama, and Louisiana for which roughness coefficients were computed. The use of these photographs would be beneficial when considering *n* values for brush- and tree-covered channels, when streambank vegetation is the major roughness factor.

Photographs of the west-central Florida stream channels used in this report are presented to aid in the determination of roughness coefficients. The photographs can be used for comparison with field situations to help assign reasonable *n* values for the many types of streams and rivers commonly encountered in west-central Florida.

SUMMARY AND CONCLUSIONS

Manning's roughness coefficients are presented for 10 streams that are representative of stream conditions in the west-central Florida area. The sites provide information for a wide range of discharges, water surface profiles, and streambank vegetation conditions. Data collected indicate Manning's roughness coefficient, *n*, decreases as depth increases, until the water surface somes in contact with streambank vegetation, and then the roughness coefficient increases sharply. Bed material for all sites presented in this report was fine sand and, consequently, there was little variation in roughness as a result of variations in bed material. Streambank vegetation appears to be the major contributor to variations in roughness values for streams in west-central Florida.

The mean computed *n* for 104 events was 0.072; the range was from 0.021 to 0.218 - an order of magnitude. The median *n* value for the 104 events used in this report was 0.060, which means that half of the time *n* was greater 0.060. In addition, 70 percent of the time, the computed *n* was greater than 0.047; 80 percent of the time, the computed *n* was greater than 0.043.

Several previously published equations were used to compute roughness coefficients for the study sites. Results were generally better for high within-bank flows when the vegetated wetted perimeter was less than 70 percent. All of the existing published equations tend to underestimate *n* values for this area.

Channel roughness can be estimated quantitatively by evaluating the interaction of all roughness factors. Photographs of sites where *n* values have been computed can be used for comparison to estimate values at similar sites. Using a base *n* value of 0.040 and increasing *n* for factors of vegetation, channel obstructions, and other factors provides the best determination of *n* values for streams in west-central Florida.

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APPENDIX

PRESENTATION OF SITE INFORMATION

The following sets of site information consist of a site description, a tabulation of the hydraulic properties related to each determination of roughness coefficient, a plan sketch of the site reach, channel cross-section plots, graphs showing the relation between Manning's roughness coefficient, *n*, and discharge, hydraulic radius, and slope. Photographs from different vantage points are also included for each site. Each data set is identified by the downstream number and name used by the U.S. Geological Survey in publication of streamflow records.

The tabulation of hydraulic parameters includes the date, gage height, discharge, cross-section area, top width, hydraulic radius, velocity, water-surface slope, friction slope, percent of wetted perimeter vegetated, type of flow regime, and the computed roughness coefficient for each event. The cross-section area, width, hydraulic radius, velocity, and percentage of vegetated wetted perimeter are averages of values computed for each cross section within the reach.

The plan-view sketch, not to scale, is presented to show the general shape of the study reach along with the location of the cross sections, and photographs. Channel cross-section plots are arranged in an upstream to downstream order. The initial station for each cross section is at the left bank. Plots are arranged so that the left bank appears on the reader's left. Horizontal lines on the cross-section plots are used to define the maximum and minimum gage heights at each cross-section used in the computation of the *n* values.

Variations in roughness coefficient values are illustrated by the plots of Manning's *n* and discharge, hydraulic radius, and water-surface slope.

Photographs are intended to show the channel alignment, streambank vegetation, and channel size in relation to flow-resisting features. Photographs were taken from a variety of perspectives, depending on accessibility afforded by bank vegetation. The camera positions and view directions are shown in the plan sketch.

Payne Creek near Bowling Green

Location of Gage.-- Lat 27°37'14", long 81°49'33", Hardee County, on downstream side of bridge on U.S. Highway 17, 0.4 mi downstream from Little Payne Creek, 1.2 mi south of Bowling Green, and 2.1 mi upstream from mouth.

Location of study reach.--A three-section, 1,365 ft long reach; cross section 1 is 1,365 ft upstream from the stream-gaging station. Crest-stage gages located at cross section 1 were used to measure water-surface elevations at the upstream boundary of the reach. The stream-gaging station was used to measure the water-surface elevations at the downstream boundary of the reach.

Drainage area.--121 mi^2.

Average discharge.--102 ft^3/s (water years 1964-94).

Maximum discharge.--3,170 ft^3/s, June 18, 1982.

Bed material.--Fine sands (99.0%); d_{50}, 0.20 mm; d_{84}, 0.36 mm.

Channel description.--The low-water channel is fairly straight, uniform, and well defined with dense brush along both sides (degree of meander = 1.04). The streambed is smooth with few if any obstructions in the channel. There is little cross section irregularity.

Bank descriptions.--Both streambanks are heavily vegetated with small trees, vines, and brush. Both banks are high and not subject to overflow. There are large trees with exposed root systems scattered along the left bank. There are hardwood trees intermingled with palmetto brush and cabbage palms along the sides and top of both banks. There is considerable overhang from trees on both banks forming a dense canopy through most of the reach

Payne Creek near Bowling Green

Hydraulic Data

[ft = foot; ft^2 = square foot; ft/s = foot per second; ft^3/s = cubic foot per second; ft/ft = foot per foot]

Date	Gage height (ft)	Discharge (ft^3/s)	Average values for reach: Area (ft^2)	Width (ft)	Hydraulic radius (ft)	Velocity (ft/s)	Percent wetted perimeter vegetated	Water surface slope (ft/ft)	Friction slope (ft/ft)	Type of flow regime	Manning's *n*
09-10-88	15.61	1,500	899	129	6.60	1.68	83	0.00103	0.00104	Upper	0.104
08-15-92	12.63	915	550	92.6	5.60	1.68	76	0.00081	0.00081	Upper	0.081
08-12-92	12.11	852	497	84.6	5.55	1.73	74	0.00070	0.00071	Upper	0.071
08-11-92	11.04	728	412	72.8	5.35	1.78	69	0.00067	0.00067	Transition	0.064
08-09-92	10.56	674	380	68.4	5.23	1.79	68	0.00071	0.00072	Transition	0.065
06-30-92	9.95	607	336	62.9	4.99	1.82	65	0.00064	0.00064	Transition	0.058
09-05-92	9.31	539	298	57.8	4.77	1.82	63	0.00064	0.00064	Lower	0.056
06-29-92	9.16	524	289	56.6	4.72	1.82	62	0.00063	0.00063	Lower	0.055
09-15-92	8.84	491	272	54.1	4.63	1.81	60	0.00066	0.00066	Lower	0.056
06-26-92	8.53	460	256	51.4	4.56	1.80	59	0.00065	0.00065	Lower	0.056

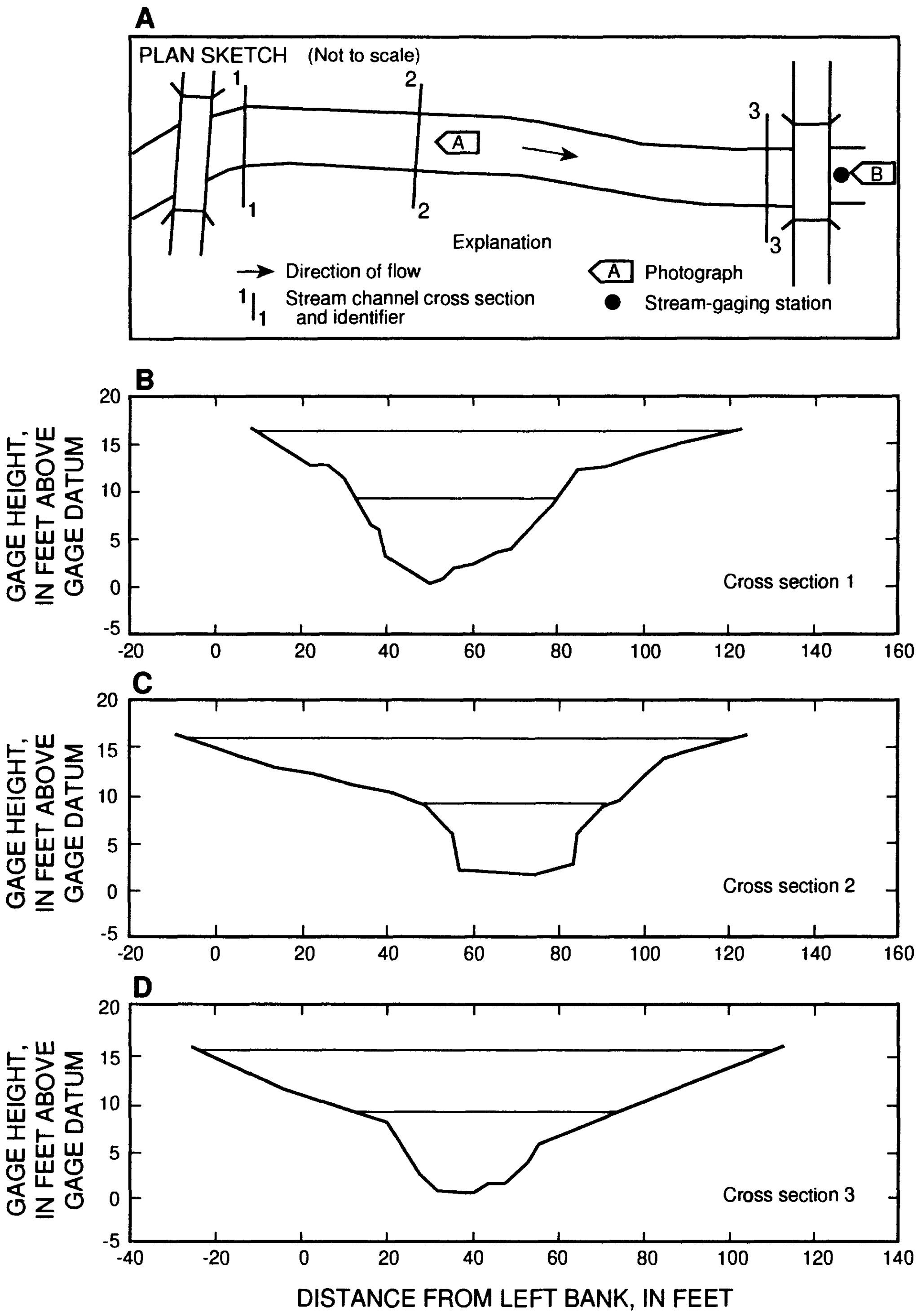

Figure 10. Payne Creek near Bowling Green. (A) plan sketch, (B) cross section 1, (C) cross section 2, and (D) cross section 3.

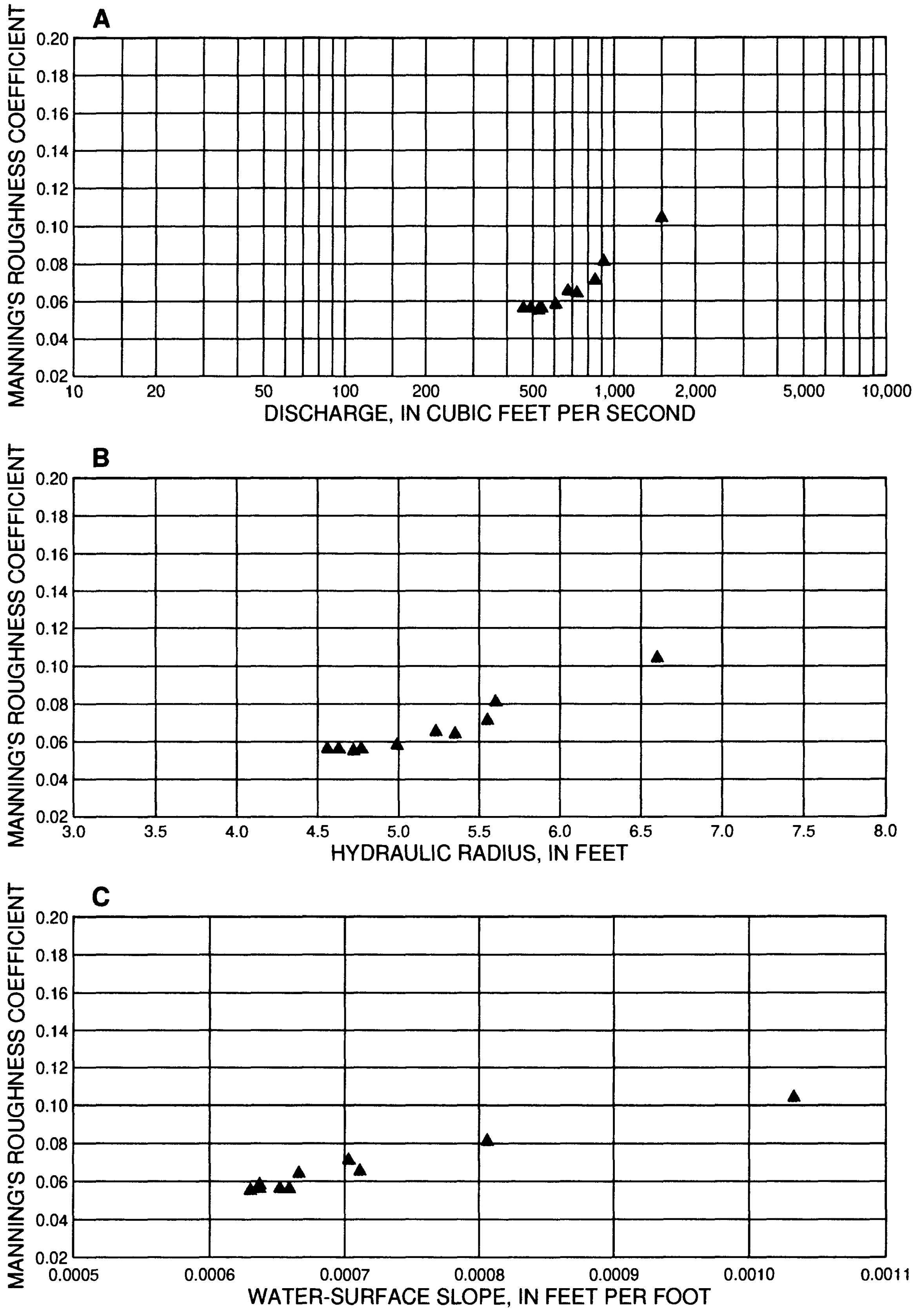

Figure 11. Payne Creek near Bowling Green. Relation of Manning's roughness coefficient to (A) discharge, (B) hydraulic radius, and (C) water-surface slope

A

B

Figure 12. Payne Creek near Bowling Green. Photographs of channel looking (A) upstream from cross section 2 and (B) looking upstream from cross section 3.

Peace River at Zolfo Springs

Location of Gage.-- Lat 27°30'15", long 81°48'04", Hardee County, near center of span on downstream side of bridge on U.S. Highway 17, 0.8 mi north of Zolfo Springs, and 69 mi upstream from mouth.

Location of study reach.--A three-section, 4,150 ft long reach with a slight curvature to the left throughout the reach; section 1 is approximately 50 ft downstream from the stream-gaging station. The stream-gaging station was used to measure water-surface elevations at the upstream boundary of the reach. Crest-stage gages at cross section 3 were used to measure water-surface elevations at the downstream boundary of the reach. Additional crest-stage gages were located at cross section 2, which was 2,250 ft downstream from the stream-gaging station.

Drainage area.--826 mi^2.

Average discharge.--620 ft^3/s (water years 1934-94).

Maximum discharge.--26,300 ft^3/s, Sept. 6, 1933.

