DISSERTATION

INVESTIGATION OF CROSS-SECTION GEOMETRY AND SEDIMENT TRANSPORT CAPACITY IN NON-COHESIVE ALLUVIAL CHANNELS

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY NIDAL ADEEB HADADIN ENTITLED "INVESTIGATION OF CROSS-SECTION GEOMETRY AND SEDIMENT TRANSPORT CAPACITY IN NON-COHESIVE ALLUVIAL CHANNELS" BE ACCEPTED AS FULFILLING IN PART THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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ABSTRACT OF DISSERTATION

INVESTIGATION OF CROSS-SECTION GEOMETRY AND SEDIMENT TRANSPORT CAPACITY IN NON-COHESIVE ALLUVIAL CHANNELS

The assumption of a channel width, which is frequently based on a regime equation (Copeland et al., 2001), is required in the design of an alluvial channel shape. However, the application of regime equations outside the range of the empirical data sets from which each equation was developed presents a potential risk that may be unacceptable to the design engineer. Most empirical equations were developed for streams transporting less than 500 ppm of sediment (Garde and Ranga Raju, 1985; Watson et al., 1999). This research develops a procedure for channel shape design that does not require the use of regime equations, and can be used for a broader range of sediment transport concentration.

In this research, the effect of the width/depth ratio (*W*/*d*) on sediment transport was demonstrated based on statistical analysis on a set of hydraulic variables, using regression analyses. Three sediment transport equations were modified to include a width/depth ratio. Two sediment transport relationships were developed, one for natural channels, and another for the laboratory flumes. The results show that the width/depth ratio has an important role in prediction of sediment transport, but the role is less important than the role of flow velocity, channel slope, and grain size. The trends from five sediment transport relationships show that the sediment transport decreases as *W/d* increases for natural channels and sediment transport increases as *W/d* increases for flumes.

A computational procedure was developed to examine the relationship between maximum sediment transport and the channel width/depth ratio. An investigation of the relationship between width/depth ratio and several different sediment transport relationships was then conducted. Examination of Engelund and Hansen (1967), Yang (1973) for sand and gravel, and Shen and Hung (1971) equations showed that the maximum sediment concentration occurred at a width/depth ratio value of 2, which almost never occurs in natural alluvial channel systems. A comparison was made between Duboys (1879) and Meyer-Peter and Müller (1948) with regime charts (USACE, 1994) for the 2-year recurrence interval discharge using a maximum sediment transport method. It was found that both of the sediment transport equations could be used for prediction of the regime (USACE, 1994) width/depth ratio. A range of width/depth ratio at maximum sediment transport was found to be 18 to 35 for channels with gravel.

For Demonstration Erosion Control (DEC) channels using regression Channel Evolution Model (CEM) relationships, the range of width/depth ratio was found to be 9.8 to 15.1 for channels with sand and top widths <50 m. A new method for stable channel design was developed by modifying the Copeland (1999) procedure. This new method uses Brownlie's (1981) sediment transport equation for sand and was compared with those of other investigators. Based on the results, it was found that this method could be used to design the cross-section geometry for non-cohesive alluvial channels with low and high sediment concentration.

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DEDICATION

This dissertation is dedicated to the memory of my mother, Jehad, and my father, Adeeb, who passed away a few years ago.

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LIST OF SYMBOLS AND ABBREVIATIONS

a, b, c, f, j, k, m, p = empirically-derived coefficients and exponents

a_1 - a_9 = coefficients

A = cross-sectional area

$AR^{2/3}$ = capacity of a channel related to the area and hydraulic radius

b_1, b_2, b_3 = constants

c = coefficient

c = scale factor in Equation (2.8)

c_f = coefficient

C = mean and total sediment concentration

C_d = coefficient

$C(d)$ = sediment concentration from the mean depth

$C/C(d)$ = ratio of sediment concentration and the concentration from the mean depth

C_i = local sediment concentration

C_{ppm} = total sand and gravel concentration in parts per millions by weight

C_w = weight concentration of sediment

d = flow depth (m)

d_{50} = median grain size of the bed material

d_i = local flow depth

d_s = grain size

d_* = non-dimension grain size

e_B = coefficient, $0.2 < e_B < 0.3$

f = Darcy-Weisbach's friction factor

f_b = Darcy-Weisbach's friction factor for bed roughness

f_w = Darcy-Weisbach's friction factor for wall roughness

F_g = grain Froude number

F_{go} = critical grain Froude number

Fr = Froude number

g = gravitational acceleration

G = specific gravity of the sediment

h = bank height

h_c = critical bank height

i = subscript for the appropriate data set

m = exponent of the theoretical hydraulic geometry equations

M = percentage silt-clay in the channel boundary

n = coefficient of Manning

n_c = composite or equivalent coefficient of roughness

n_s = bank resistance

N = number of samples

P = wetted perimeter

P_b = perimeter of the bed

P_s = perimeter of the side slope

P-value = observed significance level of a statistical test

q_b = bedload sediment discharge per unit width, sediment transport rate

q_{bv} = sediment transport rate per unit width

q_s = volumetric sediment discharge per unit width

q_s = suspended load per unit width

q_t = total sediment discharge is expressed as dry weight per unit, time, and width in any consistent system of units

q_* = dimensionless unit discharge

Q = flow rate (m^3/s)

Q = independent variable

Q_2 = flow discharge at 2-year recurrence interval

Q_s = sediment discharge

Q_{ss} = sediment transport rate

Q_b = bankfull discharge

R = hydraulic radius

$\overline{R}$ = discrepancy ratio

R_b = hydraulic radius associated with the bed

R_g = grain Reynolds number

R_s = hydraulic radius associated with the side slope

R^2 = coefficient of determination

S = channel slope, energy slope, bed slope

S_f = friction slope

S_h = variable that depends on flow velocity, energy slope, and fall velocity

u = transformation function

u_* = shear velocity

V = flow velocity (m/s), depth-average velocity

V_i = local flow velocity

$\frac{V_c}{\omega}$ = dimensionless critical average flow velocity at incipient motion

VS = unit stream power

W = channel top width at the water surface

W/d = width/depth ratio

W/d = shape factor

X = mean flow depth or mean flow width

y = increment width of cross section

Z_{bf} = bankfull depth

α = significance level

β = shape factor, exponent

γ = specific weight of water

γ_s = specific weight of sediment

δ = laminar sublayer

ν = kinematic viscosity of water

ρ = density of water

ρ_s = density of sediment

σ = geometric bed material gradation coefficient

τ_o = shear stress

τ_c = critical shear stress

τ_* = Shield parameter

τ_{*c} = critical values of the Shield parameter

$(\tau_o - \tau_c)$ = excess shear stress

$(\tau_* - \tau_{*c})$ = excess Shield parameter

$(\tau_\theta)_c$ = critical bed shear stress for initiation of bed load

ϕ = angle of repose

ψ = non-dimensional channel shape factor; width-depth ratio

ω = settling velocity

$(\omega - \omega_{cr})$ = excess stream power per unit width

Abbreviations

ACOP	Alluvial Channel Observation Project
°C	Celsius
CEM	Channel Evaluation Models
cfs	cubic feet per second
CHOP	Canal and Headworks Observation Program
cms	cubic meter per second

DEC	Demonstration Erosion Control
ft	feet
km	kilometer
m	meter
m^3	cubic meter
mi	mile
ppm	parts per million
sec, s	second
sq	square
USACE	U.S. Army Corps of Engineers
USBR	U.S. Bureau of Reclamation

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

Sediments are fragmented material transported by water or air (Raudkivi, 1976). The transport of sediment by water in open channels is an important issue that is the focus of hydraulic engineers. River control, reservoir capacity, design of irrigation projects, interference with harbor operation, modification of water courses, erosion, scour, and undermining are among the issues of concern. For example, in the design of irrigation projects, water must be conveyed from a storage reservoir to the field by main canals, distributaries, and minors. In such cases, determination of the shape, cross-sectional area, and slope of a channel that will carry a given discharge of water and sediment, while flowing over an erodible bed of known characteristics is difficult. Also in the design of navigation channels, improvement of river courses, and stabilization of streams, the requirements are that the channel must be stable and must be able to safely transport the water and sediment. The design of such channels is based on the law governing the resistance, sediment equation, or on empirically-derived equations from data on channels, flowing in a stable section (Garde and Ranga Raju, 1985).

Sediment transport occurs only if there is an interface between a moving fluid and erodible boundary. The activity of this interface is extremely complex. Once the sediment is transported, the flow is no longer a simple fluid flow since two materials are involved, water and sediment. Typically, sediment transport mechanics are classified into bed load and suspended load. The sediments can be transported along the river either in contact with the streambed or in suspension supported by the upward component of the river turbulence. The amount of material carried by the stream is called bed load, and the suspended load is the amount of material transported in suspension (Julien, 1998). Sediment discharge refers to the transport rate of sediment load. Total load can be divided based on the source of the sediment load, which consists of suspended particles of a size large enough to occur in appreciable quantities at the surface of the stream bed, and wash load which consists of suspended sediment particles of a size finer than those present in significant quantities in the bed (Woo et al., 1986).

Sediment transport rates are a function of flow hydraulics, bed composition, and upstream sediment supply. Open-channel flow problems are relatively more difficult to solve than those of closed-conduit because the shape and size of a natural channel vary in a wide range from rivulets to large rivers. While the artificial (manmade) channel has a regular geometric shape, the cross-sectional shape of natural channels may be very irregular. In a movable boundary channel the cross section undergoes deformation due to scour and deposition of sediment transport by the flow in the channel. Flow depth, width, longitudinal and side slopes, and plan of the channels can change with discharge. An open channel in which the shape and size of the cross section, and the slope of the bottom are not constant is termed nonprismatic (Jain, 2001).

The cross-sectional form of natural channels is characteristically irregular in outline and locally variable. The cross geometry of a channel is usually described quantitatively by the top width, hydraulic depth, and top width to hydraulic depth ratio (*W*/*d*). Brownlie (1981) developed another shape factor (β), he used a power function as a relationship between depth and width, $d = cW^{\beta}$, where c is a coefficient and the exponent β is a shape factor. These two shape factors were used in this research.

1.2 PROBLEM STATEMENT

In many circumstances channel instability is of great economic and social impact. Channel widening due to bank erosion is one of the most important problems in river morphology. Landowners complain of bank erosion and channel shifting, which cause land loss. Moreover, erosion is hazardous to hydraulic structures and highways. Artificial channels such as irrigation channels carrying silt-laden water from rivers may be seriously impaired by the scour or deposition of sediment. Many poorly designed canals have silted up and become inoperable due to failure to carry the sediment load. In these examples, the engineer is seeking to understand the process and to design a stable channel.

There are many variables that have an effect on the sediment transport such as flow velocity, channel slope, bed material grain size, roughness, bank materials composition, relative roughness, gradation coefficient, channel cross-section geometry, etc. The effect of many variables on sediment transport has been understood; however, the influence of other variables still required additional research. Bagnold's (1980) research implies that for a given discharge and slope, larger sediment load requires wider channels, whereas Henderson's (1966) threshold channel equations imply the contrary. White et al. (1982) proposed that maximum transporting capacity is attained at some intermediate width and they indicated that maximum sediment transport is a function of width, but cross-section shape was not addressed.

1.3 OBJECTIVE

The objective of this research was to investigate the relationship between width/depth ratio (*W/d*) and sediment transport, and to use the results of this investigation in predicting stable channel morphology based on an analytical approach. Additionally, the objective of this study was to develop several regression relationships for hydraulic geometry for the Demonstration Erosion Control (DEC) Project incised streams, and to show how the streams have adjusted through the processes of erosion and deposition.

CHAPTER 2
LITERATURE REVIEW

Quantitative relationships for the channel geometry hydraulics and sediment transport in alluvial rivers are numerous. All relationships are based, at least in part, on empirical relationships and are, therefore, limited to similar streams from which data were used in the derivation of the empirical relationship. Proof of a good relationship is to apply it to other streams that have the same range of characteristics as used in the derivations. If the results agree with the observed data, then the relationship can be used with confidence on this type of stream.

Deriving an equation applicable to all rivers is difficult because of the characteristics of alluvial streams. Alluvial stream channel geometry is a function of the channel hydraulics and sediment transport, which in turn is a function of the channel geometry. Thus, a significant problem is in the interrelation between the variables involved. The number of variables involved in the mechanics of flow in alluvial rivers also makes general relationships difficult to derive (Simons and Sentürk, 1992).

The literature review is divided into four parts: channel morphology, sediment transport relationships, stable channel design, and incised channels.

2.1 CHANNEL MORPHOLOGY

2.1.1 Hydraulic Geometry

The hydraulic geometry of a river channel refers to, and is described by, the relationships between discharge and certain hydraulic characteristics of the channel, such as width, depth, and velocity. The following literature summarizes research in the field of hydraulic geometry and stochastic hydraulics as it relates to the present study.

Early relationships were developed for canals in India and Pakistan. Regime theory implies that a channel is non-silting and non-scouring (Julien, 2002). Empirical relationships have been developed by Kennedy (1895), Lacey (1929), and Blench (1969), among many others. Regime theory consists of a set of empirical equations which can be manipulated to give the width (*W*), depth (*d*), and slope (*S*) of an approximately stable live-bed channel with a cross-sectional form maintained by a local balance between erosion and deposition (Knighton, 1998).

The relationships developed by Leopold and Maddock (1953) are in the form of power functions, as follows:

$$W = aQ^b \tag{2.1a}$$

$$d = cQ^f \tag{2.1b}$$

$$V = kQ^m \tag{2.1c}$$

$$Q_{ss} = pQ^j \tag{2.1d}$$

where W = channel top width at the water surface (m);

d = flow depth (m);

V = flow velocity (m/s);

Q = flow rate (m^3/s);

Q_{ss} = sediment transport rate; and

a, b, c, f, j, k, m, p = empirically-derived coefficients and exponents.

Numerous researchers have used this approach to describe channel shape and form, to classify rivers, and to correlate channel geometry to geomorphologic variables (Buhman, 2001). Richards (1973) pointed out that for many rivers, the scatter of points on hydraulic geometry diagrams is often better fit by polynomial relationships (fit to the logarithms of the variables) rather than by linear relationships.

Downstream hydraulic geometry deals with variation in a cross section along a stream, where cross-section form adjusts to accommodate the discharge and sediment load supplied from the drainage basin, within the additional constraints imposed by boundary composition, bank vegetation, and valley slope. A single channel-forming discharge is assumed to represent the channel morphology at a location, for various sites along the channel. Channel dimensions are not arbitrary but are adjusted, through the processes of erosion and deposition, to the quantity of water moving through the cross section so that the channel contains flow. Since discharge increases downstream with drainage area, width and mean depth should similarly vary (Knighton, 1998).

Ackers (1964) obtained a constant width/depth ratio for stable laboratory streams, using a small stream for his experimentation, he developed width and depth relationships in terms of discharge. The bed and bank materials used were sand with a median diameter that ranged between 0.16 mm to 0.34 mm and the discharge values ranged between 0.4 cubic feet per second (cfs) to 5.4 cfs. Sediment concentrations up to 400 parts per million (ppm) were observed.

A regime analysis of the data gave the following equations:

$$W = 3.6Q^{0.42} \tag{2.2a}$$

$$d = 0.28Q^{0.43} \tag{2.2b}$$

$$\frac{W}{d} = 12.9Q^{-0.01} \tag{2.2c}$$

The width/depth ratio in Equation (2.2c) is almost a constant and is equal to 12.9.

Schumm (1960) studied the effects that the percentage of silt-clay (alluvial material smaller than 0.074 mm) in the banks had on the shape of stream channels. He used a power function to relate the width/depth ratio to the percentage of silt-clay in the channel banks and found that downstream changes in width and depth are greatly influenced by sediment type, specifically that channels containing little silt-clay are relatively wide and shallow. The greater percentage of silt and clay in the perimeter produces a low width/depth ratio cross section, and coarser bed and bank material produces a high width/depth ratio cross section. Based on these considerations, Schumm presented empirical relationships for channel width, depth, meander, wavelength, and amplitude as functions of the amount of silt and clay and mean annual discharge or mean annual flood. Schumm (1963) subdivided channels into three types on the basis of the dominant mode of sediment transport, using the percentage silt-clay (M) in the channel boundary as his criterion:

- Bed load channels ($M \leq 5$);
- Mixed-load channels ($5 < M < 20$); and
- Suspended-load (or wash load) channels ($M \geq 20$).

Bank strength is an important factor controlling a channel cross-sectional shape. Bank strength depends, not only on bank material properties, but also on bank vegetation. This is illustrated by Hey and Thorne (1986) who identified four classes of bank vegetation based on type and density of the plants:

- Type I: grassy banks with no trees or shrubs;
- Type II: 1 to 5% tree/shrub cover;
- Type III: 5 to 50% tree/shrub cover; and
- Type IV: > 50% tree/shrub cover.

Rhoads (1991) described downstream hydraulic geometry analysis as an analysis of the bivariate relationship between channel parameters (such as width and depth) and an average or recurring discharge. Describing hydraulic properties of channel cross sections as a power function of flow depth was strongly supported by Garbrecht (1990).

Julien (1988) proposed four fundamental relationships of downstream hydraulic geometry of non-cohesive alluvial channels. He considered four fundamental concepts of hydraulics and sediments: flow continuity, flow resistance, longitudinal sediment mobility, and radial sediment mobility. Julien and Wargadalam (1995) examined the downstream hydraulic geometry from a three-dimensional stability analysis of non-cohesive particles under two-dimensional flows. They developed semi-theoretical equations, the hydraulic geometry relationship for mean depth (m) and surface flow width (m) are:

$$d = 0.20 Q^{\frac{2}{6m+5}} d_s^{\frac{6m}{6m+5}} S^{\frac{-1}{6m+5}} \tag{2.3a}$$

$$W = 1.330 Q^{\frac{4m+2}{6m+5}} d_s^{\frac{-4m}{6m+5}} S^{\frac{-(2m+1)}{6m+5}} \tag{2.3b}$$

where Q = (m^3/s);

d_s = d_{50} (m); and

$$m = \frac{1}{\ln \frac{12.2d}{d_s}}$$

Huang and Nanson (2000) studied the self-adjusting mechanism of alluvial channels. They found that by introducing a channel shape factor (width/depth), the self-adjusting mechanism of alluvial channels could be illustrated with the basic flow relationships of continuity, resistance, and sediment transport. They applied Lacey's flow resistance and Duboys' sediment transport relationships. For a stable canal and rectangular cross section they found that the width/depth ratio varies within a limited range (2.5 to 30).

Wolman (1955) recognized that local variations in cross-sectional form are a possible source of scatter in downstream hydraulic geometry relationships. In particular, such variations can be related systematically to channel pattern and bed topography.

Knighton (1998) documented that the dominant controls of channel form are discharge and sediment discharge, both of which integrate the effects of climate, vegetation, soils, geology, and other variables. However, Harvey (1975) sought to correlate riffle spacing to channel geometry variables such as cross-sectional area, wetted perimeter, and channel width. Harvey concluded that the closest correlation exists in the relationship between riffle spacing and the widths associated with relatively frequent discharges, rather than the discharge of the channel bankfull width.

At-a-station hydraulic geometry utilizes a range of discharge up to bankfull for single cross-section geometry. The work of Western et al. (1997) presented a method for characterizing stream channels using surveyed cross sections. The method allows for characterization of longitudinal variability in channel shape, size, and slope. They determined a set of parameters to describe the geometry and location of each cross section and then used statistical analysis of the parameters to test specific hypotheses. The parameter set they developed consisted of four variables. The size of the cross section was characterized using bankfull depth (Z_{bf}). The form of the cross section was described using the bankfull width/depth ratio (ω) and a shape parameter (ψ) defined as the ratio of the bankfull hydraulic mean depth to Z_{bf}. The final parameter described the vertical location of the cross section as the ratio of the deviation of the actual cross-section thalweg elevation from the expected thalweg elevation to Z_{bf}. To obtain the hydraulic characteristics of the cross section as a function of depth, they employed a power function relationship between the width and depth:

$$W^* = \alpha Z^{*\beta}$$

where $W^* = W / Z_{bf}$; and

$$Z^* = Z / Z_{bf}.$$

Ridenour and Giardino (1995) observed that finding correlations between geomorphologic variables and channel form is difficult because a stream is such a complex system with many interacting variables; the influence that one variable has on the river system may diminish as other variables change. They used log ratio linear modeling to investigate correlation between at-a-station hydraulic geometry and median grain size (d_{50}) of the bed material. They found a lack of correlation between the bed grain size and at-a-station hydraulic geometry but concluded that this is expected in streams where the roughness is dominated by planform characteristics, vegetation elements, macroscale bar features, or bedforms. They suggested that the use of d_{84} might be more appropriate.

2.1.2 Regime

The India Canal data, on which the Kennedy (1895) and Lacey (1929) regime relationships are based, did not have any record of the rate of bed material transport. But the majority of the India Canal data indicate that conforming channels approximately carry, on the average, bed material load of the order of 500 ppm (Garde and Ranga Raju, 1985).

Simons and Albertson (1963) developed a method for designing uniform alluvial channels. Their design theories, which are recommended include: (1) a modification of the regime theory on India, and (2) a modification of the tractive-force theory. The results of their investigation are based on a field study of stable alluvial irrigation channels, and other existing alluvial data, which are applicable. The principal finding of their study was that the regime equations, as developed in India (Garde and Ranga Raju, 1985), are valid for channels having sand beds and slightly cohesive to cohesive banks, which are formed by berming of the suspended material with less than 500 ppm sediment loads over a sustained period of time. The hydraulic geometry relationship for mean depth (m) and surface flow width (m) for sandy banks are:

$$W = 5.23Q^{0.50} \tag{2.4a}$$

$$d = 0.69Q^{0.36} \tag{2.4b}$$

The U.S. Army Corps of Engineers (USACE, 1994) Hydrologic Engineering Center, suggested regime design charts for stable channels. The USACE (1994) empirical data set is representative of a limited amount of data for the wide range of stream and watershed types, and is not applicable outside the range of data for which each relationship was developed. The concentration of sediment being transported is small, less than 500 ppm, and the method requires that bed and bank materials are static. While these methods are applicable within the limits for which each was developed, the two primary constraints listed dictate that empirical methods have limited application for natural streams (Watson et al., 1999).

2.1.3 Shape Factor

Simons (Simons and Sentürk, 1992) stated:

> "The shape factor for the reach must enter into the analysis of natural river because the shape factor affects the energy losses. This is due to bends and banks and the effect of the shape factor on the velocity distribution, causing variation in velocity, width, depth, boundary shear and secondary circulation. Variations of these variables and combinations of variables cause multiple bed roughness in the channel section and play a significant role in the size and location of bars, such as point bars and alternate bars. Detailed knowledge of these factors in natural channels is quite limited."

Einstein (1950) documented that:

> "The shape of the channel cross section is one of the factors influencing the bed load function. If this section is not influenced either structurally or by vegetation it is only a function of the sediment and of the flow. We have today no clear concepts of how to analyze these relationships rationally even though we seem to have some workable rules for

> expressing the influence of the shape of the known cross section on the rate of transport."

Einstein emphasizes the point made by several of the references, i.e., a solution of hydraulic processes cannot predict the channel shape if the boundary materials are affected either structurally or by vegetation.

The shape of a cross section in a stream depends on the point along the channel with reference to the plan geometry, the type of channel, and the characteristics of the sediment forming and being transported within the channel. The cross section in a bend is deeper at the concave (outer bank) side with a nearly vertical bank, and has a shelving bank as formed by the point bar on the convex side. The cross section will be more trapezoidal or rectangular in a crossing. Cross-section shape can be described by a number of variables, such as the area, width, and maximum depth. The width/depth (W/d) ratio is the channel width divided by the average depth (d) of the channel. The average depth is calculated by dividing the cross-sectional area by the channel width. The hydraulic radius (R), which is important in hydraulic computations, is defined as the cross-sectional area divided by the wetted perimeter. In wide channels with W/d greater than approximately 20, the hydraulic radius and the mean depth are approximately equal. The conveyance, or capacity of a channel is related to the area and hydraulic radius and is defined as $AR^{2/3}$ (Watson et al., 1999).

Brownlie (1981) used a combined data set of over 7,000 points for his numerical analysis. By statistical analysis of available data, he found that the concentration for field data is on the average 26.8% higher than for laboratory data. During the course of his investigation, it was noted that the field data tended to have slightly higher sediment concentrations than laboratory data for a similar range of dimensionless groups. Brownlie stated that:

> "One principal difference between laboratory and field observation is that the laboratory channels tend to be much more rectangular in cross section than river channels. For irregular channels, the concentration computed from cross sectional averaged hydraulic variables would be different from concentration calculated from local hydraulic properties and integrated over the cross section."

The analysis presented by Brownlie suggests that the variability of river cross sections could be responsible for the observed higher values of field measurements of sediment concentration over laboratory measurements.

Brownlie (1981) used the subscript i to indicate values of velocity, depth, and concentration for the i^{th} element in the cross section. He developed an expression for the local velocity and the local concentration:

$$V_i = a_1 d_i^{b_1} \tag{2.5}$$

$$C_i = a_2 V_i^{b2} d_i^{b3} \tag{2.6}$$

where a_1, a_2 = coefficients;

b_1, b_2, b_3 = constants;

V_i = local velocity; and

C_i = local concentration.

Brownlie used a power function as a relationship between depth and width:

$$d = cW^{\beta} \tag{2.7}$$

where c = coefficient; and

β = shape factor.

If $\beta = 2$, then the above equation provides a parabolic cross section.

The ratio between mean sediment concentration and the concentration from the mean depth was developed in Brownlie (1981, Equation 6.20 on p. 185) and is as follows:

$$\frac{C}{C(d)}=\left(\frac{\beta+1}{\beta}\right)^{b1b2+b3}\frac{\int_0^1\left(1-u^{\beta}\right)^{1+b1+b1b2+b3}du}{\int_0^1\left(1-u^{\beta}\right)^{1+b1}du} \tag{2.8}$$

where C = mean sediment concentration in the cross section;

$C(d)$ = sediment concentration calculated from the mean depth;

β = shape factor; and

u = transformation function $u=\frac{2y}{W}$, where y is the increment width of each trapezoidal element and W is the total width of the cross section.

Brownlie used Simpson's Rule to solve Equation (2.8) for a range of β. The average value of β = 1.53 from Leopold and Maddock (1953) yields $C/C(d)$ = 1.43 as shown in Figure 2.1. Brownlie's approach will be used in this study to investigate the relationship between sediment transport and shape factor (β), and the results are presented in Chapter 4.

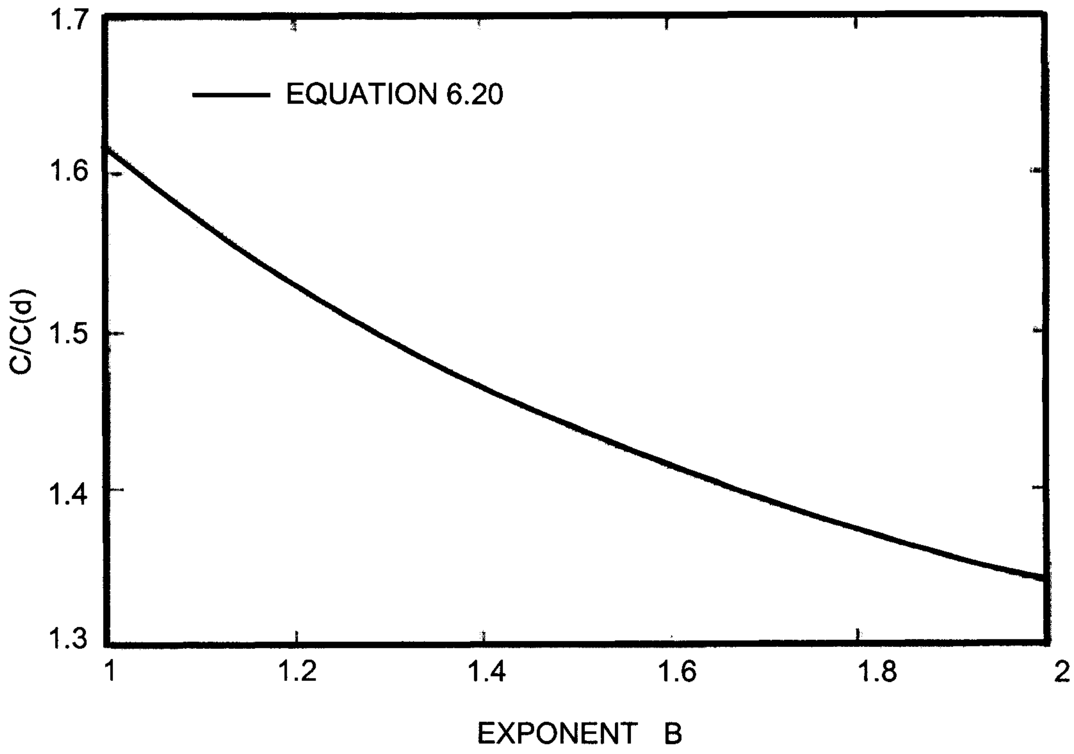

Figure 2.1: **Ratio of cross-sectionally integrated concentration to concentration calculated from mean depth, as a function of the value of exponent β (adapted from Brownlie (1981)).**

Bagnold's (1980) research implies that for a given discharge and slope, larger sediment load requires a wider channel (Equation. (2.9)),

$$q_{bv} \cong (\omega - \omega_{cr})^{3/2} d^{-2/3} d_s^{-1/2} \tag{2.9}$$

whereas Henderson's (1966) threshold channel equations imply the contrary, sediment transport increases as depth increases; therefore, the width/depth ratio decreases. A resolution of these arguments is achieved by the extremal hypothesis proposed by White et al. (1982), in which maximum transporting capacity is attained at some intermediate width. This hypothesis was applied to the prediction of hydraulic and geometric characteristics of alluvial channels with sand and gravel beds. The analyses and comparisons made by White et al. (1982) show that the maximization of sediment discharge and minimization of stream power, or slope for a given water discharge, will give the same result if sediment discharge is a variable that can be maximized. An example of their comparison is shown in Figure 2.2.

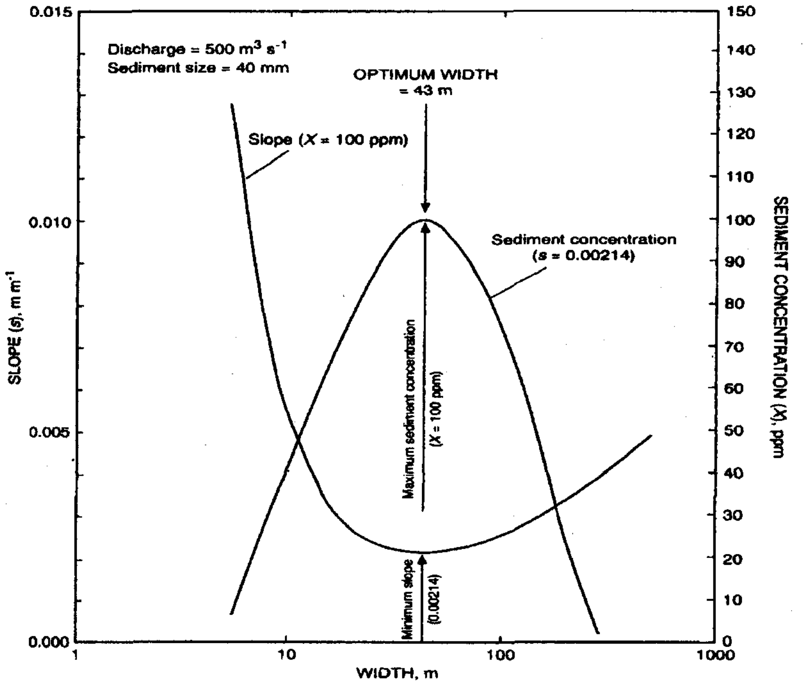

Figure 2.2: Slope and sediment concentration vs. channel width (after White et al. (1982)).

2.2 SEDIMENT TRANSPORT RELATIONSHIPS

Many researchers have attempted to predict the rate of sediment transport. Sediment transport equations are founded on the premise that a specific relationship exists between hydraulic variables, sedimentlogical parameters, and the rate at which sediment is transported.

Carson and Griffith (1987) stated that a simple, readily predictable, and widely applicable equation for bedload transport probably cannot be developed. What may be the most efficient approach is to develop a series of equations with each equation having a narrow range of applicability, which is defined by the most important control parameters, including channel gradient, relative roughness, grain size distribution, bedform presents, and velocity distribution.

There are many ways, and consequently many equations, to approach the study of sediment transport, namely:

- Excess shear arguments ($\tau_0-\tau_\chi$) (e.g., Duboys (1879), Meyer-Peter and Müller (1948));
- Probabilistic arguments (e.g., Einstein (1942));
- Stream power (e.g., Bagnold (1980), Engelund and Hansen (1967), Yang (1973)); and
- Computer optimization (e.g., Brownlie (1981), Shen and Hung (1971)).

The first bedload equation was developed by Duboys (1879), he assumed that the bed material moves in a series of layers parallel to the bed, the velocity of each layer varying from a maximum for the top layer on the bed surface to zero for the lowest layer.

Meyer-Peter and Müller (1948) developed a bedload equation based on the median sediment size (d_{50}). His equation is similar in form to Duboys' (1879) in the sense that the sediment transport rate is related to an effective shear stress.

The volume of bed material in motion per unit width and time (q_{bv}) is calculated from:

Duboys (1979) equation –

$$q_{bv} = \frac{0.173}{d_s^{3/4}} \tau_o \left(\tau_o - \tau_c\right) \tag{2.10}$$

Meyer-Peter and Müller (1948) equation –

$$\frac{q_{bv}}{\sqrt{(G-1)gd_s^{\,3}}} = 8(\tau_* - \tau_{*c})^{3/2} \tag{2.11}$$

where q_{bv} = sediment transport rate per unit width;

$(\omega - \omega_{cr})$ = excess stream power per unit width;

$(\tau_o - \tau_c)$ = excess shear stress;

$(\tau_* - \tau_{*c})$ = excess Shield parameter;

d = flow depth;

d_s = grain size; and

G = specific gravity of the sediment.

Shen and Hung (1971) began with the assumption that the sediment transport is such a complex phenomenon that no single Reynolds number, Froude number, or combination of these can be found to describe sediment motion under all conditions. They recommended that a regression method be used to develop a equation based on all available data for immediate engineering processes. They selected the bed material load concentration (C) as the dependent variable and the fall velocity (ω) in ft/sec of the median sediment particle of the bed sample, the flow velocity (V) in ft/sec, and energy slope (S) as independent variables. The concentration of bed sediment by weight (in ppm) is given as a power series of the flow parameter based on 587 data points:

$$\log C_{ppm} = -107404.459 + 324214747 S_h -$$

$$326309.589 S_h^{\,2} + 109503.872 S_h^{\,3} \tag{2.12}$$

$$S_h = \left[\frac{VS^{0.57159}}{\omega^{0.31988}}\right]^{0.00750189} \tag{2.13}$$

where S_h = variable that depends on ω, V, and S.

Shen and Hung (1971) estimated the parameters of a non-linear system by using the linearization method, and they used the results of linear least squares in a succession of stages. Approximations of parameters were assumed and the correction was found, the iteration was continued until the solution converged.

Bagnold (1966) developed a sediment transport equation based on the concept of energy balance. He stated that the available power of the flow supplies the energy for sediment transport. The resulting bed sediment transport combined bedload and suspended load:

$$q_t = q_b + q_s = \frac{\tau_0 V}{G-1}\left(e_B + 0.01\frac{V}{w}\right) \tag{2.14}$$

where q_t = total sediment discharge expressed as dry weight per unit time and width in any consistent system of units;

q_b = bedload;

q_s = suspended load;

τ_o = shear stress;

V = depth-average velocity;

G = specific gravity of the sediment;

ω = settling velocity; and

e_B = coefficient, $0.2 < e_B < 0.3$.

More recent efforts have utilized Bagnold's approach and more sophisticated dimensional arguments. The most popular is that of Engelund and Hansen (1967). They applied Bagnold's stream power concept and the similarity principle to obtain the sediment concentration by weight as follows:

$$C_w = 0.05\left(\frac{G}{G-1}\right)\frac{VS_f}{\left[(G-1)gd_s\right]^{1/2}}\left[\frac{R\,S_f}{(G-1)d_s}\right]^{0.5} \tag{2.15}$$

where C_w = weight concentration of sediment;

d_s = grain size;

S_f = friction slope;

R = hydraulic radius;

V = depth-average velocity;

g = gravitational acceleration; and

G = specific gravity of the sediment.

Yang (1973) suggested that the total sediment concentration is related to potential energy dissipation (stream power) per unit weight of water. He expressed unit stream power as the product of the velocity and slope. The dimensionless regression relationships for the total sediment concentration (C) in ppm by weight are:

For sand –

$$\log C_{ppm} = 5.435 - 0.286\log\frac{\omega d_s}{v} - 0.457\log\frac{u*}{\omega} +$$

$$\left(1.799 - 0.409\log\frac{\omega d_s}{v} - 0.314\log\frac{u*}{\omega}\right)\times\log\left(\frac{VS}{\omega} - \frac{V_c S}{\omega}\right) \tag{2.16}$$

For gravel –

$$\log C_{ppm} = 6.681 - 0.633\log\frac{\omega d_s}{v} - 4.816\log\frac{u*}{\omega} +$$

$$\left(2.784 - 0.315\log\frac{\omega d_s}{v} - 0.282\log\frac{u*}{\omega}\right)\times\log\left(\frac{VS}{\omega} - \frac{V_c S}{\omega}\right) \tag{2.17}$$

where C_{ppm} = total sand and gravel concentration (ppm by weight);

ω = terminal fall velocity of sediment particles;

d_s = median particle diameter;

v = kinematic viscosity of water;

u_* = shear velocity; and

VS = unit stream power.

The dimensionless critical average flow velocity $\frac{V_c}{\omega}$ at incipient motion can be expressed as:

$$\frac{V_c}{\omega} = \frac{2.5}{\log\left(\frac{u_* d_s}{v}\right)} + 0.66 \quad \text{for } 1.2 < \frac{u_* ds}{v} < 70 \tag{2.18}$$

$$\frac{V_c}{\omega} = 2.05 \qquad \text{for } \frac{u_* ds}{v} \geq 70 \tag{2.19}$$

Brownlie (1981) obtained the following equation for the concentration (C_{ppm}):

$$C_{ppm} = 7155 c_f \left(F_g - F_{g0}\right)^{1.978} S^{0.6601}\left(\frac{R_b}{d_{50}}\right)^{-0.3301} \tag{2.20}$$

where c_f = 1 for laboratory data; and

c_f = 1.268 for field data.