Bed material.--Mostly sands (84.0%) with some gravel (15.7%); d_{50}, 0.33 mm; d_{84}, 1.96 mm.

Channel description.--The low-water channel is about 100 ft wide, well defined, and has a slight curvature to the left throughout the reach (degree of meander = 1.00). There is little cross section irregularity. Channel shape varies from trapezoidal in upper portion of the reach to triangular in the lower portion of the reach with a smooth transition between variations. The streambed is smooth with no obstructions in the main channel; however, there are occasional deadfalls along both edges of the low-water channel.

Bank descriptions.--Both streambanks are vegetated with hardwood trees of various sizes, palmettos, vines. The upper portion of the reach has fairly dense brush. In the mid and lower sections of the reach, the left bank is more open with scattered hardwood trees, small palms, and grassy areas, while the vegetation cover on the right bank is much thicker. In the mid and lower-portions of the reach the left bank of the main channel has a moderate smooth slope while the right bank is also smooth, but much steeper. Both banks are high with the left bank subject to overflow only during extreme flooding.

Peace River at Zolfo Springs

Hydraulic Data

[ft = foot; ft^2 = square foot; ft/s = foot per second; ft^3/s = cubic foot per second; ft/ft = foot per foot]

			Average values for reach								
Date	Gage height (ft)	Discharge (ft^3/s)	Area (ft^2)	Width (ft)	Hydraulic radius (ft)	Velocity (ft/s)	Percent wetted perimeter vegetated	Water surface slope (ft/ft)	Friction slope (ft/ft)	Type of flow regime	Manning's *n*
08-12-92	15.02	3,010	1310	166	7.12	2.39	47	0.00017	0.00017	Lower	0.032
09-05-92	13.68	2,300	1100	159	6.26	2.17	44	0.00016	0.00016	Lower	0.031
08-31-92	12.66	1,860	947	147	5.84	2.02	40	0.00014	0.00014	Lower	0.029
06-30-92	12.52	1,810	925	145	5.77	2.01	39	0.00013	0.00014	Lower	0.029
10-05-92	12.39	1,760	904	144	5.71	2.00	39	0.00013	0.00013	Lower	0.029
09-17-92	10.28	1,120	644	118	5.48	1.77	18	0.00010	0.00010	Lower	0.029
09-30-92	9.15	865	523	111	4.94	1.68	10	0.00008	0.00008	Lower	0.026
10-13-92	9.02	837	504	109	4.88	1.68	8	0.00009	0.00009	Lower	0.029
02-04-93	8.80	790	477	101	4.73	1.68	6	0.00011	0.00011	Lower	0.030

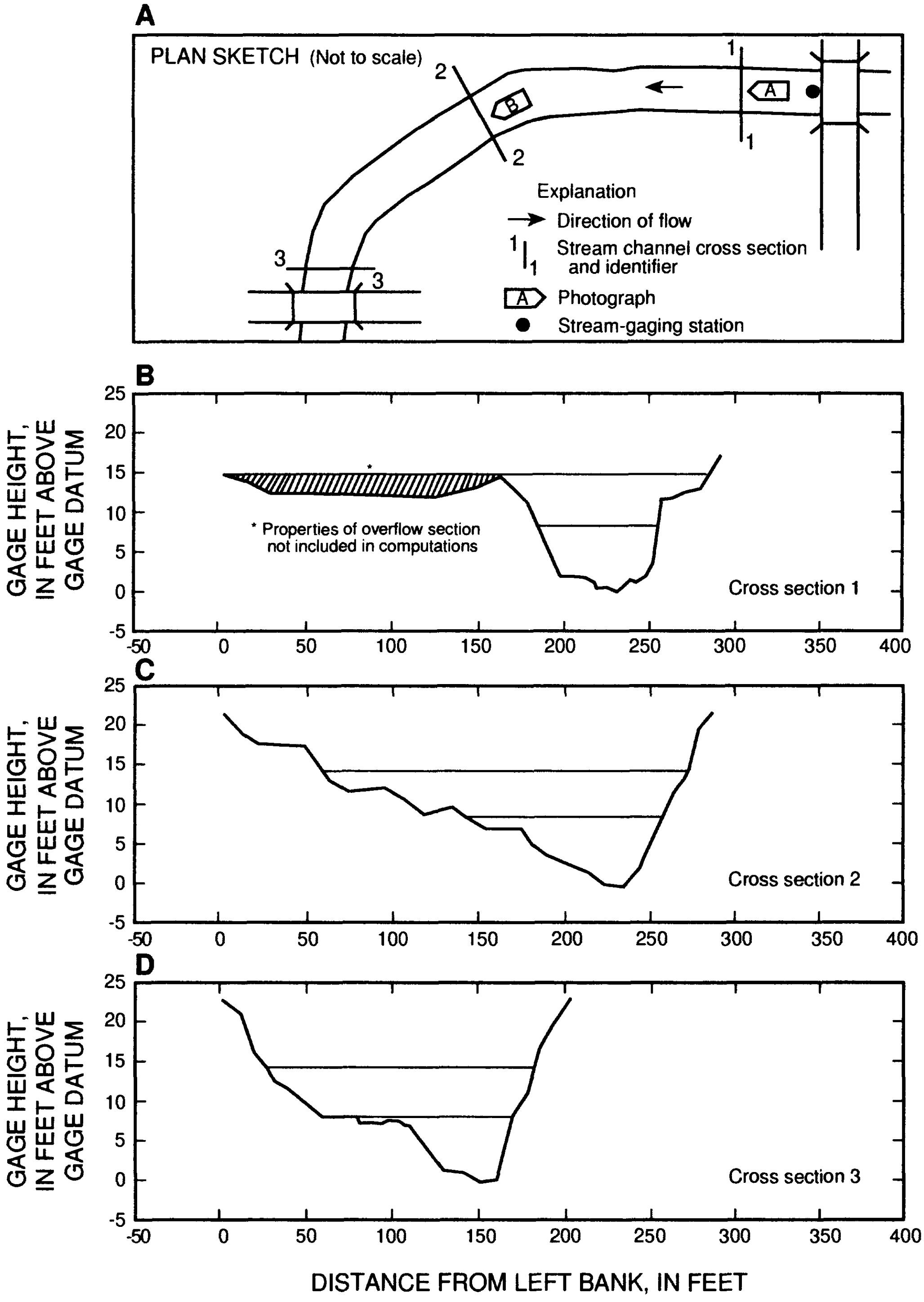

Figure 13. Peace River at Zolfo Springs. (A) plan sketch, (B) cross section 1, (C) cross section 2, (D) cross section 3.

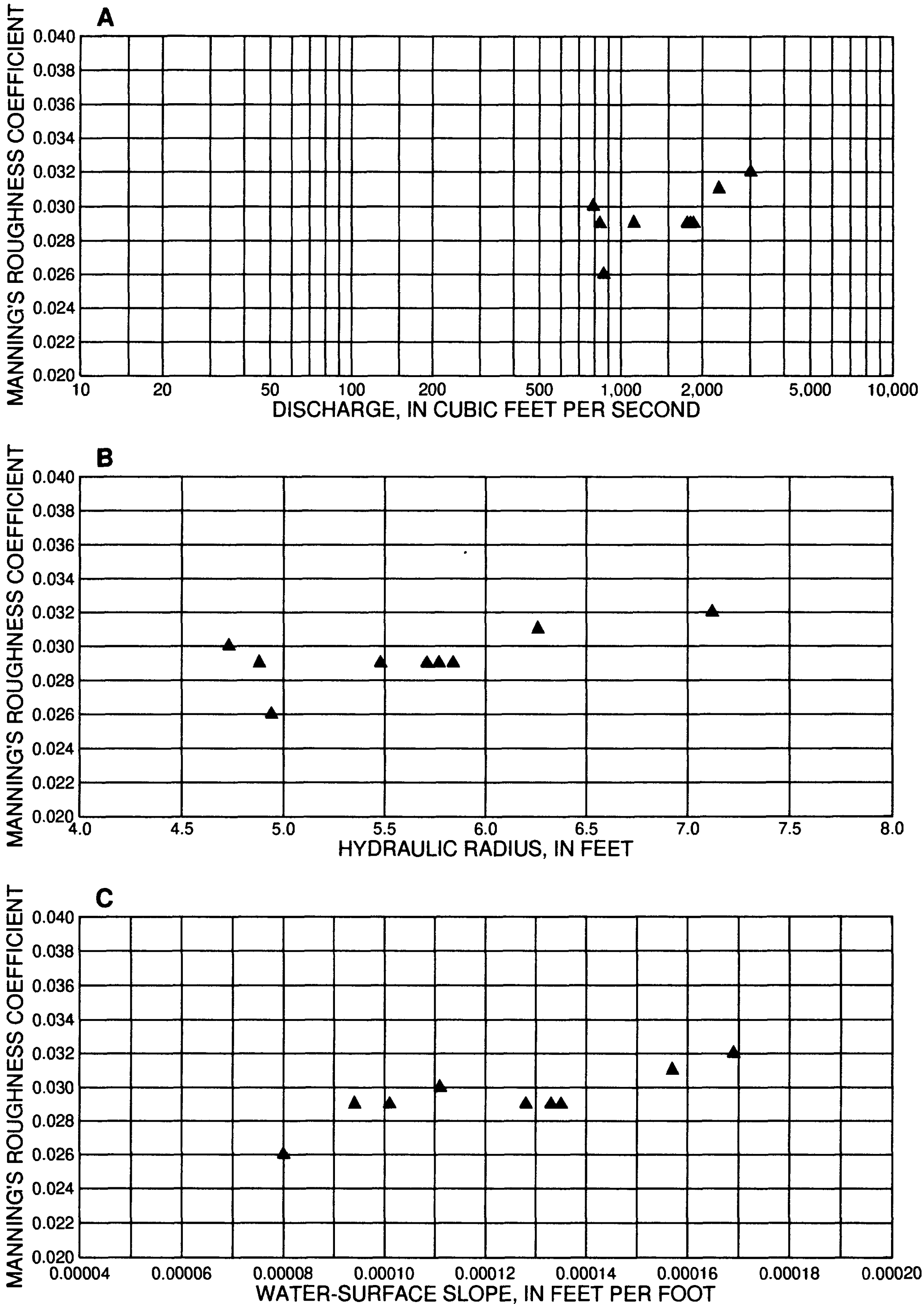

Figure 14. Peace River at Zolfo Springs. Relation of Manning's roughness coefficient to (A) discharge, (B) hydraulic radius, and (C) water-surface slope.

A

B

Figure 15. Peace River at Zolfo Springs. Photographs of channel looking (A) downstream from above cross section 1 and (B) looking downstream from above cross section 2.

Horse Creek near Myakka Head

Location of Gage.-- Lat 27°29'13", long 82°01'25", Hardee County, near left bank on downstream side of bridge on State Highway 64, 3.5 mi northeast of Myakka Head and 39.5 mi upstream from mouth.

Location of study reach.--A two-section, 374 ft long reach; cross section 1 is approximately 700 ft upstream from the stream-gaging station. Crest-stage gages at cross section 1 were used to measure water-surface elevations at the upstream boundary of the reach. The stream-gaging station was used to measure water-surface elevations at the downstream boundary of the reach.

Drainage area.--42 mi^2.

Average discharge.--29.6 ft^3/s (water years 1978-94).

Maximum discharge.--2,310 ft^3/s, Sept. 6, 1988.

Bed material.--Fine sands (98.5%); d_{50}, 0.27 mm; d_{84}, 0.39 mm.

Channel description.--The low-water channel is about 20 ft wide and well defined throughout the reach. The channel curves to the left through cross section 1, is fairly straight for a short stretch and then curves back to the right. The channel is straight above and below cross section 2 (degree of meander = 1.10). There is little cross-section irregularity. Channel shape varies from triangular in upper portion of the reach to trapezoidal in the lower portion of the reach with a smooth transition between variations. The streambed is somewhat irregular. There is a small gravel bar with light vegetation about half-way between cross sections 1 and 2.

Bank descriptions.--Both streambanks are vegetated with small trees, vines, and fairly dense brush which overhangs the main channel. Both banks are high and not subject to overflow except at extremely high stages. There are large oak trees and thick palmetto stands along the top of the both banks.

Horse Creek near Myakka Head

Hydraulic Data

[ft = foot; ft^2 = square foot; ft/s = foot per second; ft^3/s = cubic foot per second; ft/ft = foot per foot]

Date	Gage height (ft)	Discharge (ft^3/s)	Average values for reach: Area (ft^2)	Width (ft)	Hydraulic radius (ft)	Velocity (ft/s)	Percent wetted perimeter vegetated	Water surface slope (ft/ft)	Friction slope (ft/ft)	Type of flow regime	Manning's *n*
09-02-94	17.53	529	232	62.1	3.43	2.40	76	0.00160	0.00171	Upper	0.060
04-01-93	17.14	495	208	57.0	3.36	2.50	74	0.00147	0.00158	Upper	0.054
08-11-92	17.05	488	203	55.7	3.35	2.50	73	0.00160	0.00171	Upper	0.056
03-13-93	13.36	211	73.3	19.4	3.00	2.89	37	0.00163	0.00168	Upper	0.044
09-17-92	10.85	69	31.1	14.1	1.84	2.24	8	0.00150	0.00154	Lower	0.039
10-13-92	10.12	37	22.9	13.2	1.49	1.60	0	0.00227	0.00227	Lower	0.058
02-04-93	9.76	22	18.3	12.7	1.28	1.20	0	0.00241	0.00239	Lower	0.071

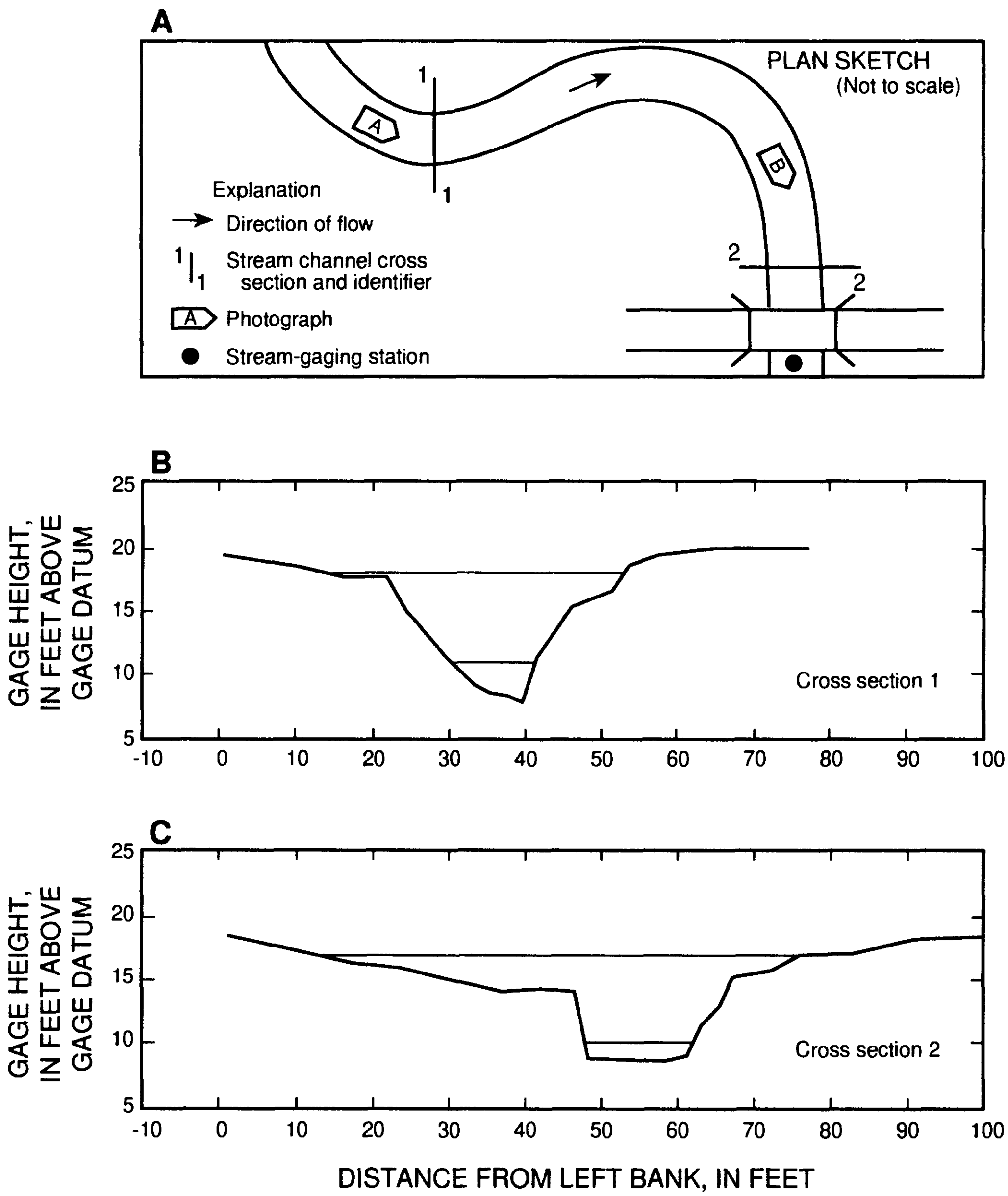

Figure 16. Horse Creek near Myakka Head. (A) plan sketch, (B) cross section 1, and (C) cross section 2.