Grain Froude number –

$$F_g = \frac{V}{\sqrt{\left(\frac{\gamma_s - \gamma}{\gamma}\right) g d_{50}}}$$

F_{go} = critical grain Froude number determined from:

$$F_{go} = 4.596\tau_*^{0.5293} S^{-0.1405} \sigma^{-0.1606} \tag{2.21}$$

$$\tau_{*_o} = 0.22Y + 0.06(10)^{-7.7Y} \tag{2.22}$$

where $$Y = \left(\sqrt{\frac{\rho_s - \rho}{\rho}} R_g\right)^{-0.6} \tag{2.23}$$

Grain Reynolds number –

$$R_g = \frac{\sqrt{g d_s^{\,3}}}{\nu} \tag{2.24}$$

where R_b = hydraulic radius associated with the bed;

d_{50} = median grain size;

S = bed slope;

V = average velocity;

d = water depth;

g = acceleration of gravity; and

ν = kinematics viscosity.

2.3 STABLE CHANNEL DESIGN

In comparison to the design process typically used for lined channels, the design of stable, unlined or erodible, earthen channels is a complex process involving numerous parameters, most of which cannot be accurately quantified. The complexity of the erodible channel design process results in channel stability dependent not only on hydraulic parameters but also the properties of the material, which composes the bed and sides of the channel (Henderson, 1966).

The concept of a stable river is one that has generated controversy between engineers, scientists, landowners, and politicians for many years. An individual's definition of stability is often subjectively based on past experiences or project objectives. To the navigation engineer, a stable river might be one that maintains adequate depths and alignment for safe navigation. The flood control engineer, on the other hand, is more concerned with the channel maintaining the ability to pass the design flood, while to the local landowner a stable river is one that does not erode the bankline (Watson et al., 1999). A stream is defined as stable when it has the ability to pass the incoming sediment load without significant degradation or aggradation and when the width, depth, and slope are fairly consistent over time. Equilibrium of alluvial channels implies a balance between incoming and outgoing water discharge and sediment load. Whenever a balance is obtained between incoming and outgoing sediment discharge, the cross-sectional geometry may locally change as the deposition volume is equal to the erosion volume (Julien, 2002).

Copeland et al. (2001) defines two classes of channels, i.e., threshold channels and alluvial channels. A threshold channel is a channel in which channel boundary material movement is not considered during the design flow. Threshold design procedures are those in which the applied forces remain less than the threshold for boundary material movement.

In contrast, alluvial stream boundary materials are formed from the material transported by the stream under existing flow conditions. An exchange of material between the inflowing sediment load and the stream bed and banks occurs, and the alluvial channel adjusts morphology in response to this exchange.

2.3.1 Threshold Channel Design Procedures

Hydraulic design procedures for threshold channels are numerous and are well established. Maximum permissible velocity method guidance can be found in the USACE (1994) EM 1110-2-1601 (see Appendix B), Fortier and Scobey (1926), and the USDA (1977). Lane (1955) developed the critical tractive force method for channel design. As Copeland et al. (2001) point out, threshold design methods do not provide unique solution of channel width, depth, and slope. This limitation is not critical because the boundary materials are immobile.

More recent efforts to develop threshold design procedures include theoretical methods that have been developed to include lateral turbulent diffusion of downstream momentum in a cross section with a laterally-uniform gradation (Parker, 1978; Ikeda et al., 1988; Ikeda and Izumi, 1990; Diplas and Vigilar, 1992).

2.3.2 Alluvial Channel Design Procedures

Alluvial channel design procedures include width, depth, slope, and planform as dependent variables, and independent variables include water and sediment discharge, bank materials, and the variability of the water and sediment supply. Water and sediment continuity and the geotechnical stability of the banks are essential considerations in the design of alluvial channels.

Copeland et al. (2001) summarize alluvial design procedures and point out that to determine width, depth, and slope, three equations are required. Manning's equation can be one, and a sediment transport equation such as Brownlie's can be the second equation. One additional equation is required. Four alternatives can be considered as the third equation: (1) reference reach or analogy methods; (2) hydraulic geometry; (3) constraint of one of the variables; or (4) adopting an extremal hypothesis.

2.3.2.1 Analogy Methods

If a channel is unstable in the project reach, a reference reach may be selected and characterized, which will serve as a model for the new channel design. Reference reaches must be selected in a physiographically similar watershed, and must have similar discharge characteristics, boundary conditions, and boundary materials. The previous historical stable dimensions of the presently unstable channel may be used. However, reference reach methods are inappropriate if the unstable reach to be designed is in an unstable watershed, and it is equally inappropriate to use the historical condition if the watershed conditions have changed over time.

2.3.2.2 Hydraulic Geometry Methods

Hydraulic geometry has been previously discussed. Hydraulic geometry methods can be useful, however, as with the case of any empirical procedure, caution must be exercised to select a relationship developed to represent conditions similar to those needed for the design channel. Boundary materials, sediment discharge rate, and physiographic similarity must be similar to the conditions in the unstable reach. As with any empirical method, the limitations in the flexibility of the design are limited to the acquired empirical data set, for example, if the sediment yield of the watershed is to be altered, the empirical data set must be acquired over the range of variability required.

One advantage of using the hydraulic geometry method is that the literature is rich in data sets that have been carefully analyzed.

2.3.2.3 Constrained Variable Methods

In many practical circumstances, the third equation is not required due to legal, construction, or project constraints. Examples include bedrock boundary materials, limited construction right of way, and the necessity to provide flood control. Hazardous materials may require that width, depth, or slope be controlled to avoid public health endangerment. For these and other reasons, the selection of one of the dependent variables may be based of factors beyond the realm of science and engineering.

2.3.2.4 Extremal Hypotheses Methods

If the previous three methods are not applicable, especially when sediment transport is significant, analytical methods that are dependent on an extremal hypothesis may be appropriate (Copeland et al., 2001). They suggest that the advantage of using an extremal hypothesis is that a unique solution can be obtained for the dependent variables of width, depth, and slope. In addition, they caution that field experience indicates that channels may be stable over a range of dependent variables that are not found at extremal conditions, and that the sensitivity of energy minima or sediment transport maxima to driving forces may be low.

The lack of sensitivity of extremal methods may be due to the inability to compute or measure sediment transport with a high degree of precision, especially when comparing field channel morphology to measured or computed sediment transport rates. As previously mentioned in this review of literature, hydraulic computation cannot include factors affecting channel morphology caused by variable resistance to erosion of the boundary materials.

Two basic extremal hypotheses are minimization of the time rate of energy expenditure (Chang, 1980; Yang, 1973; Copeland, 1994, 1999; USACE, 1998), and the assumption that sediment transport is maximized (White et al., 1982; Millar and Quick, 1993). These are equivalent processes.

Copeland's (1999) method for stable channel design is an analytical technique that calculates channel dimensions by simultaneously solving equations, which govern water and sediment continuity. The method uses Brownlie (1981) for flow resistance and sediment transport equations. These equations are for sand bed rivers, based on approximately 7,000 records from 31 sets of laboratory and field data sets. Brownlie's equations for predicting flow resistance are used to compute the bed roughness in SAM (Thomas et al., 1994). The flow resistance equations are based on four dimensionless quantities: grain Froude number (F_g), ratio of the median grain size to the laminar sublayer (d_{50} / δ), bed slope (S), and geometric bed material gradation coefficient (σ). These quantities account for both bedform and grain roughness in a channel cross section. However, the gradation coefficient (σ) is reported by Brownlie to have a small effect on his analysis. Bedform roughness is the roughness that is the result of bedforms such as ripples or dunes.

These bedforms occur in the lower regime when the flow is generally subcritical ($Fr < 1$) (Julien, 1998). Form roughness varies with the flow rate in the channel. Therefore, a small change in the discharge may have a considerable impact on the computed stable channel dimensions. The grain roughness is the roughness associated with the size of the sediment particles on the bed. This type of roughness typically dominates in the upper flow regime (Julien, 1998).

In Copeland's method the Manning resistance for the bed for the lower and upper regimes are:

Lower regime –

$$n_b = \left(1.6940 \left(\frac{R}{d_{50}} \right)^{0.1374} S^{0.1112} \sigma^{0.1605} \right) 0.034 \left(d_{50} \right)^{0.167} \tag{2.27}$$

Upper regime –

$$n_b = \left(1.0213 \left(\frac{R}{d_{50}} \right)^{0.0662} S^{0..0395} \sigma^{0.1282} \right) 0.034 \left(d_{50} \right)^{0.167} \tag{2.28}$$

where σ = geometric bed material gradation coefficient,

$$\sigma = 0.5 \left(\frac{d_{84}}{d_{50}} + \frac{d_{50}}{d_{16}} \right) \tag{2.29}$$

the composite Manning (n_c) value is defined by:

$$n_c = \left[\frac{\sum_{i=1}^{n} \left(p_i n_i^{1.5} \right)}{p} \right]^{2/3} \tag{2.30}$$

where n_c = composite or equivalent coefficient of roughness; and

p = wetted perimeter.

Brownlie developed separate resistance equations for upper- and lower-regime flow. The equations are dimensionless and can be used with any consistent set of units.

Upper regime –

$$R_b = 0.2836 d_{50} q_*^{0.6248} S^{-0.2877} \sigma^{0.0813} \tag{2.31}$$

Lower regime –

$$R_b = 0.3742 d_{50} q_*^{0.6539} S^{-0.2542} \sigma^{0.1050} \tag{2.32}$$

where q_* is a dimensionless unit discharge, given by:

$$q_* = \frac{Vd}{\sqrt{g d_{50}^{\,3}}} \tag{2.33}$$

where R_b = hydraulic radius associated with the bed;

d_{50} = median grain size;

S = slope;

V = average velocity;

d = water depth; and

g = acceleration of gravity.

The hydraulic radius of the side slope is calculated using Manning's equation:

$$R_s = \left(\frac{V n_s}{S^{0.5}} \right)^{1.5} \tag{2.34}$$

$$A = R_b P_b + R_s P_s \tag{2.35}$$

where A = total cross-sectional area;

P_b = perimeter of the bed; and

P_s = perimeter of the side slope.

According to Brownlie (1983), the upper regime occurs if $S > 0.006$ or if $F_g > 1.25 F_g^{\backslash}$, and the lower regime occurs if $F_g < 0.8 F_g^{\backslash}$, between these limits is the transition zone.

Grain Froude number –

$$F_g = \frac{V}{\sqrt{\left(\frac{\gamma_s - \gamma}{\gamma}\right) g d_{50}}} \tag{2.36}$$

where γ_s = specific weight of sediment;

γ = specific weight of water; and

$F_g^{\backslash} = \dfrac{1.74}{S^{0.3333}}$.

This method assumes that the average velocity for the total cross section is representative of the average velocity in each sub-section.

Copeland solved Brownlie's equation (Equation (2.20)). The input data required to use Copeland's method are base width, side slope, bank roughness coefficient, bed material median grain diameter, gradation coefficient, average slope, and flow discharge. The second step in the method is to develop a family of slope-width solutions that satisfy the resistance to the flow and sediment transport equations as shown in Figure 2.3.

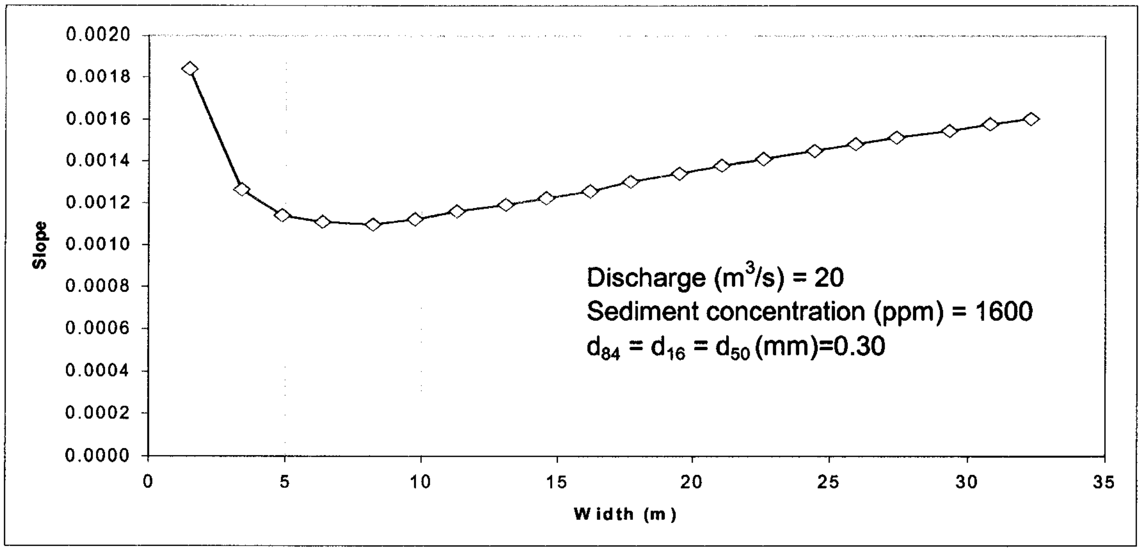

Figure 2.3: Slope vs. channel width (after Copeland (1999)).

2.4 INCISED CHANNEL

Watson et al. (2002) stated that incised channels are caused by an imbalance between sediment transport and sediment supply to the stream. The resulting bed and bank erosion alter channel morphology and stability. Geomorphological models of incised channel evaluation can provide guidance in the selection of engineering design alternatives for incised channel rehabilitation.

Channel incision, or bed lowering by erosion, results from an imbalance in the power available to move a sediment load and the power needed to move a sediment load. When the sediment transport capacity of a sand bed channel exceeds the sediment supply delivered to the channel, erosion will occur on either the bed or banks or both, depending on the relative erosion resistance of the two (Watson et al., 2002).

The DEC Project seeks to develop and demonstrate a watershed systems approach to address problems associated with watershed instability: erosion, sedimentation, flooding, and environmental degradation. The DEC Project is intended to provide sediment, erosion, and flood control for 16 watersheds in the Yazoo River Basin in Mississippi. The DEC Project currently includes 33 sites and a total of approximately 64 km of stream. Many of the sites were channelized in the past and are now actively incising.

Watson et al. (2001) used conceptual incised Channel Evolution Models (CEM) to study the watershed and channel dynamics, and characterized a stable reach of these channels. In each reach of an idealized channel, CEM Types I through V occur in series as shown in Figure 2.4. The CEM describes the systematic response of a channel to base-level lowering and encompasses conditions that range from disequilibrium to a new state of dynamic equilibrium.

Watson et al. (2001) developed several regression relationships from field stability analysis of a stream based on CEM concepts. Four variables were used in their analysis: drainage area, and flow depth, flow width, and energy slope at 2-year discharge. The analysis was divided into two parts, the first part for a cross section (CEM Type II or III) and the second part for a cross section (CEM Type IV or V). Descriptions of each type are as follows:

CEM Type I reaches are characterized by a sediment transport capacity that exceeds sediment supply, with little or no sediment stored in the channel bed. CEM Type I reaches are located upstream of the actively degrading reach and have not yet experienced significant bed or bank instabilities. Bank height (h) that is less than the critical bank height (h_c), and is a U-shaped cross section.

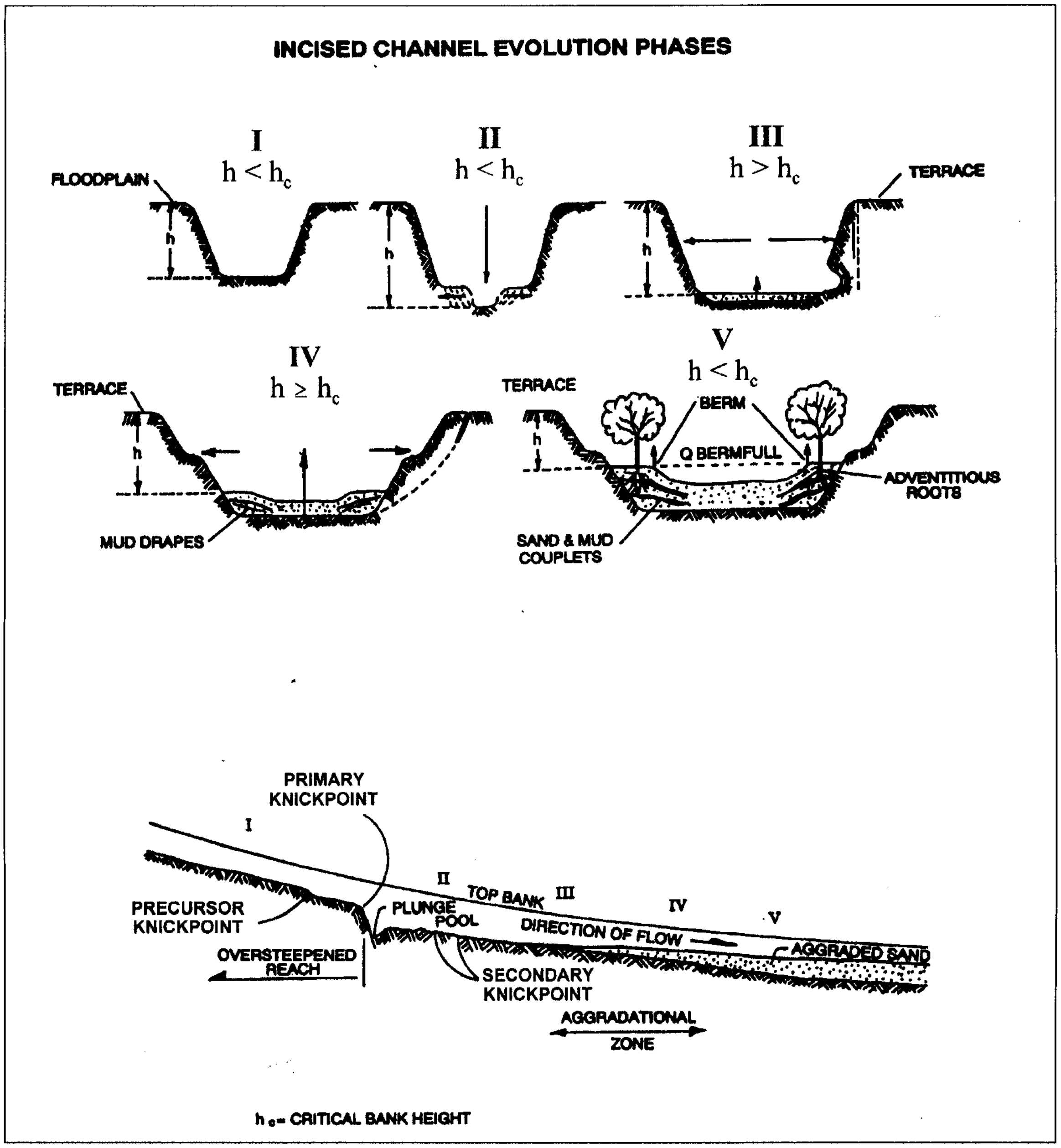

Figure 2.4: Incised channel evolution sequences (after Schumm et al. (1984)).

CEM Type II reaches are located downstream of CEM Type I reaches. CEM Type II reaches are encountered, bed degradation is the dominant process in this type, and are characterized by a sediment transport capacity that exceeds the sediment supply. Although the channel is actively degrading the bank heights (*h*) have not exceeded the critical bank height (h_c). Therefore, banks are not geotechnically unstable, but hydraulically are unstable.

CEM Type III reaches are located downstream of CEM Type II and are characterized by a sediment transport capacity that is highly variable with respect to the sediment supply, a bank height (h) that is greater than the critical bank height (h_c). As bed degradation continues, the bank heights and angles will continue to increase. When the bank heights have exceeded the critical bank height for stability, mass failure (geotechnical instability) begins to occur in this type. The dominant process in the CEM Type III reach is channel widening.

CEM Type IV reaches are located downstream of CEM Type III and represent the first manifestation of the incised channel returning to a new state of dynamic equilibrium. CEM Type IV reaches are characterized by a sediment supply exceeding the sediment transport capacity resulting in aggradation of the channel bed, a bank height that approaches the critical bank height with a rate of bank failure lower than CEM Type III. In the CEM Type IV reaches, geotechnical bank instabilities and channel widening may continue, but at a much reduced rate.

CEM Type V reaches are located downstream of CEM Type IV and are characterized by a dynamic balance between sediment transport capacity and sediment supply, bank heights are generally less than the critical bank, and therefore, geotechnical bank instabilities do not exist.

CHAPTER 3
DATA SOURCES

Four main sources of data were collected for the purpose of this study. These sources are:

- DEC Project (Watson et al., 2001);
- natural streams and canals (Kodoatie, 2000);
- flume data (Kodoatie, 2000); and
- flume data (Gessler et al., 1994).

Data sets collected for this study include:

- a total of 577 data sets for hydraulic geometry measurements for 7 incised streams in the DEC Project;
- a total of 1,026 data sets from 17 rivers and canals in different locations in the world; and
- a total of 812 data sets for laboratory flumes from 15 different sources.

These data sets are presented in Appendices C through G.

3.1 DEMONSTRATION EROSION CONTROL (DEC) PROJECT (WATSON ET AL., 2001)

The DEC Project currently includes 33 sites and a total of approximately 64 km of stream and 16 watersheds in the Yazoo River Basin in Mississippi. Many of the sites were channelized in the past and are now actively incising.

A total of 437 data sets at downstream hydraulic geometry were obtained from 7 incised streams (CEM Types IV and V) in the DEC Project. These data sets contain 2-year water discharge (m^3/s), flow velocity (m/s), flow width (m), flow depth (m), mean bed diameter (mm), and water surface slope (m/m), and a total of 140 data sets at-a-station were obtained from Abiaca Creek at 7 cross sections. The at-a-station data contain water discharge (m^3/s), flow width (m), flow velocity, and flow depth (m). These data sets are shown in Appendix C.

The following streams in the DEC Project were used in the analysis (Watson et al., 2001):

- **Abiaca Creek, Site No. 6**

  Approximate watershed area at the downstream end of Site No. 6 is 257 sq km (99 sq mi). The thalweg profile and channel dimensions have been relatively constant since 1992.

- **Burney Branch**

  The study reach is 1,824 m (6,000 ft) long. Approximate watershed area at the downstream end of Burney Branch is 26 sq km (10 sq mi). A 1997 survey of the entire reach indicated widening with very little change in slope since 1995. No significant changes were recorded in 2001.

- **Harland Creek, Site No. 1**

  Approximate watershed area at the downstream end of Site No. 1 is 70 sq km (27 sq mi). Harland Creek is a mixed, sand and gravel bed stream, exhibiting some of the original meandering tendency. The 2000 inspection provided clear evidence of a more stable reach that was originally visited in 1997. Some locations exhibited wetland vegetation in the bed of the stream. At the present time, it is unknown if the apparent stability is a result of reservoir control of peak discharges, or an artifact of a relatively low precipitation period.

- **Hickahala Creek, Site No. 11**

  Site No. 11 is 1,216 m (4,000 ft) long, extending 1,216 m (4,000 ft) downstream of the County road bridge. Approximate watershed area at the downstream end of Site No. 11 is 26 sq km (10 sq mi). Upstream the channel is a CEM Type IV and downstream the channel is CEM Types III to IV.

- **Long Creek (2)**

  The Long Creek study reach is 2,432 m (8,000 ft) long, extending 1,824 m (6,000 ft) upstream and 608 m (2,000 ft) downstream of the County road bridge that crosses Long Creek (2). This reach transitions from CEM Type V at the lower end to CEM Type II at the upper end.

- **Perry Creek (1) and (2)**

  The study reach is 3,040 m (10,000 ft) long; Segment 1 is between river stations 0+00 and 10+00; Segment 2 is between river stations 15+00 and

50+00. Approximate watershed area at the downstream end is 20.8 sq km (8 sq mi).

Table 3.1 summarizes the range of hydraulic parameter values for the DEC Project data sets.

Table 3.1: The range of values in the DEC Project data set (CEM Types IV and V) at downstream hydraulic geometry.

Hydraulic Parameters	Minimum	Maximum	Mean	Median
Q_2 (m^3/s)	27.2	75.4	48.7	50.7
S (m/m)	0.000156	0.0134	0.0018	0.00146
d_s (mm)	0.33	0.51	0. 416	0.38
W (m)	7.6	46.0	21.03	20.1
d (m)	0.7	2.77	1.67	1.71

3.2 NATURAL STREAMS AND CANALS DATA (KODOATIE, 2000)

These data sets contain water discharge (m^3/s), channel width (m), channel depth (m), flow velocity (m/s), mean bed diameter (mm), water surface slope (m/m), water temperature (^{o}C), and transported sediment concentration (ppm). The 1,026 data sets are representative of a wide variety of locations, including rivers in the U.S., South America, and Asia (Kodoatie, 2000). These data sets are shown in Appendices D and E.

- **Atchafalaya River**

  A total of 72 data sets were obtained from Toffaletti (1968) on the Atchafalaya River at Simmesport, Louisiana. The concentration is the combination of the measured suspended load and unmeasured load calculated by Toffaletti's procedure. The given concentration is for sand particles (>0.0625 mm).

- **American Canal**

  Simons (1957) collected a total of 24 sets of canal data in Colorado, Nebraska, and Wyoming. However, only 12 completed sets of data were used in this study, since in some cases there were not sufficient variables.

- **India Canal**

  Chitale (1966) collected 32 sets of canal data in India.

- **Chippewa River**

  A total of 66 data sets were collected on the Chippewa River near Carryville, near Durand, and near Pepin, Wisconsin, by Williams and Rosgen (1989). However, only 47 complete sets of data were used in this study because in some cases there were not sufficient variables.

- **Colorado River**

  A total of 100 data sets were collected on the Colorado River by the U.S. Bureau of Reclamation (USBR, 1958).

- **Hii River**

  Shinohara and Tsubaki (1979) collected 38 data sets on the Hii River in Japan.

- **Middle Loup River**

  Fifteen data sets that were collected on the Middle Loup River at Dunning, Nebraska, by Hubbell and Matejka (1959) were used in this research.

- **Niobrara River**

  Colby and Hembree (1955) collected a total of 51 data sets of field measurements on the Niobrara River near Cody, Nebraska. Nineteen sets of data were obtained at the gauging station section and contracted section and these are the data sets that were used in this study. This river has a natural contracted section and its cross section is almost rectangular.

- **Mountain Creek**

  Einstein (1944) collected 100 data sets on Mountain Creek. Records 1 to 81 were collected on the Mountain Creek, a tributary of the Enoree River in Greenville County, South Carolina. Records 82 to 100 were collected on the west Goose Creek in the Tallahatchie River basin about 4 miles west of Oxford.

- **Red River**

  A total of 29 data sets were obtained from Toffaletti (1968) for Red River at Alexandria, Louisiana.

- **Rio Grande Convey Channel**

  A total of 9 data sets were obtained from a larger data set of Culbertson et al. (1972).

- **Rio Grande River near Bernalillo**

  A total of 38 data sets were obtained from Toffaletti (1968) on the Rio Grande near Bernalillo.

- **West Pakistan Canal (CHOP)**

  A total of 33 data sets for nine canals in West Pakistan were collected by Chaudry et al. (1970) under the Canal and Headworks Observation Program (CHOP) of the West Pakistan Water and Power Development Authority.

- **Wisconsin River**

  A total of 20 data sets were collected on the Wisconsin River at Muscoda, Wisconsin, by Williams and Rosgen (1989). However, only 9 complete data sets were used in this study.

- **Pakistan Canal (ACOP)**

  A total of 142 data sets were collected and recorded by Mahmood et al. (1979) on five canals in Pakistan.

- **Amazon River**

  A total of 82 data sets were obtained from Posada Garcia (1995). The river systems include: the Amazon, Orinoco, Apure Rivers, and their tributaries.

- **Mississippi River**

  There are three kinds of data for this river, two data sets from Toffaletti (1968) and one data set from Posada Garcia (1995). A total of 249 data sets were obtained from Tarbert Landing, St. Louis, Missouri, Upper and Lower Mississippi Rivers, and their tributaries. Total load discharge is the sum of suspended sediment discharge in the measured zone plus the sediment discharge computed with a modified Einstein procedure for the unmeasured zone, this method was developed by Colby and Hembree (1955).

Table 3.2 summarizes the range of hydraulic parameter values for the natural rivers and canals data sets.

Table 3.2: The range of values in the natural rivers and canals data set.

Hydraulic Parameters	Minimum	Maximum	Mean	Median
Q (m^3/s)	0.0009	235000	5816.8	279.8
S (m/m)	0.0000021	0.0113	0.0004914	0.0001116
d_s (mm)	0.02	15.5	0. 433	0.29
W (m)	0.346	3338	342.1	139.4
d (m)	0.0189	68	5.58	2.64

3.3 LABORATORY FLUME DATA

3.3.1 Flume Data Sets (Kodoatie, 2000)

A total of 704 data sets for laboratory flumes from 14 sources were selected, these data are presented in Appendix F and include:

- Barton and Lin (1955) – 30 data sets;
- Laursen (1958) – 24 data sets;
- Nomicos (in Toffaletti, 1968; Vanoni and Brooks, 1957) – 38 data sets;
- Onishi et al. (1976) – 14 data sets;
- Stein (1965) – 57 data sets;
- Straub (1954) and Straub et al. (1958) – 24 data sets;
- Guy et al. (1966) – 290 data sets, 19 data sets containing sediment concentrations less than 5 ppm were removed for this study;

- Taylor and Vanoni (1972) – 6 data sets;
- Vanoni and Brooks (1957) – 15 data sets;
- Williams (1970) – 83 data sets;
- Willis et al. (1972) – 96 data sets;
- Vanoni and Hwang (1967) – 16 data sets;
- Brooks (Vanoni and Brooks, 1957) – 21 data sets; and
- Kennedy and Brooks (1963) – 9 data sets.

3.3.2 Flume Data Sets (Gessler et al., 1994)

A total of 108 flume data sets from Gessler et al. (1994) were used in this study. These data sets were compiled using three different bank angles, three grain size distributions, four bank roughnesses, and three discharges.

These data sets contain the depth of flow, water surface slope, velocity, discharge, total load, and suspended load distribution in the flume. Typical depths of flow ranged from 4 to 8 inches while velocities ranged from 0.5 to 2.5 ft/sec. Grain size particle mean diameters ranged from 0.18 to 0.54 mm. These laboratory measurements are shown in Appendix G.

CHAPTER 4

METHODOLOGICAL APPROACH AND DATA ANALYSIS

The available field natural channel and flume data sets listed in Chapter 3 are analyzed in this chapter. This chapter presents the relationship between cross-section geometry and sediment transport, to develop the hydraulic geometry relationships for incised streams, and to develop a new method for stable channel design based on an analytical approach. This chapter addresses the following topics:

- Regression relationships for DEC Project data for incised streams are presented for downstream and at-a-station hydraulic geometry.
- Evaluation of the performance of selected sediment equations and modification to include a shape factor (*W/d*) was conducted for: Shen and Hung (1971), Yang (1973) for sand and gravel, and Engelund and Hansen (1967).
- New sediment transport equations that include a shape factor (*W/d*) are presented for natural channels and flumes.

- Brownlie (1981) is used to find the relationship between the ratio of sediment concentration and the concentration from the mean depth ($C/C(d)$) and the shape factor (β).
- The effect of the width/depth ratio on the sediment transport is studied based on continuity, sediment transport, and resistance equations, for selected sediment equations, bed load relationships (Duboys, 1879; Meyer-Peter and Müller, 1948), and bed material load relationships (Engelund and Hansen, 1967; Yang, 1973 for sand and gravel; Shen and Hung, 1971; Brownlie, 1981).
- A new method for stable channel design based upon analytical approach is conducted by modifying Copeland (1999).

4.1 REGRESSION RELATIONSHIPS

The DEC Project data presented in Appendix C were used to develop several regression relationships for incised channels (CEM Type IV or V), from the field stability analysis of streams based on CEM concepts. Five variables were used in this analysis: flow depth, flow width, flow discharge, energy slope, and grain size. Regression relationships for DEC Project data were presented for downstream and at-a-station hydraulic geometry.

4.1.1 Downstream Hydraulic Geometry

Seven streams from the DEC Project were used to develop regression relationships for incised channels. A total of 437 data sets were used in developing the downstream hydraulic geometry regression equations. These data sets contain 2-year water discharge (m^3/s), flow width (m), flow depth (m), flow velocity (m/s), mean bed diameter (mm), and water surface slope (m/m). The dependent variables are a function of the 2-year discharge (Q_2), median grain size (d_s), and slope (S). These data are presented in Appendix C, Table C1.

Downstream hydraulic geometry relationships were expressed in the form of a power function of the dependent variables of Q_2, S, d_s:

$$X = a_1 Q^{a_2} S^{a_3} d_s^{\,a_4} \tag{4.1}$$

Coefficients a_1, a_2, a_3, and a_4 are determined from the regression model, and X is either a mean flow depth or a mean flow width.

The regression relationships were linearized to the form:

$$\log X = b + a_2 \log Q + a_3 \log S + a_4 \log d_s \tag{4.2}$$

where $b = \log a_1$.

The new empirical channel geometry equations for average flow depth, top width, and shape factor (*W/d*), were developed using Microsoft Excel 2000 regression analysis. The results are shown in Tables 4.1 and 4.2.

Table 4.1: Regression summary for mean depth equation.

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-1.09075747	0.138588393	-7.87048	2.86E-14	-1.363147268	-0.81837
Q(m^3/s)	0.37545459	0.019920454	18.84769	2.68E-58	0.336301751	0.414607
S(m/m)	-0.13995274	0.009490072	-14.7473	3.58E-40	-0.158605087	-0.1213
d$_s$(m)	-0.08265133	0.039569819	-2.08875	0.037314	-0.160424187	-0.00488

Table 4.2: Regression summary for mean width equation

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.37747	0.210783515	1.790795	0.074025	-0.0368164	0.79175635
Q(m^3/s)	0.3702323	0.030297655	12.21983	1.04E-29	0.31068353	0.42978112
S(m/m)	-0.2542434	0.014433754	-17.6145	9.29E-53	-0.2826123	-0.22587443
d_s(m)	0.123692	0.060183002	2.055264	0.040453	0.00540473	0.24197917

The new empirical channel geometry equations are:

Mean depth (m) –

$$d = 0.0811 Q_2^{0.375} S^{-0.140} d_s^{-0.083} \tag{4.3}$$

Mean width (m) –

$$W = 2.385 Q_2^{0.370} S^{-0.254} d_s^{0.124} \tag{4.4}$$

Shape factor ψ –

$$\psi = \frac{W}{d} = 29.39 Q_2^{-0.005} S^{-0.114} d_s^{0.206} \tag{4.5a}$$

where Q_2 = 2-year discharge (m^3/s);

d_s = bed material median grain size (m); and

S = slope.

The flow discharge is eliminated from the shape factor equation because the exponent of flow discharge is very small (-0.005), which is approximately equal to zero. The flow is an insignificant variable in prediction of the shape factor (*W/d*) for downstream hydraulic geometry, however, flow is very significant for depth and is somewhat significant for width.

With elimination of the flow discharge from Equation (4.5a), the equation of the shape factor (ψ) becomes:

$$\psi = \frac{W}{d} = 29.39 S^{-0.114} d_s^{\,0.206} \tag{4.5b}$$

The shape factor is directly proportional to the grain size and inversely proportional to the bed slope. The physical meaning is that low slope and coarse grain size produces a large width/depth ratio, and steep slope and fine grain size produces a small width/depth ratio.

The regression summaries show that there are ranges of possible solutions of regression equations. The advantage of using confidence intervals (95% upper level and 95% lower level) is that these account for variability in regression constants and may be used to describe the variability and uncertainty in channel geometry (Soar and Thorne, 2001).

The ranges of possible solutions of regression equations are as follows:

Mean depth (m) –

$$d = (0.043) to (0.152) Q_2^{(0.336) to (0.415)} S^{(-0.159) to (-0.121)} d_s^{(-0.160) to (-0.005)} \tag{4.6}$$

Mean width (m) –

$$W = (0.919) to (6.191) Q_2^{(0.311) to (0.430)} S^{(-0.283) to (-0.226)} d_s^{(0.005) to (0.242)} \tag{4.7}$$

Shape factor $\psi = \frac{W}{d}$ –

$$\psi = (21.2) to (40.75) S^{(-0.124) to (-0.1046)} d_s^{(0.166) to (0.247)} \tag{4.8}$$

Table 4.3 presents a comparison of regression relationships for incised channels for the DEC Project with downstream hydraulic geometry relationships developed by Huang and others (Huang and Warner, 1995; Huang and Nanson, 1995, 1998), and by Julien and Wargadalam (1995). There are minor differences between the exponents of flow discharge and channel slope. A discrepancy ratio between 0.5 and 2.0 was considered an acceptable range for determining the accuracy of computed flow depth and flow width to observed measurements (Julien and Wargadalam, 1995). Figures 4.1 and 4.2 show the comparison between prediction depth and width that was obtained from this study, Julien and Wargadalam (1995) and from Huang and Nanson (2000), with 437 data observations (DEC Project data).

Table 4.3: Downstream hydraulic geometry relationships as a function of flow discharge and channel slope.