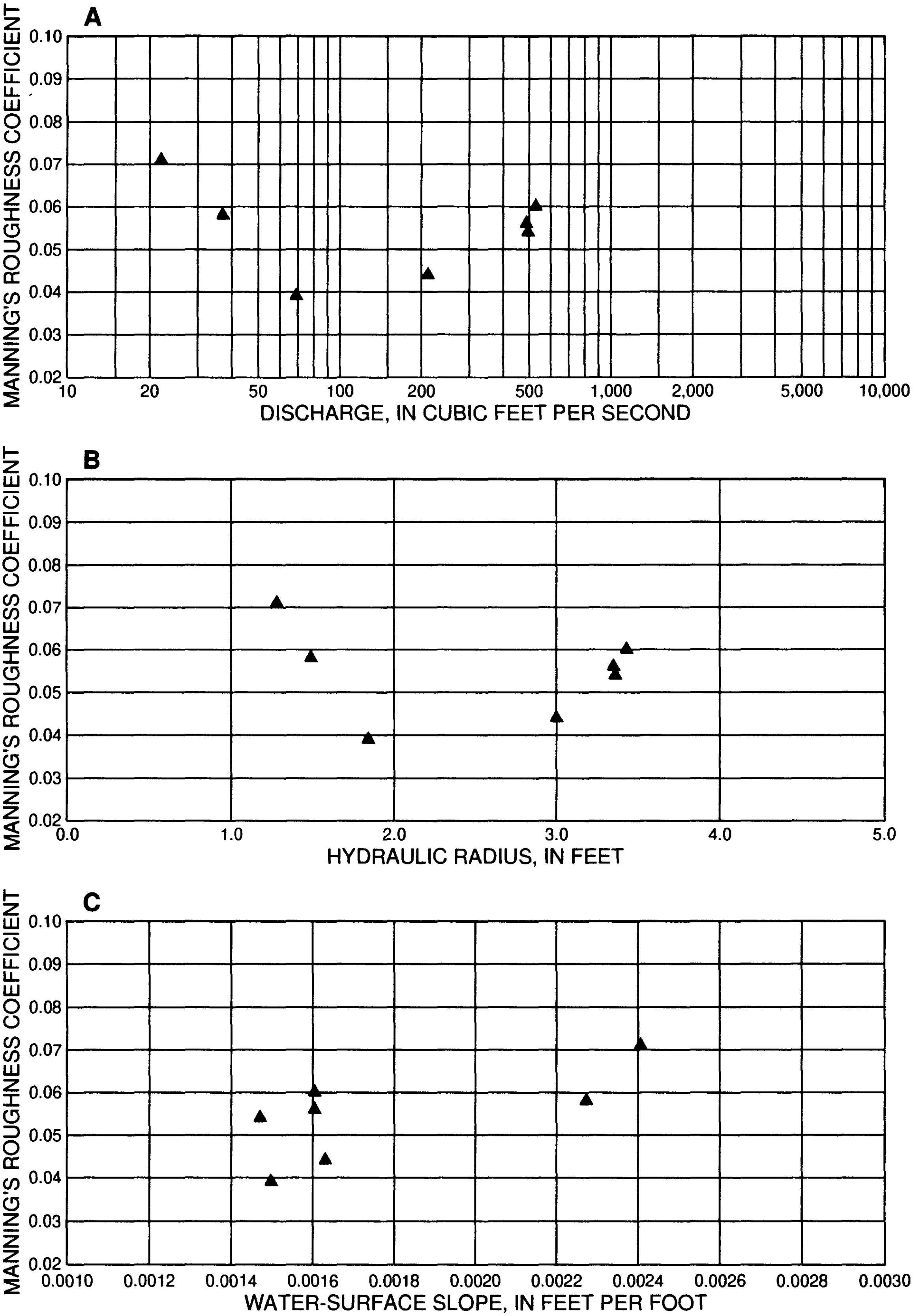

Figure 17. Horse Creek near Myakka Head. Relation of Manning's roughness coefficient to (A) discharge, (B) hydraulic radius, and (C) water-surface slope.

A

B

Figure 18. Horse Creek near Myakka Head. Photographs of channel looking (A) downstream from above cross section 1 and (B) looking downstream from above cross section 2.

South Creek near Vamo

Location of Gage.-- Lat 27°11'46", long 82°27'46", Sarasota County, on right bank, 10 ft upstream from concrete bridge at Bay Street extension, 1.3 mi north of Oscar Scherer State Park, 2.8 mi southeast of Vamo, and 3.9 mi upstream from mouth at Dryman Bay.

Location of study reach.--A three-section, 420 ft long reach; cross section 1 is located 168 ft downstream from the stream-gaging station. The stream-gaging station was used to measure water-surface elevations at the upstream boundary of the reach. Crest-stage gages at cross section 3 were used to measure water-surface elevations at the downstream boundary of the reach. The reach is straight and fairly uniform.

Drainage area.--15.4 mi^2.

Average discharge.-- 14.3 ft^3/s (water years 1992-93).

Maximum discharge.-- 442 ft^3/s, June 26, 1992.

Channel description.--The low-water channel is about 20 ft wide and well defined throughout the reach. The channel bends to the left about 100 ft above cross section 1, is straight throughout the reach (degree of meander = 1.01), and then bends to the left below cross section 3. Channel shape is trapezoidal throughout the reach. There is little cross-section irregularity.

Bed material.--Fine sands (98.2%); d_{50}, 0.23 mm; d_{84}, 0.41 mm. There is heavy vegetation growth throughout the channel with some seasonal changes.

Bank descriptions.--Both streambanks are vegetated with small vines, grasses, and small brush. There are some scattered medium-sized oaks, sycamores, and other hardwoods along the tops of both banks. Growth on the left bank is considerably thicker than the right bank with numerous mature cabbage palms. Both banks are high and not subject to overflow except at extremely high stages.

South Creek near Vamo

Hydraulic Data

[ft = foot; ft^2 = square foot; ft/s = foot per second; ft^3/s = cubic foot per second; ft/ft = foot per foot]

			Average values for reach								
Date	Gage height (ft)	Discharge (ft^3/s)	Area (ft^2)	Width (ft)	Hydraulic radius (ft)	Velocity (ft/s)	Percent wetted perimeter vegetated	Water surface slope (ft/ft)	Friction slope (ft/ft)	Type of flow regime	Manning's *n*
04-02-93	12.17	166	114	27.9	3.58	1.47	58	0.00038	0.00040	Lower	0.047
04-05-93	11.37	130	93.1	25.9	3.18	1.41	54	0.00036	0.00037	Lower	0.043
03-13-93	10.52	94	72.2	23.6	2.74	1.30	50	0.00033	0.00034	Lower	0.040
01-16-93	9.55	59	50.3	20.0	2.26	1.24	40	0.00041	0.00037	Lower	0.043
10-05-92	9.45	55	48.6	19.5	2.23	1.13	40	0.00038	0.00037	Lower	0.043
01-26-93	9.33	50	46.0	18.8	2.18	1.09	39	0.00041	0.00040	Lower	0.045
02-27-93	8.34	20	29.7	15.5	1.72	0.66	24	0.00036	0.00035	Lower	0.059
10-14-92	8.20	13	26.4	15.0	1.59	0.50	21	0.00052	0.00052	Lower	0.090

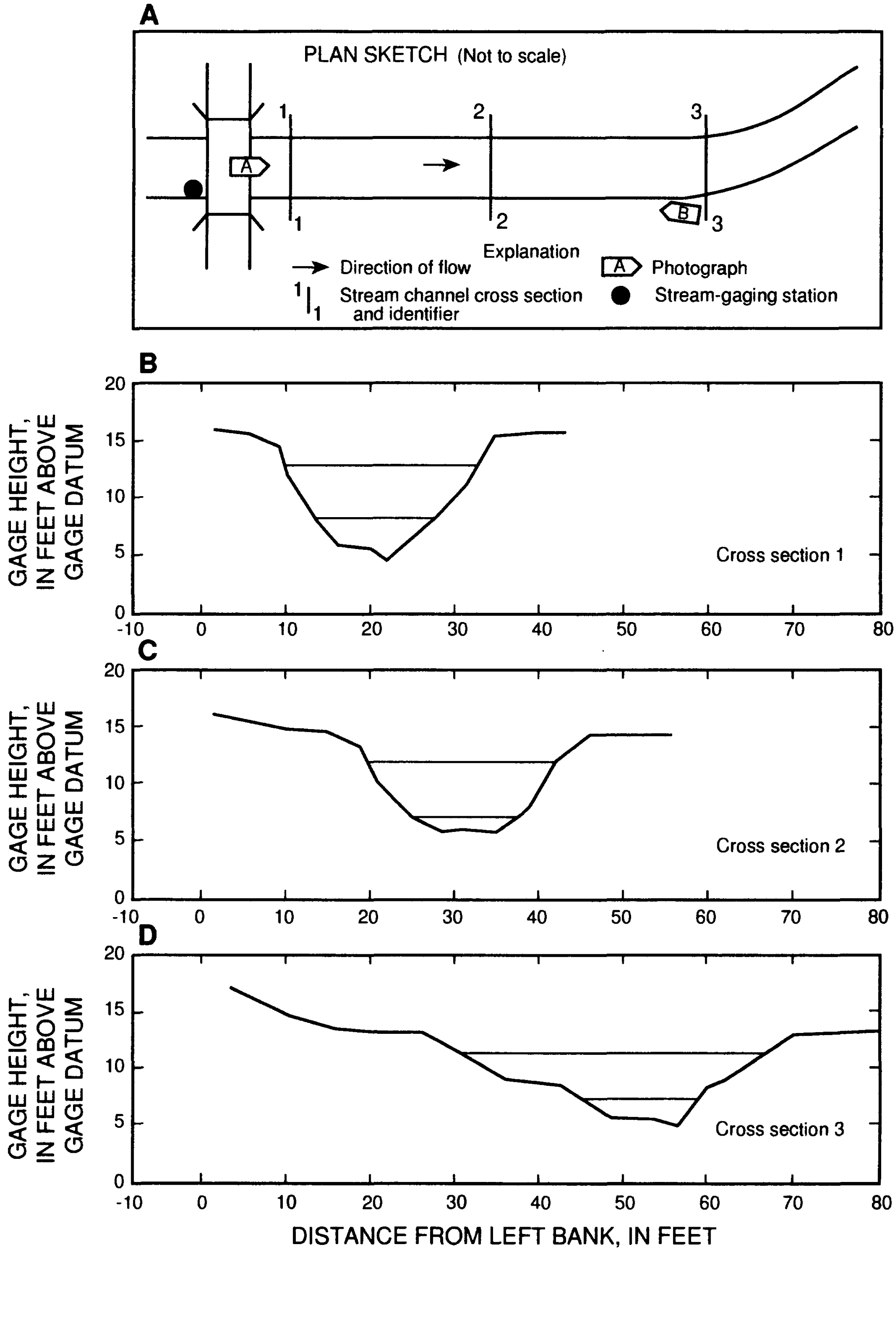

Figure 19. South Creek near Vamo. (A) plan sketch, (B) cross section 1, (C) cross section 2, and (D) cross section 3.

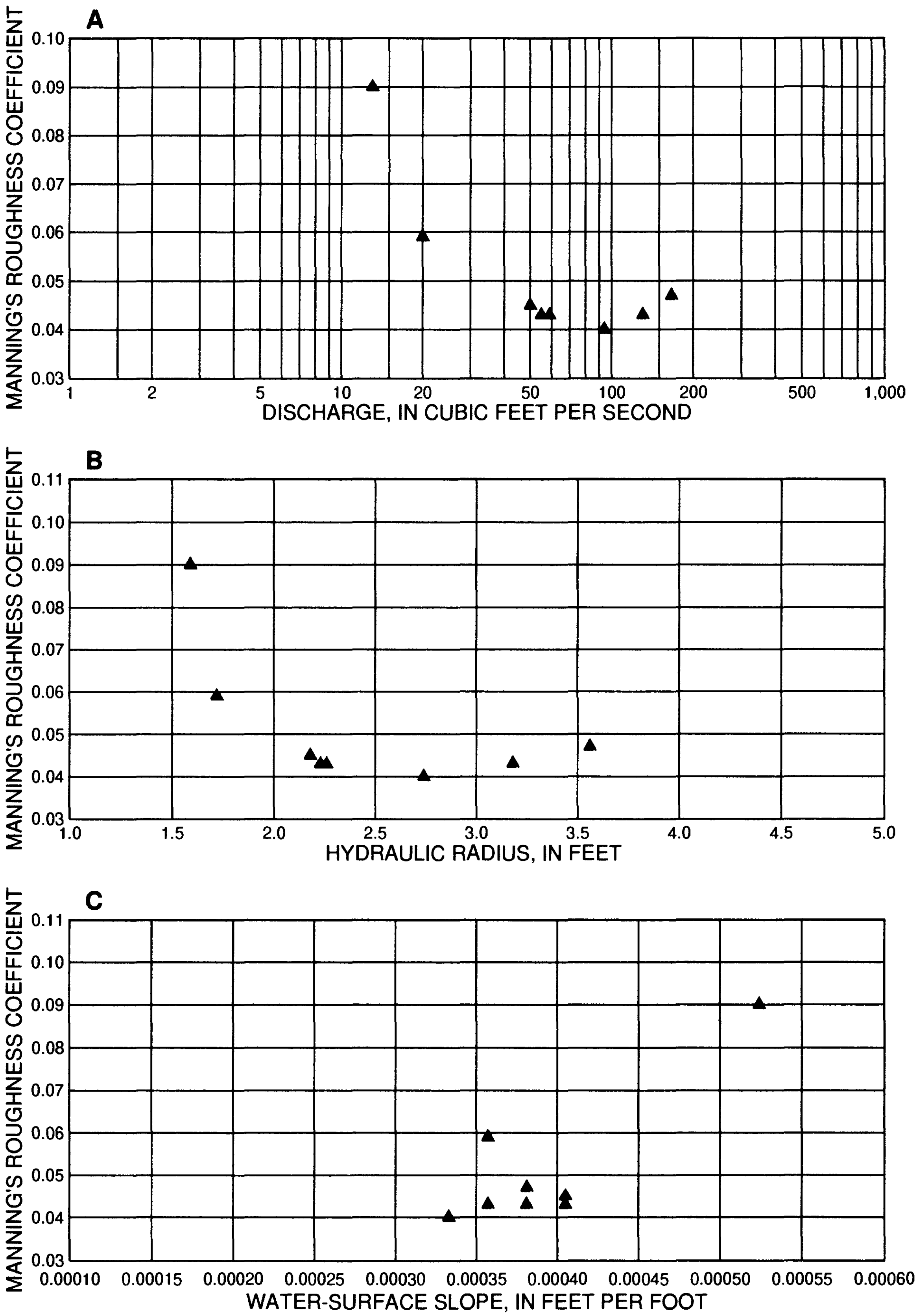

Figure 20. South Creek near Vamo. Relation of Manning's roughness coefficient to (A) discharge, (B) hydraulic radius, and (C) water-surface slope.