Huang and Warner (1995); Huang and Nanson (1995,1998)	$W \propto Q^{0.501} S^{-0.156}$	$d \propto Q^{0.299} S^{-0.206}$
Julien and Wargadalam (1995)	$W \propto Q^{0.4-0.5} S^{-(0.2-0.25)}$	$d \propto Q^{0.4-0.25} S^{-(0.2-0.125)}$
Huang and Nanson (2000)	$W \propto Q^{0.478} S^{0.076}$	$d \propto Q^{0.289} S^{-0.350}$
This Study	$W \propto Q^{(0.311) to (0.430)} S^{(-0.283) to (-0.226)}$	$d \propto Q^{(0.336) to (0.415)} S^{(-0.159) to (-0.121)}$

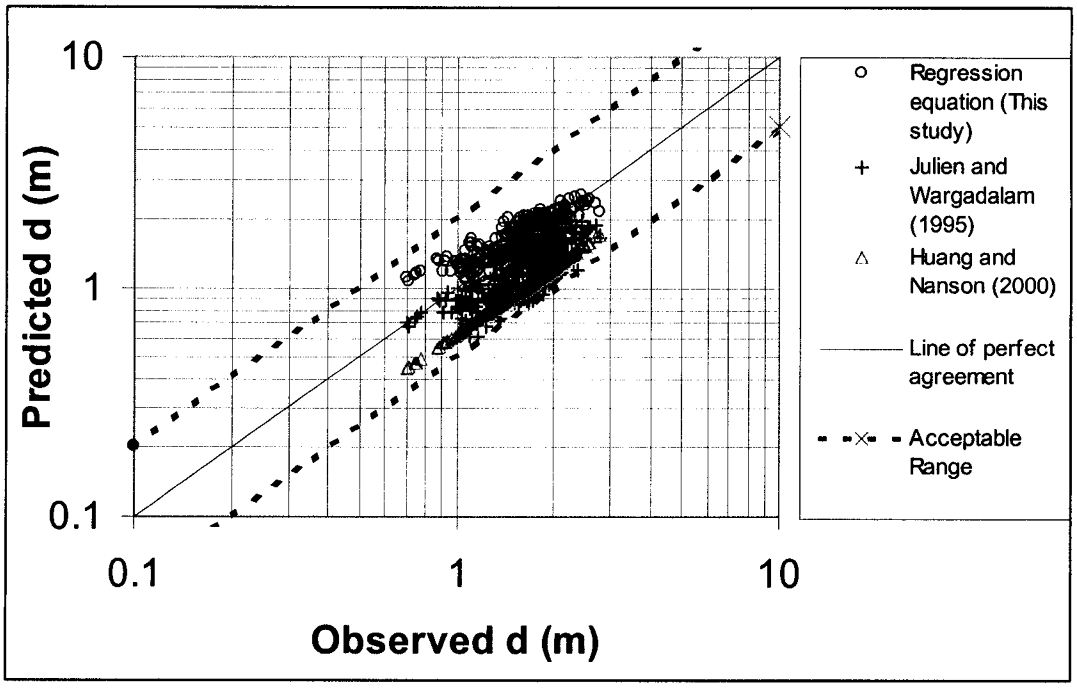

Figure 4.1: Comparison between observed depth of the 2-year discharge and predicted depth for DEC Project data.

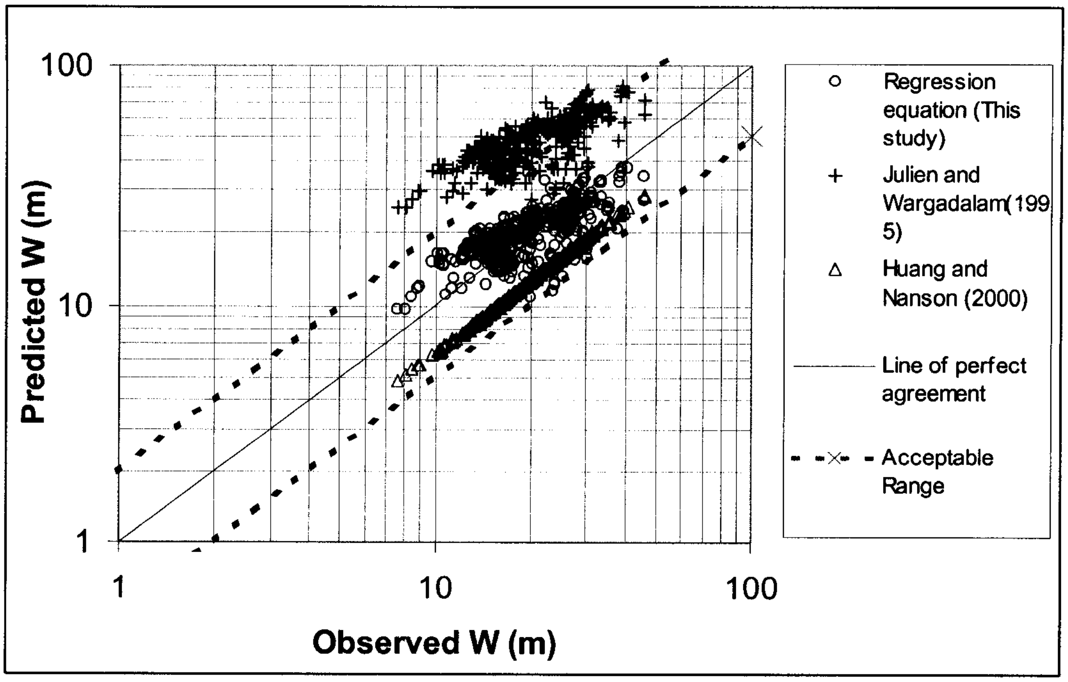

Figure 4.2: Comparison between observed width of the 2-year discharge and predicted width for DEC Project data.

A total of 1,026 data sets of available field data were used to show the performance of regression hydraulic geometry equations for incised channels developed in this study. The data were representative of a wide variety of locations, including 17 rivers and canals in the U.S., South America, and Asia. The data sets used to verify the regression equations are included in Appendices D and E. The analyses show the predicted width is less than the observed width, and the predicted depth is more than the observed depth. The results are shown in Figures 4.3 and 4.4.

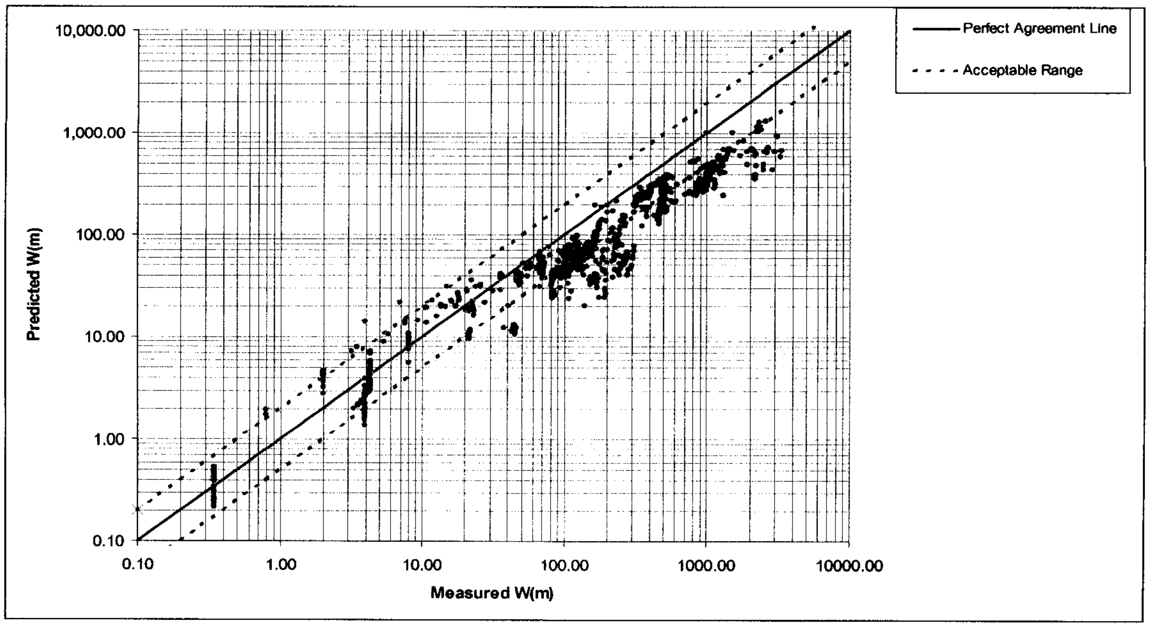

Figure 4.3: **Computed vs. observed water width to verify the new regression equation based on 1,026 of available field data sets.**

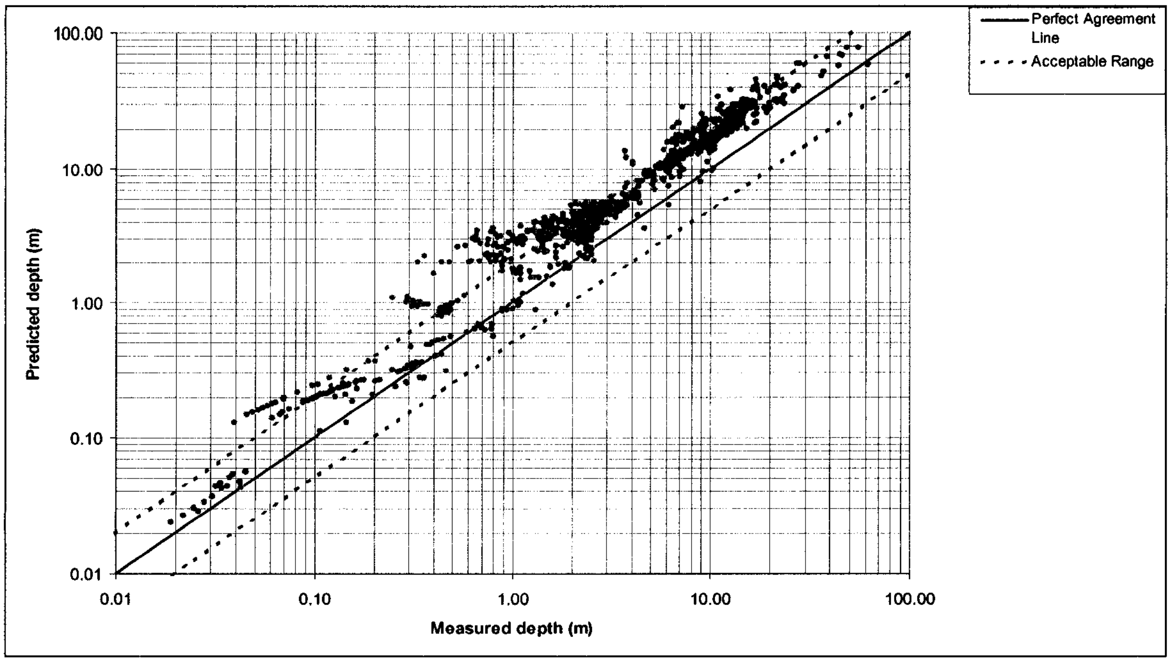

Figure 4.4: **Computed vs. observed water depth to verify the new regression equation based on 1,026 of available field data sets.**

4.1.1.1 Summary

Downstream hydraulic geometry relationships were developed for CEM Types IV and V streams in the DEC Project of the Yazoo Basin, Mississippi. The relatively stable incised streams indicate that the incised streams are narrower and deeper as compared to hydraulic geometry relationships developed by Julien and Wargadalam (1995). The range of the *W*/*d* ratio for the DEC Project data was from a minimum of 5.5 to a maximum of 34.9.

4.1.2 At-a-station Hydraulic Geometry

Data from the Abiaca Creek site No. 6 was used to develop several at-a-station hydraulic geometry equations. Seven cross sections were used to develop the empirical equations. The dependent variables are top width (m), depth (m), and shape factor $\left(\psi = \frac{W}{d}\right)$. Each is a function of an independent variable (Q). The range of flow discharge is between 2.86 m^3/s to 57.2 m^3/s. These data sets were discussed in Chapter 3 and are presented in Appendix C, Table C2.

$$\text{Dependent variables} = f(Q) = aQ^b$$

The results of this overall non-linear regression analysis are listed in Table 4.4.

Table 4.4: Results of non-linear regression analysis for at-a-station hydraulic geometry.

River Station	Dependent	Coefficient (a)	Exponent (b)	R^2
1000	W	22.22	0.054	0.89
	d	0.148	0.62	0.99
	ψ	138.25	-0.55	0.99
1500	W	21.05	0.048	0.92
	d	0.148	0.61	0.99
	ψ	142.36	-0.57	0.99
2000	W	18.05	0.076	0.92
	d	0.177	0.56	0.99
	ψ	102.0	-0.48	0.98
2500	W	19.02	0.08	0.80
	d	0.26	0.48	0.99
	ψ	71.97	-0.40	0.97
3000	W	15.68	0.088	0.91
	d	0.104	0.69	0.99
	ψ	150.7	-0.61	0.97
3500	W	20.9	0.041	0.83
	d	0.166	0.578	0.99
	ψ	126.06	-0.54	0.99
4000	W	24.5	0.22	0.99
	d	0.162	0.53	0.99
	ψ	151.02	-0.31	0.94
Average	W	20.2	0.086	
	d	0.166	0.58	
	ψ	126	-0.49	

The new empirical channel geometry equations are:

Mean depth (m) –

$$d = 0.166Q^{0.58} \tag{4.9}$$

Mean width (m) –

$$W = 20.2Q^{0.086} \tag{4.10}$$

Shape factor ψ –

$$\psi = 126.05Q^{-0.49} \tag{4.11}$$

where Q is in m^3/s.

Figures 4.5 through 4.7 show the channel geometry equation relationships for the Abiaca Creek at station 10+00 ft.

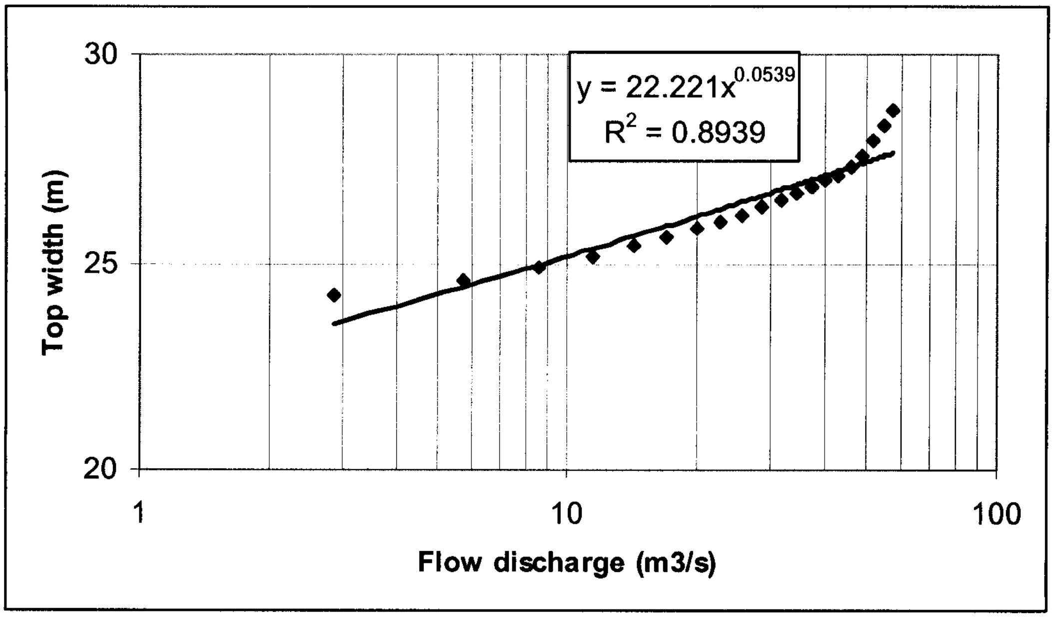

Figure 4.5: Flow discharge vs. top width for Abiaca Creek at station 10+00 ft.

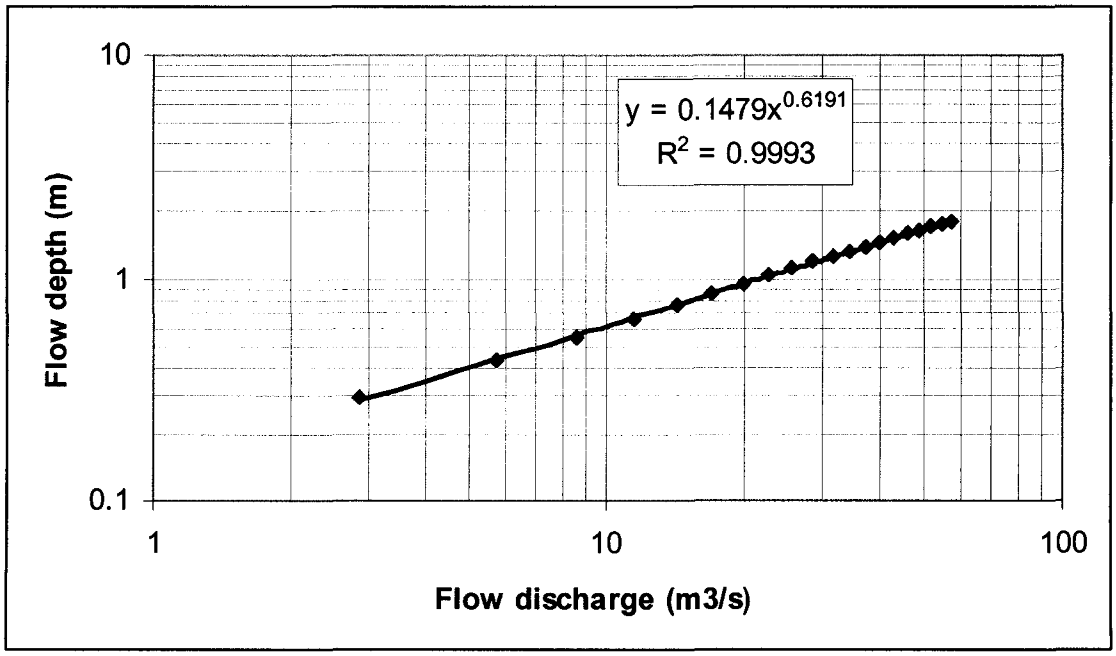

Figure 4.6: Flow discharge vs. flow depth for Abiaca Creek at station 10+00 ft.

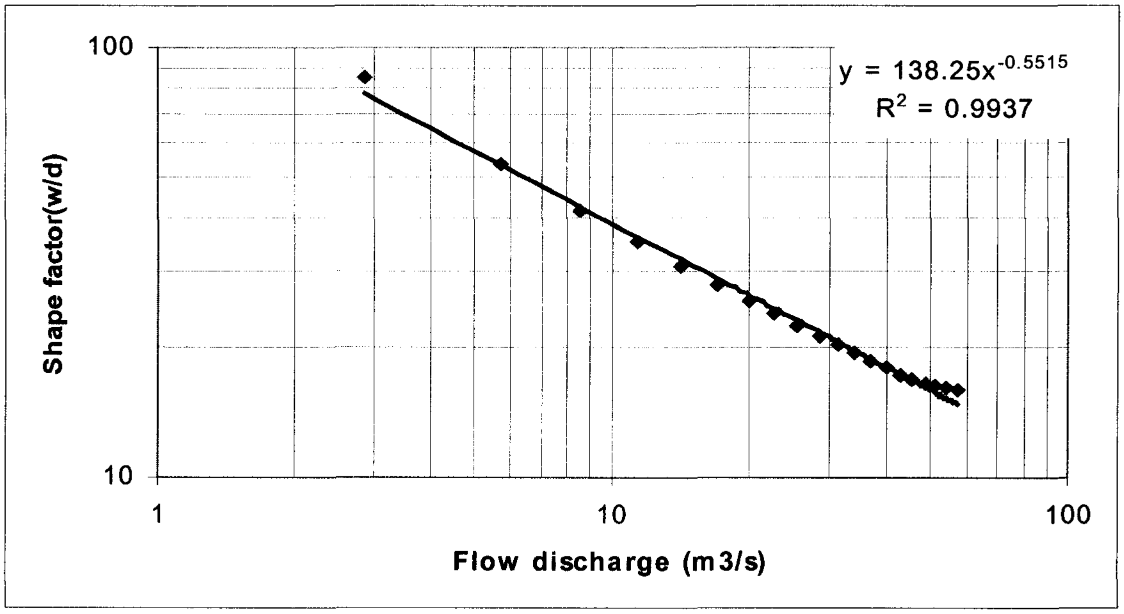

Figure 4.7: Flow discharge vs. shape factor for Abiaca Creek at station 10+00 ft.

4.2 EVALUATION OF SELECTED SEDIMENT TRANSPORT RELATIONSHIPS

As reported in the following sections, seven sediment transport relationships were evaluated. As explained in the subsequent paragraph, the discrepancy ratio for each original equation will be developed. The percentage of predicted values falling outside the range of 0.2 and 5 times the actual observed data was also noted. The sediment transport relationships evaluated were:

- Shen and Hung (1971);
- two relationships by Yang (1973) for sand and for gravel;
- Engelund and Hansen (1967);
- Brownlie (1981); and
- two new relationships were developed in this research – one for natural channel data and another for flume data.

The new relationships and the Brownlie (1981) relationship were formulated with a shape factor. The remaining four equations were not originally formulated using a shape factor, and these four equations were evaluated using the original formulation and with a modified formulation that includes a shape factor (W/d).

For each relationship, all or a portion of 1,026 data sets were used to evaluate the relationship. For the six equations requiring statistical analysis for the modified formulation or a new relationship, 550 data sets presented in Appendix D were initially used to develop the statistical relationship and the remaining 476 data sets presented in Appendix E were used to verify the relationship. The Brownlie (1981) sediment transport relationship used only the initial 550 data sets were used for comparison with the other six sediment transport relationships.

For some relationships the *P*-value was utilized to judge the significance of a variable used in the reformulation of a transport relationship. The *P*-value gives the probability of obtaining the test statistics, which must be less than the value of the significance level (α). The significance level (α) usually has a value of 0.05 or 0.10. Any independent variable has a *P*-value more than the significance level (α) the variable will not be significant, the variable is significant if its *P*-value is less than the significant level (α) (Freedman et al., 1997). Figure 4.8) shows the *t* distribution, acceptance region, and rejection region of the statistical model.

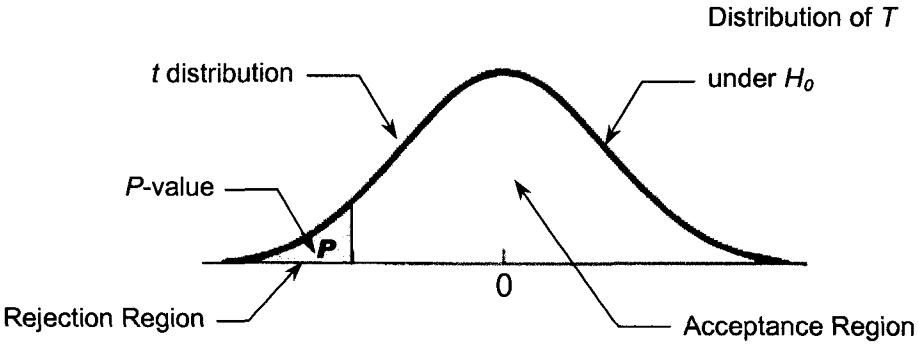

Figure 4.8: The *t* distribution and *P*-value (adapted from Freedman et al. (1997)).

To evaluate the accuracy of computed and measured sediment transport, Yang (1984), Van Rijn (1984), and others have used a discrepancy ratio defined as:

$$\frac{q_b(computed)}{q_b(measured)}$$

where q_b = sediment transport rate.

In the past work for sand bed streams, a discrepancy ratio between 0.5 and 2.0 has often been considered an acceptable range for determining the accuracy of computed measurements (Van Rijn, 1984; Alonso, 1980). No comprehensive explanation was found to justify the use of the discrepancy ratio between 0.5 and 2.0. To determine a range for comparison of computed and observed sediment transport; measured fluctuations of sediment transport were examined. Hubbell et al. (1987) documented a discrepancy ratio range of 0.15 to 4.48. They noted during testing for a bed load sampler that bed load movement appears to have extreme and generally cyclic variations. Raphelt (1996) stated that:

> "Analysis of the little Granite Creek bed transport data collected by Bill Emmett in which two sediment discharge measurements were taken immediately in succession varied by a factor of two, and it was not uncommon for the difference between the two measurements vary by a factor of five. Therefore, Emmett documents a discrepancy ratio of 0.2 to 5.0."

Therefore, a discrepancy ratio ($\overline{R}$) between 0.2 and 5.0 was considered an acceptable range for determining the accuracy of computed measurements. The selection of this value for the discrepancy ratio is only for evaluating the performance of sediment transport relationships, and it has no effect on the general results of this research.

$$\overline{R} = \frac{\sum_{i=1}^{i=n} R_i}{N} \tag{4.12a}$$

where N = number of samples

$$R_i = \frac{C_i(computed)}{C_i(measured)} \tag{4.12b}$$

where C_i = sediment concentration; and

i = appropriate data set.

Analyses of available field data, discussed in Chapter 3 and presented in Appendices D and E, were conducted utilizing nonlinear regression analysis using Microsoft Excel Solver 2000. Existing sediment transport equations were modified by including a shape factor (*W/d*), and the effect of the shape factor on the modified relationship was assessed.

4.2.1 Modified Shen and Hung (1971) Method

Shen and Hung's equations (Equations (2.12) and (2.13)) were analyzed, and were previously presented in Chapter 2 as:

$$\log C_{ppm} = -107404.459 + 324214747 S_h - $$

$$-326309.589 S_h^2 + 109503.872 S_h^3 \tag{2.12}$$

$$S_h = \left[\frac{V S^{0.57159}}{\omega^{0.31988}} \right]^{0.00750189} \tag{2.13}$$

The observed measurements and the computed sediment transport by applying Shen and Hung's equation and the 0.2 to 5 band for 550 field data sets are presented in Figure 4.9. The analyses of these data show 254 data sets (46.2%) of computed sediment concentrations were below the selected accuracy range, and 296 data sets were within the range.

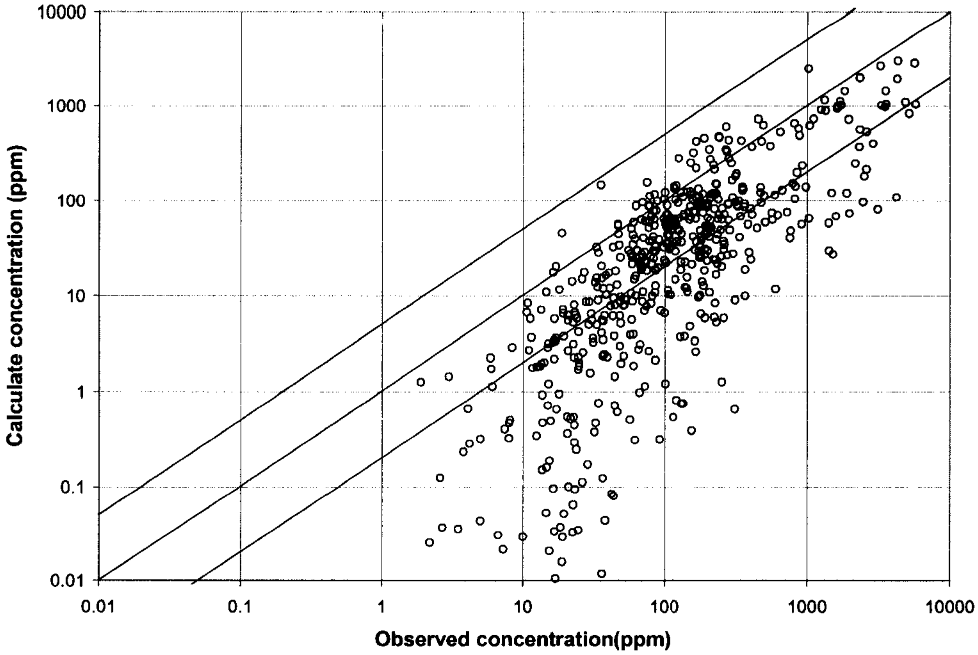

Figure 4.9: Computed vs. observed sediment transport using Shen and Hung's (1971) method.

The mean discrepancy ratio ($\overline{R}$) is 0.366. This value was calculated by using Equation (4.12). The sediment concentration was calculated by using Shen and Hung's equation (Equations (2.12) and (2.13)). It is concluded from this analysis that Shen and Hung's (1971) equation significantly underestimated the sediment transport prediction; however, the original Shen and Hung (1971) equation was not specifically calibrated to the data shown.

A modified Shen and Hung sediment transport equation is presented that includes a shape factor (*W/d*) and is calibrated to the data shown. The shape factor is used in the new equation and is as follows:

From Equation (2.13) –

$$S_h = f(V, S, \omega) \tag{4.13}$$

A non-dimensional channel shape factor width/depth ratio $\left(\psi = \frac{W}{d}\right)$ is introduced, and a nonlinear regression of 550 data sets was conducted using the following functional relationship:

$$S_h = f(Q, \psi, S, \omega) \tag{4.14}$$

For the development of a new transport relationship, four variables $(Q,\ \psi, S, \omega)$ were chosen to be used in the nonlinear regression analysis.

Equation (2.13) is modified to become:

$$S_h = \left[\frac{Q^{a1} S^{a2}}{\psi^{a3} \omega^{a4}}\right]^{a5} \tag{4.15}$$

Equation (2.12) is modified to become:

$$\log C_{ppm} = a_6 + a_7 S_h + a_8 S_h^{\ 2} + a_9 S_h^{\ 3} \tag{4.16}$$

Coefficients a_1 through a_9 were solved using Microsoft Excel Solver 2000 for non-linear optimization by iteration procedures to find the minimum value of the sum of the squares or the residuals.

Equations (4.15) and (4.16) were solved using the English system of units and the results are:

$$S_h = \left[\frac{Q^{0.0612} S^{0.345}}{\psi^{0.08} \omega^{0.304}}\right]^{0.292} \tag{4.17}$$

$$\log C_{ppm} = -8.577 + 32.136 S_h - 26.469 S_h^{\ 2} + 7.193 S_h^{\ 3} \tag{4.18}$$

The observed measurements and sediment transport were computed by applying the modified Shen and Hung equation for 550 field data sets are presented in Figure 4.10. The analysis of these data show 11 data sets (2.0%) of computed sediment concentrations were below the selected accuracy range and 17 data sets (3.1%) were above the selected range, 522 data sets were within the range, and the mean discrepancy ratio ($\bar{R}$) was 1.452. With the shape factor eliminated from Equation (4.6) and a re-analysis of the non-linear regression, the results show that 22 measurements were above the selected range and 15 measurements were below the selected range. The mean discrepancy ratio ($\bar{R}$) is 1.513 and the result is shown in Figure 4.11.

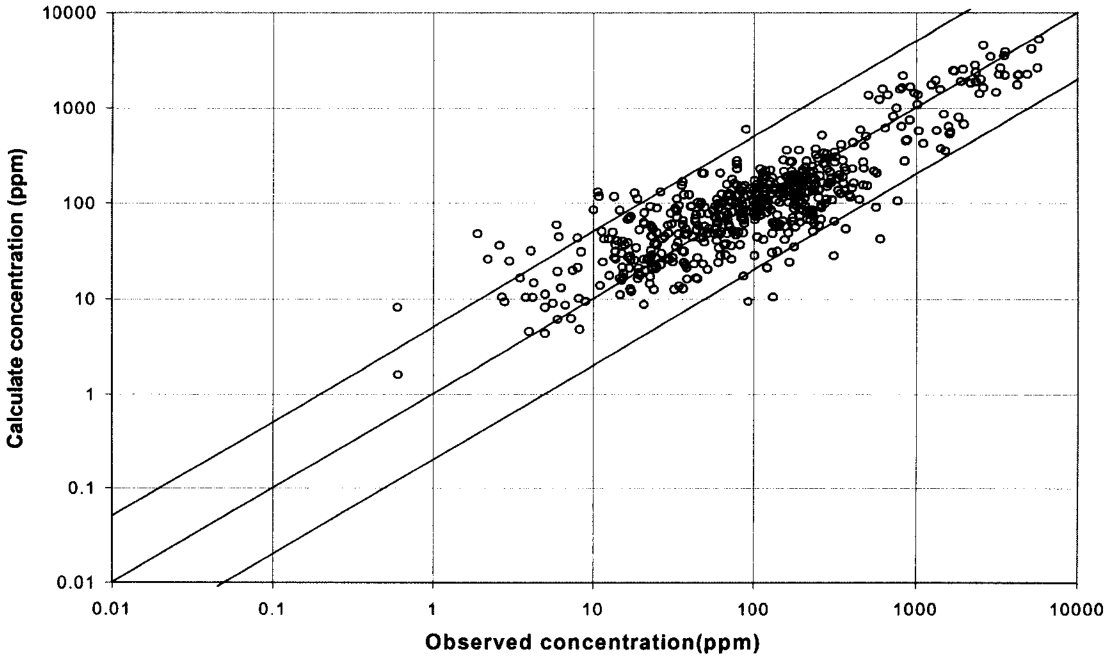

Figure 4.10: Computed vs. observed sediment transport using the modified Shen and Hung (1971) method.

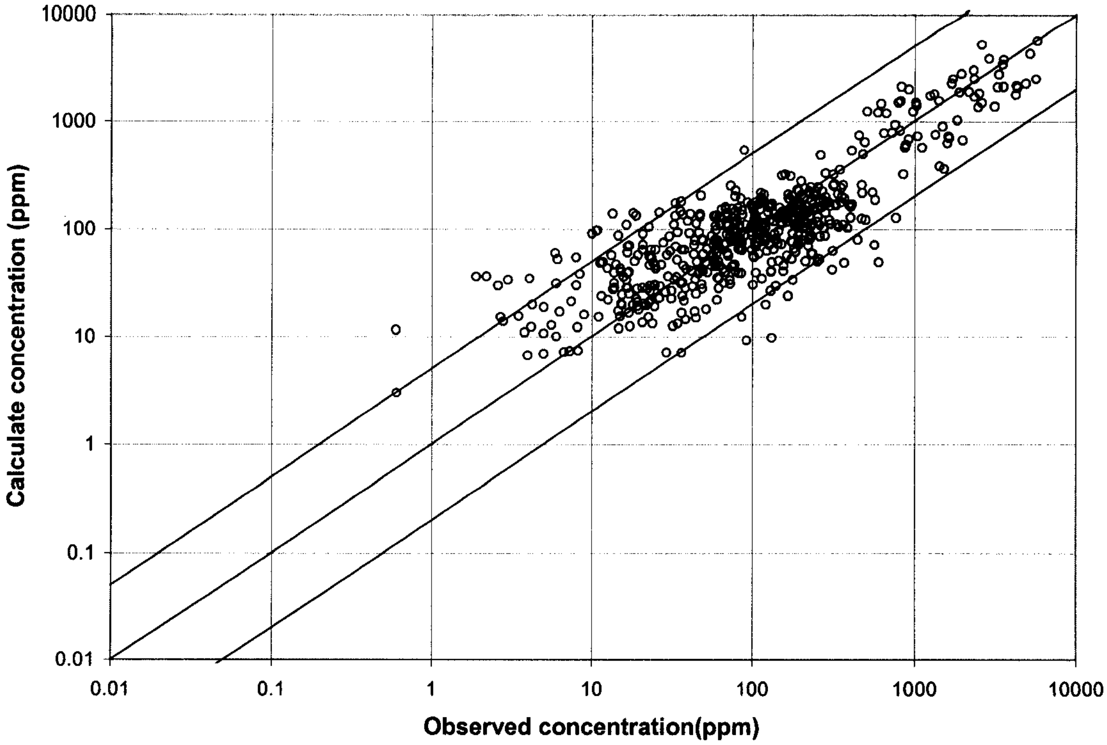

Figure 4.11: Computed vs. observed sediment transport using the modified Shen and Hung (1971) method neglecting *W/d*.

To verify the developed equation (Equation (4.18)) a total of 476 data sets were used; these data were not used in developing the modified equation. The analyses show that 23 measurements were above the selected range, 14 measurements were below the selected range, and 439 data sets (92.2%) were within the range. The mean discrepancy ratio ($\overline{R}$) was 1.63 and the result is shown in Figure 4.12.

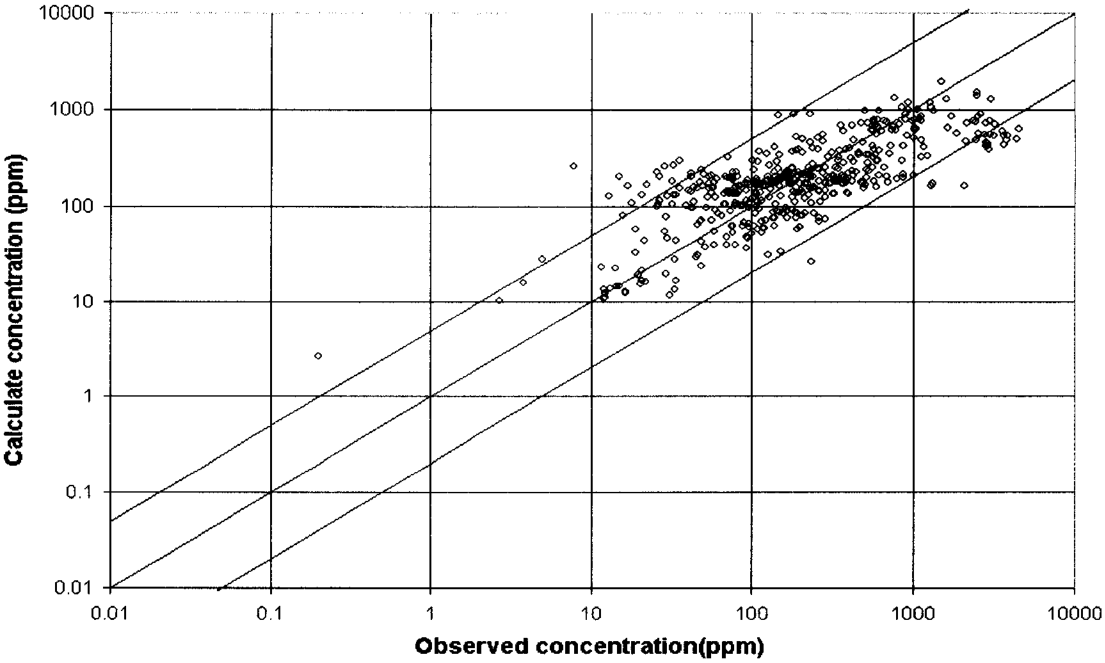

Figure 4.12: Computed vs. observed sediment transport to verify the modified Shen and Hung (1971) method.

4.2.2 Modified Engelund and Hansen (1967) Method

A total of 1,026 data sets were used to analyze the Engelund and Hansen (1967) equation, and was previously presented in Chapter 2 as:

$$C_w = 0.05\left(\frac{G}{G-1}\right)\frac{VS_f}{[(G-1)gd_s]^{1/2}}\left[\frac{R\ S_f}{(G-1)d_s}\right]^{0.5} \tag{2.15}$$

The observed measurements and the sediment transport computed by applying the Engelund and Hansen (1967) (Equation (2.15)) for 550 field data sets are presented in Figure 4.13. The analyses of these data show 45 data sets of computed sediment concentrations were below the selected accuracy range, 14 data sets were above the selected range, and 491 data sets were within the range. The mean discrepancy ratio ($\overline{R}$) was 1.302, and 89.3% of the data were within the acceptable range.

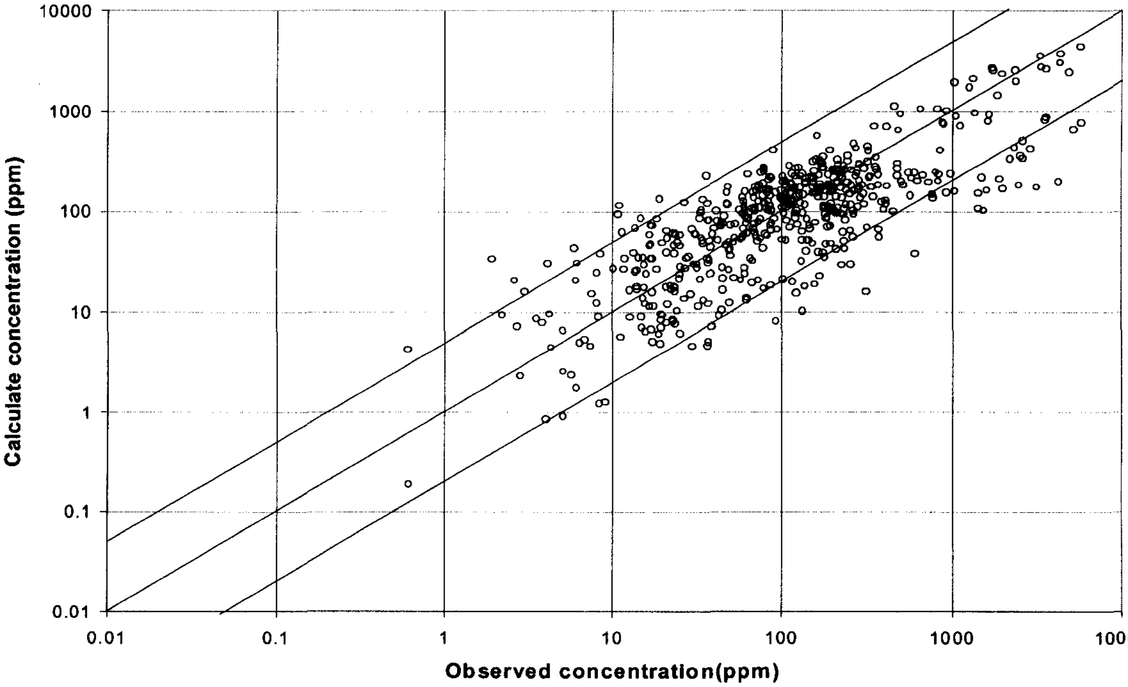

Figure 4.13: Computed vs. observed sediment transport using Engelund and Hansen's (1967) equation.

A portion of the 1,026 data sets (550 data sets) was used to modify Engelund and Hansen, and the remaining 476 data sets were used to verify the modified equation. A discrepancy ratio between 0.2 and 5.0 was considered an acceptable range for determining the accuracy of computed sediment transport to observed measurements.

A modified Engelund and Hansen method was developed using a shape factor:

$$R = \frac{A}{p} = \frac{Wd}{W + 2d} = \frac{Wd}{d\left(\frac{W}{d} + 2\right)} = \frac{\psi}{\psi + 2} d \tag{4.19}$$

where R = hydraulic radius;

A = cross-sectional area;

p = wetted perimeter;

S_f = friction slope;

W = channel width;

d = channel depth; and

g = gravitational acceleration.

Substituting the value of hydraulic radius in Equation (2.15) yields:

$$C_w = 0.05\left(\frac{G}{G-1}\right)\frac{VS_f}{[(G-1)gd_s]^{1/2}}\left[\frac{\left(\frac{\psi d}{\psi+2}\right)S_f}{(G-1)d_s}\right]^{0.5} \tag{4.20}$$

where C_w = weight concentration of sediment;

d_s = grain size;

V = depth-average velocity; and

G = specific gravity of sediment.

From Equation (4.20), it is shown that the sediment transport is a function of V, S_f, d, d_s, and ψ. Equation (4.20) is modified to a dimensionless equation as:

$$\log C_{ppm} = a_1 + a_2 \log\left(\frac{V}{[gd_s]^{1/2}}\right) + a_3 \log\left[\frac{d}{d_s}\right] + a_4 \log S + a_5 \log\psi \tag{4.21}$$

Coefficients a_1 through a_5 were solved using Microsoft Excel 2000 regression analysis for linear optimization, the results are shown in Table 4.5. Although ψ is shown to be significant ($P = 4.6\times10^{-10}$) and is less than the value of significance level (α), which is equal to 0.05 in this model, ψ is the least significant (largest P-value) of the five parameters included.

Table 4.5: The results of linear regression analysis for the modified Engelund and Hansen (1967) equation.

Regression Statistics	
Multiple R	0.851796596
R Square	0.725557442
Adjusted R Square	0.723543184
Standard Error	0.347643624
Observations	550

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	174.1347231	43.53368	360.2109	1.8891E-151
Residual	545	65.86656851	0.120856		
Total	549	240.0012916			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	3.592469212	0.137516271	26.12396	3.75E-98	3.322342336	3.862596089
Log(V/(gds) ^ 0.5)	2.627703305	0.155113923	16.94047	5.02E-52	2.323008892	2.932397718
Log(d/ds)	-0.555503687	0.087413024	-6.35493	4.41E-10	-0.72721142	-0.383795954
Log(S_f)	0.54128125	0.072773578	7.437881	4E-13	0.39833017	0.684232329
Log(W/d)	-0.193108196	0.030420192	-6.348027	4.6E-10	-0.25286339	-0.133353003

With the shape factor (*W/d*) eliminated from the original model, and re-analysis of the linear regression, the results show that the determination coefficient (R^2) was equal to 0.695. Although ψ is shown to be significant ($P = 4.6 \times 10^{-10}$) and is less than the value of significance level (α), which is equal to 0.05 in this model, ψ is nearly the least significant (largest P-value) of the five parameters included.

Equation (4.21) was solved and the result was:

$$\begin{aligned} \log C_{ppm} &= 3.592 + 2.627\log\left(\frac{V}{[gd_s]^{1/2}}\right) - \\ &0.555\log\left[\frac{d}{d_s}\right] + 0.541\log S - 0.193\log\psi \end{aligned} \tag{4.22}$$

The observed measurements and the sediment transport computed by applying the modified Engelund and Hansen (1967) equation and the 0.2 to 5 band for 550 field data sets are presented in Figure 4.14. The analysis of these data show 20 data sets of computed sediment concentrations were below the selected accuracy range, 11 data sets were above the selected range, and 519 data sets were within the range. The mean discrepancy ratio ($\bar{R}$) is 1.369 and 94.4% of the data were within the acceptable range. In the modified Engelund and Hansen equation the mean discrepancy ratio is greater than in the original equation, but the number of data within the selected range in the modified Engelund and Hansen equation is greater than those in the original equation.

To verify the developed equation, a total of 476 data sets were used, these data were not used in developing the modified equation. The analyses show that 14 measurements were above the selected range, 6 measurements were below the selected range, and 456 data sets (95.8%) were within the range. The mean discrepancy ratio ($\bar{R}$) was 1.659 and the result is shown in Figure 4.15.

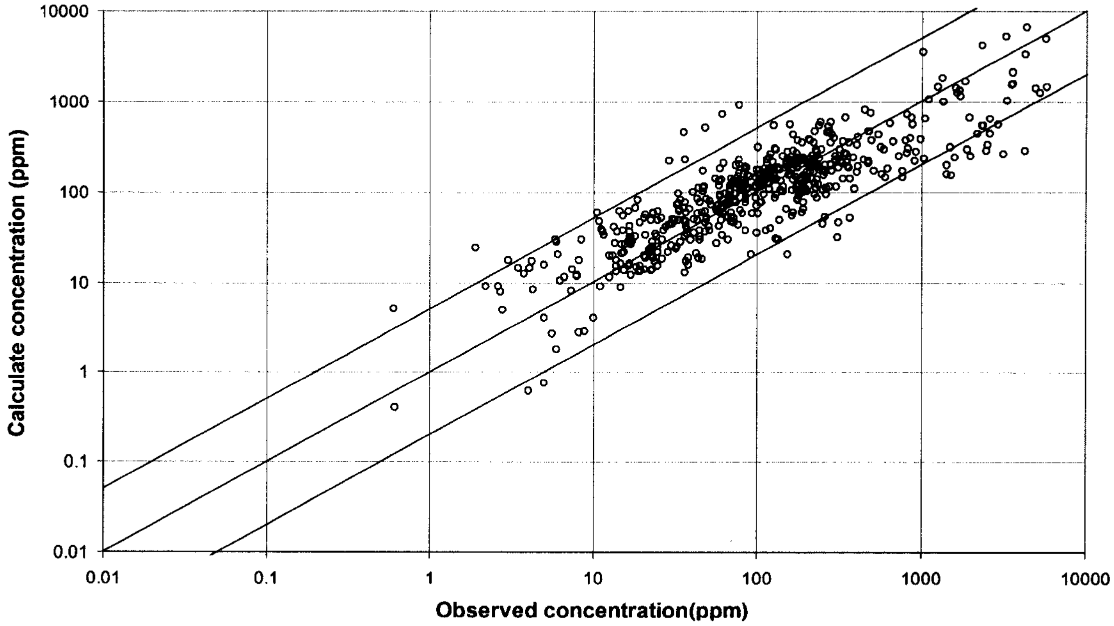

Figure 4.14: Computed vs. observed sediment transport using the modified Engelund and Hansen (1967) equation.

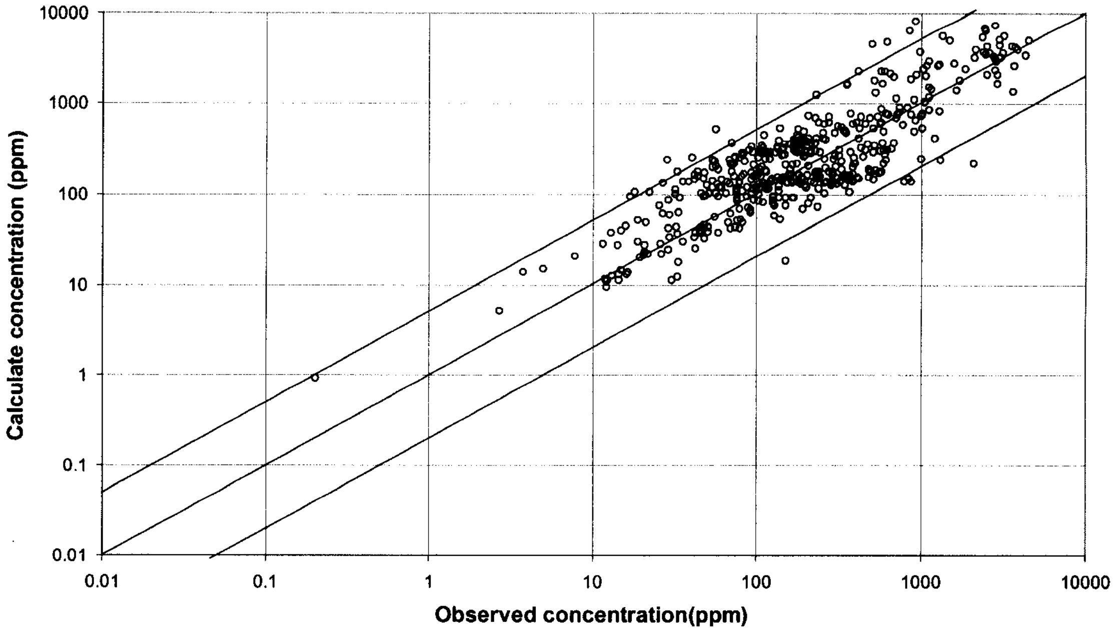

Figure 4.15: Computed vs. observed sediment transport to verify the modified Engelund and Hansen (1967) equation.

4.2.3 Modified Yang (1973) Method

Yang's (1973) equations (Equations (2.16) and (2.17)) were analyzed, and were previously presented in Chapter 2 as:

For sand –

$$\log C_{ppm} = 5.435 - 0.286\log\frac{\omega d_s}{v} - 0.457\log\frac{u*}{\omega} +$$

$$\left(1.799 - 0.409\log\frac{\omega d_s}{v} - 0.314\log\frac{u*}{\omega}\right)\times\log\left(\frac{VS}{\omega} - \frac{V_cS}{\omega}\right) \tag{2.16}$$

For gravel –

$$\log C_{ppm} = 6.681 - 0.633\log\frac{\omega d_s}{v} - 4.816\log\frac{u*}{\omega} +$$

$$\left(2.784 - 0.315\log\frac{\omega d_s}{v} - 0.282\log\frac{u*}{\omega}\right)\times\log\left(\frac{VS}{\omega} - \frac{V_cS}{\omega}\right) \tag{2.17}$$

A total of 1,026 data sets were used in this analysis. A portion of the data sets, 550 data sets, was used to develop the modified Yang equation and the remaining 476 data sets were used to verify the modified equation. Yang's method was applied to the observed measurements and the computed sediment transport and are presented in Figure 4.16. The analyses of these data show 157 data sets of computed sediment concentrations were below the selected accuracy range, 1 data set was above the selected range, and 392 data sets were within the range, and the mean discrepancy ratio ($\bar{R}$) was 0.60. A total of 71.3% of the data were within the acceptable range. It is concluded from this analysis that Yang's (1973) equation significantly underestimated sediment transport.

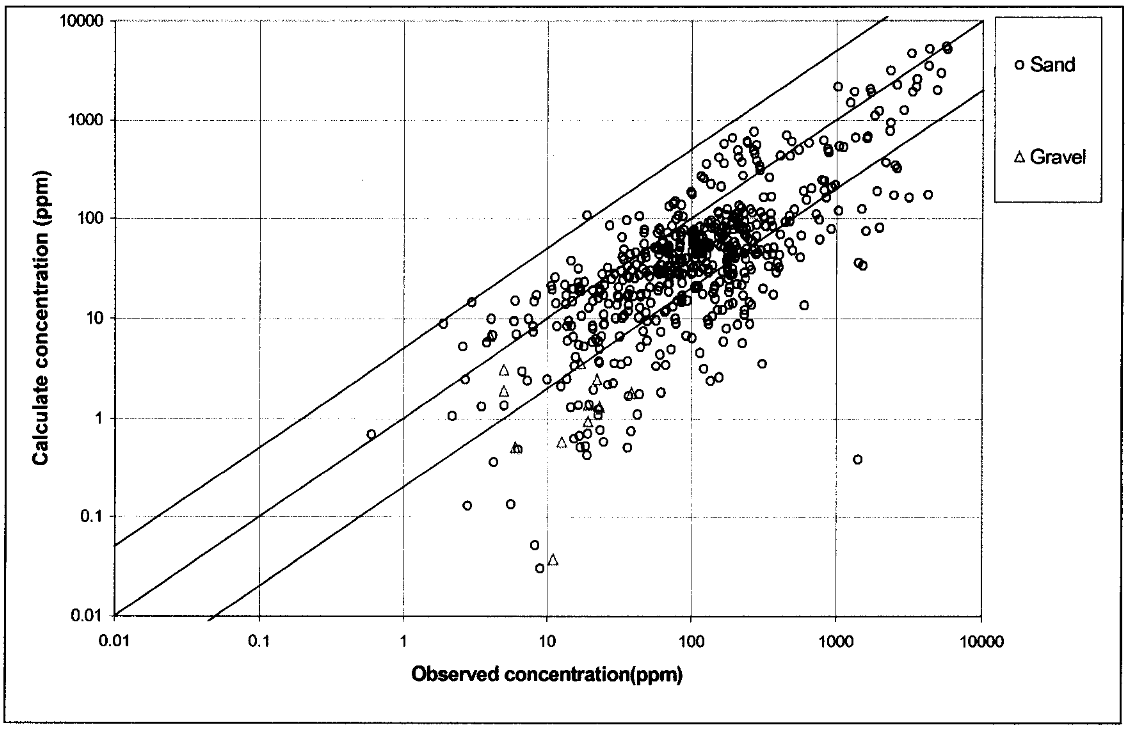

Figure 4.16: Computed vs. observed sediment transport using Yang (1973) equation.

A modified Yang sediment transport equation is presented that includes a shape factor. A non-dimensional channel shape factor width-depth ratio $\left(\psi = \frac{W}{d}\right)$ is introduced, and nonlinear regression of 550 data sets was conducted using the following functional relationship:

$$u_* = \sqrt{gRS} \text{ , where } R = \frac{\psi}{\psi + 2} d \tag{4.23}$$

$$u_* = \sqrt{g\left(\frac{\psi}{\psi + 2}\right) d S_f} \tag{4.24}$$

Substituting the value of shear velocity (u_*) in Equation (2.16) yields:

$$\begin{aligned}\log C_{ppm} &= 5.435 - 0.286 \log \frac{\omega d_s}{v} - 0.457 \log \frac{\sqrt{g d S_f \left(\frac{\psi}{\psi+2}\right)}}{\omega} + \\ &\left(1.799 - 0.409 \log \frac{\omega d_s}{v} - 0.314 \log \frac{\sqrt{g d S_f \left(\frac{\psi}{\psi+2}\right)}}{w}\right) \times \log\left(\frac{VS}{\omega} - \frac{V_c S}{\omega}\right)\end{aligned} \tag{4.25}$$

let:

$$\begin{aligned}\log C_{ppm} &= a_1 + a_2 \log \frac{\omega d_s}{v} + a_3 \log \frac{\sqrt{g d S_f}}{\omega} + a_4 \log \psi + \\ &\left(a_5 + a_6 \log \frac{\omega d_s}{v} + a_7 \log \frac{\sqrt{g d S_f}}{\omega} + a_8 \log \psi\right) \times \log\left(\frac{VS}{\omega} - \frac{V_c S}{\omega}\right)\end{aligned} \tag{4.26}$$

Coefficients a_1 through a_8 were solved using Microsoft Excel Solver 2000 for non-linear optimization by iteration procedures to find the minimum value of the sum of the squares or the residuals.

Equation (4.26) is developed for both sand and gravel, and the result is:

$$\log C_{ppm} = 5.123 - 0.730\log\frac{\omega d_s}{\nu} - 1.179\log\frac{\sqrt{gdS_f}}{\omega} + 0.202\log\psi + \left(1.069 - 0.245\log\frac{\omega d_s}{\nu} - 0.393\log\frac{\sqrt{gdS_f}}{\omega} + 0.103\log\psi\right)\times\log\left(\frac{VS}{\omega} - \frac{V_c S}{\omega}\right) \tag{4.27}$$

The modified Yang equation was applied to the observed measurements and the computed sediment transport, and is presented in Figure 4.17. The analysis of these data show 11 data sets of computed sediment concentrations were below the selected accuracy range, 13 data sets were above the selected range, and 526 data sets were within the selected range. The mean discrepancy ratio ($\overline{R}$) was 1.333, and 95.6% of the data was found to be in the acceptable range.

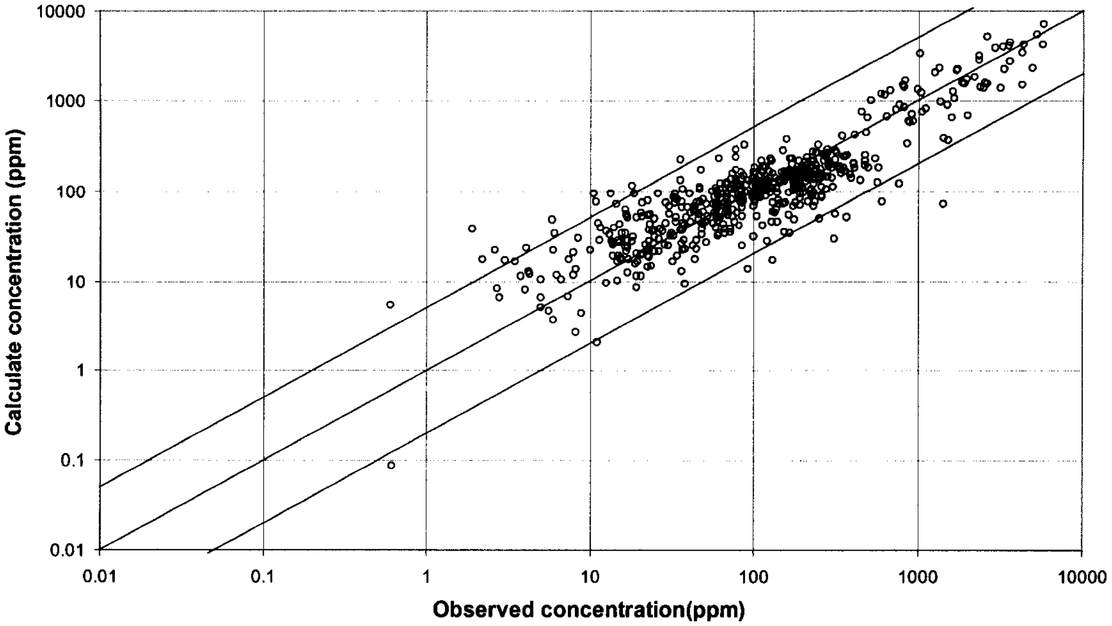

Figure 4.17: Computed vs. observed sediment transport using the modified Yang (1973) equation.

To verify the developed equation a total of 476 data sets were used. The analyses showed that 15 measurements were above the selected range, 4 measurements were below the selected range, and 457 data sets (96.0%) were within the range. The mean discrepancy ratio $\overline{R}$ was 1.479 and the result is shown in Figure 4.18.

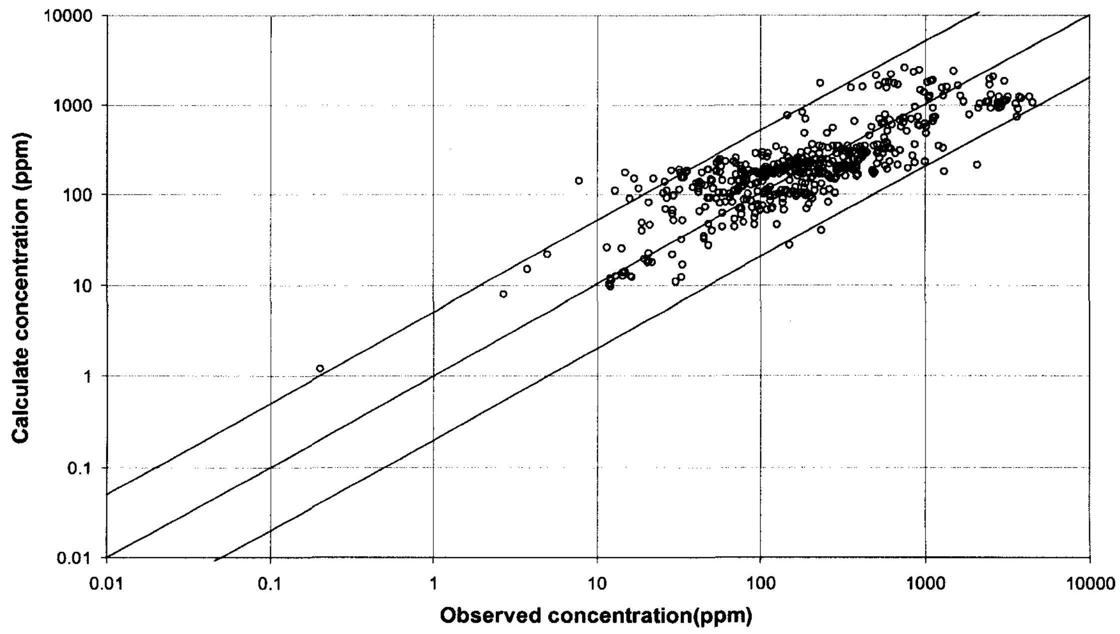

Figure 4.18: Computed vs. observed sediment transport to verify the modified Yang (1973) equation.

4.2.4 Evaluation of the Performance of the Brownlie (1981) Equation

Brownlie (1981) developed two equations related to sediment transport. Equation (2.20) can be used to compute sediment transport, and Equation (2.8) may be used to determine the ratio between the mean sediment concentration in the cross section and the sediment concentration at the mean depth. Both equations are evaluated in subsequent paragraphs. Equation (2.20), presented in Chapter 2 and repeated below, does not specifically include a shape factor. Equation (2.8), presented in Chapter 2 and repeated below, includes the shape factor (β). However, as shown, the coefficient (c_f) varies depending on the source of the data. Flume data are generally representative of low width/depth channels, and field data includes a broad range of larger width/depth ratio data. Therefore, while width/depth is not specifically included in the formulation of Equation (2.20), consideration of the shape of the channel is given by use of the coefficient.

$$C = 7155 c_f \left(F_g - F_{g0}\right)^{1.978} S^{0.6601} \left(\frac{R_b}{d_{50}}\right)^{-0.3331} \tag{2.20}$$

where c_f = 1 for laboratory data; and

c_f = 1.268 for field data.

A total of 550 data sets discussed in Chapter 3 and presented in Appendix D were used in this analysis. The observed measurements and the sediment transport computed by applying Brownlie (1981) and the 0.2 to 5 band for 550 field data sets are presented in Figure 4.19. Analyses of these data show 60 data sets (10.9%) of computed sediment concentrations were below the selected accuracy range, 4 data sets (0.72%) were above the selected range, and 486 data sets were within the range. The mean discrepancy ratio ($\overline{R}$) was 0.968, and 88.4% of the data were found to be in the acceptable range.

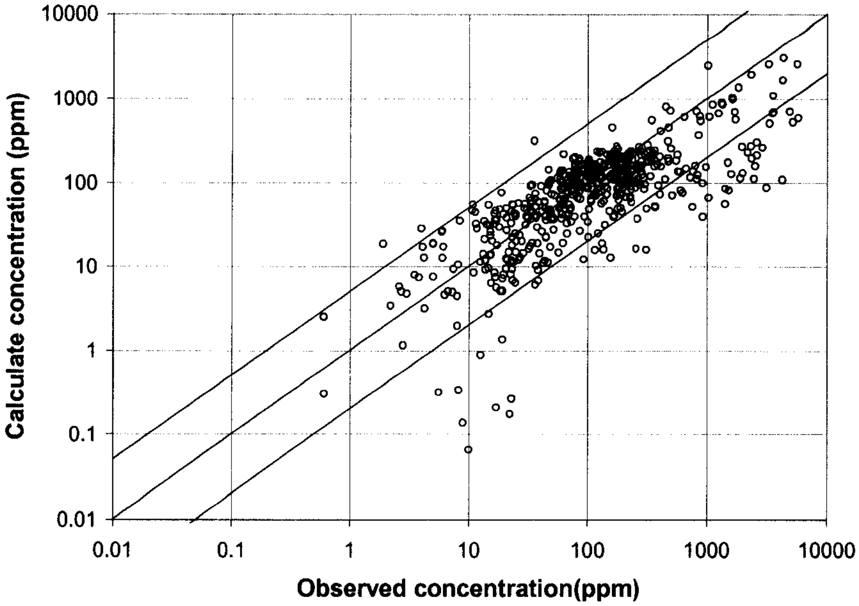

Figure 4.19: Computed vs. observed sediment transport using Brownlie's (1981) equation.

Brownlie (1981) suggested using relationships between the shape factor (β) and sediment transport, and these were previously presented in Chapter 2 as:

$$\frac{C}{C(d)}=\left(\frac{\beta+1}{\beta}\right)^{b1b2+b3}\frac{\int_0^1\left(1-u^{\beta}\right)^{1+b1+b1b2+b3}du}{\int_0^1\left(1-u^{\beta}\right)^{1+b1}du} \tag{2.8}$$

$$V_i=a_1d_i^{\,b_1} \tag{2.5}$$

$$C_i=a_2V_i^{\,b2}d_i^{\,b3} \tag{2.6}$$

$$d=cW^{\beta} \tag{2.7}$$

As presented in Section 2.2, Brownlie (1981) suggested a constant value of β = 1.53 and $C/C(d)$ = 1.43.

Values of b_1, b_2, and b_3 were determined by applying non-linear regression on available field data sets of the Colorado River, the Mississippi River at St. Louis, and the

Red River. The value of b_1 was determined using Equation (2.5), as the flow velocity (V_i) is a power function of flow depth (d_i). The value of b_2 and b_3 were determined using Equation (2.6), as the sediment concentration (C_i) is a power function of flow velocity and flow depth. The results of nonlinear regression are shown in Table 4.6.

Table 4.6: The results of the non-linear regression using Brownlie (1981).

River	b_1	b_2	b_3	c	β
Colorado River	0.284	0.908	-0.190	0.822	0.222
Mississippi River at St. Louis	1.015	3.06	-1.531	5.96E-06	2.292
Red River	0.998	3.634	-1.130	6.96E-06	2.638

By substituting these coefficients in Equation (2.8), Microsoft Mathcad (2001) was used to calculate the integrals of Equation (2.8), assuming a range of β and using the regression shape factor (β) for each river. The results are plotted in Figure 4.20 as the shape factor (β) vs. $C/C(d)$.

As shown in Table 4.11, the range of the value of β is not constant, ranging from 0.222 to 2.638. Figure 4.20 indicates the variability of ratio $C/C(d)$ (Equation (2.8)) as a function of β for the three streams tested. Because of these inconsistencies with observed field data, application of Equation (2.8) to stable channel design appears to be unfeasible.

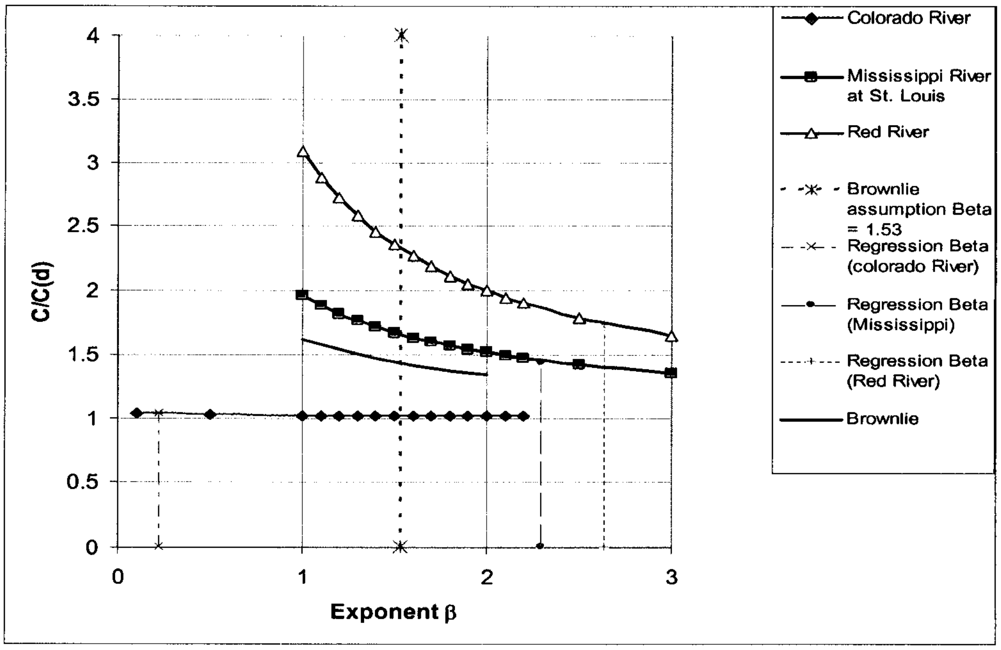

Figure 4.20: The relationship between shape factor (β) and the ratio between sediment concentration and the concentration from the mean depth *C*/*C*(*d*) for the Colorado River, Mississippi River at St. Louis, and Red River.

4.2.5 New Sediment Transport Equations

For the development of a new relationship, seven dimensionless variables were originally chosen to be used in the linear regression analysis, as follows;

$$\log C_{ppm} = a_1 + a_2 \log \psi + a_3 \log F_g + a_4 \log \frac{d}{d_s} +$$

$$a_5 \log \frac{u_*}{\omega} + a_6 \log \frac{\omega d_s}{\nu} + a_7 \log \tau_* + a_8 \log \frac{VS}{\omega} \tag{4.28}$$

where $a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8$ = coefficients determined from the regression analysis,

C_{ppm} = total sand and gravel concentration (ppm by weight);

ψ = shape factor;

F_g = grain Froude number;

d = average flow depth;

d_s = median particle diameter;

u_* = shear velocity;

v = kinematic viscosity of water;

ω = terminal fall velocity of sediment particles;

V = average flow velocity; and

S = energy slope.

Table 4.7 shows the seven selected variables results of the linear regression analysis in a relationship predicting the sediment transport with $R^2 = 0.82$.

Table 4.7: The results of linear regression analysis for the new sediment transport relationship.

Regression Statistics	
Multiple R	0.905511531
R Square	0.819951133
Adjusted R Square	0.817625779
Standard Error	0.28235946
Observations	550

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	7	196.7893311	28.112762	352.6134	3.6642E-197
Residual	542	43.21196053	0.0797269		
Total	549	240.0012916			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	4.30580995	0.167526285	25.702295	7.32E-96	3.976729793	4.634890107
Log (W/d)	-0.226974325	0.042199758	-5.378569	1.12E-07	-0.309869394	-0.144079256
Log (Fg)	2.371453973	0.200217487	11.84439	6.07E-29	1.978156874	2.764751072
Log (d/ds)	-1.123116966	0.119182985	-9.423467	1.25E-19	-1.357233989	-0.888999943
Log (u^*/ω)	0.60731116	0.159375844	3.8105596	0.000155	0.294241317	0.920381003
Log ($\omega ds/\nu$)	-0.086156137	0.053465742	-1.611427	0.107669	-0.191181535	0.018869261
Logτ^*	0.155763716	0.087872299	1.7726145	0.076854	-0.016848182	0.328375614
Log (V.S/ω)	-0.025620854	0.116773364	-0.219407	0.826416	-0.255004542	0.203762833

With elimination of the variables that had the largest *P*-value $\left(\frac{\omega d_s}{\nu}, \tau_*, \frac{VS}{\omega}\right)$, the regression was repeated with four variables $\left(\psi, F_g, \frac{d}{d_s}, \frac{u_*}{\omega}\right)$. The equation could then be written as:

$$\log C_{ppm} = a_1 + a_2 \log \psi + a_3 \log F_g + a_4 \log \frac{d}{d_s} + a_5 \log \frac{u_*}{\omega} \tag{4.29}$$

The result of the regression analysis using four selected variables is presented in Table 4.8. This tables shows the regression results with $R^2 = 0.819$.

Table 4.8: Regression result summary for natural channels.

Regression Statistics	
Multiple R	0.904774541
R Square	0.818616969
Adjusted R Square	0.817285718
Standard Error	0.282622586
Observations	550

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	196.46913	49.11728	614.9228	2.0796E-200
Residual	545	43.53216162	0.079876		
Total	549	240.0012916			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	4.025068245	0.089827394	44.80892	6.9E-185	3.8486179	4.20151859
Log (W/d)	-0.20547736	0.024516634	-8.381141	4.48E-16	-0.253636037	-0.1573187
Log (Fg)	2.422842646	0.10125533	23.92805	4.93E-87	2.223944101	2.62174119
Log (d/ds)	-1.0989539	0.028747235	-38.22816	2.3E-156	-1.155422857	-1.0424849
Log (u*/ω)	0.824514691	0.043256705	19.06097	1.9E-62	0.739544392	0.90948499

The simplified equation has $R^2 = 0.819$, indicating that the variables removed from the model did not significantly affect the value of R^2.

The new relationship is:

$$\log C_{ppm} = 4.025 - 0.205 \log \psi + 2.423 \log F_g - 1.10 \log \frac{d}{d_s} + 0.825 \log \frac{u_*}{\omega} \tag{4.30}$$

Eliminating $W/d, F_g$, $\frac{d}{d_s}$, or $\frac{u_*}{\omega}$ from the model and a re-analysis of the linear regression, show that the determination coefficients (R^2) are equal to 0.77, 62.8, 0.332, and 0.697, respectively, as shown in Table 4.9. These values are less than the coefficient of determination (R^2) of the original model (0.819), indicating that the shape factor has an important role in prediction of sediment transport, but the role is less important than the role of other hydraulic variables.

Table 4.9: The results of eliminating independent variables from Equation (4.30).

Variable eliminated from Equation	The new equation	R^2
W/d	$\log C_{ppm} = 3.65 + 2.54\log F_g - 1.12\log\frac{d}{d_s} + 0.84\log\frac{u_*}{\omega}$	0.77
F_g	$\log C_{ppm} = 4.61 - 0.29\log\psi - 0.59\log\frac{d}{d_s} + 1.39\log\frac{u_*}{\omega}$	0.62
$\frac{d}{d_s}$	$\log C_{ppm} = 2.79 - 0.30\log\psi - 0.44\log F_g + 0.98\log\frac{u_*}{\omega}$	0.33
$\frac{u_*}{\omega}$	$\log C_{ppm} = 3.27 - 0.22\log\psi + 3.48\log F_g - 1.15\log\frac{d}{d_s}$	0.70

Equation (4.30) was applied to two sets of data. The first data set (550 data sets) was used to generate the equation. The second data set (476 data records) was not used in the original data sets and was used as a verification of the new equation.

The observed measurements and the sediment transport computed by applying the new relationship (Equation (4.30)) on 550 field data sets are presented in Figure 4.21. The analysis of these data show 11 data sets (2%) of computed sediment concentrations were below the selected accuracy range, 9 data sets (1.6%) were above the selected range, and a total of 530 data sets were within the range. The mean discrepancy ratio $\overline{R}$ was 1.248, with 96.4% of the data within the accepted range.