A

B

Figure 21. South Creek near Vamo. Photographs of channel looking (A) downstream from cross section 1 and (B) looking upstream from cross section 3.

Walker Creek near Sarasota

Location of Gage.-- Lat 27°22'03", long 82°32'40", Sarasota County, on downstream side of 38th Street bridge, 0.6 mi upstream from Whitaker Bayou, and 2.2 mi north of Sarasota.

Location of study reach.--A three-section, 410 ft long reach; cross section 1 is located 220 ft downstream from the stream-gaging station. The stream-gaging station was used to measure water-surface elevations at the upstream boundary of the reach. Crest-stage gages at cross section 3 were used to measure water-surface elevations at the downstream boundary of the reach.

Drainage area.--4.91 mi^2.

Average discharge.-- 7.74 ft^3/s (water years 1992-94).

Maximum discharge.-- 971 ft^3/s, June 25, 1992.

Channel description.--The low-water channel is straight, well defined, and about 20 ft wide throughout the reach (degree of meander = 1.01). Channel shape is trapezoidal throughout the reach. There is little, if any, variation in the channel cross section. A few scattered obstructions may be found as is typical of any urban stream.

Bed material.--Fine sands (92.4%); d_{50}, 0.29 mm; d_{84}, 0.71 mm. There is considerable urban debris (tires, trash) throughout the entire reach.

Bank descriptions.--Both streambanks are vegetated with small vines, grasses, and small brush and an occasional mature sycamore or oak. Both banks are high and not subject to overflow except at extremely high stages. The top of the left bank has a fairly moderate growth of mature hardwoods, while the top of the right bank is covered with low grasses.

Walker Creek near Sarasota

Hydraulic Data

[ft = foot; ft^2 = square foot; ft/s = foot per second; ft^3/s = cubic foot per second; ft/ft = foot per foot]

			Average values for reach								
Date	Gage height (ft)	Discharge (ft^3/s)	Area (ft^2)	Width (ft)	Hydraulic radius (ft)	Velocity (ft/s)	Percent wetted perimeter vegetated	Water surface slope (ft/ft)	Friction slope (ft/ft)	Type of flow regime	Manning's *n*
06-25-92	13.01	971	316	60.4	4.49	3.09	61	0.00095	0.00101	Upper	0.042
07-23-92	8.93	438	166	31.8	4.14	2.57	32	0.00093	0.00098	Upper	0.045
08-07-92	8.29	398	157	29.3	4.40	2.29	27	0.00080	0.00086	Upper	0.044
04-01-93	7.74	312	131	26.8	3.79	2.40	19	0.00097	0.00102	Upper	0.048
04-01-93	7.36	278	121	25.9	3.63	2.32	18	0.00095	0.00099	Transition	0.047
01-15-93	6.77	242	107	24.4	3.40	2.29	12	0.00093	0.00097	Transition	0.045
01-15-93	6.63	217	103	24.0	3.33	2.14	11	0.00100	0.00103	Transition	0.049
01-14-93	5.39	141	73.8	21.3	2.74	1.94	0	0.00105	0.00108	Lower	0.048
09-27-94	2.74	19	25.0	12.8	1.53	0.80	0	0.00148	0.00149	Lower	0.094
02-29-92	3.07	13	26.7	13.1	1.60	0.53	0	0.00192	0.00193	Lower	0.155
10-14-92	2.31	9.4	20.1	11.9	1.33	0.54	0	0.00151	0.00151	Lower	0.121
03-12-93	2.09	4.8	17.8	11.5	1.22	0.32	0	0.00148	0.00149	Lower	0.194
11-16-92	2.08	4.6	16.3	11.3	1.15	0.33	0	0.00170	0.00170	Lower	0.190
12-14-92	2.03	3.9	16.2	11.2	1.15	0.28	0	0.00163	0.00163	Lower	0.218

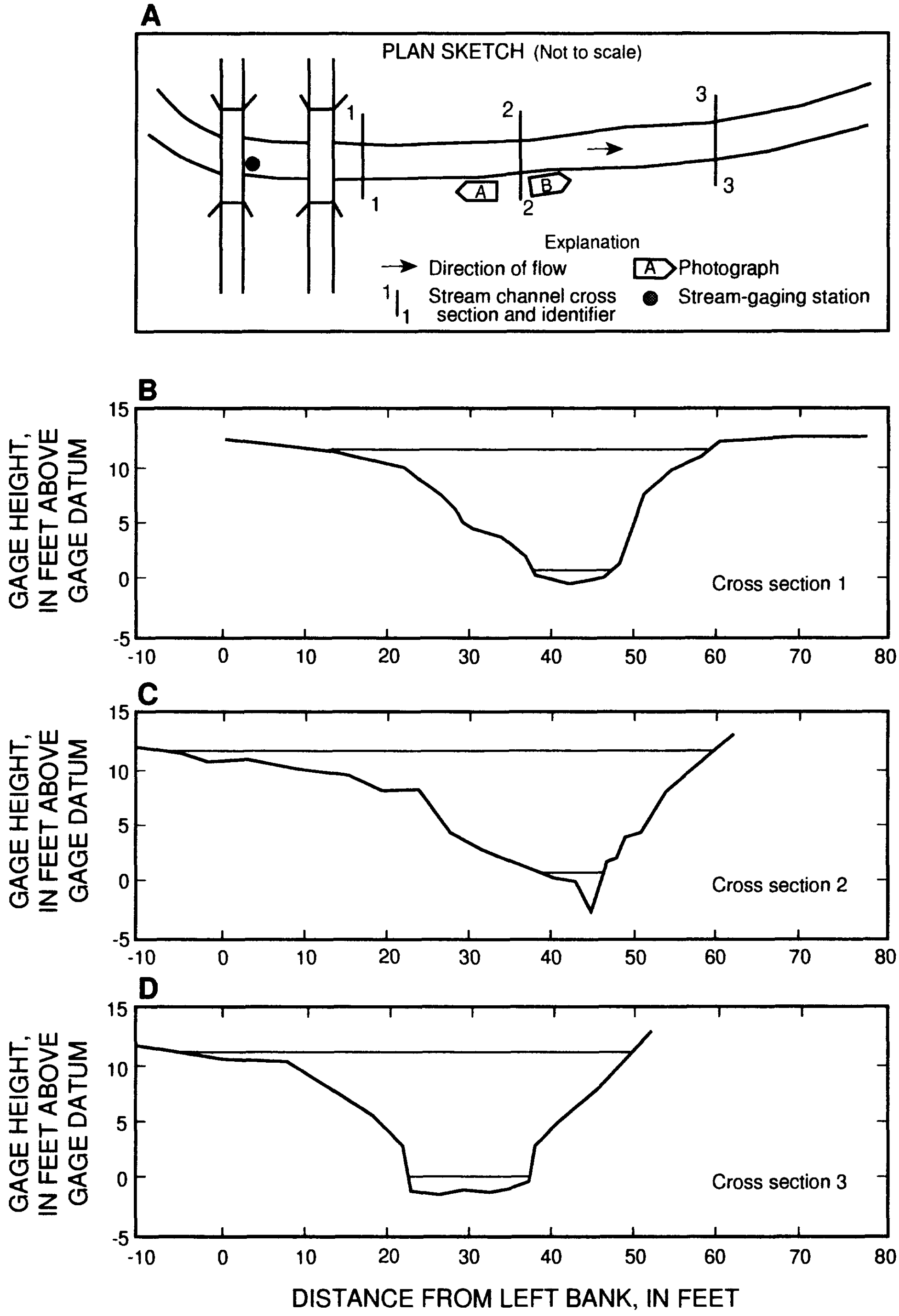

Figure 22. Walker Creek near Sarasota. (A) plan sketch, (B) cross section 1, (C) cross section 2, and (D) cross section 3.

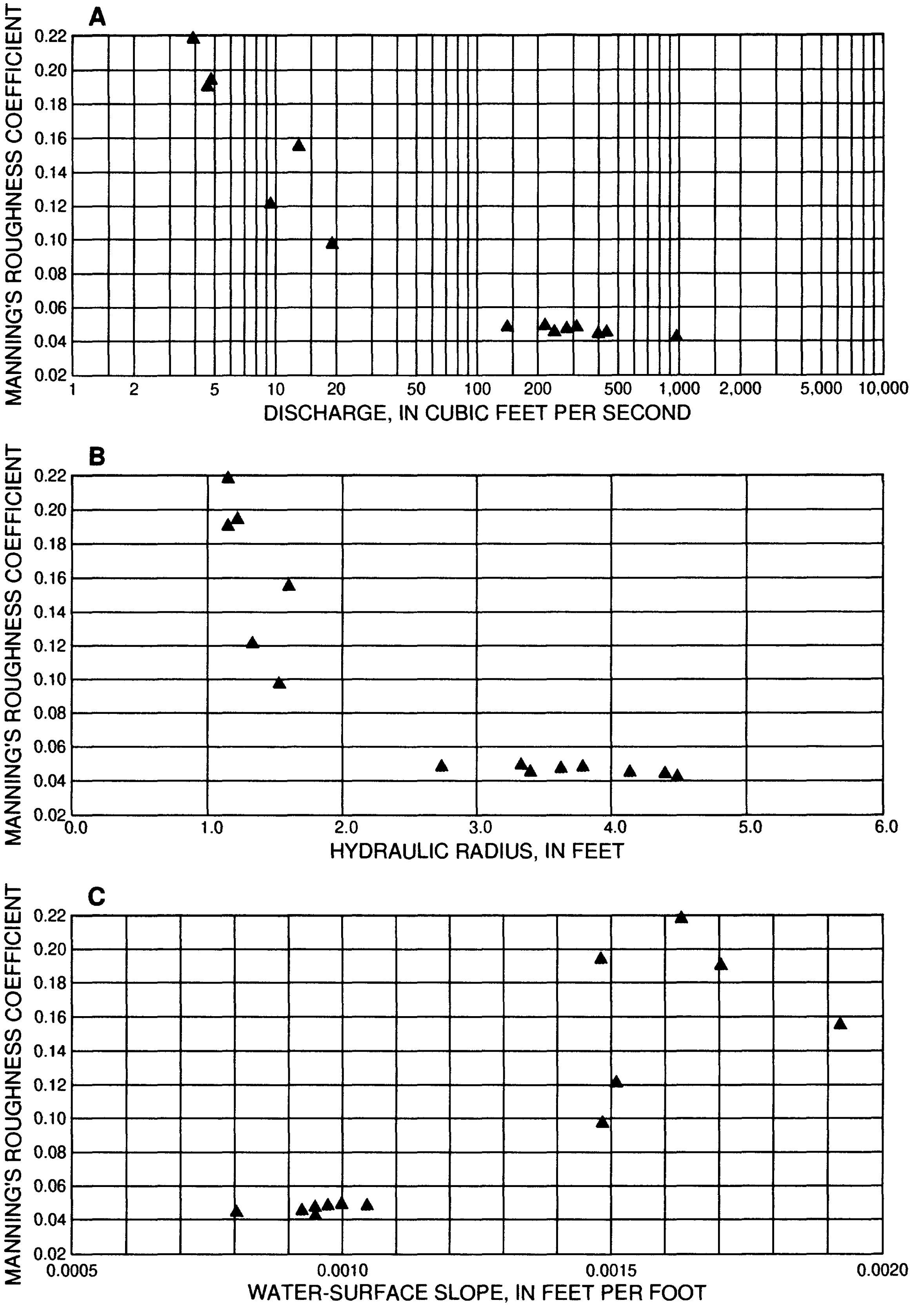

Figure 23. Walker Creek near Sarasota. Relation of Manning's roughness coefficient to (A) discharge, (B) hydraulic radius, and (C) water-surface slope.

A

B

Figure 24. Walker Creek near Sarasota. Photographs of channel looking (A) upstream from cross section 2 and (B) looking downstream from cross section 2.

Bullfrog Creek near Wimauma

Location of Gage.-- Lat 27°47'30", long 82°21'08", Hillsborough County, near center of span on downstream side of bridge on State Highway 672-S, 0.6 mi downstream from Little Bullfrog Creek, 6.0 mi northwest of Wimauma, and 8.7 mi upstream from mouth.

Location of study reach.--A five-section, 1,035 ft long reach; cross section 1 is located 530 ft downstream from the stream-gaging station. Crest-stage gages located at cross sections 1, 3, and 5 were used to measure water-surface elevations. The reach meanders through a park and the low-water channel is fairly uniform.

Drainage area.--291 mi^2.

Average discharge.--40.6 ft^3/s (water years 1957-94).

Maximum discharge.--5,200 ft^3/s, Sept. 11, 1960.

Channel description.--The low-water channel is smooth and well defined, trapezoidal in shape, and with little cross-section irregularity. The low-water channel is about 30 ft wide throughout the reach with a slight variation near cross section 4 where it is about 50 ft wide. It does meander through a wooded area (degree of meander = 1.38). There are a few obstructions between cross sections 1 and 2, otherwise the channel is clear.

Bed material.--Fine sands (100%); d_{50}, 0.29 mm; d_{84}, 0.42 mm.

Bank descriptions.--Both streambanks are vegetated with small vines, grasses, and small brush. The top of both banks are covered with dense palmetto stands and large oaks and other hardwoods. The right bank is lower than the left bank and will overflow at high stages. The left bank is subject to overflow only at very high stages.