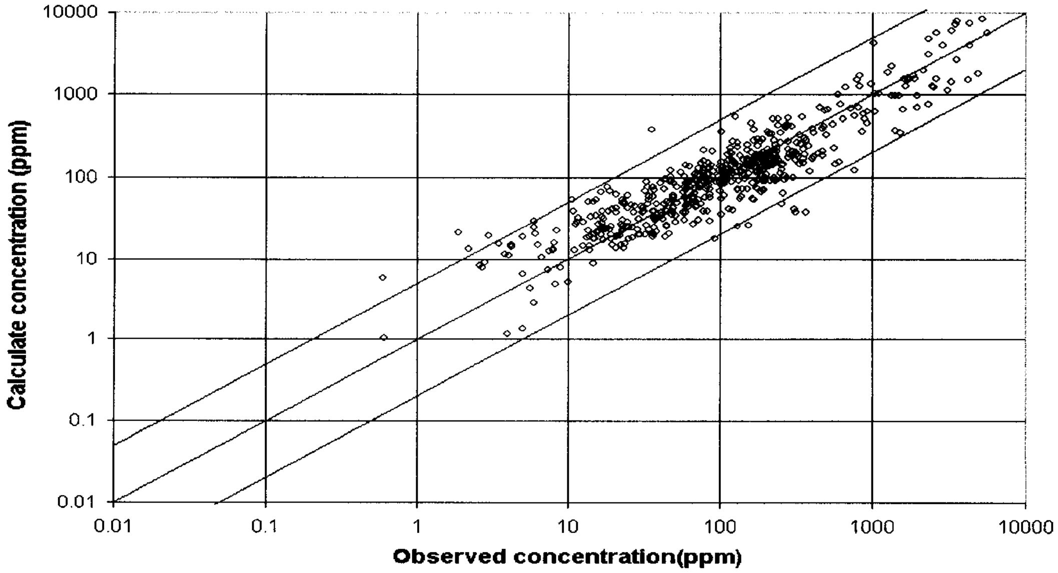

Figure 4.21: **Computed vs. observed sediment transport using new equation for 550 data values.**

To verify the developed equation, a total of 476 data sets were used. The analyses show that 22 measurements (4.6%) were above the selected range, 3 measurements (0.6%) were below the selected range, and 451 data sets (94.8%) were within the range. The mean discrepancy ratio $\overline{R}$ was 1.72 and the result is shown in Figure 4.22.

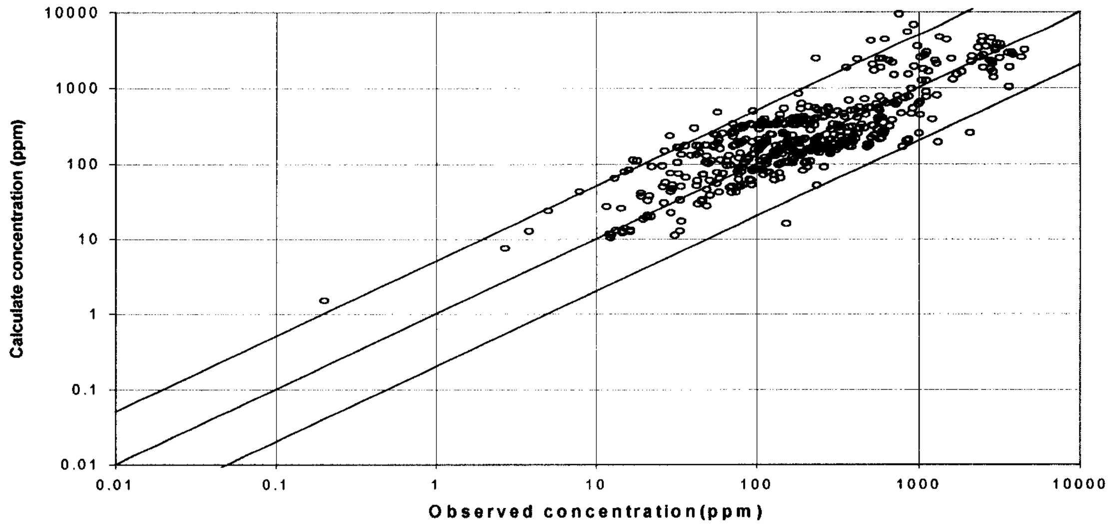

Figure 4.22: Computed vs. observed sediment transport to verify the new equation on 476 data values not used in development of the equation.

A total of 108 flume data sets were used in this study. These data sets (Gessler et al., 1994) were collected using three different bank angles, three grain size distributions, four bank roughnesses, and three discharges (see Appendix G). Regression analysis of available data sets was used to develop the relationships between sediment transport and shape factor (*W/d*) among other hydraulic variables. For the development of a new relationship, six dimensionless variables were selected to use in the regression analysis. Microsoft Excel 2000 data analysis regression was used.

$$\log C_{mg/l} = a_1 + a_2 \log\psi + a_3 \log\frac{\omega d_s}{\nu} + a_4 \log F_g + a_5 \log\frac{d}{d_s} +$$

$$a_6 \log\frac{u_*}{\omega} + a_7 \log f \qquad (4.31)$$

where f = Darcy-Weisbach friction factor.

The results of the regression analysis using the selected parameters are shown in Table 4.10 with $R^2 = 0.822$.

Table 4.10: Regression result summary for flume data.

Regression Statistics	
Multiple R	0.906708591
R Square	0.822120469
Adjusted R Square	0.811553368
Standard Error	0.165980885
Observations	108

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	12.860179	2.143363	77.8	1.24686E-35
Residual	101	2.782515089	0.02755		
Total	107	15.64269409			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.744988172	1.361102095	1.282041	0.202763	-0.955071876	4.44504822
Log (W/d)	0.944317249	0.166027137	5.687728	1.26E-07	0.614964115	1.27367038
Log (ωds/v)	0.908844234	0.226910428	4.0053	0.000119	0.458715046	1.35897342
Log F_g	1.48514036	0.387233506	3.835258	0.000219	0.716973355	2.25330736
Log (d/ds)	-0.958334997	0.533521144	-1.796246	0.075445	-2.016697284	0.10002729
Log (u*/ω)	3.012173933	0.894673782	3.366785	0.001077	1.237382063	4.7869658
Log f	-0.588993617	0.189456662	-3.108857	0.00244	-0.964824618	-0.21316262

The new flume equation is:

$$\log C_{mg/l} = 1.745 + 0.944\log\psi + 0.909\log\frac{\omega d_s}{v} + 1.485\log F_g - 958\log\frac{d}{d_s} +$$

$$3.012\log\frac{u_*}{\omega} - 0.589\log f \qquad (4.32)$$

The new flume relationship for 108 field data sets were applied to the observed measurements and the computed sediment transport and are presented in Figure 4.23. The analysis of these data show all the data sets were within the selected range, and the mean discrepancy ratio $\overline{R}$ was 1.076.

With the shape factor (*W/d*), eliminated from the model and a re-analysis of the linear regression, the results show that the coefficient of determination (R^2) is equal to 0.765, which is less than the coefficient of determination (R^2) of the original model. This result indicates that the shape factor has a significant role in predicting sediment transport in flumes. The shape factor (*W*/*d*) is shown to be significant ($P = 1.2 \times 10^{-7}$) and is less than the value of significance level (α), which is equal to 0.05 in this model.

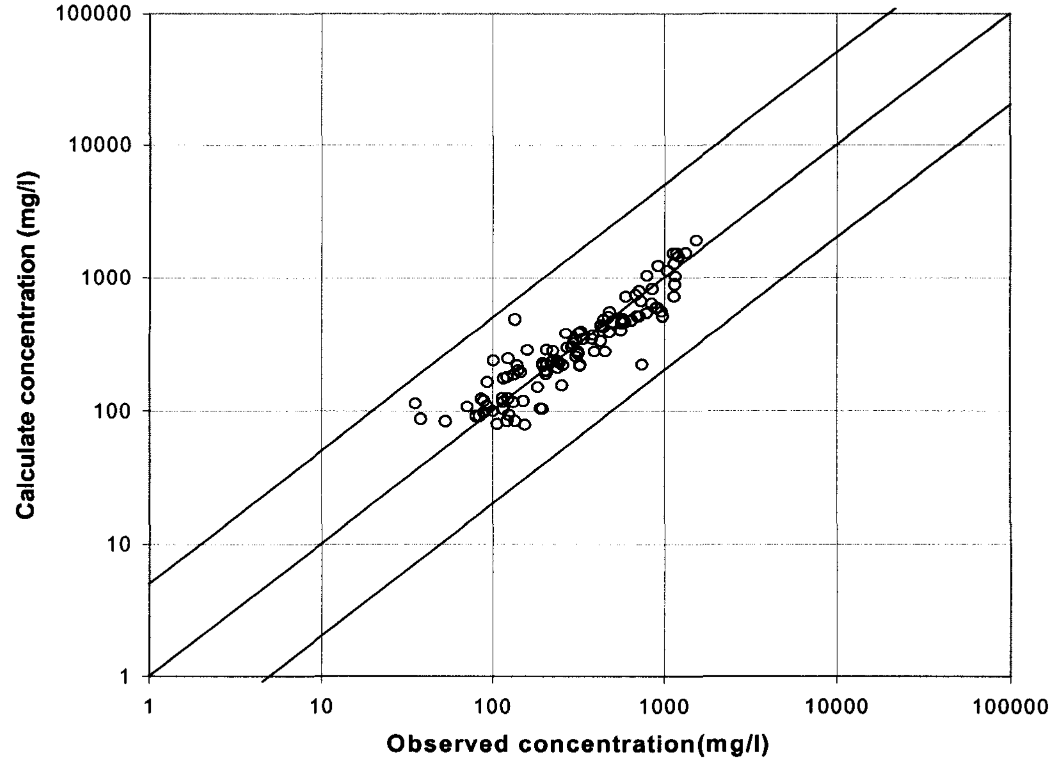

Figure 4.23: Computed vs. observed sediment transport using the new equation for flume data.

A total of 704 data sets of flume data from 14 sources were used to verify the developed equation. These data are not used in developing the modified equation. These data are discussed in Chapter 3 and presented in Appendix F. The analyses show that 44 measurements were above the selected range, 9 measurements were below the selected range, and 651 data sets (92.5%) were within the range. The mean discrepancy ratio $\overline{R}$ was 1.878. The result is shown in Figure 4.24.

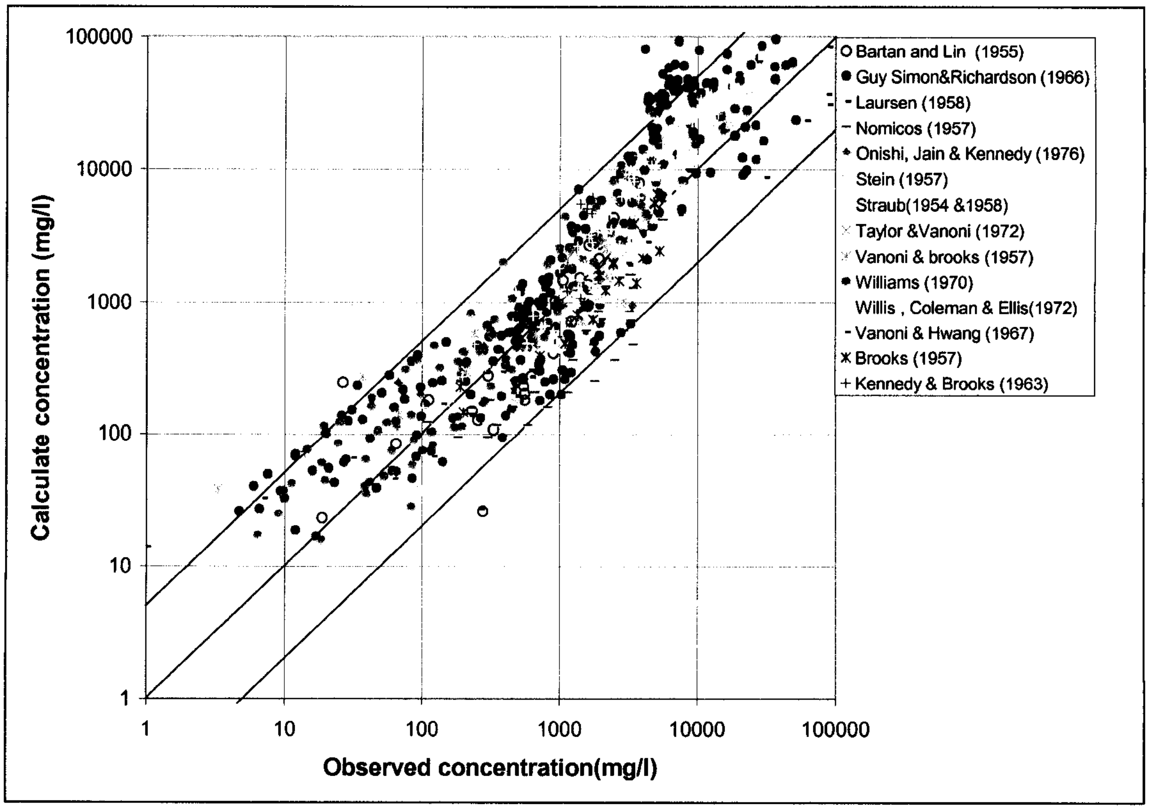

Figure 4.24: Computed vs. observed sediment transport to verify the new equation for flume data.

4.2.6 Summary

Table 4.11 and Figure 4.25 provide a summary of evaluations of sediment transport relationships. As would be expected, the relationships developed and calibrated specifically for the data yield a higher percentage in the discrepancy range (0.2 to 5) than that of the original equations from the literature. The difference between the verification percentage within the discrepancy range and the modified percentage within the discrepancy range was found to be less than 2%.

Table 4.11: Summary of evaluations of sediment transport relationships.

		Below	Above	Within	Mean Discrepancy
Shen and Hung (1971)	original	46.20%	0.00%	53.80%	0.366
	modified	2.00%	3.10%	94.90%	1.452
	verification	3.00%	4.80%	92.20%	1.63
Engelund and Hansen (1967)	original	8.20%	2.50%	89.30%	1.302
	modified	3.60%	2.00%	94.40%	1.369
	verification	1.30%	2.90%	95.80%	1.659
Yang (1973) combined	original	28.50%	0.20%	71.30%	0.600
	modified	2.00%	2.40%	95.60%	1.330
	verification	0.80%	3.20%	96.00%	1.479
Brownlie (1981) Equation (2.20)		10.90%	0.72%	88.40%	0.968
New Natural Channel	new	2.00%	1.60%	96.40%	1.248
	verification	0.60%	4.60%	94.80%	1.720
New Flume	new	0.00%	0.00%	100.00%	1.076
	verification	1.30%	6.20%	92.50%	1.870

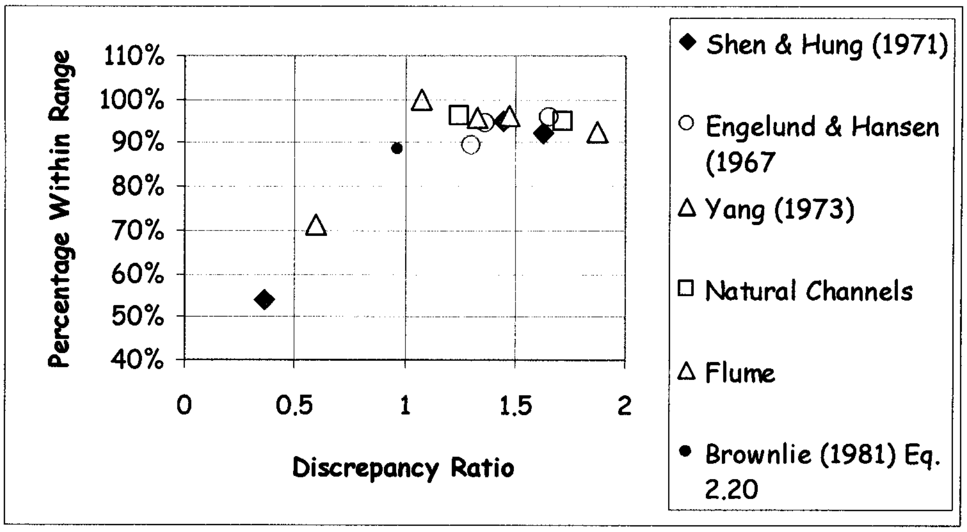

Figure 4.25: Plot summarizing sediment transport relationships.

The original equation predictions of sediment concentration fell within the discrepancy range between 53.8% and 89.3% of the total occurrences. Engelund and Hansen (1967) has the highest percentage (89.3%), with Brownlie (1981) very close at 88.4%. Brownlie's (1981) equation (Equation (2.20)) has a mean discrepancy ratio the closest to 1.00 (0.968), which is a better ranking, by this measure, than the new equation specifically developed for natural channels using this data set. On the basis of the percentage of predicted sediment transport concentration falling within a discrepancy range (0.2 to 5 times perfect agreement with observed data) and on the basis of the discrepancy ratio, Brownlie's (1981) equation (Equation (2.20)) was shown to be the appropriate choice for sand bed channels. Brownlie's (1981) relationship (Equation (2.8)) using the shape factor (β) to describe the relationship between mean sediment concentration and the concentration at mean depth was shown to be inappropriate for channel design. This was due to the data requirements for solving unknown coefficients and exponents (Equations (2.5) through (2.7)) and the lack of agreement of Brownlie's (1981) assumed $C/C(d)$ value of 1.43 with observed data.

Figure 4.26 shows that the modified relationships for Shen and Hung (1971), Engelund and Hansen (1967), Yang (1973), and the new natural channel equation exhibit a trend of decreasing sediment concentration with increasing width/depth ratio. Figure 4.27 indicates that the new flume relationship indicates a trend of increasing sediment concentration with increasing width/depth ratio.

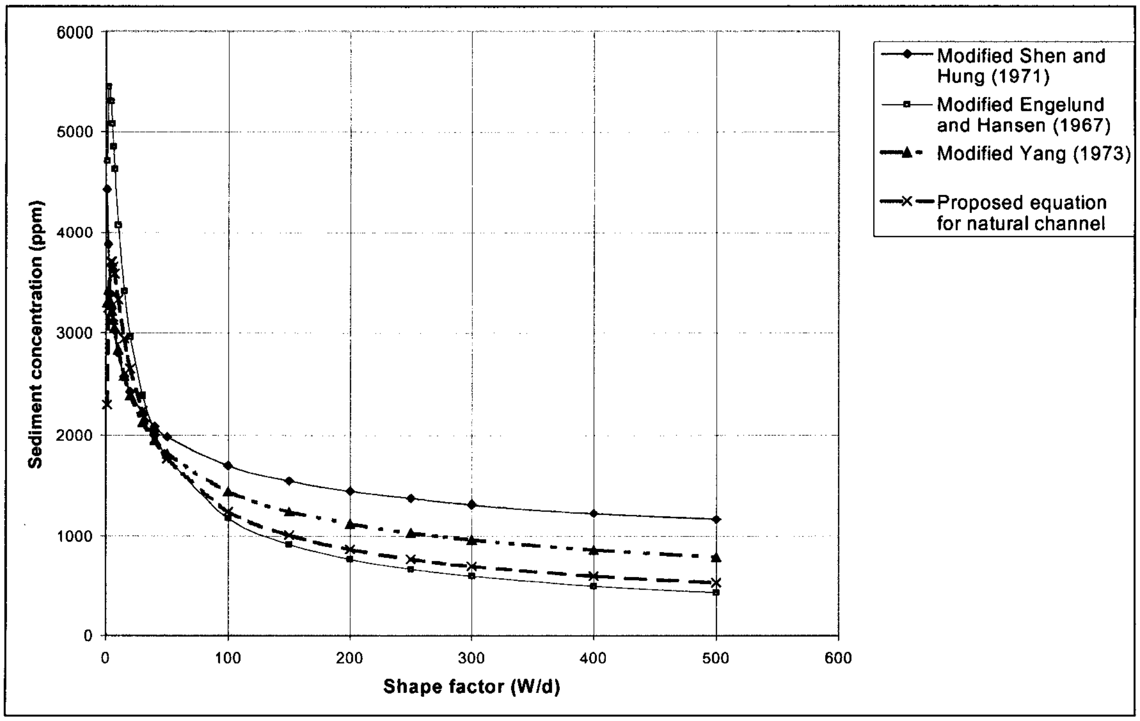

Figure 4.26: Trends from sediment transport relationships for natural channels.

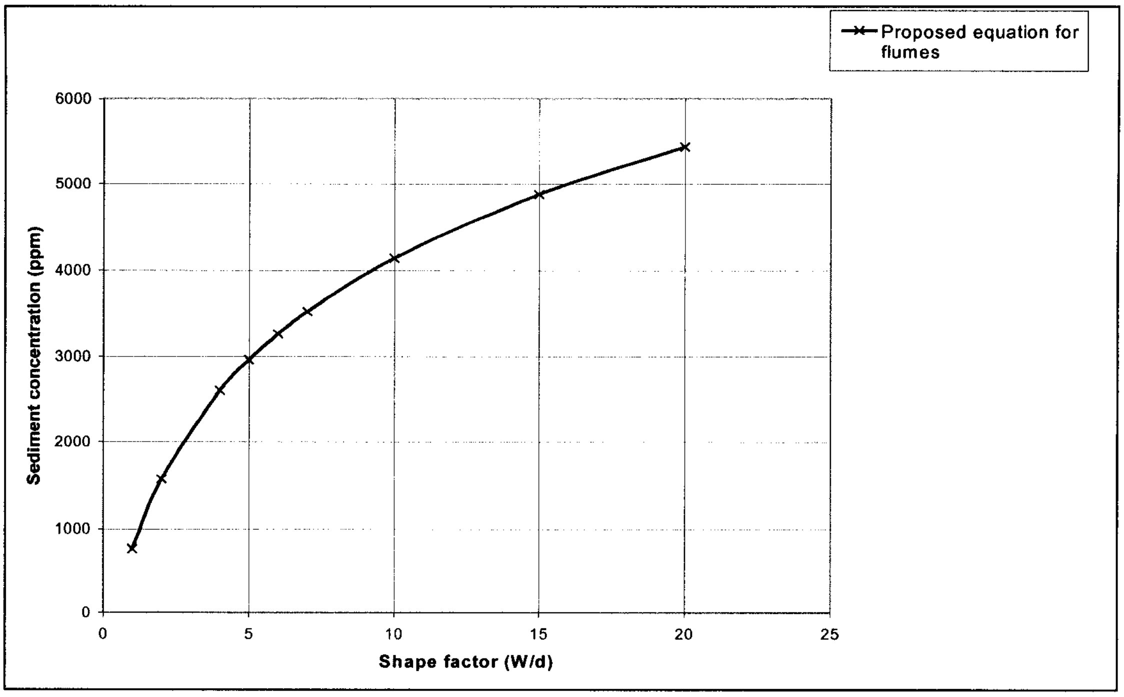

Figure 4.27: Trends from sediment transport relationships for flumes.

4.3 STABLE CHANNEL DESIGN

4.3.1 Engelund and Hansen (1967) Equation

$$C_w = 0.05\left(\frac{G}{G-1}\right)\frac{VS_f}{\left[(G-1)gd_s\right]^{1/2}}\left[\frac{R\,S_f}{(G-1)d_s}\right]^{0.5} \tag{4.33}$$

where C_w = weight concentration of sediment;

d_s = grain size;

S_f = friction slope;

R = hydraulic radius;

V = depth-average velocity;

g = gravitational acceleration; and

G = specific gravity of sediment.

A direct solution of Equation (4.33) is presented, which includes the width/depth ratio as an independent variable.

From continuity –

$Q = AV$ and $V = \dfrac{Q}{\psi d^2}$.

From the Manning equation –

$V = \dfrac{1}{n}R^{2/3}S_f^{1/2}$ and $R = \dfrac{\psi}{\psi+2}d$.

Substituting the values of V and R in Equation (4.33), yields:

$$C_w = 0.05\left(\frac{G}{G-1}\right)\frac{\dfrac{QS_f}{\psi d^2}}{\left[(G-1)gd_s\right]^{1/2}}\left[\frac{\dfrac{\psi d}{\psi+2}S_f}{(G-1)d_s}\right]^{0.5} \tag{4.34}$$

Substituting the values of V and R in the Manning equation yields:

$$\frac{Q}{\psi d^2} = \frac{1}{n}\left(\frac{\psi}{\psi+2}d\right)^{2/3} S_f^{\,1/2} \tag{4.35}$$

$$\psi d^2\left(\frac{\psi}{\psi+2}d\right)^{2/3} = \frac{Qn}{S_f^{\,1/2}} \tag{4.36}$$

$$d = \left[\frac{Qn}{S_f^{\,1/2}\psi(\frac{\psi}{\psi+2})^{2/3}}\right]^{3/8} = \left(\frac{Qn}{S_f^{\,1/2}}\right)^{3/8}\frac{(\psi+2)^{1/4}}{\psi^{5/8}} \tag{4.37}$$

$$C_w = 0.05\frac{G}{(G-1)^2}\left(\frac{Q^{7/16}Sf^{57/32}}{n^{9/16}g^{1/2}d_s}\right)\left(\frac{\psi^{7/16}}{(2+\psi)^{7/8}}\right) \tag{4.38}$$

Equation (4.38) is plotted as shown in Figure 4.28 to illustrate how Q_s changes with possible changes in the channel shape factor. The values of Q, S, and d_s are 100 m^3/s, 0.001, 1 mm, respectively. The maximum efficiency of the channel is at $(W/d) = 2$. Therefore, the Engelund and Hanson (1967) relationship combined with the maximum sediment transport-extremal hypothesis assumption yields a prediction that is much less than observed for either of the two benchmarks.

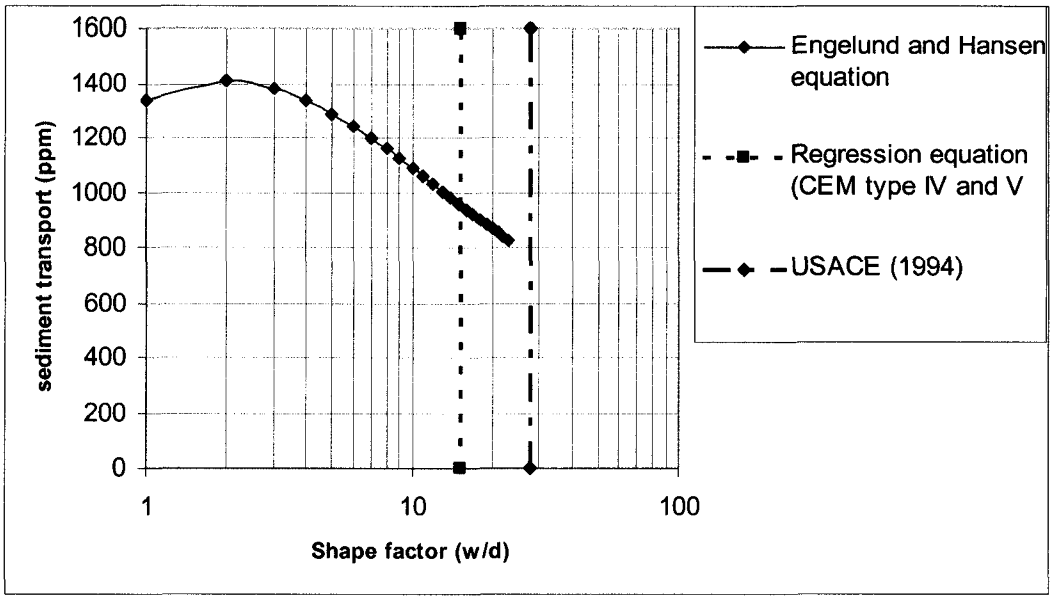

Figure 4.28: Shape factor (*W/d*) vs. sediment transport using Engelund and Hansen's (1967) equation ($Q = 100$ m^3/s, $S = 0.001$, $d_s = 1.0$ mm).

4.3.2 Yang (1973) Equations

An iterative procedure was required to evaluate Yang's (1973) equations for determination of channel shape. The following procedure was followed:

STEP 1: Assume values for channel shape factor (ψ) and channel width (W). Initially these should be a minimum and then increase in sequence.

STEP 2: Calculate the channel depth $\left(d = \dfrac{W}{\psi}\right)$ and the hydraulic radius $\left(R = \dfrac{\psi}{\psi + 2} d\right)$ for the rectangular cross section.

STEP 3: Calculate the average flow velocity from continuity using the trial $Q = AV$ and $V = \dfrac{Q}{\psi d^2}$.

STEP 4: Calculate the shear velocity $\left(u_* = \sqrt{gRS}\right)$.

STEP 5: Calculate the sediment transport:

For sand –

$$\log C_{ppm} = 5.435 - 0.286\log\frac{\omega d_s}{\nu} - 0.457\log\frac{u_*}{\omega} +$$

$$\left(1.799 - 0.409\log\frac{\omega d_s}{\nu} - 0.314\log\frac{u_*}{\omega}\right)\times\log\left(\frac{VS}{\omega} - \frac{V_c S}{\omega}\right) \qquad (2.16)$$

For gravel –

$$\log C_{ppm} = 6.681 - 0.633\log\frac{\omega d_s}{\nu} - 4.816\log\frac{u_*}{\omega} +$$

$$\left(2.784 - 0.315\log\frac{\omega d_s}{\nu} - 0.282\log\frac{u_*}{\omega}\right)\times\log\left(\frac{VS}{\omega} - \frac{V_c S}{\omega}\right) \qquad (2.17)$$

STEP 6: Calculate the flow discharge $\left(Q = \frac{1}{n}R^{2/3}S^{\ 1/2}(W.d)\right)$.

STEP 7: Compare the trial flow discharge (Step 3) and the resulting Q calculated, if these are not equal, apply the Goal Seek tool by changing the channel width. When convergence occurs between the trial Q and the calculated Q the calculations are correct for a single shape factor.

STEP 8: Repeat the procedure with a small incremental increase in shape factor until the maximum sediment transport is identified.

The results are shown in Figure 4.29 for sand and in Figure 4.30 for gravel. The maximum efficiency of the channel for both sand and gravel bed occurs at $W/d = 2$, even though the values of Q, d_s, and slope are changed. A $W/d = 2$ was defined by Yang (1981) as the theoretical width/depth ratio at minimum unit stream power. Therefore, using the Yang (1973) equations with the maximum sediment transport-extremal hypothesis assumption would produce a cross section much narrower than the benchmark methods.

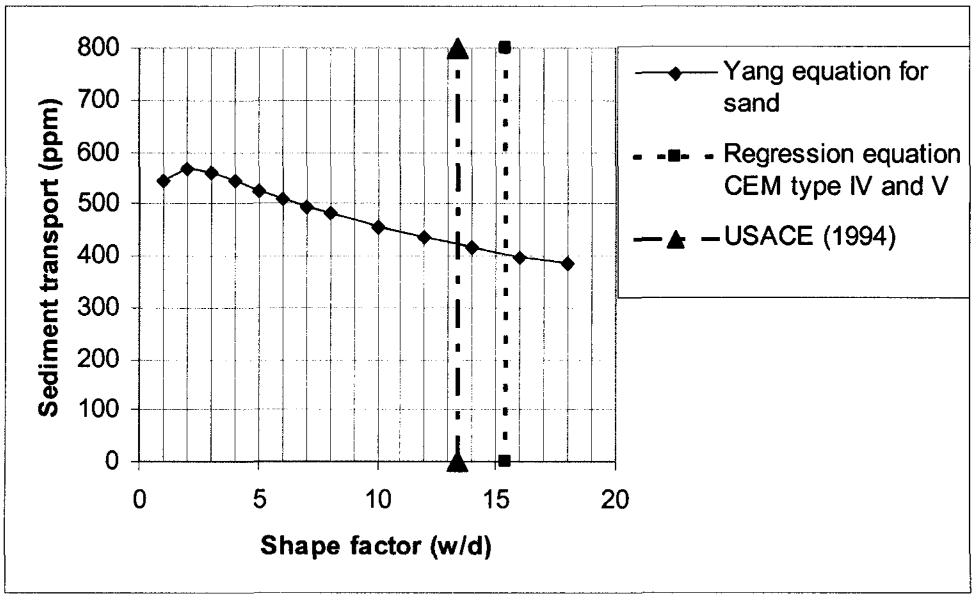

Figure 4.29: Shape factor (*W/d*) vs. sediment transport using Yang's (1973) equation for sand (Q = 10 m^3/s, S = 0.001, d_s = 1.0 mm).

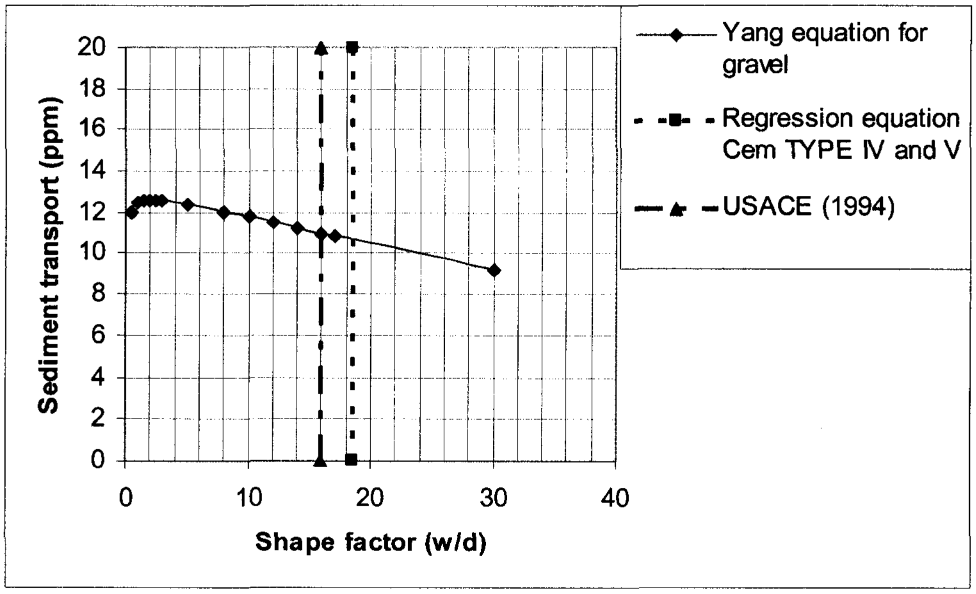

Figure 4.30: Shape factor (*W/d*) vs. sediment transport using Yang's (1973) equation for gravel (Q = 10 m^3/s, S = 0.001, d_s = 3 mm).

4.3.3 Shen and Hung (1971) Equation

An iterative procedure was required to evaluate the Shen and Hung (1971) equations for determination of channel shape. The subsequent procedure was followed:

STEP 1: Assume a channel shape factor (ψ) and channel width (*W*). Initially these should be a minimum and then increase in sequence.

STEP 2: Calculate the channel depth $\left(d = \dfrac{W}{\psi}\right)$ and the hydraulic radius $\left(R = \dfrac{\psi}{\psi + 2} d\right)$ for a rectangular cross section.

STEP 3: Calculate the average flow velocity from continuity using a trial $Q = AV$ and $V = \dfrac{Q}{\psi d^2}$.

STEP 4: Calculate the sediment transport:

$$\log C_{ppm} = -107404.459 + 324214747 S_h -$$

$$326309.589 S_h^{\ 2} + 109503.872 S_h^{\ 3} \qquad (2.12)$$

$$S_h = \left[\frac{VS^{0.57159}}{\omega^{0.31988}} \right]^{0.00750189} \qquad (2.13)$$

STEP 5: Calculate the flow discharge $\left(Q = \dfrac{1}{n} R^{2/3} S^{\ 1/2} (W.d)\right)$.

STEP 6: Compare the discharge (Step 3) and the resulting *Q* calculated (Step 5), and if these are not equal, apply the Goal Seek tool by changing the channel width. When there is convergence between the trial *Q* and the calculated *Q* the calculations are correct for a single shape factor.

STEP 7: Repeat the above procedure with a small incremental increase in shape factor until a maximum sediment transport rate is identified.

The result is shown in Figure 4.31 and the data indicate Shen and Hung's equation does not match either benchmark. The maximum transport efficiency of the channel occurs at *W/d* = 2, which is much less that the two benchmarks.

Also comparisons were made for stable channel design between Deboys (1879), Meyer-Peter and Müller (1948), and the USACE (1994), and the results are presented in Appendix A.

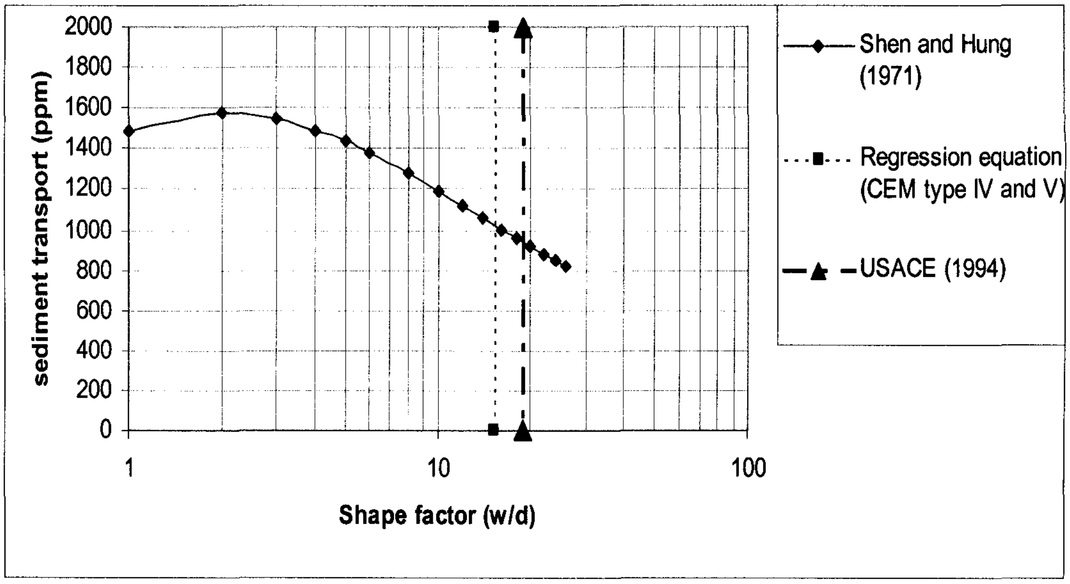

Figure 4.31: Shape factor (*W/d*) vs. sediment transport using Shen and Hung's (1971) equation (Q = 100 m^3/s, S = 0.001, d_s = 1 mm).

4.3.4 Brownlie (1981) Equation

Using Brownlie's (1981) equations for the lower and upper regimes, equations that govern water and sediment continuity, hydraulic resistance, and sediment transport were solved using the following iterative procedure in Microsoft Excel Goal Seek 2000:

STEP 1: Assume the channel shape factor (ψ) and channel width (W). Initially these should be a minimum and then increase in sequence.

STEP 2: Calculate the channel depth $\left(d = \frac{W}{\psi}\right)$ and the hydraulic radius $\left(R = \frac{\psi}{\psi + 2} d\right)$ for a rectangular cross section.

STEP 3: Calculate the average flow velocity from continuity $Q = AV$ and $V = \frac{Q}{\psi d^2}$.

STEP 4: Calculate the hydraulic radius associated with the bed using Brownlie equations:

For the upper regime –

$$R_b = 0.2836 d_{50} q_*^{0.6248} S^{-0.2877} \sigma^{0.0813} \tag{2.31}$$

For the lower regime –

$$R_b = 0.3742 d_{50} q_*^{0.6539} S^{-0.2542} \sigma^{0.1050} \tag{2.32}$$

where $q_* = \frac{Vd}{\sqrt{g d_{50}^3}}$.

According to Brownlie (1983), the upper regime occurs if $S > 0.006$ or if $F_g > 1.25 F_g^{\backslash}$, and the lower regime occurs if $F_g < 0.8 F_g^{\backslash}$, between these limits is the transition zone, and $F_g = \frac{V}{\sqrt{\left(\frac{\gamma_s - \gamma}{\gamma}\right) g d_{50}}}$

$F_g^{\backslash} = \frac{1.74}{S^{0.3333}}$.

STEP 5: Calculate the hydraulic radius of the side slope by applying Manning's equation:

$$R_s = \left(\frac{Vn_s}{S^{0.5}}\right)^{1.5} .$$

STEP 6: Calculate the total cross-sectional area (Einstein, 1950):

$$A = R_b P_b + R_s P_s$$

where A = total cross-sectional area;

P_b = perimeter of the bed; and

P_s = perimeter of the side slope.

STEP 7: Calculate:

Grain Reynolds number –

$$R_g = \frac{\sqrt{gd_s^{\,3}}}{\nu},$$

Grain Froude number –

$$F_g = \frac{V}{\sqrt{\left(\frac{\gamma_s - \gamma}{\gamma}\right) gd_{50}}},$$

Critical grain Froude number –

$$F_{go} = 4.596\tau_*^{\,0.5293} S^{-0.1405} \sigma^{-0.1606}$$

Critical dimensionless shear stress for initiation of motion –

$$\tau_{*o} = 0.22Y + 0.06(10)^{-7.7Y} ,$$

where $Y = \left(\sqrt{\frac{\rho_s - \rho}{\rho}} R_g\right)^{-0.6}$

STEP 8: Calculate the sediment transport:

$$C = 9022\left(F_g - F_{g0}\right)^{1.978} S^{0.6601}\left(\frac{R_b}{d_{50}}\right)^{-0.3301}$$

STEP 9: Calculate the flow discharge ($Q = A.V$), where A is calculated from Step 6 and V is calculated from Step 3.

STEP 10: Compare the trial flow discharge and the resulting Q calculated, if these are not equal, apply the Goal Seek tool by changing the channel width. When there is convergence between the trial Q and the calculated Q the calculations are correct for a single shape factor.

STEP 11: Repeat the above procedure with a small incremental increase in shape factor, and go through the process again until the maximum sediment transport is reached. Then plot the sediment transport vs. the shape factor.

Comparisons were made in this study for stable channel design among the USACE (1994) hydraulic geometric design, CEM Types IV and V, Simons and Albertson (1963), and Copeland (1999) procedures. The results are presented in Table 4.12. Figures 4.32 to 4.43 show examples of the design stable channel shape using the maximum sediment transport-extremal hypotheses approach for the lower regime and at low and high sediment concentrations.

This new method for the design of stable channels could be applied for the flow at lower and upper regimes. Figures 4.44 and 4.45 show the relationship between maximum sediment transport and shape factor for the upper regime. The flow discharge (Q), bed slope (S), and bed material grain size (d_s) are values as given in each figure caption.

Table 4.12: Comparisons between the results of this study with those of other investigators at low and high sediment concentration.

Example and Parameters	Method	W (m)	d (m)	S	W/d
Example No. 1 Low sediment concentration Given data: $Q = 30\ \mathrm{m^3/s}$ $S = 0.00025$ m/m $d_s = 0.15$ mm $C = 220$ ppm	Copeland (1999) Procedure	13.55	2.72	0.000186	4.98
	Simons and Albertson (1963)	28.64	2.34	0.000139	12.2
	USACE (1994) Design Charts	26.8	2.07	0.00022	11.5
	CEM IV and V	23.29	1.92	0.00025	12.1
	This Research	22.03	1.85	0.00025	11.85
Example No. 2 Low sediment concentration Given data: $Q = 50\ \mathrm{m^3/s}$ $S = 0.00015$ m/m $d_s = 0.10$ mm $C = 158$ ppm	Copeland (1999) Procedure	18.2	3.55	0.000111	5.12
	Simons and Albertson (1963)	36.98	2.82	0.000115	13.11
	USACE (1994) Design Charts	34.57	2.59	0.00019	13.3
	CEM IV and V	30.47	2.59	0.00015	11.77
	This Research	29.59	2.43	0.00015	12.2
Example No. 3 High sediment concentration Given data: $Q = 15\ \mathrm{m^3/s}$ $S = 0.002$ m/m $d_s = 0.4$ mm $C = 2{,}025$ ppm	Copeland (1999) Procedure	6.6	1.65	0.00146	4.0
	Simons and Albertson (1963)	20.25	1.83	0.000037	11.07
	USACE (1994) Design Charts	18.9	1.77	0.00023	10.714
	CEM IV and V	11.99	1.02	0.002	11.73
	This Research	11.51	1.055	0.002	10.94
Example No. 4 High sediment concentration Given data: $Q = 10\ \mathrm{m^3/s}$ $S = 0.0015$ m/m $d_s = 0.20$ mm $C = 1{,}902$ ppm	Copeland (1999) Procedure	5.85	1.48	0.00122	3.95
	Simons and Albertson (1963)	16.53	1.58	0.000039	10.46
	USACE (1994) Design Charts	15.46	1.46	0.00025	10.57
	CEM IV and V	10.19	0.97	0.0015	10.53
	This Research	10.40	0.93	0.0015	11.20

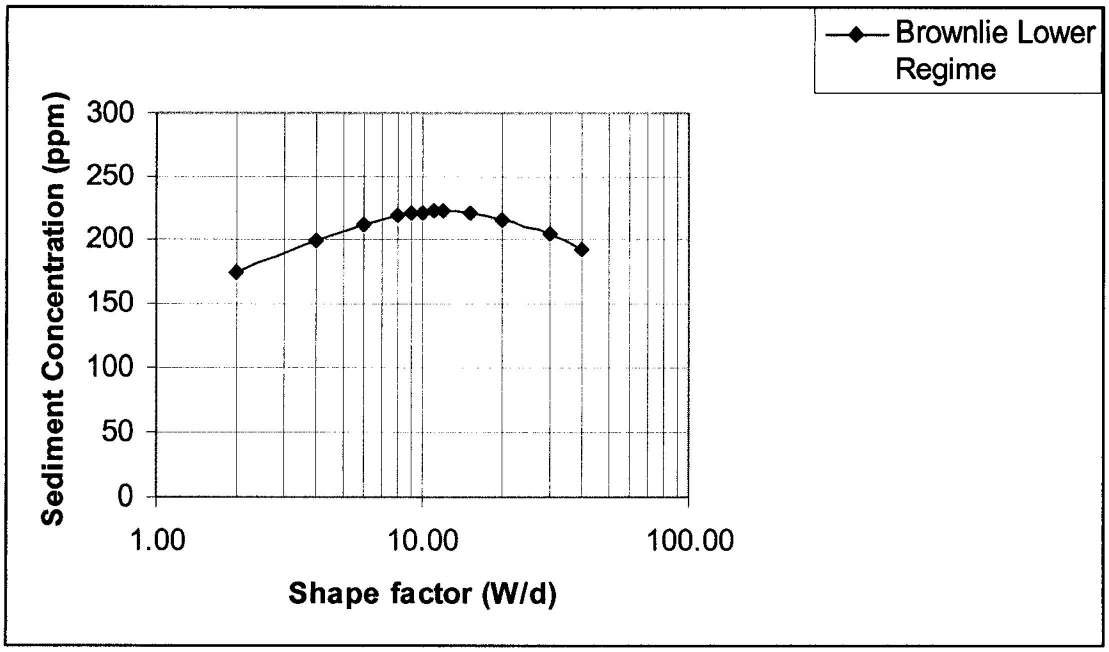

Figure 4.32: Shape factor (*W/d*) vs. sediment transport using Brownlie's (1981) equation for the lower regime for Example No. 1.

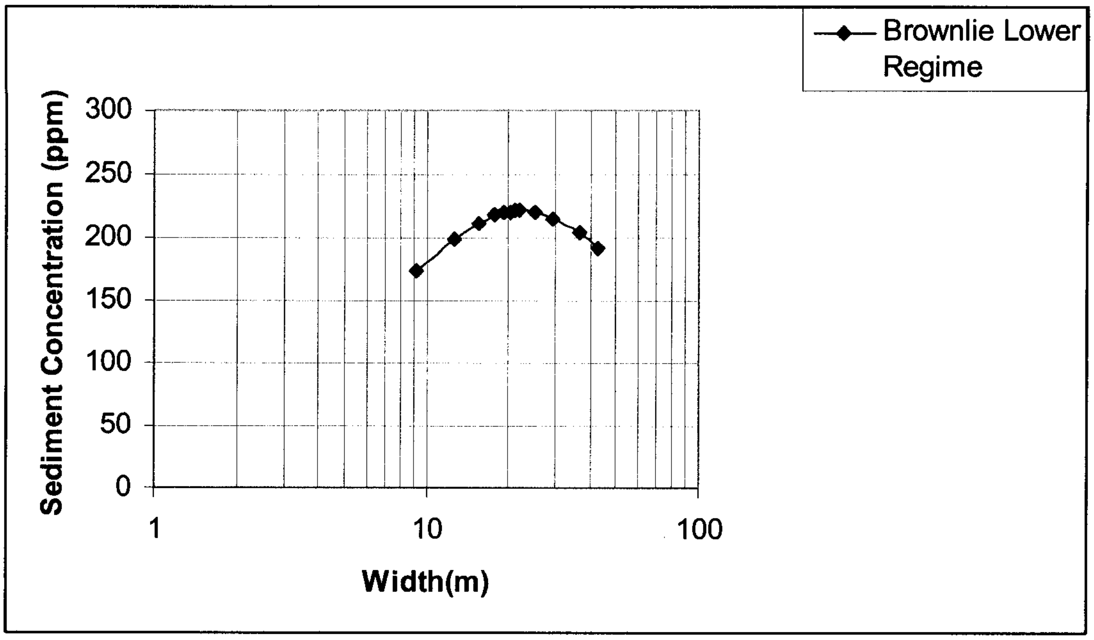

Figure 4.33: Width vs. sediment transport using Brownlie's (1981) equation for the lower regime for Example No. 1.

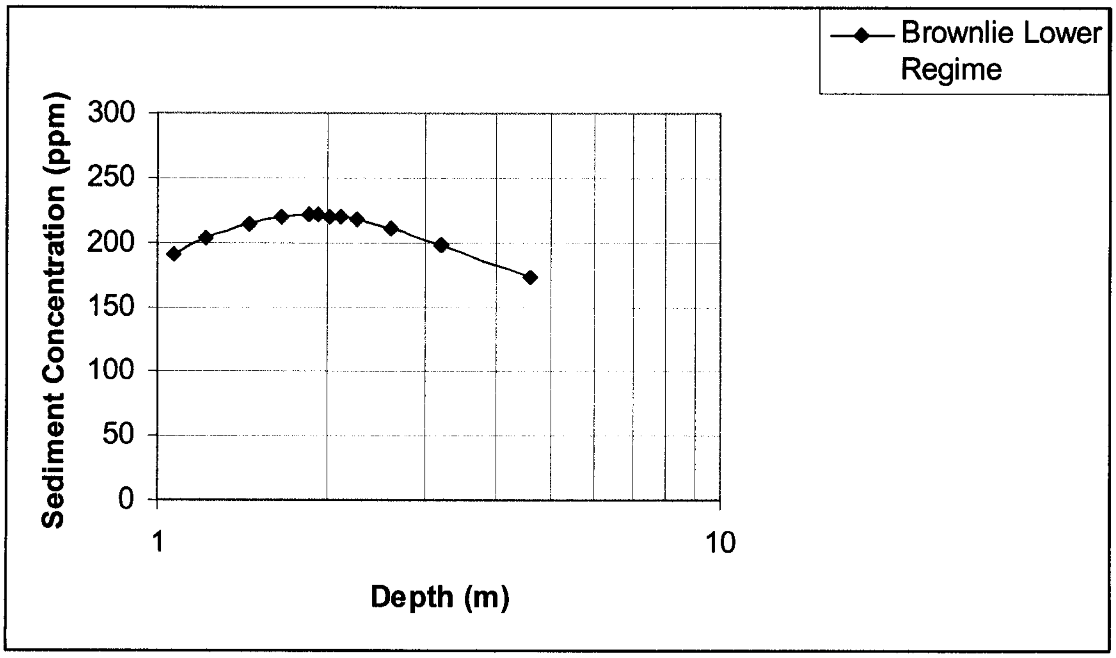

Figure 4.34: Depth vs. sediment transport using Brownlie's (1981) equation for the lower regime for Example No. 1.

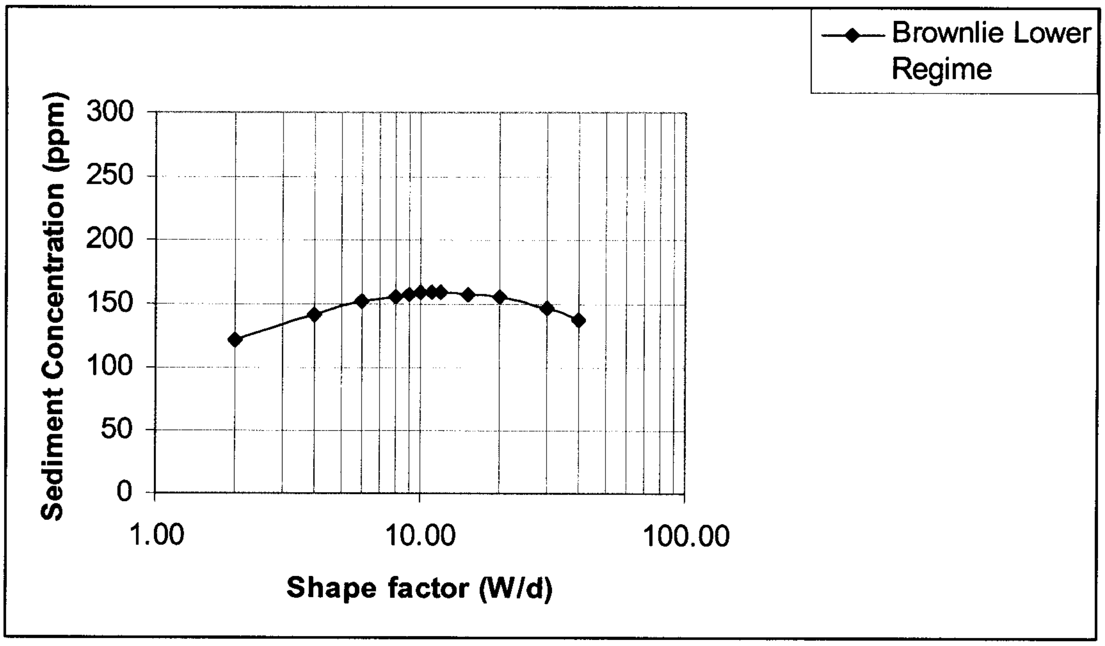

Figure 4.35: Shape factor (*W/d*) vs. sediment transport using Brownlie's (1981) equation for the lower regime for Example No. 2.

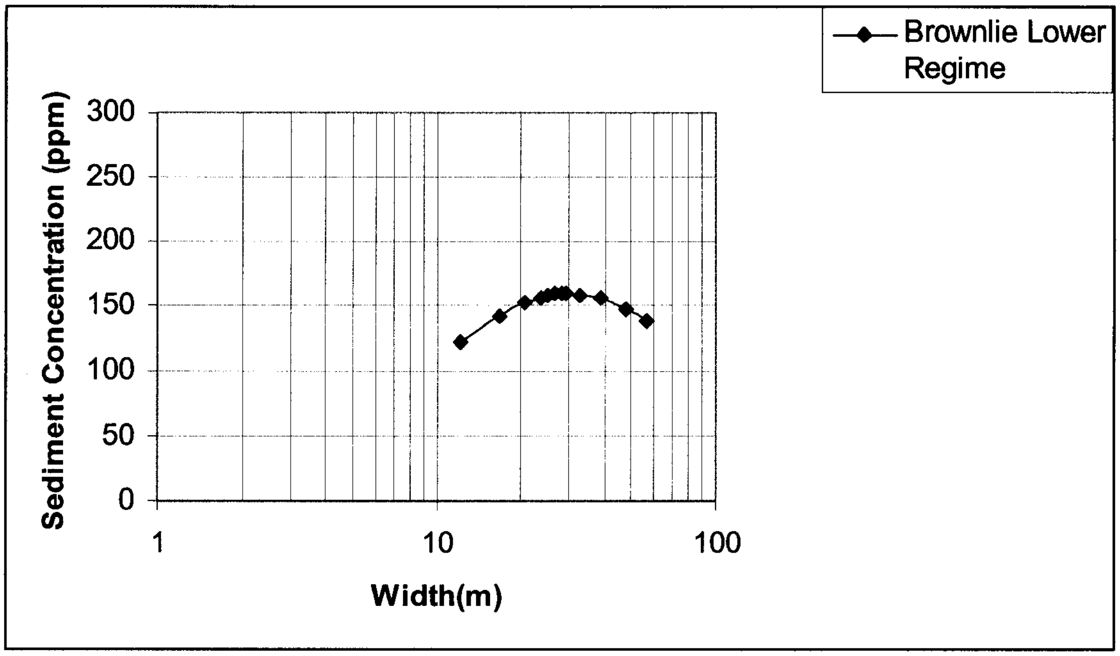

Figure 4.36: Width vs. sediment transport using Brownlie's (1981) equation for the lower regime for Example No. 2.

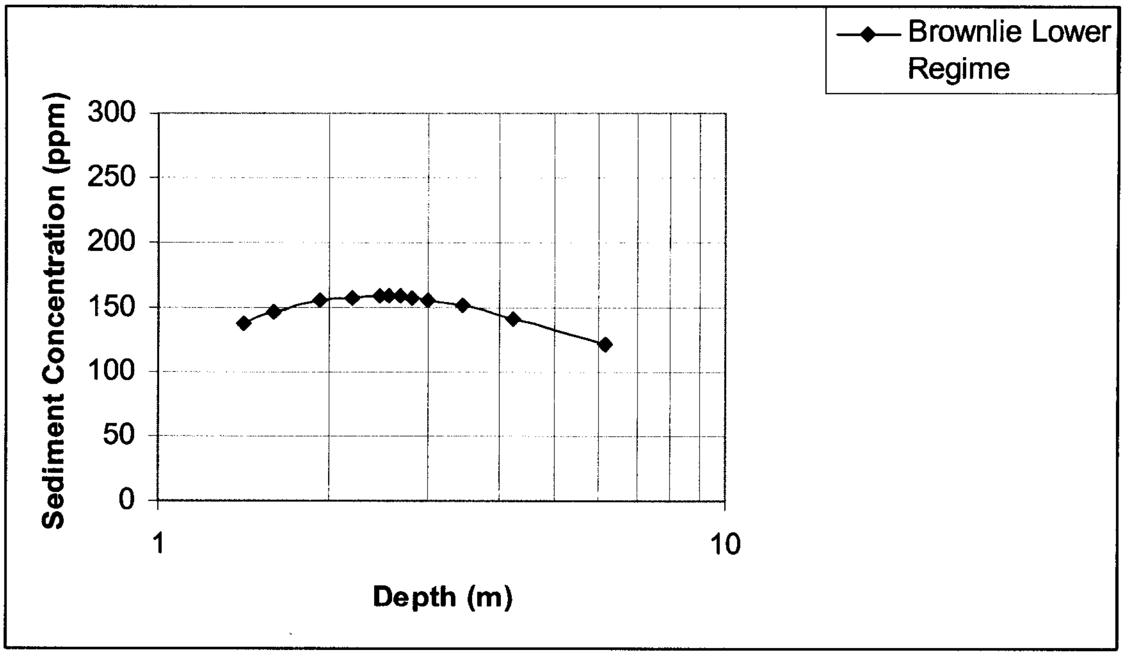

Figure 4.37: Depth vs. sediment transport using Brownlie's (1981) equation for the lower regime for Example No. 2.

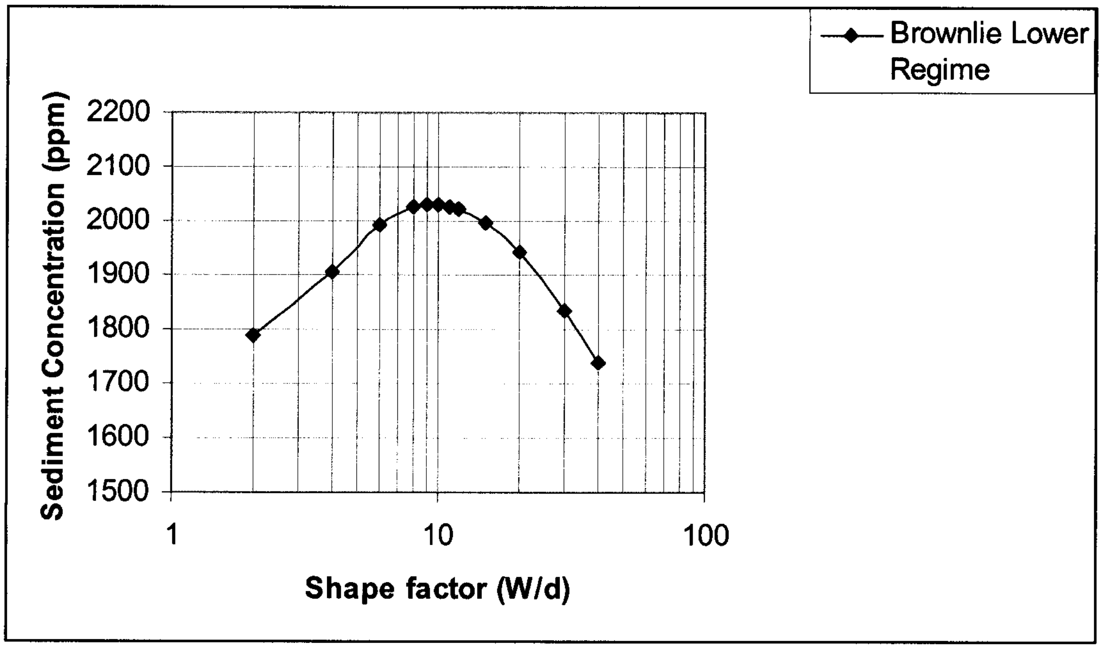

Figure 4.38: Shape factor (*W/d*) vs. sediment transport using Brownlie's (1981) equation for the lower regime for Example No. 3.

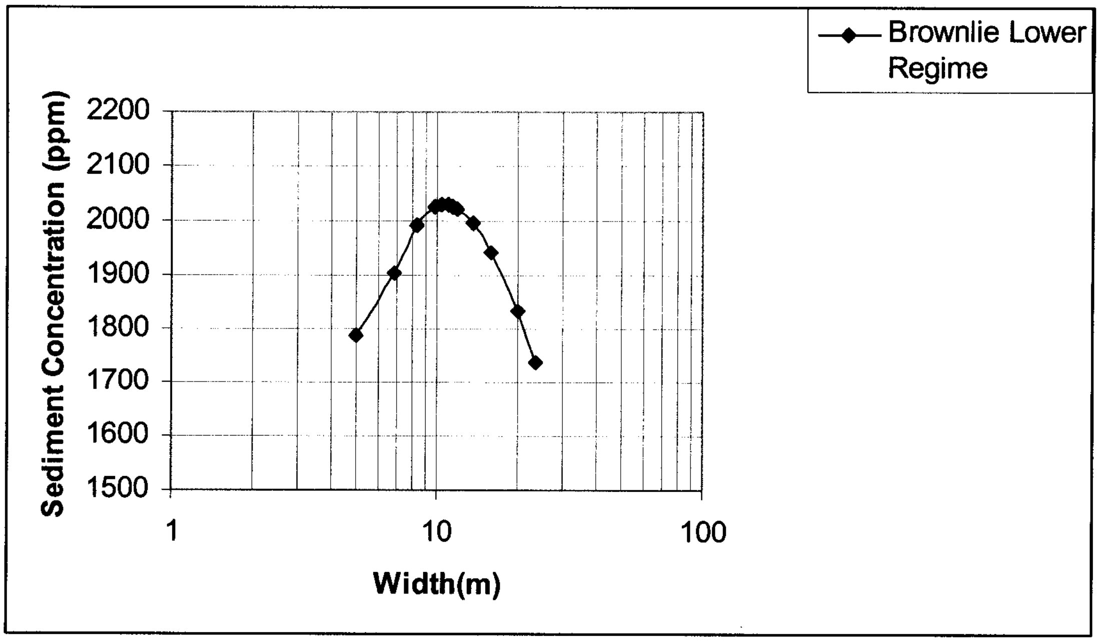

Figure 4.39: Width vs. sediment transport using Brownlie's (1981) equation for the lower regime for Example No. 3.

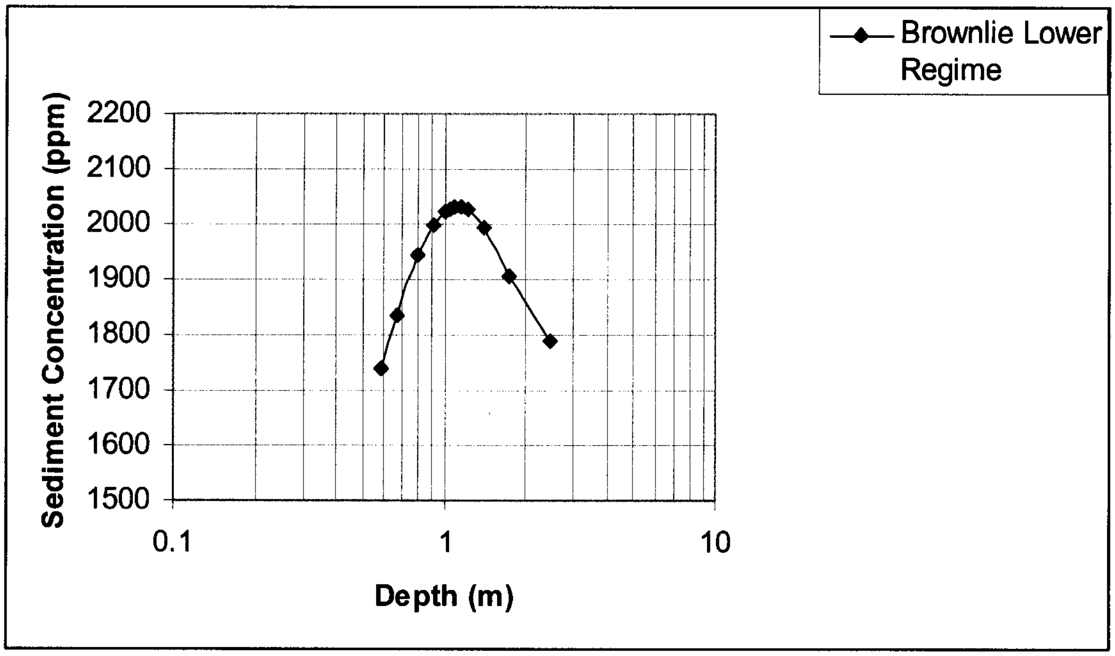

Figure 4.40: Depth vs. sediment transport using Brownlie's (1981) equation for the lower regime for Example No. 3.

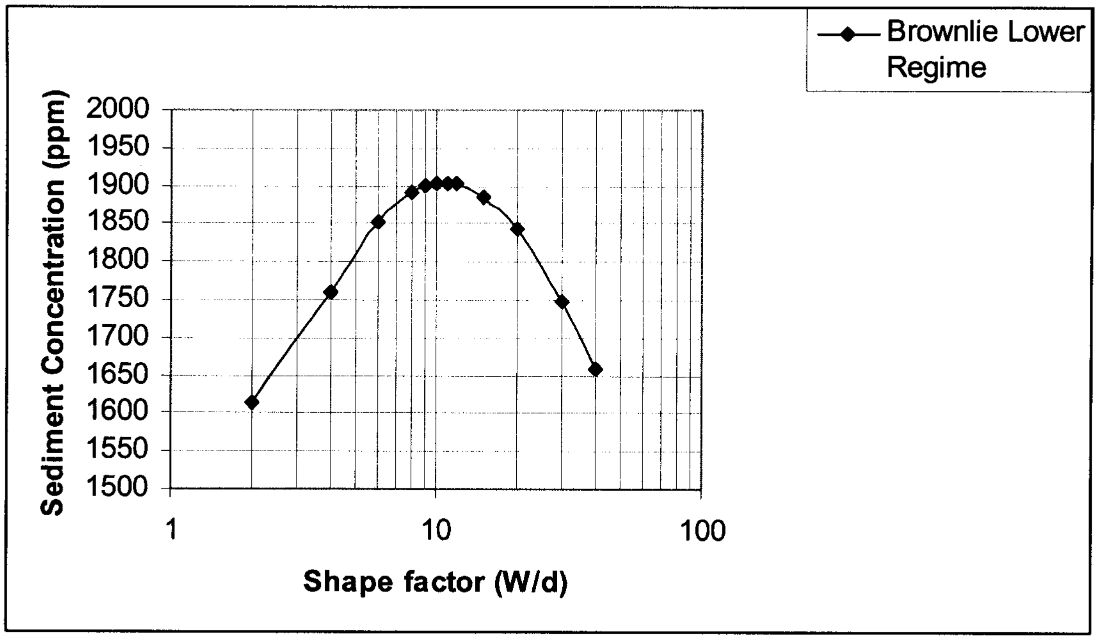

Figure 4.41: Shape factor (*W/d*) vs. sediment transport using Brownlie's (1981) equation for the lower regime for Example No. 4.

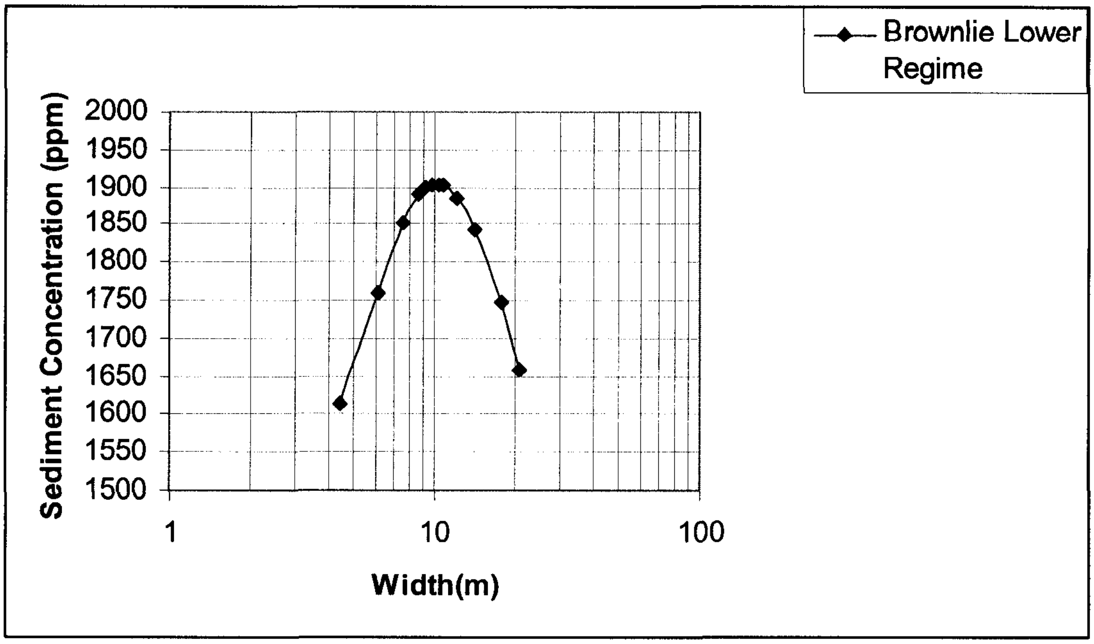

Figure 4.42: Width vs. sediment transport using Brownlie's (1981) equation for the lower regime for Example No. 4.

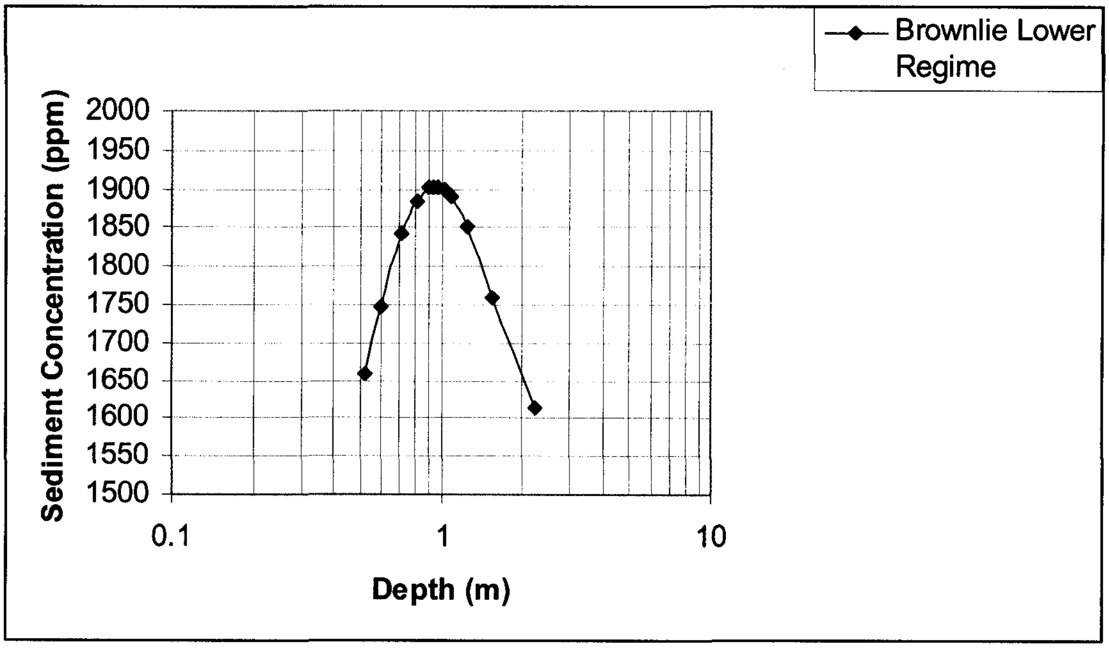

Figure 4.43: Depth vs. sediment transport using Brownlie's (1981) equation for the lower regime for Example No. 4.

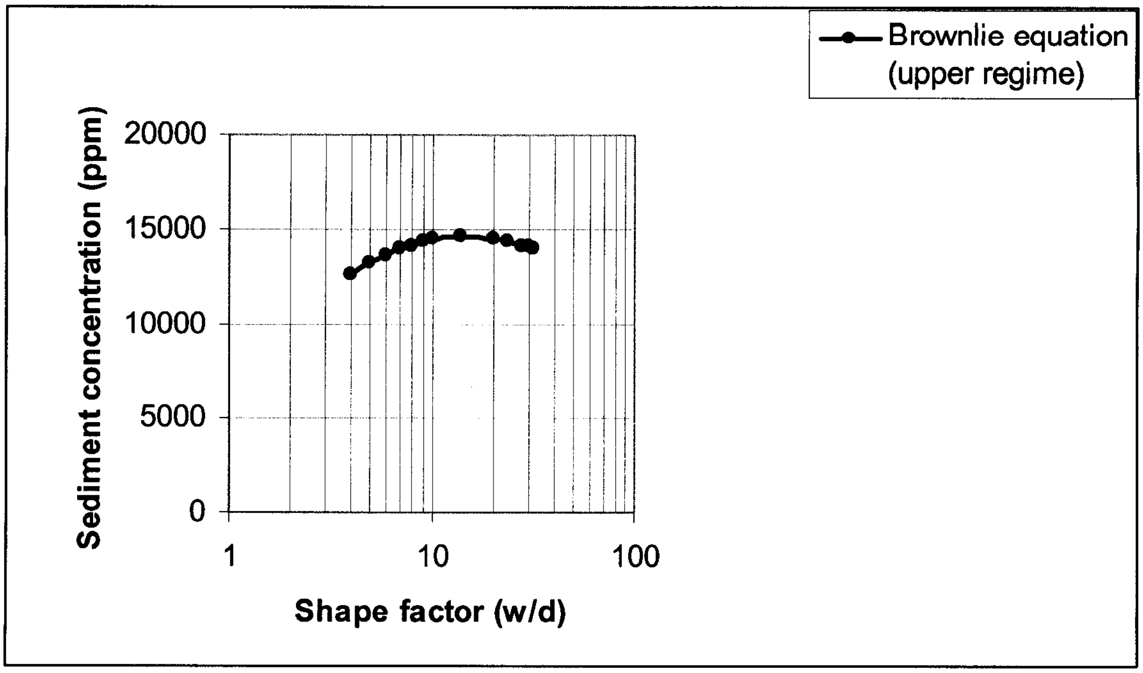

Figure 4.44: Shape factor (W/d) vs. sediment transport using Brownlie's (1981) equation for the upper regime ($Q = 100$ m^3/s, $S = 0.007$, $d_s = 2$ mm).