Bullfrog Creek near Wimauma

Hydraulic Data

[ft = foot; ft^2 = square foot; ft/s = foot per second; ft^3/s = cubic foot per second; ft/ft = foot per foot]

Date	Gage height (ft)	Discharge (ft^3/s)	Average values for reach: Area (ft^2)	Width (ft)	Hydraulic radius (ft)	Velocity (ft/s)	Percent wetted perimeter vegetated	Water surface slope (ft/ft)	Friction slope (ft/ft)	Type of flow regime	Manning's *n*
03-13-93	24.34	356	211	47.9	4.00	1.82	63	0.00074	0.00074	Lower	0.059
04-16-93	23.31	264	163	39.2	3.79	1.71	54	0.00072	0.00073	Lower	0.062
06-08-92	22.65	216	131	36.7	3.28	1.73	48	0.00082	0.00082	Lower	0.058
04-25-92	21.47	142	90.8	29.7	2.72	1.61	35	0.00063	0.00064	Lower	0.055
01-09-93	21.45	141	95.1	30.4	2.79	1.53	36	0.00080	0.00080	Lower	0.057
09-16-92	18.51	19	21.0	22.5	0.90	0.93	10	0.00083	0.00083	Lower	0.045
11-16-92	18.15	11	14.7	21.7	0.67	0.78	5	0.00091	0.00091	Lower	0.047

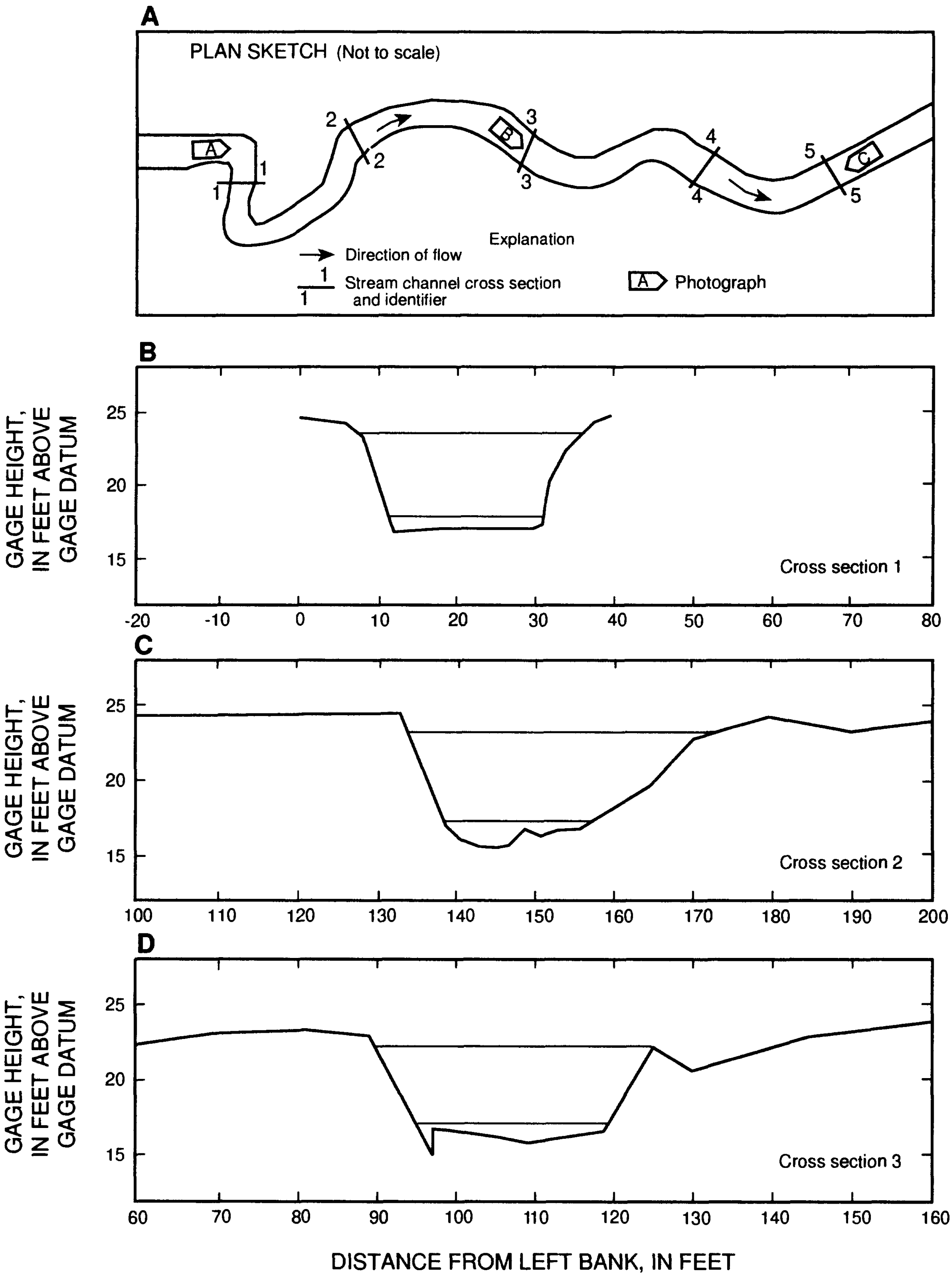

Figure 25. Bullfrog Creek near Wimauma. (A) plan sketch, (B) cross section 1, (C) cross section 2, (D) cross section 3, (E) cross section 4, and (F) cross section 5.

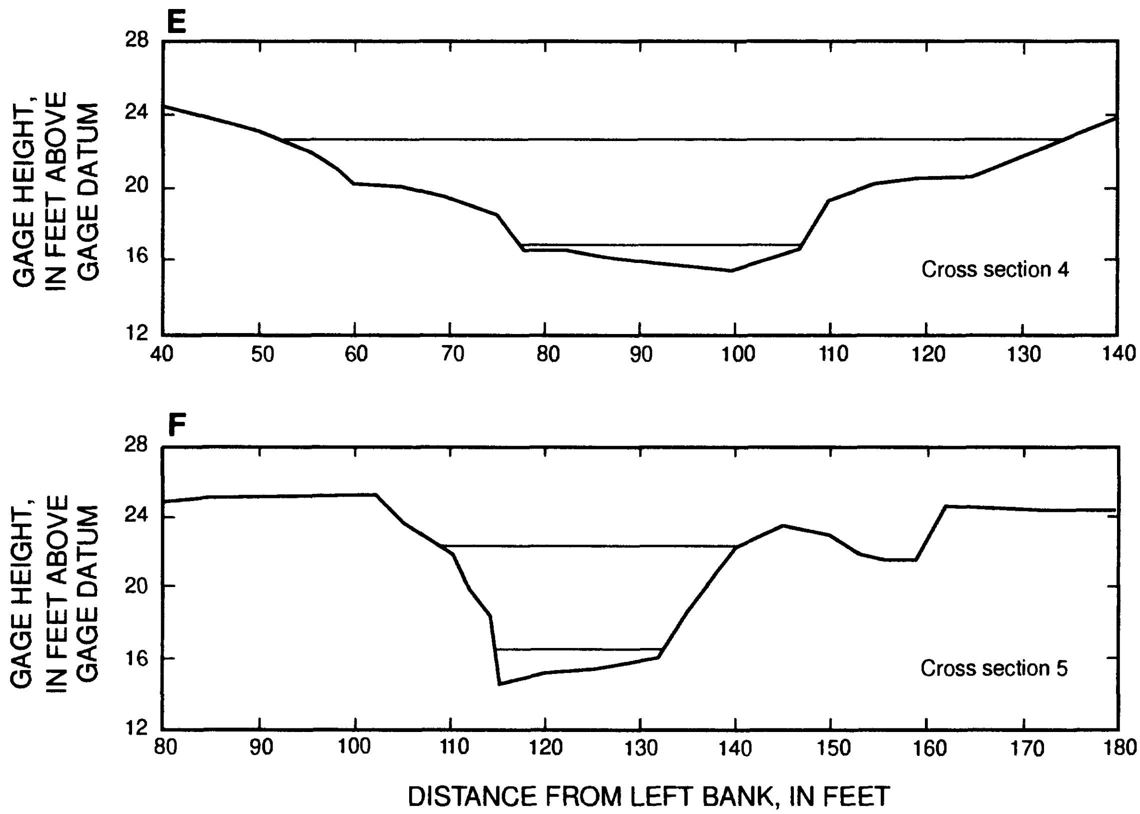

Figure 25. Bullfrog Creek near Wimauma. (A) plan sketch, (B) cross section 1, (C) cross section 2, (D) cross section 3, (E) cross section 4, and (F) cross section 5--**Continued.**

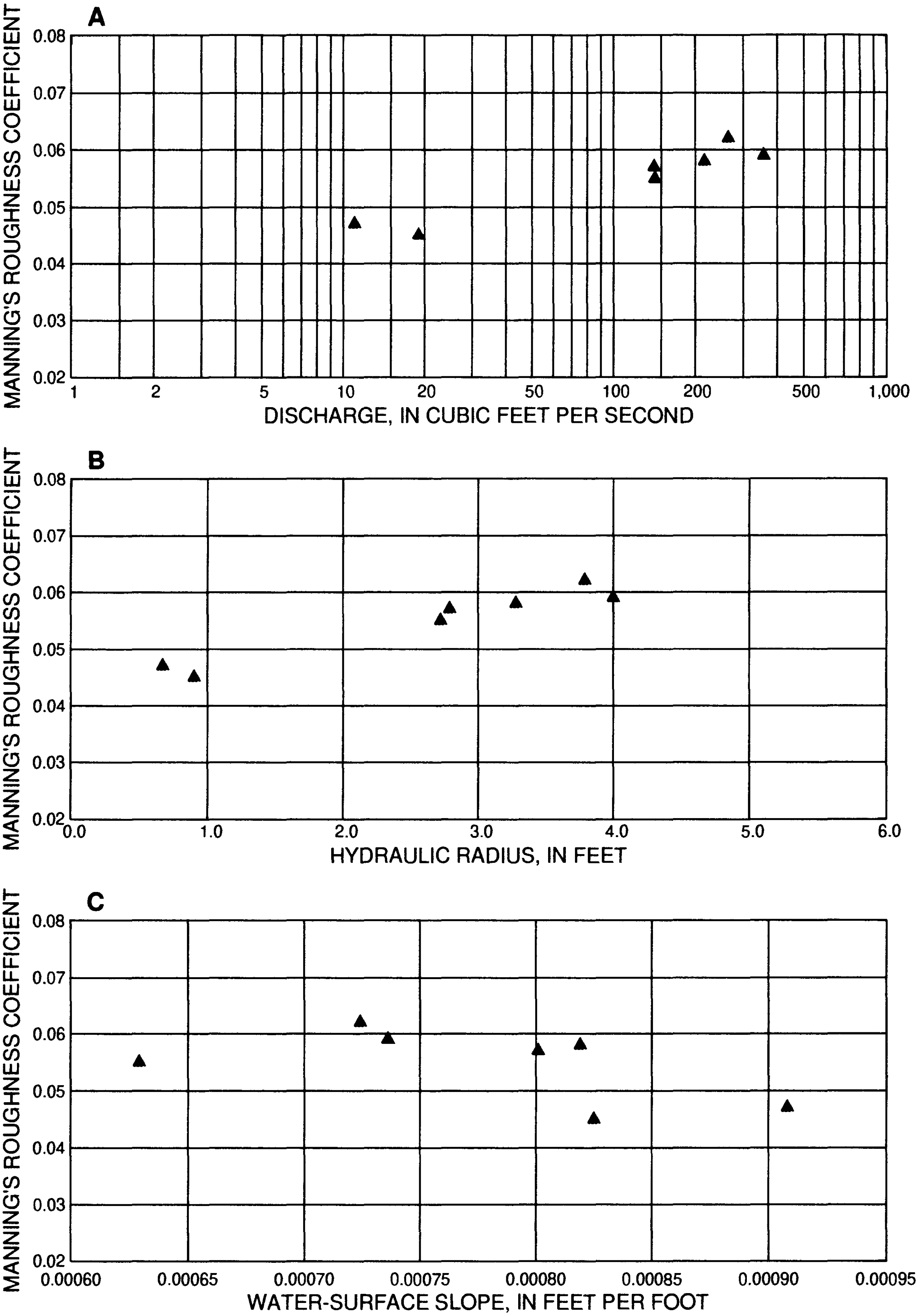

Figure 26. Bullfrog Creek near Wimauma. Relation of Manning's roughness coefficient to (A) discharge, (B) hydraulic radius, and (C) water-surface slope.

A

B

Figure 27. Bullfrog Creek near Wimauma. Photographs of channel looking (A) downstream from above cross section 1, (B) looking downstream from cross section 3, and (C) looking upstream from cross section 5.

C

Figure 27. Bullfrog Creek near Wimauma. Photographs of channel looking (A) downstream from above cross section 1, (B) looking downstream from cross section 3, and (C) looking upstream from cross section 5--**Continued.**

Delaney Creek near Tampa

Location of Gage.-- Lat 27°55'32", long 82°21'52", Hillsborough County, on left bank at south end of Darlington Street, 1.8 mi south of intersection State Highway 60 and U.S. Highway 301, near southeastern city limits of Tampa.

Location of study reach.--A three-section, 654 ft long straight reach; cross section 1 is located about 50 ft downstream from the stream-gaging station. The stream-gaging station was used to measure water-surface elevations at the upstream boundary of the reach. Crest-stage gages at cross section 3 were used to measure water-surface elevations at the downstream boundary of the reach. An additional crest-stage gage was located at cross section 1.

Drainage area.--16.1 mi^2.

Average discharge.--29.6 ft^3/s (water years 1978-94).

Maximum discharge.--2,310 ft^3/s, Sept. 6, 1988.

Channel description.--The low-water channel is straight, trapezoidal in shape,well defined, and about 15 ft wide throughout the reach (degree of meander = 1.00). Channel has a smooth bottom with some aquatic growth at various times and some occassional urban debris (bicycles, tires, shopping carts). There are no permament obstructions.

Bed material.--Fine sands (99.6%); d_{50}, 0.28 mm; d_{84}, 0.41 mm.

Bank descriptions.--Both streambanks are vegetated with grasses, and small brush. There are some cabbage palms and larger hardwood trees along the left bank with limbs and vines that overhang the main channel throughout the reach. The top of the right bank is covered with grass. Both banks are high and seldom subject to overflow.

Delaney Creek near Tampa

Hydraulic Data

[ft = foot; ft^2 = square foot; ft/s = foot per second; ft^3/s = cubic foot per second; ft/ft = foot per foot]

			Average values for reach								
Date	Gage height (ft)	Dis-charge (ft^3/s)	Area (ft^2)	Width (ft)	Hydraulic radius (ft)	Vel-ocity (ft/s)	Percent wetted perimeter vegetated	Water surface slope (ft/ft)	Friction slope (ft/ft)	Type of flow regime	Manning's *n*
06-28-92	8.86	496	224	45.0	4.56	2.22	75	0.00057	0.00058	Lower	0.045
09-06-93	5.99	222	113	34.1	3.09	1.97	66	0.00030	0.00031	Lower	0.028
09-04-92	4.41	119	67.0	25.9	2.40	1.79	56	0.00029	0.00035	Lower	0.024
09-28-94	3.79	80	42.0	20.6	1.90	1.94	44	0.00100	0.00100	Lower	0.035
09-27-94	3.67	76	39.8	20.2	1.84	1.94	43	0.00090	0.00050	Lower	0.032
10-03-92	2.65	37	22.9	16.8	1.29	1.67	30	0.00091	0.00091	Lower	0.029
08-17-93	2.68	31	21.5	16.4	1.24	1.52	29	0.00095	0.00095	Lower	0.031
10-06-92	2.24	20	15.7	14.8	1.00	1.39	20	0.00105	0.00105	Lower	0.032
09-16-92	1.97	11	12.2	13.7	0.84	1.00	12	0.00087	0.00087	Lower	0.035
02-05-93	1.95	5.6	10.0	12.6	0.75	0.63	5	0.00103	0.00103	Lower	0.055
09-28-92	1.78	4.7	10.1	12.3	0.77	0.53	3	0.00091	0.00090	Lower	0.063
09-22-92	1.75	4.4	9.8	11.9	0.77	0.51	0	0.00090	0.00090	Lower	0.065
04-26-93	1.52	1.8	6.4	10.7	0.56	0.35	0	0.00102	0.00102	Lower	0.080
10-23-92	1.59	1.8	7.8	11.2	0.65	0.27	0	0.00098	0.00098	Lower	0.112

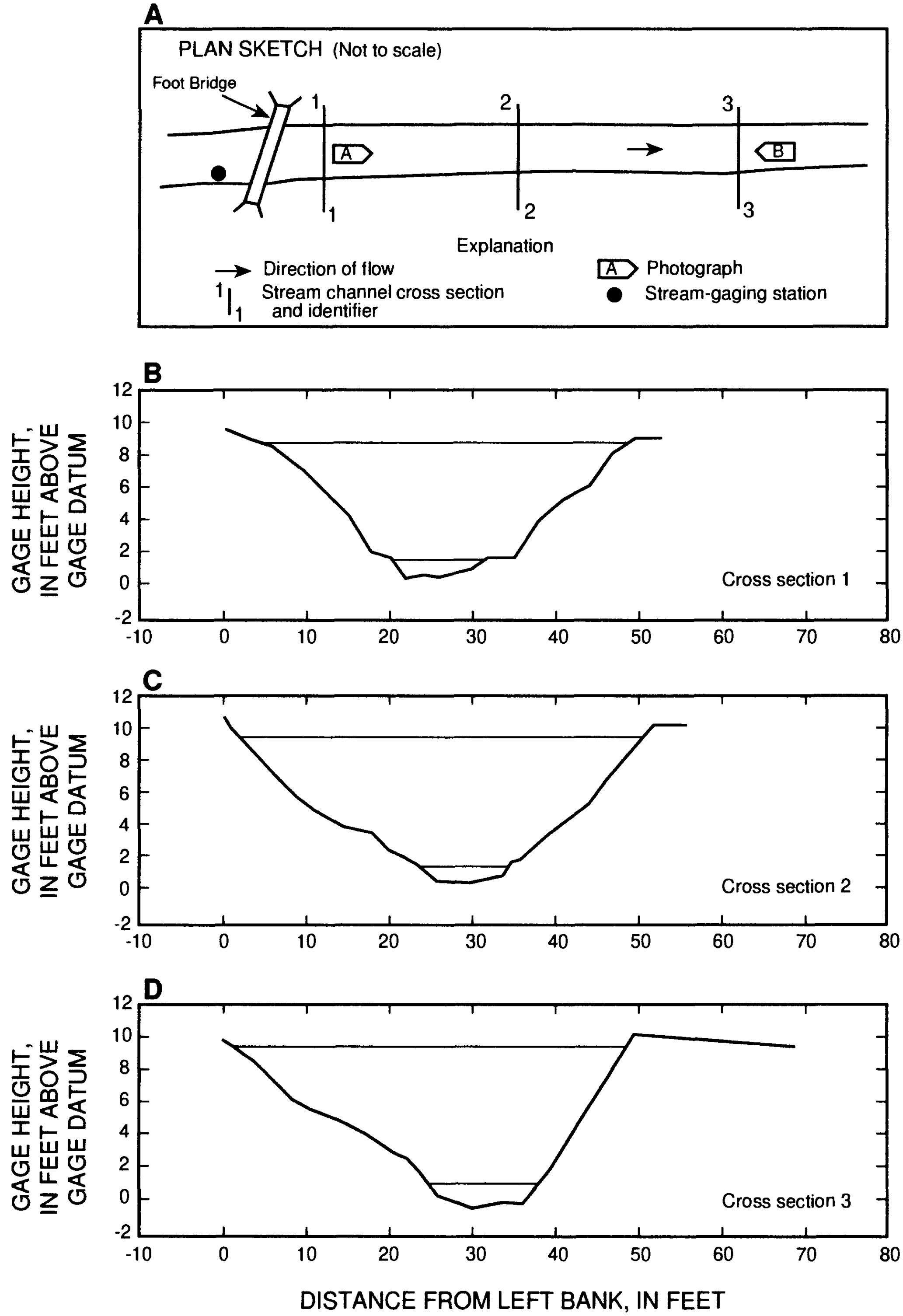

Figure 28. Delaney Creek near Tampa. (A) plan sketch, (B) cross section 1, (C) cross section 2, and (D) cross section 3.

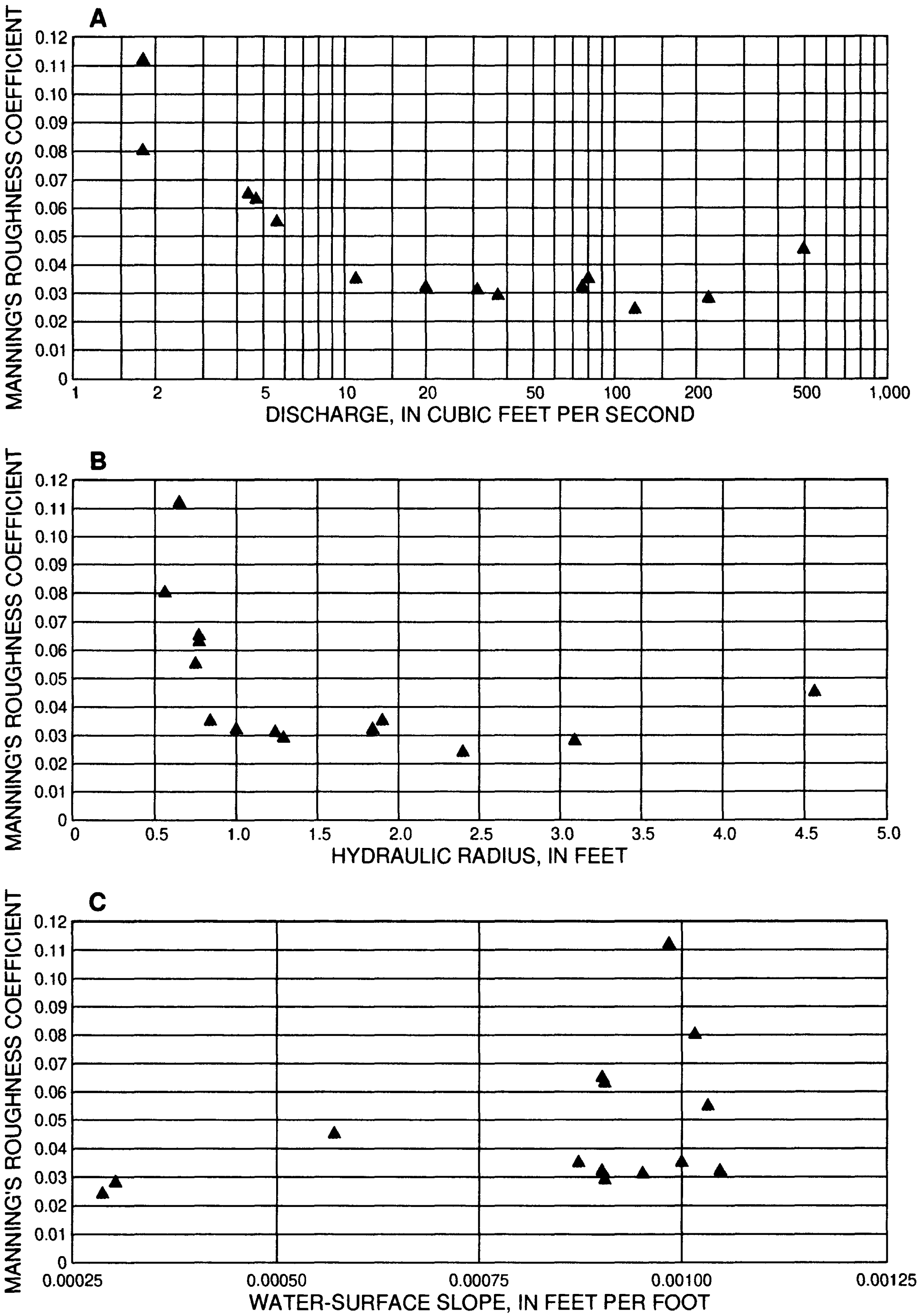

Figure 29. Delaney Creek near Tampa. Relation of Manning's roughness coefficient to (A) discharge, (B) hydraulic radius, and (C) water-surface slope.

A

B

Figure 30. Delaney Creek near Tampa. Photographs of channel looking (A) downstream from cross section 1 and (B) looking upstream from cross section 3.

Baker Creek at McIntosh Road near Antioch

Location of Gage.-- Lat 28°01'41", long 82°14'41", Hillsborough County, on upstream side of bridge on McIntosh Road, 2,000 ft north of the intersection of McIntosh Road and Interstate 4, 1.25 mi southeast of Antioch, 2.5 mi upstream from mouth.

Location of study reach.--A four-section, 700 ft long reach; cross section 1 is approximately 700 ft upstream from the stream-gaging station. A crest-stage gage at cross section 1 was used to measure water-surface elevations at the upstream boundary of the reach. The stream-gaging station was used to measure water-surface elevations at the downstream boundary of the reach. Additional crest-stage gages were located at cross section 2, which was 447 ft upstream from the stream-gaging station and at cross section 3, which was 272 ft upstream from the stream-gaging station.

Drainage area.--27.4 mi^2.

Average discharge.--23.3 ft^3/s (water years 1993-94).

Maximum discharge.--332 ft^3/s, Sept. 1, 1992.

Channel description.--The channel is about 25 ft wide, trapezoidal in shape, and straight (degree of meander = 1.01). The streambed is very irregular with some rock outcrops.

Bed material.--Fine sands (97.8%); d_{50}, 0.25 mm; d_{84}, 0.40 mm. The stream bottom is irregular with some deep pools below several of the small falls in the reach.

Bank descriptions.--Both streambanks are vegetated with small trees, vines, and dense brush. The top of both banks are high, covered with dense ground cover, cabbage palms, and mature hardwood trees. Both banks are not subject to overflow except at extremely high stages.

Baker Creek at McIntosh Road near Antioch

Hydraulic Data
[ft = foot; ft^2 = square foot; ft/s = foot per second; ft^3/s = cubic foot per second; ft/ft = foot per foot]

			Average values for reach								
Date	Gage height (ft)	Dis-charge (ft^3/s)	Area (ft^2)	Width (ft)	Hydraulic radius (ft)	Vel-ocity (ft/s)	Percent wetted perimeter vegetated	Water surface slope (ft/ft)	Friction slope (ft/ft)	Type of flow regime	Manning's *n*
08-30-94	7.83	310	108	30.8	3.10	3.12	50	0.00223	0.00232	Upper	0.051
10-03-92	5.53	151	57.9	21.6	2.34	3.02	28	0.00324	0.00338	Upper	0.058
08-27-93	5.17	128	49.3	20.5	2.13	2.88	23	0.00476	0.00444	Upper	0.066
09-06-93	4.37	81	40.6	19.4	1.88	2.14	18	0.00427	0.00368	Upper	0.095
08-28-93	4.31	78	37.3	18.9	1.78	2.23	15	0.00415	0.00456	Upper	0.088
09-07-93	3.89	51	30.0	17.8	1.54	1.79	9	0.00424	0.00453	Upper	0.108
08-25-94	3.77	43	28.0	17.4	1.47	1.63	7	0.00451	0.00452	Upper	0.118

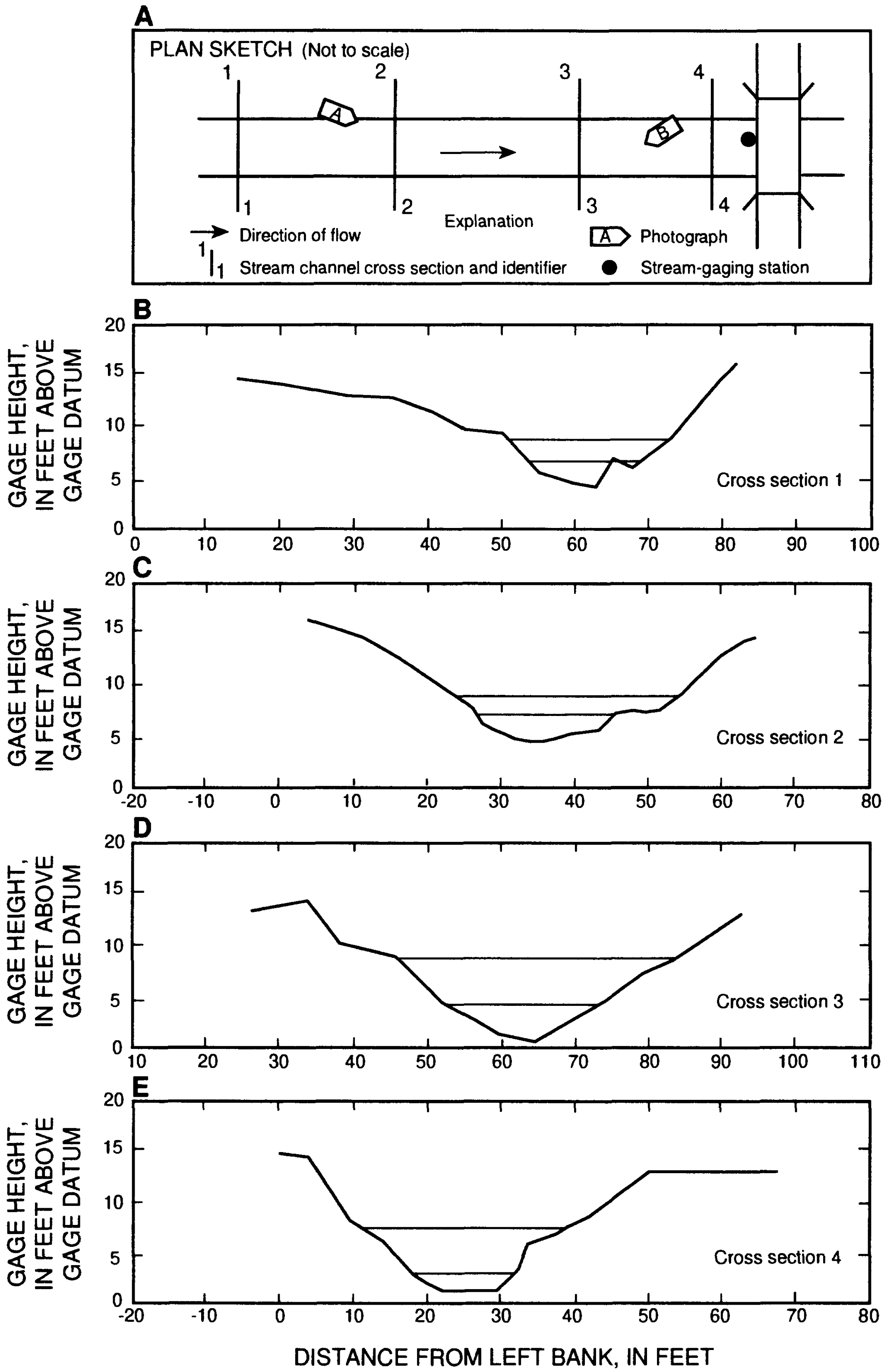

Figure 31. Baker Creek at McIntosh Road near Antioch. (A) plan sketch, (B) cross section 1, (C) cross section 2, (D) cross section 3, and (E) cross section 4.