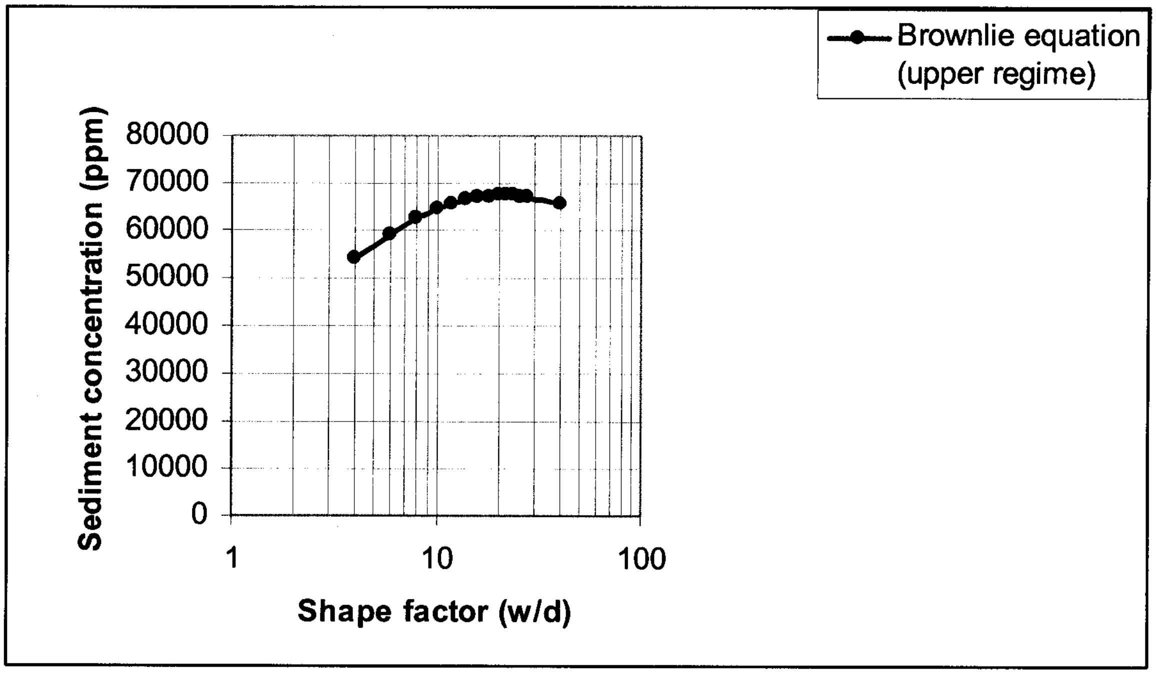

Figure 4.45: Shape factor (W/d) vs. sediment transport using Brownlie's (1981) equation for the upper regime ($Q = 50$ m^3/s, $S = 0.008$, $d_s = 0.3$ mm).

Table 4.12 provides the results of four examples comparing the maximum sediment transport-extremal hypothesis assumption stable channel design procedure with four other stable channel design procedures: Copeland (1999) is a minimum slope extremal hypothesis procedure; Simons and Albertson (1963) is a regime procedure; USACE (1994) is a regime design procedure; and the incised channel CEM Types IV and V hydraulic geometry relationships. Discharge in the four examples ranged from 10 to 50 cubic meters per second (cms), slope ranged from 0.00015 to 0.002, and sand was transported at concentrations ranging from 158 to 2,025 ppm.

For two examples (No. 1 and No. 2), in which the concentration was less than 500 ppm, the procedure developed in the present research was within 1% for Example No. 1 and within 7% for Example No. 2 of the average width/depth ratio of the regime and hydraulic geometry regression methods. The Copeland (1999) procedure was 58% too low for Example No. 1 and 61% too low for Example No. 2 as compared to the average width/depth ratio of the regime and hydraulic geometry regression methods. Slope differences are minor between the USACE (1994), the incised channel hydraulic geometry regression, and the present research. Copeland (1999) predicts widths that are about half than that predicted by the other methods.

In Examples No. 3 and No. 4, sediment concentration and slope are an order of magnitude greater. The sediment concentration is 3 and 4 times greater than the upper limit suggested by the original authors for the USACE (1994) and Simons and Albertson (1963). Although not strictly applicable, the two regime procedures are utilized for comparison. For Examples No. 3 and No. 4, the USACE (1994) regime method and the Simons and Albertson (1963) method predict slopes that are much lower than either the

Copeland (1999) method or the present research. The incised channel hydraulic geometry method is in close agreement with the present research method for all parameters in both examples. For two examples (No. 3 and No. 4) the present research was within 2% for Example No. 3 and within 2% for Example No. 4 of the average width/depth ratio of the regime and hydraulic geometry regression methods. The Copeland (1999) procedure was 64% too low for Example No. 3 and 65% too low for Example No. 4 as compared to the width/depth ratio of the regime and hydraulic geometry regression methods.

The conclusions that are evident from these four examples is that the Copeland (1999) procedure consistently predicts a narrower channel than any of the other methods. At low sediment concentrations the regime, hydraulic geometry, and the method of the present research closely agree. As the concentration increases, the regime methods are not applicable, which is consistent with the original author's recommendations. The incised channel hydraulic geometry procedure and the present research method agree for high and low concentrations, which can be explained by the broad range of sediment concentration for the stream used in developing the CEM Types IV and V regression. The present research performs well for all four examples.

CHAPTER 5
SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The uncertainties associated with the variation of the physical characteristics of natural rivers, limited sample data, and inherent measurement errors will cause uncertainty in the parameters that describe the channel (Gates et al., 1998). The statistical characterization used in this study aids in quantification of those uncertainties and of channel cross-section geometry.

5.1 SUMMARY

5.1.1 Incised Channel Analysis

The DEC Project data presented in Appendix C was used to develop several regression relationships for incised channels (CEM Type IV or V). The shape factor that was developed for downstream hydraulic geometry regression analysis of CEM Types IV and V incised channel data is $\psi = 29.39S^{-0.114}d_s{}^{0.206}$. The effect of discharge on the shape factor is negligible. This result agrees with Ackers (1964) (Equation (2.2)). The physical meaning of this equation is that small slopes and coarse grain sizes produce large width/depth ratios, and steep slopes and fine grain sizes produce small width/depth ratio. The shape factor (*W/d*) is directly proportional to the bed material size and inversely proportional to the slope. These results appear to be in agreement with Schumm (1960); however, Schumm (1960) is based on the percentage of silt and clay in the perimeter, which includes forces and channel responses that are gravity-driven mass wasting, and not hydraulic processes.

Two regression equations were developed for the hydraulic geometry for top width and mean depth with 95% upper and lower confidence interval for incised channels (CEM Types IV and V) in the DEC Project (Equations (4.6) and (4.7)). There were minor differences between the exponents of flow discharge and channel slope between this study and Huang and Warner (1995), Huang and Nanson (1995, 1998), and Julien and Wargadalam (1995), as presented in Table 4.3 in Chapter 4.

The downstream hydraulic geometry for DEC Project data (Equations (4.3) and (4.4)) were compared with Julien and Wargadalam's (1995) downstream hydraulic geometry equations for flow depth and width, and was previously presented in Chapter 2 as:

$$d = 0.20 Q^{\frac{2}{6m+5}} d_s^{\frac{6m}{6m+5}} S^{\frac{-1}{6m+5}} \tag{2.3a}$$

$$W = 1.330 Q^{\frac{4m+2}{6m+5}} d_s^{\frac{-4m}{6m+5}} S^{\frac{-(2m+1)}{6m+5}} \tag{2.3b}$$

where $m = \dfrac{1}{\ln \dfrac{12.2d}{d_s}}$;

Q = (m^3/s); and

d_s = d_{50} (m).

As shown in Figure 4.1 there is a reasonable agreement (for regression depth) between the result of this study and Julien and Wargadalam's (1995) results; however, the regression yields channel width less than Julien and Wargadalam's results, as shown in Figure 4.2. The results of the incised channel data analysis were compared with Huang and Nanson's (2000) downstream hydraulic geometry equations, and the regression depth and width equations yielded greater channel depth and width than for Huang and Nanson's results.

A total of 1,026 data sets (Appendices D and F) for 17 rivers and canals were compared with the downstream regression relationships for width and depth developed from DEC data. The results indicated that 27% of the data were less than the acceptable range (0.5 to 2) for width and 23% of the data were more than the acceptable range for depth. This indicated that downstream regression DEC relationships for width and depth are not generally applicable for large rivers. These results were expected, since DEC regression equations are for incised channels where the width/depth ratio was significantly affected by erosion-resistant clay bank channels.

Data from Abiaca Creek were used to develop several at-a-station regression equations. The mean average of these regression equations results in a proposed regression channel geometry equation in which $\psi = 126.05Q^{-0.49}$.

5.1.2 Sediment Transport Equations

It was found that Shen and Hung (1971) and Yang (1973) underestimated the sediment transport prediction. Engelund and Hansen's (1967) and Brownlie's (1981) equations gave better estimates of sediment transport prediction than the previous two relationships. Shape factor (*W/d*) was included in three existing sediment transport equations: Shen and Hung (1971), Yang (1973) for sand and gravel, and Engelund and

Hansen (1967). The modified Shen and Hung (1971) equation (Equations (4.17) and (4.18)) and the modified Engelund and Hansen (1967), Table 4.5, indicate that the width/depth ratio is less important than channel slope and settling velocity (or grain size) in the prediction of sediment transport.

A new equation was suggested, based on the effect of the cross-section geometry on sediment transport for natural channels. The sediment transport (C_{ppm}) in the new equation for natural channels is a function of ψ ,F_g,$\frac{d}{d_s}$, and $\frac{u_*}{\omega}$. These dimensionless variables were chosen according to the *P*-value by using Microsoft Excel linear regression. The *P*-value for *W/d* in Table 4.8 is very low (4.48E^{-16}), which indicates the *W/d* had a significant effect on the sediment transport in the new equation (Equation (4.30)). The new equation performs well, as shown in Figure 4.20. The coefficient of the shape factor in Equation (4.30) is –0.205, which indicates that as *W/d* increases the sediment transport decreases.

The sediment transport ($C_{mg/l}$) in the new equation (for the flumes) is a function of ψ, $\frac{\omega d_s}{v}$,F_g,$\frac{d}{d_s}$, $\frac{u_*}{\omega}$, f. These variable were chosen according to the *P*-value using Microsoft Excel linear regression. The *P*-value for *W/d* for the new flume equation in Table 4.10 is equal to 1.26E10^{-7}, and is less than the value of significance level, which indicates the *W/d* has a significant effect on the sediment transport in the new Equation (4.32). The trends of the sediment transport relationships (Engelund and Hansen, 1967; Yang, 1973; Shen and Hung, 1971; and the new equation for natural canals, Equation (4.30)) show that the sediment transport decreases as the width/depth ratio increases as shown in Figure 4.24, and the sediment transport relationship for flumes shows that the sediment transport increases as the width/depth ratio increases, as shown in Figure 4.25.

The coefficients necessary to utilize the Brownlie (1981) approach (Equation (2.8)) were found by applying nonlinear regression analysis on available field data sets of the Colorado River, the Mississippi River at St. Louis, and the Red River using Equations (2.5), (2.6), and (2.7). After finding the coefficients b_1, b_2, and b_3, Microsoft Mathcad 2000 was used to find the ratio between sediment concentration and the concentration from the mean depth ($C/C(d)$). This ratio was plotted against the shape factor (β). The results were compared with Brownlie's (1981) recommendation: $\beta = 1.53$ and $C/C(d) = 1.43$ (Figure 2.2, Chapter 2 and Figure 4.20, Chapter 4). Actual values of β computed in this study (0.22 for the Colorado River, 2.29 for the Mississippi River at St. Louis, and 2.638 for theRed River) yield $C/C(d) = 1.03$ for the Colorado River, $C/C(d) = 1.45$ for the Mississippi River at St. Louis, and $C/C(d) = 1.72$ for the Red River. As a result, Brownlie's conclusion that an irregular cross section should be 43% higher in sediment transport than the laboratory measurements is inconsistent with the findings of the present research.

The Brownlie transport equation (Equation (2.20)) was, however, found to be the best choice for computing sand transport in streams on the basis of the discrepancy ratio and percentage of predictions of sediment concentration within the allowed discrepancy range.

5.1.3 Stable Channel Design

Several sediment transport relationships were used to design stable channel cross-section geometry. These are Duboys (1879) and Meyer-Peter and Müller (1948) for excess shear sediment transport equations; Engelund and Hansen (1967) and Yang (1973) for sand and gravel for stream power equations, and Shen and Hung (1971), and Brownlie (1981) equations for lower and upper regime. Engelund and Hansen (1967), Yang (1973) for sand and gravel, and Shen and Hung (1971) showed that the maximum sediment concentration occur at a very low width/depth ratio, which seldom occurs in natural alluvial channel systems. A comparison was made between Duboys (1879), Meyer-Peter and Müller (1948), and the USACE (1994) regime charts, which indicated that both equations provide reasonable prediction in comparison to the USACE method for *W/d* in gravel channels.

A new method for stable channel design was presented to design a stable channel cross-section geometry based on an analytical approach using an extremal hypothesis assumption based on maximum sediment transport hypotheses. The results obtained by this method were compared with hydraulic geometry charts (USACE, 1994; Simons and Albertson, 1963; Copeland, 1999) for width, depth, and slope. Good agreement was found among the new procedure, USACE (1994), and Simons and Albertson (1963), for channels with fine sand and low sediment concentration (<500 ppm). At high sediment concentration, USACE (1994) and Simons and Albertson (1963) methods are not applicable. At high and low sediment concentration, the width/depth ratio predicted by Copeland (1999) is too narrow as compared to a natural channel, and is less than the value of width/depth ratio obtained from the present study.

5.2 CONCLUSIONS

This research addressed the development of:

- a data base to evaluate the prediction worthiness of several sediment transport functions;
- evaluations of those functions;
- the effect of a width/depth ratio (*W/d*) on sediment transport;
- the utilization of the sediment transport functions; and
- an extremal hypothesis assumption to develop an analytical stable channel design methodology for alluvial streams that may be transporting moderate to high concentrations of sediment.

Primary conclusions are presented in the following paragraphs.

Table 4.11 indicates that the Shen and Hung (1971) and Yang (1973) relationships did not predict sediment transport concentrations as well as the relationships by Engelund and Hanson (1967) and Brownlie (1981). This result is based on analysis of 1,026 data sets (Appendices D and E) from 17 natural rivers and canals. The ranges of these data are presented in Table 3.2. The results of modified existing sediment transport equations and the new sediment relationship show that the width/depth ratio has a role less important than the role of flow velocity, channel slope, and grain size in prediction of the sediment transport. The trends from sediment transport relationships showed that the sediment transport decreases as *W/d* increases for natural channels and sediment transport increases as *W/d* increases for flumes.

The Shen and Hung (1971), Yang (1973), and Engelund and Hansen (1967) sediment transport concentration prediction relationships were shown to be inappropriate for prediction of the maximum sediment concentration at a realistic channel width/depth ratio (extremal hypothesis). The width/depth ratios predicted by these methods were too narrow (*W/d* = 2) as compared to the non-cohesive alluvial channels. For DEC channels using regression CEM relationships, the range of optimum width/depth ratio was found to be 9.8 to 15.1. The regression CEM relationships were applicable for alluvial channels with top widths <50 m and generally were not applicable for large rivers.

The Brownlie (1981) sediment transport concentration relationship was shown to be the appropriate choice for use with extremal hypothesis assumption. An analytical channel design method for alluvial channels was tested against existing hydraulic geometry relationships, and the width/depth ratio was shown to agree with observed width/depth ratios for DEC streams. Without an analytical prediction technique, most of the predictions of channel cross-section geometry have been based on regime or hydraulic geometry relationships that are usually based on low sediment concentration, stable streams. The analytical channel design procedure that was developed in this research does not require the use of regime or hydraulic geometry relationships, and can be used to design stable channels for a wider range of sediment concentrations.

5.3 RECOMMENDATIONS FOR FUTURE RESEARCH

In using the extremal hypothesis assumption, Copeland et al. (2001) cautioned that field experience indicates that channels may be stable over a range of dependent variables that are not found as solutions for extremal conditions. As suggested in Chapter 2, research (Schumm, 1960; Hey and Thorne, 1986) provides ample evidence of the effect of boundary materials and vegetation influencing the shape of the channel. Millar and Quick (1993, 1998) have proposed methods to include mass wasting of streambanks for gravel bed rivers, that incorporate geotechnical and erosional properties of the bank material. Additional research should be conducted to include the effects of different cohesive and granular bank materials, vegetation, and a variety of bank stabilization methods. Elevated shear stress through bends should also be considered.

Another caution from Copeland et al. (2001) is that extremal hypothesis methods may have low sensitivity to independent variables. No quantification of the relative sensitivity the extremal hypothesis methods were given and no comparison of the sensitivity of extremal hypothesis methods to other methods (hydraulic geometry, reference reach, and threshold methods) was given. From a practical view of channel design, definition of these areas of sensitivity is of critical importance.

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APPENDIX A

REGIME SHAPE FACTOR BASED ON ANALYTICAL METHOD (MAXIMUM SEDIMENT TRANSPORT HYPOTHESIS)

A.1 THEORETICAL ANALYSIS BY USING EXCESS SHEAR SEDIMENT TRANSPORT EQUATIONS

A.1.1 Duboys (1879)

The three basic flow relationships of continuity, resistance, and sediment transport was used to express a relationship between shape factor and sediment transport:

From continuity –

$$Q = AV \tag{A.1}$$

From Manning equation –

$$V = \frac{1}{n} R^{2/3} S_f^{\ 1/2} \tag{A.2}$$

From excess shear sediment transport equation –

$$Q_s = C_d \tau_o (\tau_o - \tau_c) W \tag{A.3}$$

where Q_s = total bed load discharge; and

τ_o = flow shear stress.

The coefficient (C_d) and critical shear stress for the movement of sediment (τ_c) are determined by sediment size d_s (mm), commonly in the form of $\tau_c = 0.061 + 0.093 d_s$ (kg/m^2) and $C_d = 0.173 d_s^{\ -3/4}$ (m^3/(kg.s)) (Chang, 1980).

A non-dimensional channel shape factor width/depth ratio ψ is introduced:

$$\psi = \frac{W}{d} \tag{A.4}$$

$$W = \psi d \ , \ A = \psi d^2, \ R = \frac{A}{P} = \frac{Wd}{W + 2d} = \frac{Wd}{d\left(\frac{W}{d} + 2\right)} = \frac{\psi}{\psi + 2} d \tag{A.5}$$

$$\frac{Q}{\psi d^2} = \frac{1}{n}\left(\frac{\psi}{\psi+2}d\right)^{2/3} S_f^{1/2} \tag{A.6}$$

$$\psi d^2\left(\frac{\psi}{\psi+2}d\right)^{2/3} = \frac{Qn}{S_f^{1/2}} \tag{A.7}$$

$$d = \left[\frac{Qn}{1.48S_f^{1/2}\psi(\frac{\psi}{\psi+2})^{2/3}}\right]^{3/8} = \left(\frac{Qn}{1.48S_f^{1/2}}\right)^{3/8} \frac{(\psi+2)^{1/4}}{\psi^{5/8}} \tag{A.8}$$

$$W = \psi d = \psi\left(\frac{Qn}{S_f^{1/2}}\right)^{3/8} \frac{(\psi+2)^{1/4}}{\psi^{5/8}} = \left(\frac{Qn}{S_f^{1/2}}\right)^{3/8} (\psi+2)^{1/4}\psi^{3/8} \tag{A.9}$$

$$\tau_o = \rho g R S_f \tag{A.10}$$

$$R = \frac{\psi}{\psi+2}d = \frac{\psi}{\psi+2}\left(\frac{Qn}{S_f^{1/2}}\right)^{3/8} \frac{(\psi+2)^{1/4}}{\psi^{5/8}} \tag{A.11}$$

$$\tau_o = \rho g R S_f = \rho g S_f \frac{\psi}{\psi+2}\left(\frac{Qn}{S_f^{1/2}}\right)^{3/8} \frac{(\psi+2)^{1/4}}{\psi^{5/8}}$$

$$\tau_o = \rho g\left(Q^{3/8} n^{3/8} S_f^{13/16}\right)\frac{\psi^{3/8}}{(\psi+2)^{3/4}} \tag{A.12}$$

Substitute the values of C_d, τ_o, and W in Equation (A.3) yields:

$$Q_s = C_d \rho g\left(Q^{3/8} n^{3/8} Sf^{13/16}\right)\frac{\psi^{3/8}}{(\psi+2)^{3/4}}\left[\rho g\left(Q^{3/8} n^{3/8} Sf^{13/16}\right)\frac{\psi^{3/8}}{(\psi+2)^{3/4}} - \tau_c\right] \times$$

$$\left(\frac{Qn}{S_f^{1/2}}\right)^{3/8} (\psi+2)^{1/4}\psi^{3/8} \tag{A.13}$$

Equation (A.13) is plotted as shown in Figure A.1 to illustrate how Q_s changes with possible changes in the channel shape factor. Here Q, S, and d_s are given defined values (Q = 100 m^3/s, S = 0.001, d_s = 3 mm). There is good agreement between the USACE (1994) regime equation and Duboys (1879) equation as shown in Figure A.1.

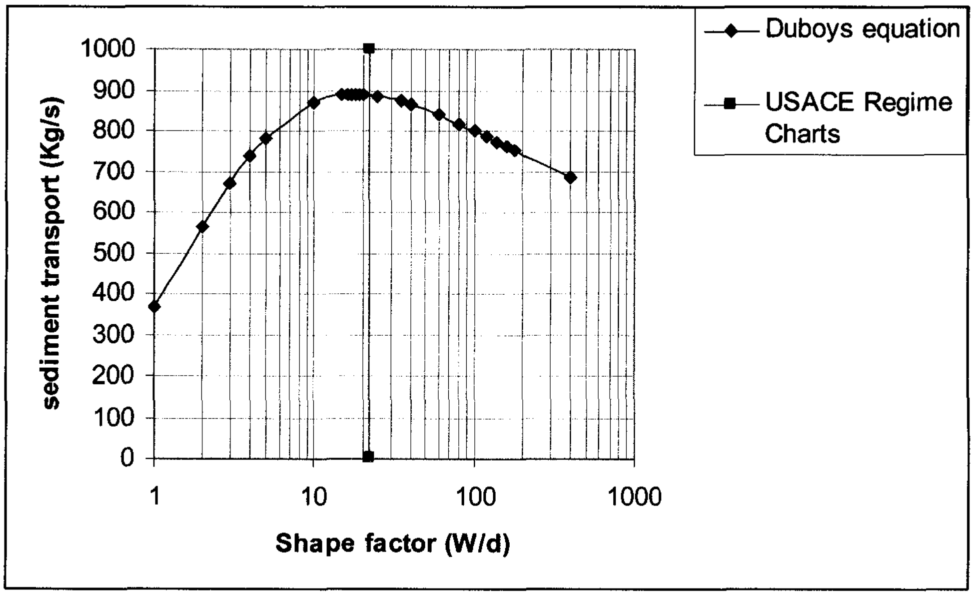


Figure A.1: Shape factor (*W/d*) vs. sediment transport using Duboys' (1879) equation (Q = 100 m^3/s, S = 0.001, d_s = 3 mm).

A.1.2 Meyer-Peter and Müller (1948)

Meyer-Peter and Müller (1948) –

$$\frac{q_{bv}}{\sqrt{(G-1)gd_s^{\,3}}} = 8(\tau_* - \tau_{*c})^{3/2} \tag{A.14}$$

$$\tau_* = \frac{\tau_o}{(\gamma_s - \gamma_m)d_s} \tag{A.15}$$

The critical values of the Shield parameter (τ_{*c}) can be approximated as follows (Julien, 1998):

$$\tau_{*c} = 0.5\tan\phi \text{ when } d_* < 0.3 \qquad \text{(A.16a)}$$

$$\tau_{*c} = 0.25 d_*^{-0.6}\tan\phi \text{ when } 0.3 < d_* < 19 \qquad \text{(A.16b)}$$

$$\tau_{*c} = 0.013 d_*^{0.4}\tan\phi \text{ when } 19 < d_* < 50 \qquad \text{(A.16c)}$$

$$\tau_{*c} = 0.06\tan\phi \text{ when } d_* > 50 \qquad \text{(A.16d)}$$

where $d_* = d_s\left[\frac{(G-1)g}{v_m^{\,2}}\right]^{1/3}$; and (A.16e)

ϕ = angle of repose.

Equations (A.14) to (A.16) are solved with Manning's equation and plotted. The results are shown in Figure A.2 to illustrate how Q_s changes with possible changes in the channel shape factor. Q, S, and d_s are given values as listed in the figure caption.

It is found that Meyer-Peter and Müller (1948) equation matches with the USACE design charts at medium gravel (d_s > 6 mm).

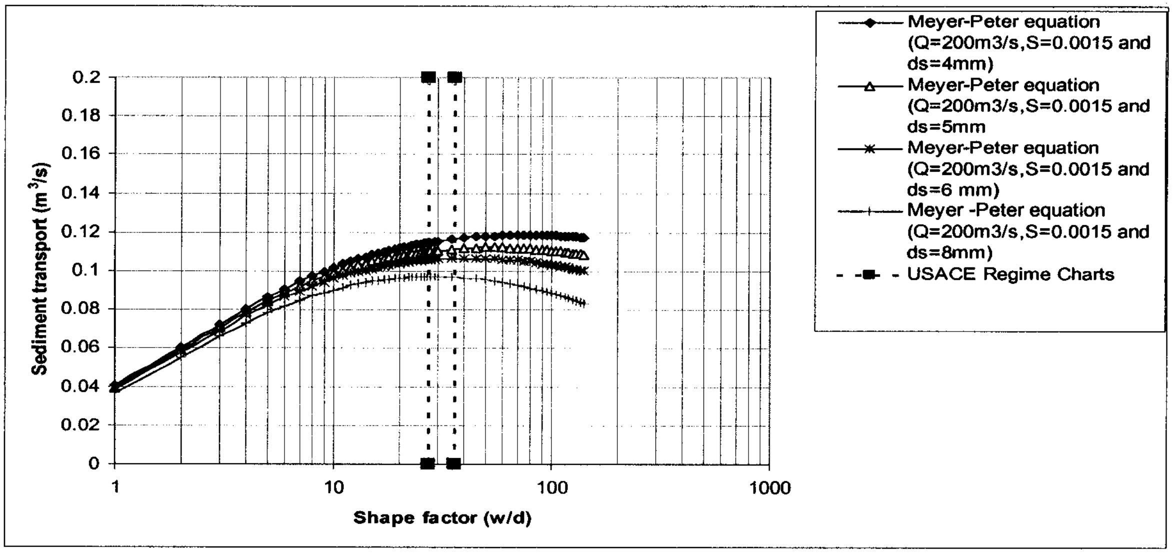
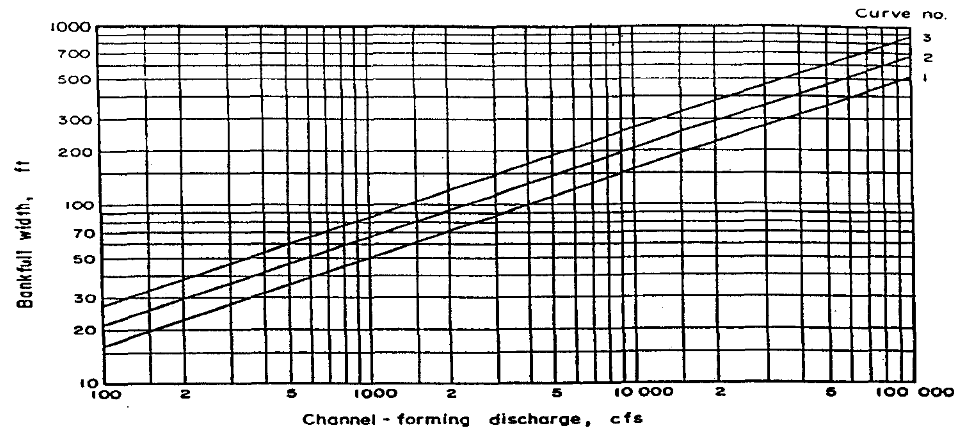


Figure A.2: Shape factor (*W*/d) vs. sediment transport using Meyer-Peter and Müller's (1948) equation.

APPENDIX B
HYDRAULIC GEOMETRY DESIGN CHARTS
(USACE, 1994)



Tentative guidance : Curve 1 : stiff cohesive or very coarse granular banks.
Curve 2 : average cohesive or coarse granular banks.
Curve 3 : sandy alluvial banks.

Figure B.1: Hydraulic geometry: mean depth versus channel forming discharge.

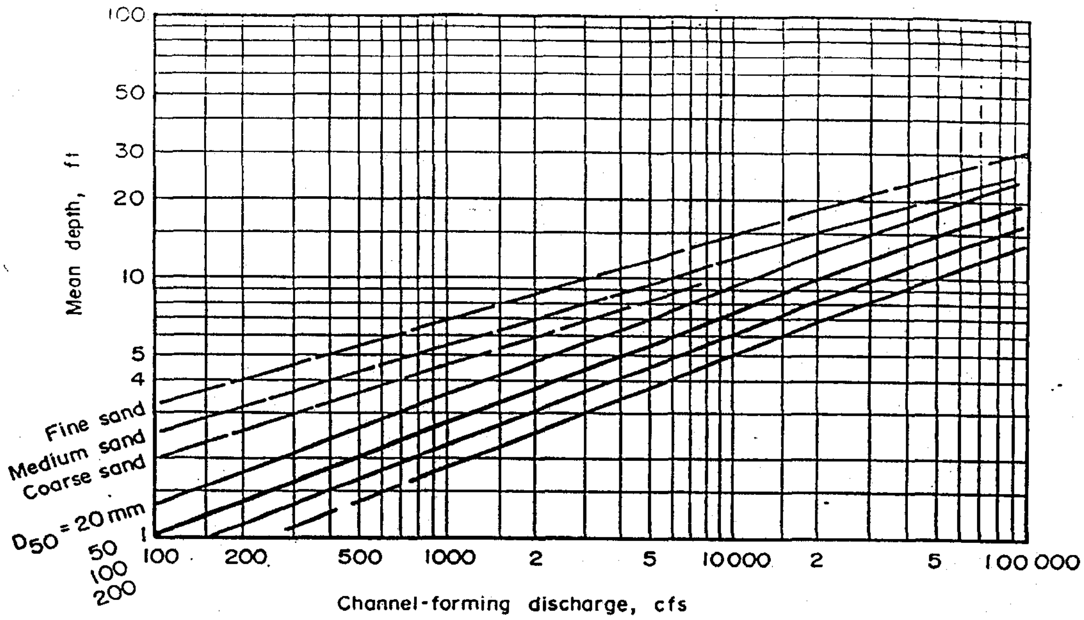
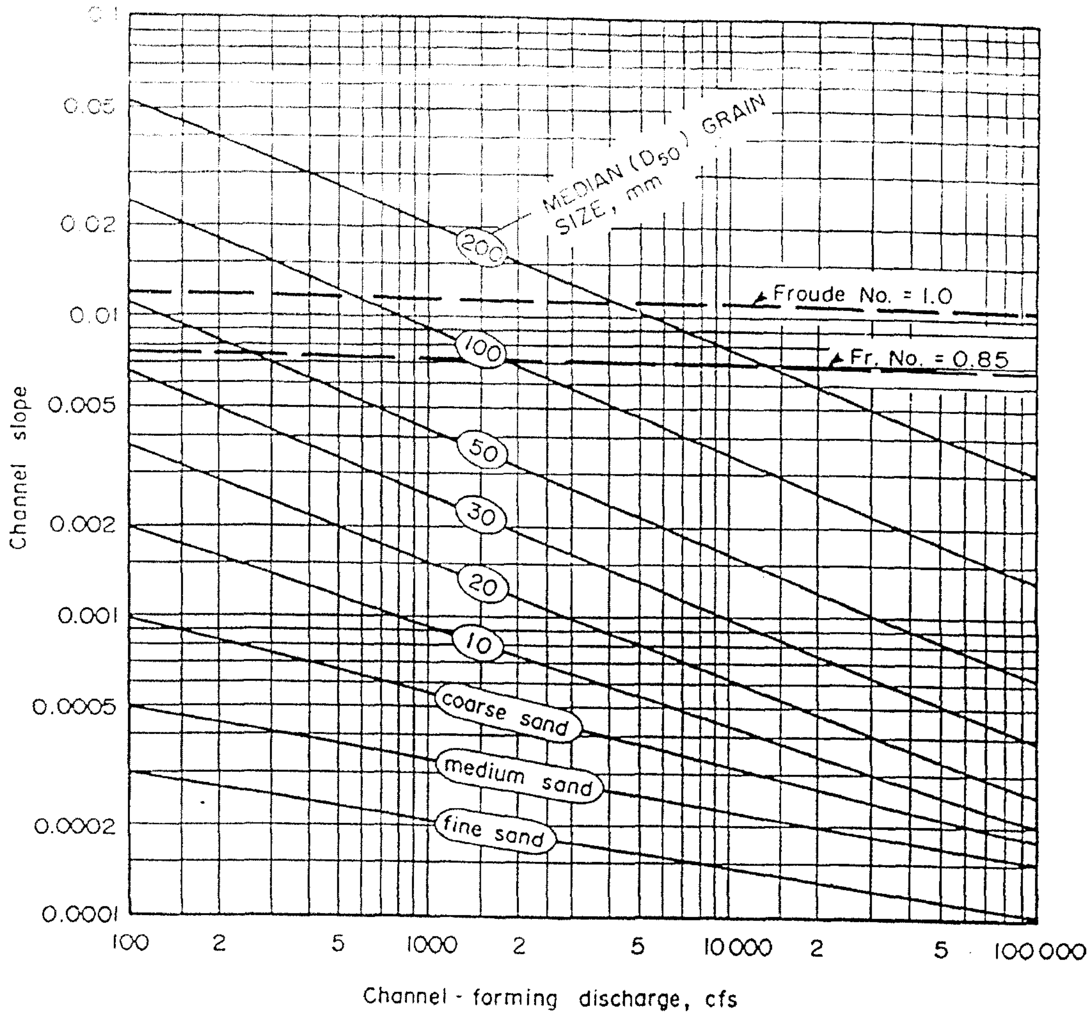


Figure B.2: Hydraulic geometry: top width versus channel forming discharge.



Note: Curves are basically for single channels with fully alluvial bed but low bed - sediment transport. Slopes may be much higher with high sediment transport, especially with sand beds.

Figure B.3: Hydraulic geometry: slope versus channel forming discharge.

APPENDIX C
DEMONSTRATION EROSION CONTROL (DEC) DATA

Table C.1: DEC Project data.