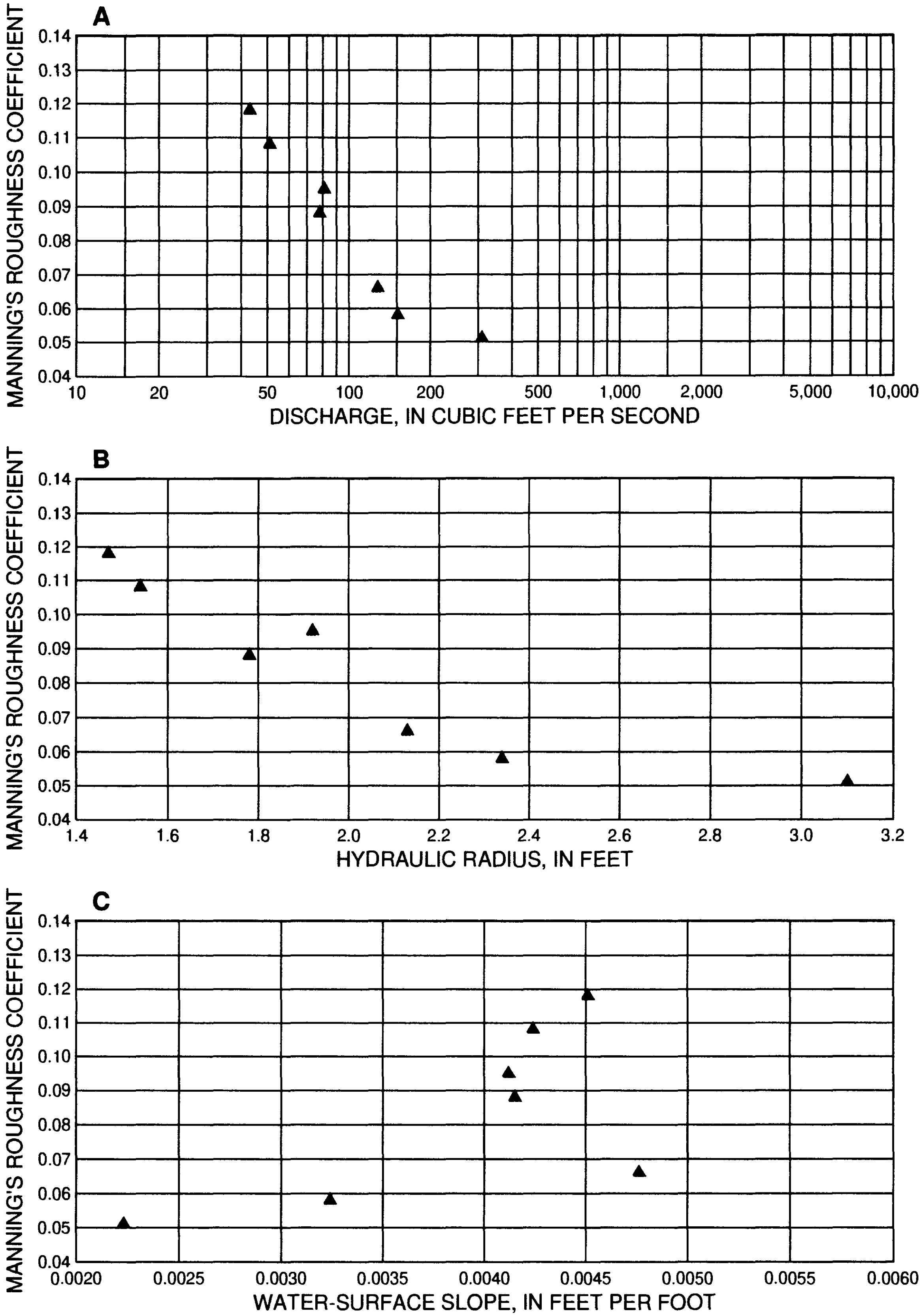

Figure 32. Baker Creek at McIntosh Road near Antioch. Relation of Manning's roughness coefficient to (A) discharge,(B) hydraulic radius, and (C) water-surface slope.

A

B

Figure 33. Baker Creek at McIntosh Road near Antioch. Photographs of channel looking (A) downstream from cross section 2 and (B) looking upstream from cross section 4.

Anclote River near Elfers

Location of Gage.-- Lat 28°12'50", long 82°40'00", Pasco County, on left bank, 40 ft downstream from bridge on State Highway 54, 3.5 east of Elfers, and 16 mi upstream from mouth.

Location of study reach.--A two-section, 555 ft long reach; cross section 1 is approximately 2,500 ft upstream from the stream-gaging station. Crest-stage gages at cross sections 1 and 2 were used to measure water-surface elevations at both the upstream and downstream boundaries of the reach.

Drainage area.--72.5 mi^2.

Average discharge.--29.6 ft^3/s (water years 1978-94).

Maximum discharge.--2,310 ft^3/s, Sept. 6, 1988.

Channel description.--The channel is well defined and meanders through a wooded area (degree of meander = 1.17). There are some cross-section irregularities. There are numerous obstructions throughout the reach consisting of exposed tree trunks, root systems, and cypress knees which may be as large as 2 ft in height.

Bed material.--Fine sands (99.6%); d_{50}, 0.17 mm; d_{84}, 0.24 mm. The stream bottom is irregular with some deep pools.

Bank descriptions.--Both streambanks are heavily vegetated with trees, vines, and dense brush. There are numerous cypress trees with exposed root systems and large cypress knees throughout the reach. Both banks are high, covered with dense stands of palmettos, brush and mature trees. Neither bank is subject to overflow except at extremely high stages.

Anclote River near Elfers

Hydraulic Data

[ft = foot; ft^2 = square foot; ft/s = foot per second; ft^3/s = cubic foot per second; ft/ft = foot per foot]

			Average values for reach								
Date	Gage height (ft)	Dis-charge (ft^3/s)	Area (ft^2)	Width (ft)	Hydraulic radius (ft)	Vel-ocity (ft/s)	Percent wetted perimeter vegetated	Water surface slope (ft/ft)	Friction slope (ft/ft)	Type of flow regime	Manning's *n*
10-05-92	17.99	782	458	66.1	6.23	1.71	84	0.00052	0.00051	Lower	0.066
09-10-92	13.14	274	194	45.8	3.85	1.42	77	0.00072	0.00070	Lower	0.068
09-06-92	12.24	209	153	39.2	3.32	1.38	75	0.00088	0.00086	Lower	0.070
09-01-92	11.68	173	128	36.4	3.16	1.36	72	0.00068	0.00066	Lower	0.060
09-10-93	11.34	152	118	35.4	3.02	1.31	71	0.00084	0.00082	Lower	0.069
09-15-92	10.50	107	94.8	32.4	2.64	1.16	68	0.00124	0.00121	Lower	0.086
03-15-93	10.37	100	89.2	31.7	2.54	1.14	67	0.00074	0.00072	Lower	0.066
04-17-93	9.87	76	72.0	28.6	2.31	1.08	63	0.00078	0.00076	Lower	0.067
04-16-93	9.68	67	63.3	26.7	2.22	1.07	60	0.00066	0.00064	Lower	0.060
04-01-93	9.43	54	61.4	26.2	2.19	0.90	59	0.00072	0.00071	Lower	0.075
11-12-92	9.22	54	54.9	24.7	2.10	1.00	56	0.00088	0.00086	Lower	0.072
10-16-92	8.94	43	47.0	23.1	1.98	0.94	52	0.00088	0.00086	Lower	0.074
01-18-93	8.77	39	43.5	22.3	1.92	0.92	49	0.00078	0.00076	Lower	0.069
11-20-92	8.11	19	30.5	17.0	1.64	0.66	38	0.00086	0.00085	Lower	0.093
12-17-92	7.57	12	22.6	15.3	1.34	0.58	31	0.00064	0.00063	Lower	0.081
02-06-93	7.50	11	21.9	15.1	1.32	0.56	30	0.00088	0.00087	Lower	0.098
10-29-92	7.48	8.0	19.7	14.6	1.23	0.46	27	0.00084	0.00083	Lower	0.112

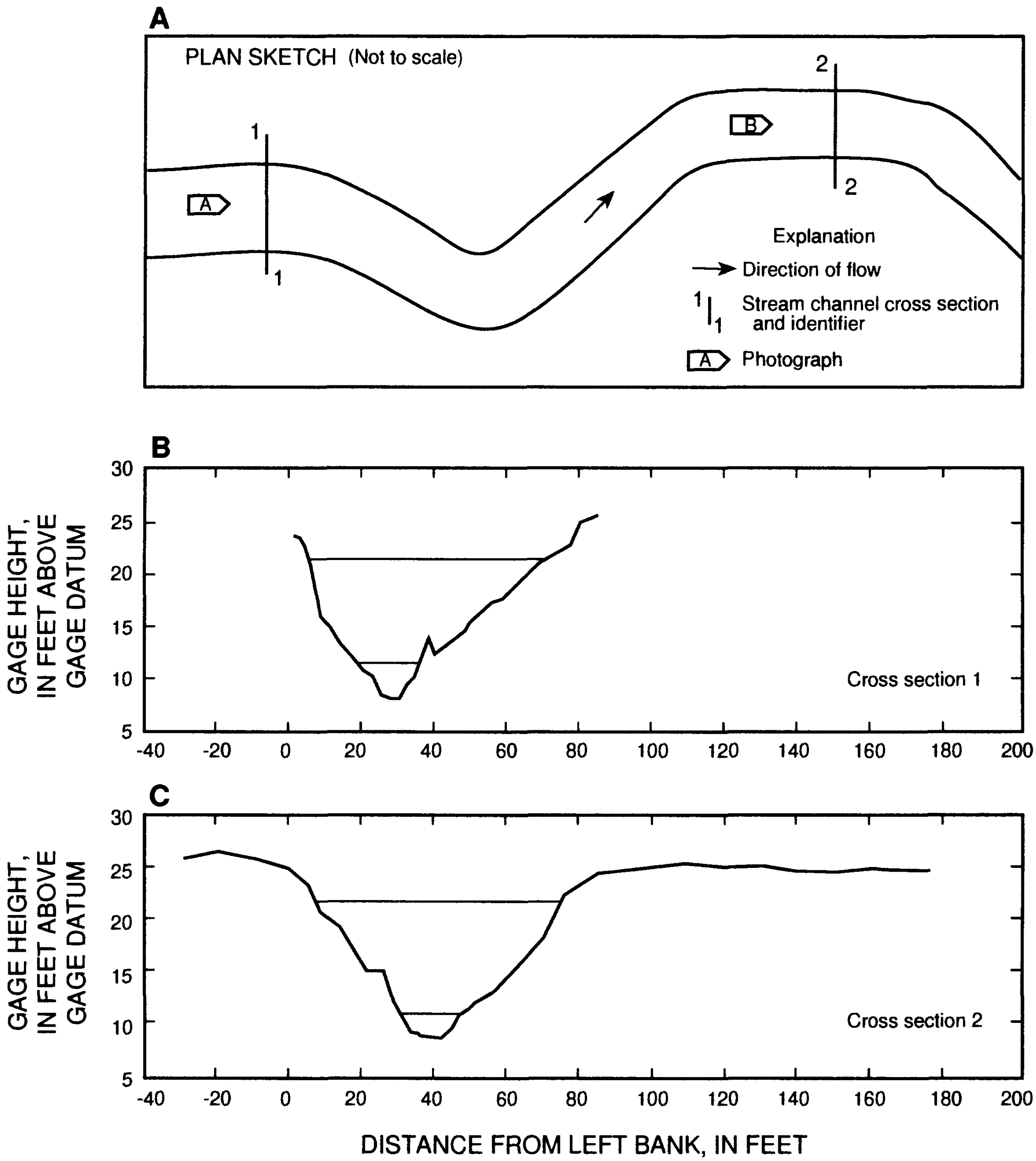

Figure 34. Anclote River near Elfers. (A) plan sketch, (B) cross section 1, and (C) cross section 2.

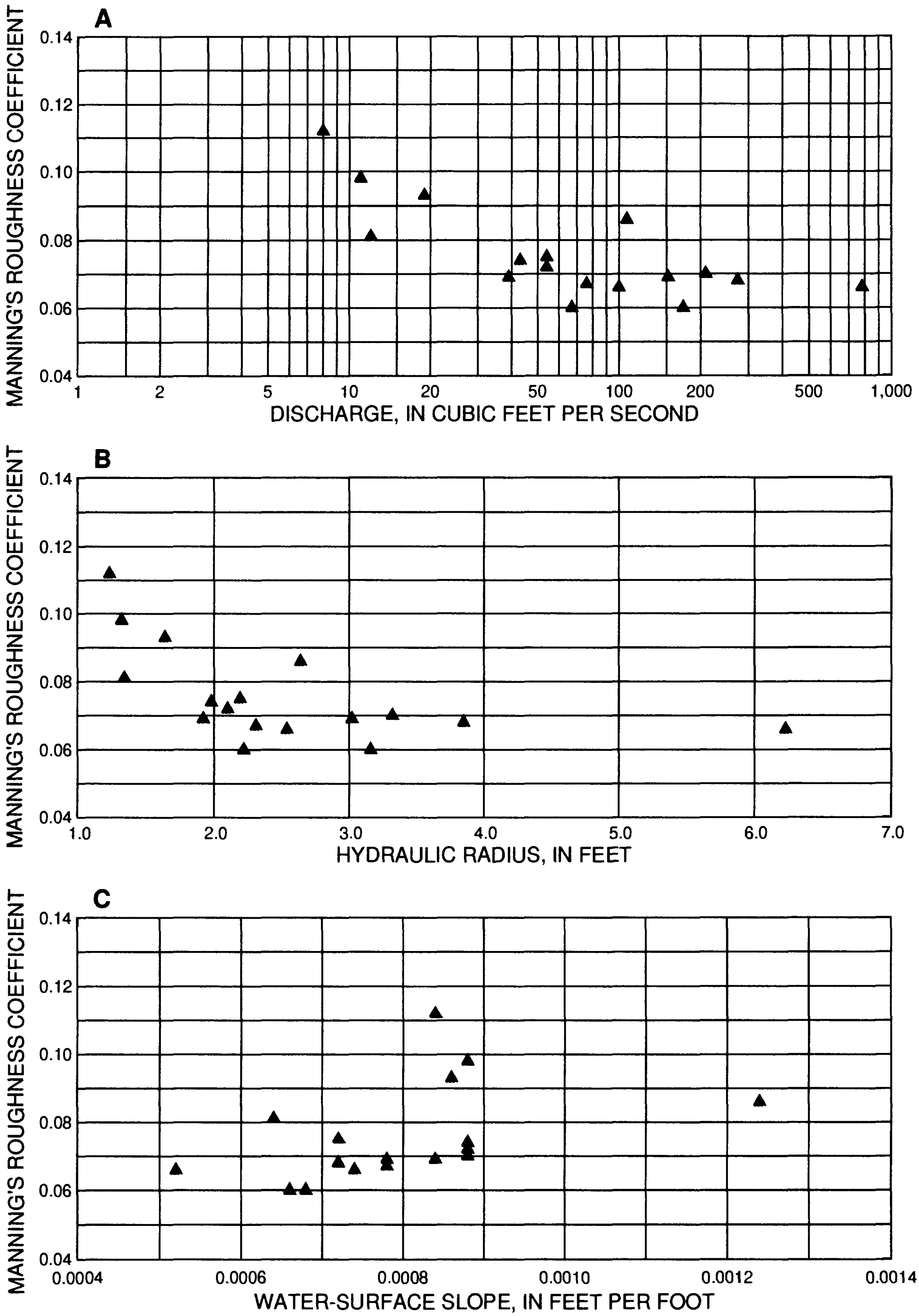

Figure 35. Anclote River near Elfers. Relation of Manning's roughness coefficient to (A) discharge, (B) hydraulic radius, and (C) water-surface slope.

A

B

Figure 36. Anclote River near Elfers. Photographs of channel looking (A) downstream from cross section 1 and (B) looking downstream from cross section 2.

Withlacoochee River at Wysong Dam at Carlson

Location of Gage.-- Lat 28°49'23", long 82°11'00", Sumter County, at downstream end of left wall of lock of Wysong Dam, at Carlson, 1.8 mi downstream from Outlet River, 2.7 mi southeast of Rutland, and 55 mi upstream from mouth.

Location of study reach.--A two-section, 2,100 ft long reach; cross section 1 is approximately 2,200 ft upstream from the stream-gaging station. Crest-stage gages at cross section 1 were used to measure water-surface elevations at the upstream boundary of the reach. The stream-gaging station was used to determine water-surface elevations at the downstream boundary of the reach.

Drainage area.--1,520 mi^2.

Average discharge.-- 615 ft^3/s (water years 1966-94).

Maximum stage.--41.10 ft, Oct. 11, 1979.

Channel description.--The channel bottom has some bottom irregularity with heavy vegetation throughout. The channel varies from 675 ft at cross section 1 to 550 ft at cross section 2 with some variation in the channel cross section.

Bed material.--Fine sands (95.1%); d_{50}, 0.19 mm; d_{84}, 0.31 mm. The stream bottom is overgrown with dense hydrilla and other aquatic growth. The water management district conducts herbicide sprayings periodically to control the aquatic growth which results in highly variable roughness effects.

Bank descriptions.--Both streambanks are low and covered with mature trees, some palms, and moderate brush. The left bank is covered with a large stand of mature bald cypress trees with dense underbrush.

Withlacoochee River at Wysong Dam at Carlson

Hydraulic Data

[ft = foot; ft^2 = square foot; ft/s = foot per second; ft^3/s = cubic foot per second; ft/ft = foot per foot]

			Average values for reach								
Date	Gage height (ft)	Discharge (ft^3/s)	Area (ft^2)	Width (ft)	Hydraulic radius (ft)	Velocity (ft/s)	Percent wetted perimeter vegetated	Water surface slope (ft/ft)	Friction slope (ft/ft)	Type of flow regime	Manning's *n*
10-15-92	37.00	352	1890	591	3.22	0.19	81	0.00005	0.00005	Lower	0.117
09-28-93	37.12	332	1970	593	3.34	0.17	81	0.00007	0.00007	Lower	0.157
10-08-92	36.90	321	1830	590	3.12	0.18	81	0.00006	0.00006	Lower	0.139
03-17-93	37.15	313	1980	593	3.36	0.16	80	0.00005	0.00005	Lower	0.148
02-02-93	36.73	284	1720	587	2.96	0.17	81	0.00005	0.00005	Lower	0.125
08-02-93	36.74	282	1720	587	2.96	0.17	81	0.00003	0.00003	Lower	0.097
12-04-92	36.67	249	1680	586	2.89	0.15	81	0.00004	0.00004	Lower	0.122
11-19-92	36.56	232	1600	584	2.77	0.15	80	0.00002	0.00002	Lower	0.086
12-18-92	36.54	226	1490	584	2.76	0.15	80	0.00002	0.00002	Lower	0.098
08-26-93	36.31	200	1490	581	2.59	0.14	80	0.00005	0.00005	Lower	0.146
06-03-93	36.59	169	1630	584	2.81	0.11	81	0.00003	0.00003	Lower	0.161

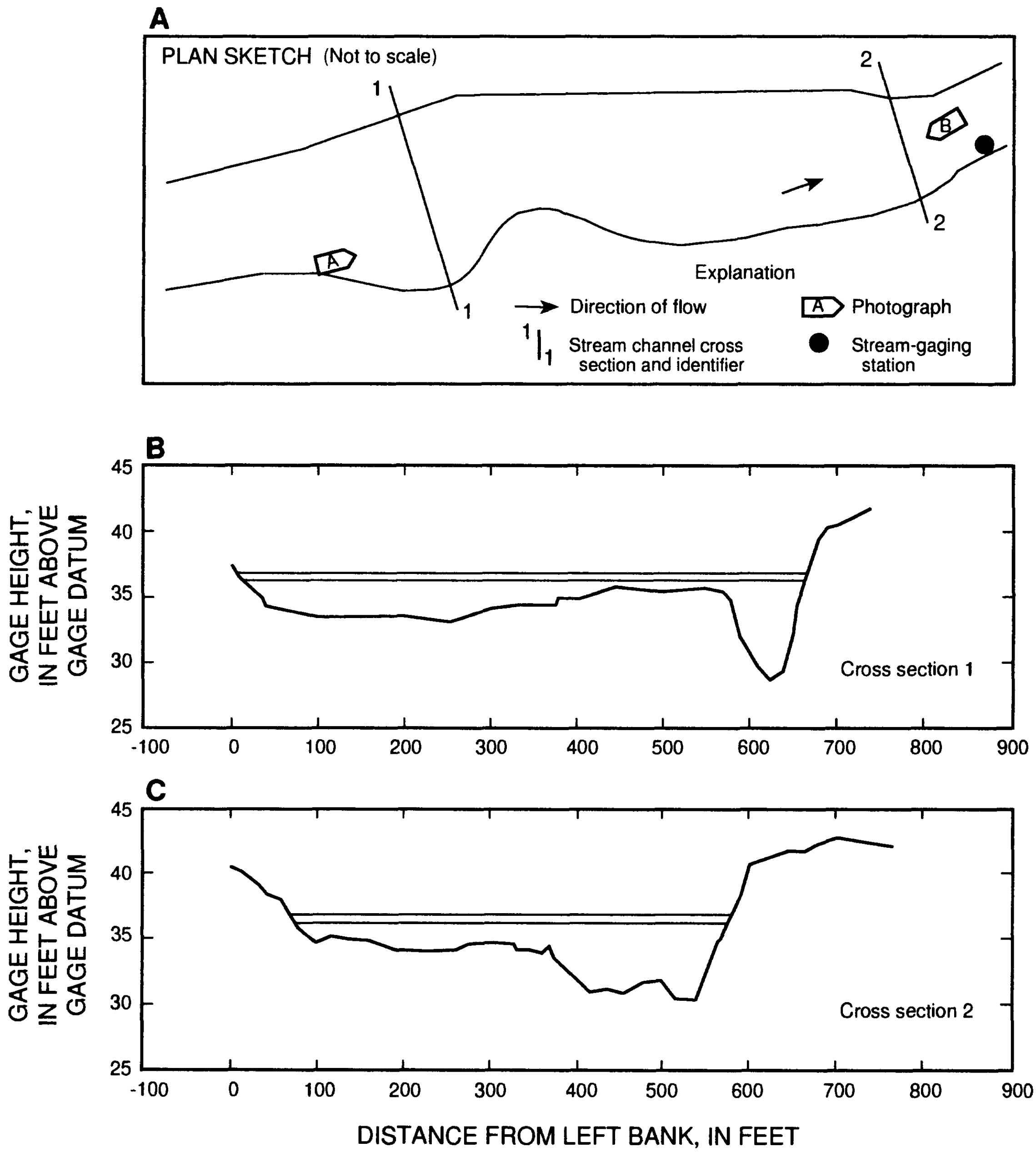

Figure 37. Withlacoochee River at Wysong Dam at Carlson. (A) plan sketch, (B) cross section 1, and (C) cross section 2.

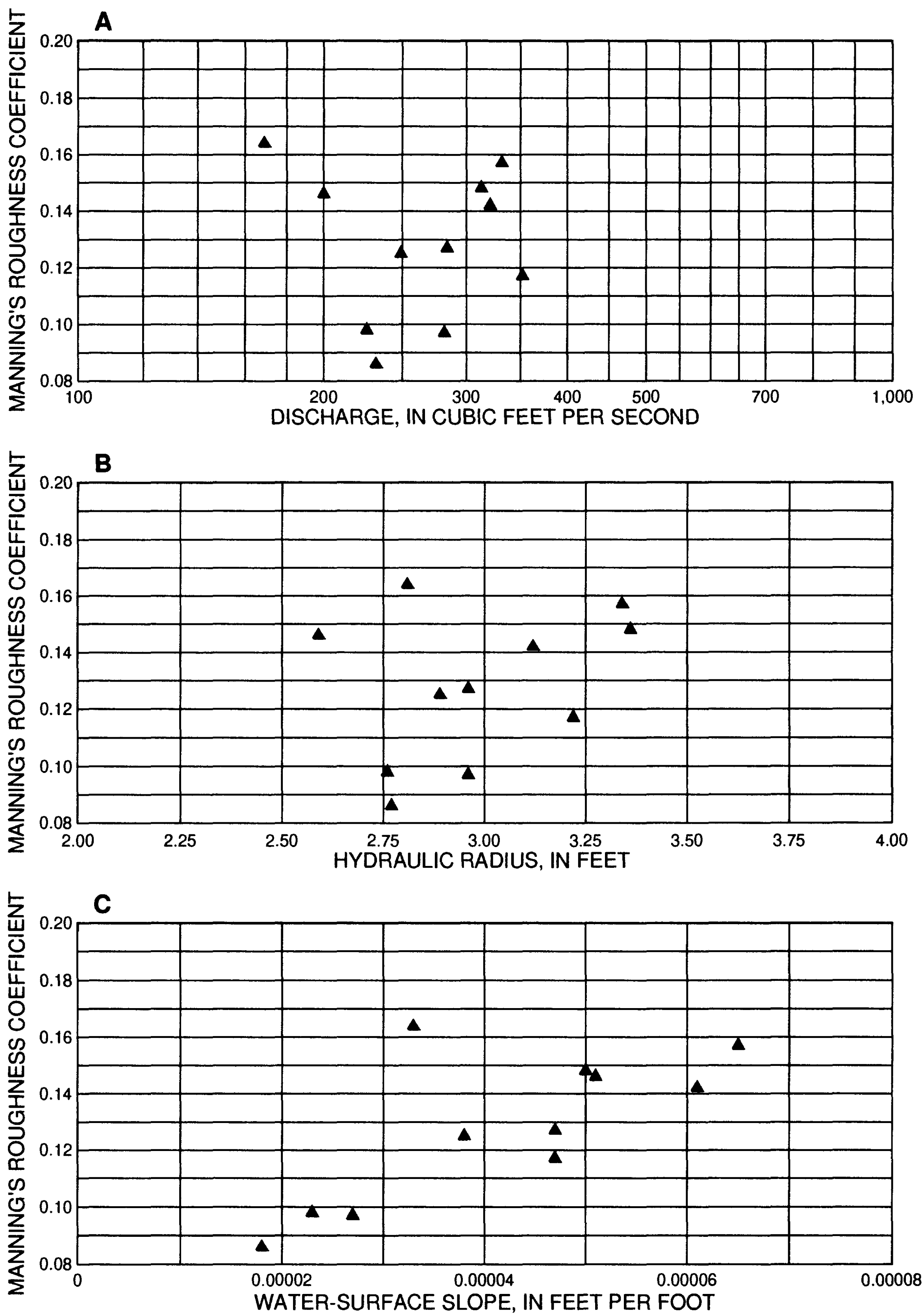

Figure 38. Withlacoochee River at Wysong Dam at Carlson. Relation of Manning's roughness coefficient to (A) discharge, (B) hydraulic radius, and (C) water-surface slope.

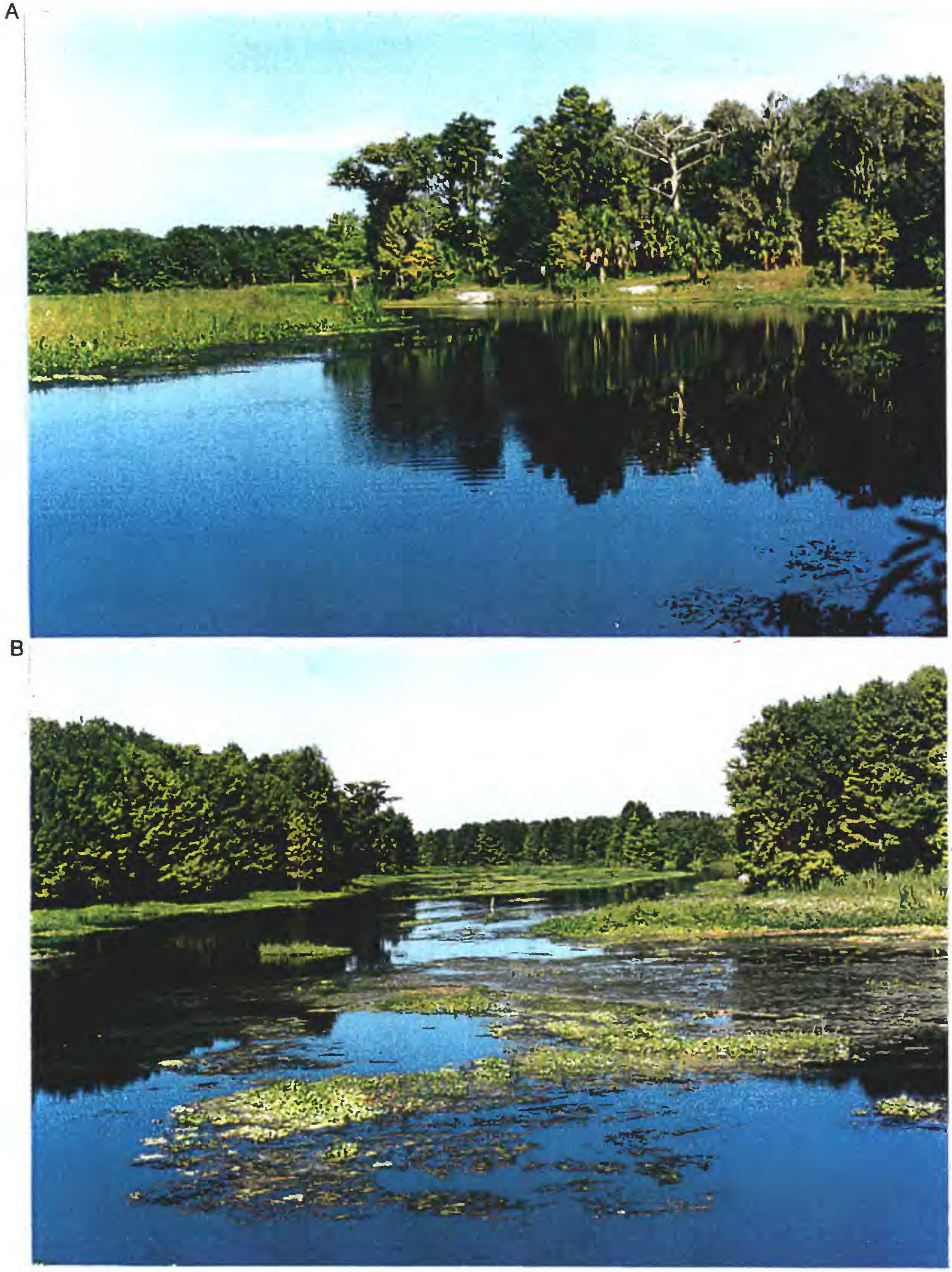

Figure 39. Withlacoochee River at Wysong Dam at Carlson. Photographs of channel looking (A) downstream from cross section 1 and (B) looking upstream from cross section 2.