River/Creek	Reach	River Station	Q_2 Total (m^3/s)	Energy Slope (m/m)	Velocity Channel (m/s)	Hydr. Depth (m)	Width (m)	d_{50} (m)
River: Abaica	1993 Cross Section	3500	57.2	0.001003	1.25	1.7	26.92	0.0005
River: Abaica	1993 Cross Section	3000	57.2	0.0017	1.47	1.45	26.84	0.0005
River: Abaica	1993 Cross Section	2500	57.2	0.001472	1.41	1.53	26.51	0.0005
River: Abaica	1993 Cross Section	2000	57.2	0.001016	1.28	1.79	24.97	0.0005
River: Abaica	1993 Cross Section	1500	57.2	0.00072	1.13	1.95	25.96	0.0005
River: Abaica	1993 Cross Section	1000	57.2	0.000712	1.11	1.87	27.56	0.0005
River: Abaica	1993 Cross Section	500	57.2	0.000832	1.18	1.8	26.93	0.0005
River: Abaica	1994 Cross Section	3500	57.2	0.000681	1.12	1.95	26.19	0.0005
River: Abaica	1994 Cross Section	3000	57.2	0.001126	1.31	1.68	25.99	0.0005
River: Abaica	1994 Cross Section	2500	57.2	0.000924	1.22	1.76	26.64	0.0005
River: Abaica	1994 Cross Section	2000	57.2	0.000872	1.21	1.86	25.42	0.0005
River: Abaica	1994 Cross Section	1500	57.2	0.000755	1.14	1.92	26.13	0.0005
River: Abaica	1994 Cross Section	1000	57.2	0.0007	1.1	1.86	27.96	0.0005
River: Abaica	1994 Cross Section	500	57.2	0.000671	1.1	1.93	26.94	0.0005
River: Abaica	1995 Cross Section	3500	57.2	0.000896	1.22	1.79	26.19	0.0005
River: Abaica	1995 Cross Section	3000	57.2	0.001609	1.48	1.59	24.31	0.0005
River: Abaica	1995 Cross Section	2500	57.2	0.00094	1.24	1.79	25.77	0.0005
River: Abaica	1995 Cross Section	2000	57.2	0.001188	1.36	1.74	24.17	0.0005
River: Abaica	1995 Cross Section	1500	57.2	0.000939	1.24	1.8	25.63	0.0005
River: Abaica	1995 Cross Section	1000	57.2	0.000856	1.17	1.76	27.78	0.0005
River: Abaica	1995 Cross Section	500	57.2	0.000923	1.21	1.75	27.01	0.0005
River: Abaica	1996 Cross Section	3500	57.2	0.001099	1.3	1.71	25.73	0.0005
River: Abaica	1996 Cross Section	3000	57.2	0.001607	1.5	1.59	23.98	0.0005
River: Abaica	1996 Cross Section	2500	57.2	0.000828	1.14	1.71	29.34	0.0005
River: Abaica	1996 Cross Section	2000	57.2	0.00111	1.33	1.76	24.44	0.0005
River: Abaica	1996 Cross Section	1500	57.2	0.000928	1.23	1.81	25.69	0.0005
River: Abaica	1996 Cross Section	1000	57.2	0.000741	1.11	1.8	28.63	0.0005
River: Abaica	1996 Cross Section	500	57.2	0.000675	1.09	1.87	28.06	0.0005
Burney Branch	1993 Cross Section	5400	75.38	0.000727	1.21	2.03	30.69	0.00037
Burney Branch	1993 Cross Section	5375.81	75.38	0.001061	1.47	2.07	24.77	0.00037
Burney Branch	1993 Cross Section	5350	75.38	0.001535	1.78	2.18	19.43	0.00037
Burney Branch	1993 Cross Section	5300	75.38	0.001679	1.84	2.14	19.14	0.00037
Burney Branch	1993 Cross Section	5200	75.38	0.001463	1.57	1.8	26.67	0.00037
Burney Branch	1993 Cross Section	5100	75.38	0.001982	1.79	1.84	22.89	0.00037
Burney Branch	1993 Cross Section	5000	75.38	0.002418	2.05	1.89	19.46	0.00037
Burney Branch	1993 Cross Section	4900	75.38	0.001023	1.42	2.07	25.64	0.00037
Burney Branch	1993 Cross Section	4800	75.38	0.001474	1.64	1.95	23.57	0.00037
Burney Branch	1993 Cross Section	4700	75.38	0.001253	1.63	2.21	20.93	0.00037
Burney Branch	1993 Cross Section	4600	75.38	0.001452	1.65	2.03	22.50	0.00037
Burney Branch	1993 Cross Section	4500	75.38	0.001233	1.63	2.27	20.37	0.00037
Burney Branch	1993 Cross Section	4400	75.38	0.002067	2.04	2.2	16.80	0.00037
Burney Branch	1993 Cross Section	4300	75.38	0.000678	1.2	2.16	29.08	0.00037
Burney Branch	1993 Cross Section	4200	75.38	0.001461	1.61	1.93	24.26	0.00037
Burney Branch	1993 Cross Section	4100	75.38	0.001463	1.6	1.89	24.93	0.00037

River/Creek	Reach	River Station	Q_2 Total (m^3/s)	Energy Slope (m/m)	Velocity Channel (m/s)	Hydr. Depth (m)	Width (m)	d_{50} (m)
Burney Branch	1993 Cross Section	4000	75.38	0.001311	1.54	1.91	25.63	0.00037
Burney Branch	1993 Cross Section	3900	75.38	0.001801	1.69	1.71	26.08	0.00037
Burney Branch	1993 Cross Section	3800	75.38	0.001856	1.68	1.66	27.03	0.00037
Burney Branch	1993 Cross Section	3700	75.38	0.001553	1.59	1.76	26.94	0.00037
Burney Branch	1993 Cross Section	3500	75.38	0.001861	1.67	1.63	27.69	0.00037
Burney Branch	1993 Cross Section	3300	75.38	0.001488	1.49	1.63	31.04	0.00037
Burney Branch	1993 Cross Section	3200	75.38	0.001698	1.55	1.55	31.38	0.00037
Burney Branch	1993 Cross Section	3100	75.38	0.001438	1.56	1.81	26.70	0.00037
Burney Branch	1993 Cross Section	3000	75.38	0.000915	1.22	1.74	35.51	0.00037
Burney Branch	1993 Cross Section	2900	75.38	0.001578	1.59	1.73	27.40	0.00037
Burney Branch	1993 Cross Section	2800	75.38	0.001137	1.31	1.62	35.52	0.00037
Burney Branch	1993 Cross Section	2700	75.38	0.000936	1.28	1.82	32.36	0.00037
Burney Branch	1993 Cross Section	2500	75.38	0.000922	1.29	1.86	31.42	0.00037
Burney Branch	1993 Cross Section	2400	75.38	0.000885	1.28	1.89	31.16	0.00037
Burney Branch	1993 Cross Section	2300	75.38	0.000888	1.3	1.98	29.29	0.00037
Burney Branch	1993 Cross Section	2200	75.38	0.000751	1.22	2.08	29.71	0.00037
Burney Branch	1993 Cross Section	2100	75.38	0.000603	1.17	2.35	27.42	0.00037
Burney Branch	1993 Cross Section	2000	75.38	0.00047	1.08	2.45	28.49	0.00037
Burney Branch	1993 Cross Section	1500	75.38	0.000418	0.93	2.11	38.41	0.00037
Burney Branch	1993 Cross Section	55	75.38	0.001753	1.84	2.04	20.08	0.00037
Burney Branch	1993 Cross Section	31.6233	75.38	0.001672	1.81	2.05	20.32	0.00037
Burney Branch	1994 Cross Section	5600	75.38	0.000411	1.03	2.49	29.39	0.00037
Burney Branch	1994 Cross Section	5400	75.38	0.000633	1.15	2.1	31.21	0.00037
Burney Branch	1994 Cross Section	5349.51	75.38	0.001338	1.61	2.01	23.29	0.00037
Burney Branch	1994 Cross Section	5300	75.38	0.002297	2.08	2.02	17.94	0.00037
Burney Branch	1994 Cross Section	5000	75.38	0.002689	2.12	1.82	19.54	0.00037
Burney Branch	1994 Cross Section	4500	75.38	0.001842	1.9	2.07	19.17	0.00037
Burney Branch	1994 Cross Section	4000	75.38	0.002223	1.91	1.78	22.17	0.00037
Burney Branch	1994 Cross Section	3500	75.38	0.002167	1.76	1.58	27.11	0.00037
Burney Branch	1994 Cross Section	3000	75.38	0.001066	1.29	1.67	34.99	0.00037
Burney Branch	1994 Cross Section	2500	75.38	0.000917	1.28	1.85	31.83	0.00037
Burney Branch	1994 Cross Section	2000	75.38	0.000462	1.07	2.46	28.64	0.00037
Burney Branch	1994 Cross Section	1500	75.38	0.000337	0.87	2.25	38.51	0.00037
Burney Branch	1994 Cross Section	55	75.38	0.001635	1.79	2.06	20.44	0.00037
Burney Branch	1994 Cross Section	33.5742	75.38	0.001618	1.78	2.06	20.56	0.00037
Burney Branch	1995 Cross Section	5400	75.38	0.000825	1.26	1.97	30.37	0.00037
Burney Branch	1995 Cross Section	5299.48	75.38	0.001277	1.54	1.93	25.36	0.00037
Burney Branch	1995 Cross Section	5200	75.38	0.002155	1.99	1.98	19.13	0.00037
Burney Branch	1995 Cross Section	5000	75.38	0.002752	2.17	1.88	18.48	0.00037
Burney Branch	1995 Cross Section	4500	75.38	0.001736	1.83	2.05	20.09	0.00037
Burney Branch	1995 Cross Section	4000	75.38	0.001958	1.87	1.92	20.99	0.00037
Burney Branch	1995 Cross Section	3500	75.38	0.002333	1.77	1.51	28.20	0.00037
Burney Branch	1995 Cross Section	3000	75.38	0.001264	1.35	1.58	35.34	0.00037
Burney Branch	1995 Cross Section	2500	75.38	0.000928	1.37	1.8	30.57	0.00037
Burney Branch	1995 Cross Section	2000	75.38	0.000347	0.97	2.59	30.00	0.00037
Burney Branch	1995 Cross Section	1500	75.38	0.00029	0.83	2.33	38.98	0.00037

River/Creek	Reach	River Station	Q_2 Total (m^3/s)	Energy Slope (m/m)	Velocity Channel (m/s)	Hydr. Depth (m)	Width (m)	d_{50} (m)
Burney Branch	1995 Cross Section	55	75.38	0.001648	1.8	2.06	20.33	0.00037
Burney Branch	1995 Cross Section	33.6084	75.38	0.001624	1.79	2.06	20.44	0.00037
Burney Branch	1997 Cross Section	5400	75.38	0.000611	1.14	2.12	31.19	0.00037
Burney Branch	1997 Cross Section	5374.91	75.38	0.000983	1.42	2.1	25.28	0.00037
Burney Branch	1997 Cross Section	5350	75.38	0.002	1.9	1.96	20.24	0.00037
Burney Branch	1997 Cross Section	5300	75.38	0.002266	1.98	1.9	20.04	0.00037
Burney Branch	1997 Cross Section	5000	75.38	0.002136	1.92	1.88	20.88	0.00037
Burney Branch	1997 Cross Section	4500	75.38	0.001378	1.68	2.16	20.77	0.00037
Burney Branch	1997 Cross Section	4000	75.38	0.002277	1.9	1.73	22.93	0.00037
Burney Branch	1997 Cross Section	3500	75.38	0.002335	1.8	1.54	27.19	0.00037
Burney Branch	1997 Cross Section	3000	75.38	0.00274	1.85	1.38	29.53	0.00037
Burney Branch	1997 Cross Section	2500	75.38	0.001383	1.5	1.72	29.22	0.00037
Burney Branch	1997 Cross Section	2000	75.38	0.000369	0.98	2.56	30.05	0.00037
Burney Branch	1997 Cross Section	1500	75.38	0.00024	0.78	2.46	39.28	0.00037
Burney Branch	1997 Cross Section	55	75.38	0.006915	2.51	1.12	26.81	0.00037
Burney Branch	1997 Cross Section	32.5961	75.38	0.007695	2.61	1.1	26.26	0.00037
River: Harland 1	1993 Cross Section	1500	55.78	0.000297	0.9	2.77	22.37	0.0005
River: Harland 1	1993 Cross Section	1000	55.78	0.000411	0.99	2.41	23.38	0.0005
River: Harland 1	1993 Cross Section	500	55.78	0.000848	1.15	1.7	28.53	0.0005
River: Harland 1	1994 Cross Section	4000	55.78	0.001198	1.43	1.9	20.53	0.0005
River: Harland 1	1994 Cross Section	3500	55.78	0.001469	1.45	1.59	24.19	0.0005
River: Harland 1	1994 Cross Section	3300	55.78	0.000678	1.1	1.88	26.97	0.0005
River: Harland 1	1994 Cross Section	3000	55.78	0.001023	1.37	1.97	20.67	0.0005
River: Harland 1	1994 Cross Section	2500	55.78	0.001342	1.52	1.9	19.31	0.0005
River: Harland 1	1994 Cross Section	2000	55.78	0.000703	1.09	1.82	28.12	0.0005
River: Harland 1	1994 Cross Section	1000	55.78	0.001761	1.47	1.42	26.72	0.0005
River: Harland 1	1994 Cross Section	500	55.78	0.002032	1.49	1.32	28.36	0.0005
River: Harland 1	1995 Cross Section	4000	55.78	0.001144	1.44	1.97	19.66	0.0005
River: Harland 1	1995 Cross Section	3500	55.78	0.001344	1.38	1.59	25.42	0.0005
River: Harland 1	1995 Cross Section	3000	55.78	0.001272	1.49	1.89	19.81	0.0005
River: Harland 1	1995 Cross Section	2500	55.78	0.000822	1.28	2.15	20.27	0.0005
River: Harland 1	1995 Cross Section	2000	55.78	0.000587	1.03	1.73	31.30	0.0005
River: Harland 1	1995 Cross Section	1500	55.78	0.00107	1.31	1.77	24.06	0.0005
River: Harland 1	1995 Cross Section	1000	55.78	0.001296	1.36	1.58	25.96	0.0005
River: Harland 1	1995 Cross Section	500	55.78	0.00108	1.23	1.58	28.70	0.0005
River: Harland 1	1996 Cross Section	4000	55.78	0.000894	1.27	1.9	23.12	0.0005
River: Harland 1	1996 Cross Section	3500	55.78	0.001039	1.23	1.59	28.52	0.0005
River: Harland 1	1996 Cross Section	3000	55.78	0.000979	1.31	1.9	22.41	0.0005
River: Harland 1	1996 Cross Section	2500	55.78	0.001045	1.35	1.97	20.97	0.0005
River: Harland 1	1996 Cross Section	2000	55.78	0.000858	1.16	1.69	28.45	0.0005
River: Harland 1	1996 Cross Section	1500	55.78	0.000927	1.22	1.71	26.74	0.0005
River: Harland 1	1996 Cross Section	1000	55.78	0.001145	1.29	1.61	26.86	0.0005
River: Harland 1	1996 Cross Section	500	55.78	0.003668	1.83	1.12	27.22	0.0005
River: Harland 1	1997 Cross Section	3500	55.78	0.001014	1.25	1.65	27.04	0.0005
River: Harland 1	1997 Cross Section	3000	55.78	0.000835	1.26	2.03	21.81	0.0005
River: Harland 1	1997 Cross Section	2500	55.78	0.001449	1.55	1.85	19.45	0.0005

River/Creek	Reach	River Station	Q_2 Total (m^3/s)	Energy Slope (m/m)	Velocity Channel (m/s)	Hydr. Depth (m)	Width (m)	d_{50} (m)
River: Harland 1	1997 Cross Section	2000	55.78	0.000655	1.08	1.91	27.04	0.0005
River: Harland 1	1997 Cross Section	1500	55.78	0.001427	1.43	1.59	24.53	0.0005
River: Harland 1	1997 Cross Section	1000	55.78	0.001686	1.48	1.51	24.96	0.0005
River: Harland 1	1997 Cross Section	500	55.78	0.00334	1.8	1.19	26.04	0.0005
River: Harland 1	1998 Cross Section	8500	55.78	0.000257	0.66	1.84	45.93	0.0005
River: Harland 1	1998 Cross Section	8000	55.78	0.000413	0.94	2.21	26.85	0.0005
River: Harland 1	1998 Cross Section	7500	55.78	0.000163	0.68	2.69	30.49	0.0005
River: Harland 1	1998 Cross Section	7000	55.78	0.000182	0.63	2.18	40.61	0.0005
River: Harland 1	1998 Cross Section	3500	55.78	0.001393	1.37	1.51	26.96	0.0005
River: Harland 1	1998 Cross Section	3000	55.78	0.001308	1.45	1.73	22.24	0.0005
River: Harland 1	1998 Cross Section	2500	55.78	0.001015	1.37	2.06	19.76	0.0005
River: Harland 1	1998 Cross Section	2000	55.78	0.000956	1.26	1.78	24.87	0.0005
River: Harland 1	1998 Cross Section	1500	55.78	0.001425	1.44	1.59	24.36	0.0005
River: Harland 1	1998 Cross Section	1000	55.78	0.001457	1.44	1.6	24.21	0.0005
River: Harland 1	1998 Cross Section	500	55.78	0.004677	2	1.07	26.07	0.0005
River: Harland 1	1999 Cross Section	8500	55.78	0.001883	1.32	1.12	37.73	0.0005
River: Harland 1	1999 Cross Section	8000	55.78	0.003173	1.95	1.41	20.29	0.0005
River: Harland 1	1999 Cross Section	7500	55.78	0.001705	1.46	1.49	25.64	0.0005
River: Harland 1	1999 Cross Section	7000	55.78	0.001387	1.38	1.53	26.42	0.0005
River: Harland 1	1999 Cross Section	6500	55.78	0.005019	2.29	1.26	19.33	0.0005
River: Harland 1	1999 Cross Section	6000	55.78	0.00099	1.32	1.87	22.60	0.0005
River: Harland 1	1999 Cross Section	5500	55.78	0.001149	1.39	1.83	21.93	0.0005
River: Harland 1	1999 Cross Section	5000	55.78	0.001095	1.34	1.78	23.39	0.0005
River: Harland 1	1999 Cross Section	4500	55.78	0.001438	1.41	1.54	25.69	0.0005
River: Harland 1	1999 Cross Section	4000	55.78	0.001921	1.69	1.69	19.53	0.0005
River: Harland 1	1999 Cross Section	3500	55.78	0.001665	1.45	1.44	26.71	0.0005
River: Harland 1	1999 Cross Section	3000	55.78	0.000649	1.16	2.14	22.47	0.0005
River: Harland 1	1999 Cross Section	2500	55.78	0.001034	1.38	2.08	19.43	0.0005
River: Harland 1	1999 Cross Section	2000	55.78	0.000761	1.14	1.83	26.74	0.0005
River: Harland 1	1999 Cross Section	1500	55.78	0.001051	1.3	1.73	24.80	0.0005
River: Harland 1	1999 Cross Section	1000	55.78	0.00103	1.26	1.71	25.89	0.0005
River: Harland 1	1999 Cross Section	500	55.78	0.00129	1.32	1.51	27.99	0.0005
Hickahala 11	1993 Cross Section	3600	36.53	0.009437	3.08	1.35	8.79	0.00051
Hickahala 11	1993 Cross Section	3550	36.53	0.008891	3.01	1.36	8.92	0.00051
Hickahala 11	1993 Cross Section	3525.66	36.53	0.003077	1.88	1.38	14.08	0.00051
Hickahala 11	1993 Cross Section	3502	36.53	0.001553	1.35	1.35	20.04	0.00051
Hickahala 11	1993 Cross Section	3470	36.53	0.000506	0.88	1.64	25.31	0.00051
Hickahala 11	1993 Cross Section	3444.96	36.53	0.000887	1.11	1.54	21.37	0.00051
Hickahala 11	1993 Cross Section	3420	36.53	0.001603	1.44	1.48	17.14	0.00051
Hickahala 11	1993 Cross Section	3370	36.53	0.001888	1.53	1.43	16.70	0.00051
Hickahala 11	1993 Cross Section	3000	36.53	0.003367	2.11	1.66	10.43	0.00051
Hickahala 11	1993 Cross Section	2500	36.53	0.00229	1.74	1.7	12.35	0.00051
Hickahala 11	1993 Cross Section	2000	36.53	0.001206	1.4	1.92	13.59	0.00051
Hickahala 11	1993 Cross Section	1900	36.53	0.001309	1.44	1.87	13.57	0.00051
Hickahala 11	1993 Cross Section	1850.26	36.53	0.001301	1.37	1.64	16.26	0.00051
Hickahala 11	1993 Cross Section	1800	36.53	0.000992	1.17	1.53	20.41	0.00051

River/Creek	Reach*	River Station	Q_2 Total (m^3/s)	Energy Slope (m/m)	Velocity Channel (m/s)	Hydr. Depth (m)	Width (m)	d_{50} (m)
Hickahala 11	1993 Cross Section	1650	36.53	0.000156	0.55	1.96	33.89	0.00051
Hickahala 11	1993 Cross Section	1637.65	36.53	0.000467	0.85	1.65	26.05	0.00051
Hickahala 11	1993 Cross Section	1625	36.53	0.001415	1.37	1.51	17.66	0.00051
Hickahala 11	1993 Cross Section	1600	36.53	0.001319	1.33	1.53	17.95	0.00051
Hickahala 11	1993 Cross Section	1500	36.53	0.002426	1.74	1.54	13.63	0.00051
Hickahala 11	1993 Cross Section	1000	36.53	0.002014	1.53	1.37	17.43	0.00051
Hickahala 11	1993 Cross Section	500	36.53	0.001016	1.29	1.88	15.06	0.00051
Hickahala 11	1994 Cross Section	3700	36.53	0.004	2.21	1.55	10.66	0.00051
Hickahala 11	1994 Cross Section	3650	36.53	0.003842	2.18	1.56	10.74	0.00051
Hickahala 11	1994 Cross Section	3600	36.53	0.013414	3.5	1.24	8.42	0.00051
Hickahala 11	1994 Cross Section	3551.13	36.53	0.003677	2.02	1.34	13.50	0.00051
Hickahala 11	1994 Cross Section	3502	36.53	0.001553	1.35	1.35	20.04	0.00051
Hickahala 11	1994 Cross Section	3470	36.53	0.000493	0.87	1.65	25.45	0.00051
Hickahala 11	1994 Cross Section	3427.93	36.53	0.000995	1.16	1.51	20.86	0.00051
Hickahala 11	1994 Cross Section	3385	36.53	0.00217	1.62	1.41	15.99	0.00051
Hickahala 11	1994 Cross Section	3300	36.53	0.001964	1.56	1.44	16.26	0.00051
Hickahala 11	1994 Cross Section	3000	36.53	0.002613	1.92	1.78	10.69	0.00051
Hickahala 11	1994 Cross Section	2500	36.53	0.001692	1.58	1.81	12.77	0.00051
Hickahala 11	1994 Cross Section	2000	36.53	0.002086	1.68	1.71	12.72	0.00051
Hickahala 11	1994 Cross Section	1900	36.53	0.002396	1.76	1.65	12.58	0.00051
Hickahala 11	1994 Cross Section	1849.80	36.53	0.002565	1.72	1.38	15.39	0.00051
Hickahala 11	1994 Cross Section	1800	36.53	0.000925	1.14	1.55	20.67	0.00051
Hickahala 11	1994 Cross Section	1600	36.53	0.000845	1.13	1.67	19.36	0.00051
Hickahala 11	1994 Cross Section	1575.27	36.53	0.001364	1.35	1.52	17.80	0.00051
Hickahala 11	1994 Cross Section	1550	36.53	0.002371	1.72	1.52	13.97	0.00051
Hickahala 11	1994 Cross Section	1500	36.53	0.001975	1.62	1.6	14.09	0.00051
Hickahala 11	1994 Cross Section	1000	36.53	0.003404	1.86	1.23	15.97	0.00051
Hickahala 11	1994 Cross Section	500	36.53	0.001783	1.59	1.65	13.92	0.00051
Hickahala 11	1995 Cross Section	4000	36.53	0.003055	1.8	1.33	15.26	0.00051
Hickahala 11	1995 Cross Section	3750	36.53	0.002495	1.68	1.41	15.42	0.00051
Hickahala 11	1995 Cross Section	3625.89	36.53	0.002907	1.66	1.16	18.97	0.00051
Hickahala 11	1995 Cross Section	3502	36.53	0.001569	1.35	1.35	20.04	0.00051
Hickahala 11	1995 Cross Section	3470	36.53	0.000594	0.93	1.58	24.86	0.00051
Hickahala 11	1995 Cross Section	3359.52	36.53	0.000842	1.14	1.73	18.52	0.00051
Hickahala 11	1995 Cross Section	3250	36.53	0.002568	1.86	1.86	10.56	0.00051
Hickahala 11	1995 Cross Section	3000	36.53	0.003772	2.12	1.67	10.32	0.00051
Hickahala 11	1995 Cross Section	2500	36.53	0.001904	1.64	1.75	12.73	0.00051
Hickahala 11	1995 Cross Section	2000	36.53	0.001152	1.38	1.96	13.51	0.00051
Hickahala 11	1995 Cross Section	1900	36.53	0.001192	1.4	1.94	13.45	0.00051
Hickahala 11	1995 Cross Section	1849.84	36.53	0.001459	1.44	1.61	15.76	0.00051
Hickahala 11	1995 Cross Section	1800	36.53	0.001008	1.17	1.53	20.41	0.00051
Hickahala 11	1995 Cross Section	1650	36.53	0.000175	0.57	1.91	33.55	0.00051
Hickahala 11	1995 Cross Section	1612.57	36.53	0.000618	0.94	1.57	24.75	0.00051
Hickahala 11	1995 Cross Section	1575	36.53	0.003277	1.85	1.32	14.96	0.00051
Hickahala 11	1995 Cross Section	1500	36.53	0.002363	1.66	1.45	15.18	0.00051
Hickahala 11	1995 Cross Section	1000	36.53	0.003116	1.84	1.33	14.93	0.00051

River/Creek	**Reach**	**River Station**	**Q_2 Total (m^3/s)**	**Energy Slope (m/m)**	**Velocity Channel (m/s)**	**Hydr. Depth (m)**	**Width (m)**	**d_{50} (m)**
Hickahala 11	1995 Cross Section	500	36.53	0.002431	1.78	1.57	13.07	0.00051
Hickahala 11	1996 Cross Section	4000	36.53	0.003825	1.94	1.28	14.71	0.00051
Hickahala 11	1996 Cross Section	3750	36.53	0.003315	1.85	1.33	14.85	0.00051
Hickahala 11	1996 Cross Section	3626.72	36.53	0.003144	1.76	1.21	17.15	0.00051
Hickahala 11	1996 Cross Section	3502	36.53	0.001554	1.35	1.35	20.04	0.00051
Hickahala 11	1996 Cross Section	3470	36.53	0.000626	0.95	1.56	24.65	0.00051
Hickahala 11	1996 Cross Section	3359.93	36.53	0.000834	1.15	1.75	18.15	0.00051
Hickahala 11	1996 Cross Section	3250	36.53	0.002502	1.92	1.86	10.23	0.00051
Hickahala 11	1996 Cross Section	3000	36.53	0.003521	2.17	1.72	9.79	0.00051
Hickahala 11	1996 Cross Section	2500	36.53	0.00183	1.62	1.78	12.67	0.00051
Hickahala 11	1996 Cross Section	2000	36.53	0.001111	1.36	2	13.43	0.00051
Hickahala 11	1996 Cross Section	1900	36.53	0.001145	1.38	1.99	13.30	0.00051
Hickahala 11	1996 Cross Section	1849.84	36.53	0.001507	1.45	1.6	15.75	0.00051
Hickahala 11	1996 Cross Section	1800	36.53	0.000991	1.17	1.53	20.41	0.00051
Hickahala 11	1996 Cross Section	1650	36.53	0.00017	0.57	1.92	33.38	0.00051
Hickahala 11	1996 Cross Section	1612.57	36.53	0.000596	0.92	1.56	25.45	0.00051
Hickahala 11	1996 Cross Section	1575	36.53	0.002995	1.77	1.33	15.52	0.00051
Hickahala 11	1996 Cross Section	1500	36.53	0.002155	1.59	1.45	15.84	0.00051
Hickahala 11	1996 Cross Section	1000	36.53	0.003486	1.91	1.27	15.06	0.00051
Hickahala 11	1996 Cross Section	500	36.53	0.001955	1.64	1.61	13.84	0.00051
Long Reach	1993 Cross Section	8000	27.18	0.001054	0.98	1.16	23.91	0.00038
Long Reach	1993 Cross Section	7500	27.18	0.001026	1	1.25	21.74	0.00038
Long Reach	1993 Cross Section	7202	27.18	0.000254	0.65	1.83	22.85	0.00038
Long Reach	1993 Cross Section	7000	27.18	0.011493	3.04	1.1	8.13	0.00038
Long Reach	1993 Cross Section	6875.22	27.18	0.005163	2.13	1.12	11.39	0.00038
Long Reach	1993 Cross Section	6750	27.18	0.001615	1.35	1.38	14.59	0.00038
Long Reach	1993 Cross Section	6500	27.18	0.00141	1.29	1.43	14.73	0.00038
Long Reach	1993 Cross Section	6000	27.18	0.001824	1.51	1.59	11.32	0.00038
Long Reach	1993 Cross Section	5500	27.18	0.002782	1.54	1.1	16.04	0.00038
Long Reach	1993 Cross Section	5000	27.18	0.001676	1.3	1.25	16.73	0.00038
Long Reach	1993 Cross Section	4700	27.18	0.002014	1.4	1.26	15.41	0.00038
Long Reach	1993 Cross Section	4674.84	27.18	0.00083	1.02	1.44	18.50	0.00038
Long Reach	1993 Cross Section	4650	27.18	0.000345	0.72	1.66	22.74	0.00038
Long Reach	1993 Cross Section	4500	27.18	0.001537	1.29	1.33	15.84	0.00038
Long Reach	1993 Cross Section	4375.29	27.18	0.002101	1.36	1.11	18.00	0.00038
Long Reach	1993 Cross Section	4250	27.18	0.003453	1.37	0.78	25.44	0.00038
Long Reach	1993 Cross Section	4000	27.18	0.005821	1.65	0.7	23.53	0.00038
Long Reach	1993 Cross Section	3500	27.18	0.001064	1.1	1.35	18.30	0.00038
Long Reach	1993 Cross Section	3000	27.18	0.001248	0.95	0.94	30.44	0.00038
Long Reach	1993 Cross Section	2250	27.18	0.002397	1.37	1	19.84	0.00038
Long Reach	1993 Cross Section	2125.55	27.18	0.001682	1.23	1.12	19.73	0.00038
Long Reach	1993 Cross Section	2000	27.18	0.000958	1.06	1.39	18.45	0.00038
Long Reach	1993 Cross Section	1900	27.18	0.00183	1.15	0.92	25.69	0.00038
Long Reach	1993 Cross Section	1862.63	27.18	0.007194	1.91	0.71	20.04	0.00038
Long Reach	1993 Cross Section	1825	27.18	0.000601	0.8	1.27	26.75	0.00038
Long Reach	1993 Cross Section	1750	27.18	0.000247	0.6	1.61	28.14	0.00038

River/Creek	Reach	River Station	Q_2 Total (m^3/s)	Energy Slope (m/m)	Velocity Channel (m/s)	Hydr. Depth (m)	Width (m)	d_{50} (m)
Long Reach	1993 Cross Section	1500	27.18	0.001097	1.17	1.45	16.02	0.00038
Long Reach	1993 Cross Section	1000	27.18	0.000658	1.01	1.84	14.63	0.00038
Long Reach	1993 Cross Section	500	27.18	0.000491	0.87	1.69	18.49	0.00038
Long Reach	1993 Cross Section	0	27.18	0.000632	0.9	1.5	20.13	0.00038
Long Reach	1993 Cross Section	-250	27.18	0.000976	1.06	1.38	18.58	0.00038
Long Reach	1993 Cross Section	-374.67	27.18	0.00062	0.84	1.34	24.15	0.00038
Long Reach	1993 Cross Section	-500	27.18	0.000276	0.66	1.69	24.37	0.00038
Long Reach	1994 Cross Section	8000	27.18	0.002051	1.28	1.04	20.42	0.00038
Long Reach	1994 Cross Section	7500	27.18	0.003485	1.8	1.17	12.91	0.00038
Long Reach	1994 Cross Section	7202	27.18	0.000836	0.97	1.31	21.39	0.00038
Long Reach	1994 Cross Section	7000	27.18	0.01141	3.09	1.16	7.58	0.00038
Long Reach	1994 Cross Section	6875.22	27.18	0.006672	2.35	1.07	10.81	0.00038
Long Reach	1994 Cross Section	6750	27.18	0.002608	1.51	1.1	16.36	0.00038
Long Reach	1994 Cross Section	6500	27.18	0.002505	1.49	1.11	16.43	0.00038
Long Reach	1994 Cross Section	6000	27.18	0.002003	1.54	1.52	11.61	0.00038
Long Reach	1994 Cross Section	5500	27.18	0.002946	1.57	1.12	15.46	0.00038
Long Reach	1994 Cross Section	5000	27.18	0.003228	1.59	1.03	16.60	0.00038
Long Reach	1994 Cross Section	4602	27.18	0.001183	1.15	1.34	17.64	0.00038
Long Reach	1994 Cross Section	4500	27.18	0.002129	1.45	1.23	15.24	0.00038
Long Reach	1994 Cross Section	4375.29	27.18	0.002872	1.51	1.02	17.65	0.00038
Long Reach	1994 Cross Section	4250	27.18	0.004607	1.54	0.74	23.85	0.00038
Long Reach	1994 Cross Section	4000	27.18	0.004256	1.5	0.75	24.16	0.00038
Long Reach	1994 Cross Section	3500	27.18	0.001141	1.15	1.35	17.51	0.00038
Long Reach	1994 Cross Section	3000	27.18	0.001813	1.1	0.89	27.76	0.00038
Long Reach	1994 Cross Section	2500	27.18	0.001683	1.15	1	23.63	0.00038
Long Reach	1994 Cross Section	2250	27.18	0.003443	1.55	0.91	19.27	0.00038
Long Reach	1994 Cross Section	2125.55	27.18	0.003565	1.62	0.96	17.48	0.00038
Long Reach	1994 Cross Section	2000	27.18	0.00257	1.52	1.14	15.69	0.00038
Long Reach	1994 Cross Section	1700	27.18	0.000844	1.07	1.55	16.39	0.00038
Long Reach	1994 Cross Section	1500	27.18	0.000898	1.09	1.53	16.30	0.00038
Long Reach	1994 Cross Section	1000	27.18	0.001398	1.28	1.4	15.17	0.00038
Long Reach	1994 Cross Section	500	27.18	0.000749	0.99	1.49	18.43	0.00038
Long Reach	1994 Cross Section	0	27.18	0.000404	0.81	1.84	18.24	0.00038
Long Reach	1994 Cross Section	-250	27.18	0.000519	0.91	1.8	16.59	0.00038
Long Reach	1994 Cross Section	-500	27.18	0.000276	0.66	1.69	24.37	0.00038
Long Reach	1996 Cross Section	5000	27.18	0.005392	2.08	1.07	12.21	0.00038
Long Reach	1996 Cross Section	4602	27.18	0.001927	1.36	1.17	17.08	0.00038
Long Reach	1996 Cross Section	4500	27.18	0.00171	1.35	1.32	15.25	0.00038
Long Reach	1996 Cross Section	4374.98	27.18	0.002775	1.54	1.11	15.90	0.00038
Long Reach	1996 Cross Section	4250	27.18	0.003581	1.84	1.28	11.54	0.00038
Long Reach	1996 Cross Section	4000	27.18	0.001761	1.13	0.99	24.30	0.00038
Long Reach	1996 Cross Section	3500	27.18	0.001663	1.29	1.22	17.27	0.00038
Long Reach	1996 Cross Section	3000	27.18	0.001626	1.03	0.87	30.33	0.00038
Long Reach	1996 Cross Section	2500	27.18	0.001445	1.1	1.06	23.31	0.00038
Long Reach	1996 Cross Section	2250	27.18	0.00154	1.12	1.04	23.33	0.00038
Long Reach	1996 Cross Section	2125.51	27.18	0.001914	1.24	1.02	21.49	0.00038

River/Creek	Reach	River Station	Q_2 Total (m^3/s)	Energy Slope (m/m)	Velocity Channel (m/s)	Hydr. Depth (m)	Width (m)	d_{50} (m)
Long Reach	1996 Cross Section	2000	27.18	0.001364	1.23	1.33	16.61	0.00038
Long Reach	1996 Cross Section	1700	27.18	0.00099	1.14	1.53	15.58	0.00038
Long Reach	1996 Cross Section	1500	27.18	0.000912	1.11	1.56	15.70	0.00038
Long Reach	1996 Cross Section	1000	27.18	0.004457	1.82	1.03	14.50	0.00038
Long Reach	1996 Cross Section	500	27.18	0.00151	1.25	1.26	17.26	0.00038
Long Reach	1996 Cross Section	0	27.18	0.000949	1.13	1.58	15.22	0.00038
Long Reach	1996 Cross Section	-250	27.18	0.001697	1.39	1.38	14.17	0.00038
Long Reach	1996 Cross Section	-375.00	27.18	0.002321	1.43	1.09	17.44	0.00038
Long Reach	1996 Cross Section	-500	27.18	0.001265	1.13	1.2	20.04	0.00038
Long Reach	1996 Cross Section	-800	27.18	0.000382	0.82	1.91	17.35	0.00038
Long Reach	1996 Cross Section	-1000	27.18	0.000535	0.93	1.79	16.33	0.00038
Long Reach	1996 Cross Section	-1500	27.18	0.000644	0.79	1.17	29.41	0.00038
Long Reach	1996 Cross Section	-2000	27.18	0.000902	1.13	1.69	14.23	0.00038
Long Reach	1996 Cross Section	-2500	27.18	0.000685	0.96	1.56	18.15	0.00038
Long Reach	1996 Cross Section	-3000	27.18	0.000708	0.94	1.44	20.08	0.00038
Long Reach	1996 Cross Section	-3198	27.18	0.000826	1	1.39	19.55	0.00038
Long Reach	1996 Cross Section	-3400	27.18	0.001664	1.45	1.54	12.17	0.00038
Long Reach	1996 Cross Section	-3500	27.18	0.001587	1.43	1.56	12.18	0.00038
Long Reach	1996 Cross Section	-4000	27.18	0.000698	1.03	1.71	15.43	0.00038
Perry Reach	1993 Cross Section	10000	50.69	0.005064	2.27	1.27	17.58	0.00033
Perry Reach	1993 Cross Section	9500	50.69	0.004041	2.39	1.73	12.26	0.00033
Perry Reach	1993 Cross Section	9200	50.69	0.003956	2.38	1.74	12.24	0.00033
Perry Reach	1993 Cross Section	9100.99	50.69	0.002328	1.94	1.85	14.12	0.00033
Perry Reach	1993 Cross Section	9002	50.69	0.001264	1.53	2.09	15.85	0.00033
Perry Reach	1993 Cross Section	8800	50.69	0.001789	1.77	2.01	14.25	0.00033
Perry Reach	1993 Cross Section	8500	50.69	0.001575	1.69	2.07	14.49	0.00033
Perry Reach	1993 Cross Section	8000	50.69	0.001643	1.68	1.99	15.16	0.00033
Perry Reach	1993 Cross Section	7500	50.69	0.004252	2.43	1.69	12.34	0.00033
Perry Reach	1993 Cross Section	7000	50.69	0.002018	1.78	1.84	15.48	0.00033
Perry Reach	1993 Cross Section	6500	50.69	0.002711	2.08	1.86	13.10	0.00033
Perry Reach	1993 Cross Section	6000	50.69	0.001903	1.81	1.98	14.14	0.00033
Perry Reach	1993 Cross Section	5700	50.69	0.001484	1.66	2.11	14.47	0.00033
Perry Reach	1993 Cross Section	5300	50.69	0.002341	1.88	1.86	14.50	0.00033
Perry Reach	1993 Cross Section	5000	50.69	0.003071	2.06	1.72	14.31	0.00033
Perry Reach	1993 Cross Section	4500	50.69	0.002579	1.89	1.64	16.35	0.00033
Perry Reach	1993 Cross Section	4000	50.69	0.003398	2.22	1.73	13.20	0.00033
Perry Reach	1993 Cross Section	3000	50.69	0.001936	1.73	1.75	16.74	0.00033
Perry Reach	1993 Cross Section	2500	50.69	0.000658	0.91	1.41	39.51	0.00033
Perry Reach	1993 Cross Section	2000	50.69	0.000386	0.84	1.9	31.76	0.00033
Perry Reach	1993 Cross Section	1500	50.69	0.000281	0.79	2.26	28.39	0.00033
Perry Reach	1993 Cross Section	1400	50.69	0.000355	0.86	2.12	27.80	0.00033
Perry Reach	1993 Cross Section	1200	50.69	0.001299	1.31	1.48	26.15	0.00033
Perry Reach	1993 Cross Section	1000	50.69	0.001471	1.38	1.45	25.33	0.00033
Perry Reach	1993 Cross Section	500	50.69	0.001792	1.47	1.38	24.99	0.00033
Perry Reach	1994 Cross Section	10000	50.69	0.004502	2.21	1.31	17.51	0.00033
Perry Reach	1994 Cross Section	9500	50.69	0.003689	2.28	1.67	13.31	0.00033

River/Creek	Reach	River Station	Q_2 Total (m^3/s)	Energy Slope (m/m)	Velocity Channel (m/s)	Hydr. Depth (m)	Width (m)	d_{50} (m)
Perry Reach	1994 Cross Section	9200	50.69	0.002633	2.02	1.88	13.35	0.00033
Perry Reach	1994 Cross Section	9002	50.69	0.00084	1.32	2.32	16.55	0.00033
Perry Reach	1994 Cross Section	8800	50.69	0.002828	2.07	1.74	14.07	0.00033
Perry Reach	1994 Cross Section	8500	50.69	0.002441	1.96	1.8	14.37	0.00033
Perry Reach	1994 Cross Section	8000	50.69	0.001707	1.64	1.81	17.08	0.00033
Perry Reach	1994 Cross Section	7500	50.69	0.003522	2.26	1.7	13.19	0.00033
Perry Reach	1994 Cross Section	7000	50.69	0.001682	1.66	1.82	16.78	0.00033
Perry Reach	1994 Cross Section	6500	50.69	0.002599	2.07	1.94	12.62	0.00033
Perry Reach	1994 Cross Section	6000	50.69	0.002007	1.83	1.93	14.35	0.00033
Perry Reach	1994 Cross Section	5700	50.69	0.001803	1.75	1.89	15.33	0.00033
Perry Reach	1994 Cross Section	5502	50.69	0.002228	1.88	1.8	14.98	0.00033
Perry Reach	1994 Cross Section	5300	50.69	0.003627	2.18	1.57	14.81	0.00033
Perry Reach	1994 Cross Section	5000	50.69	0.003551	2.17	1.58	14.78	0.00033
Perry Reach	1994 Cross Section	4500	50.69	0.003017	1.93	1.63	16.11	0.00033
Perry Reach	1994 Cross Section	3500	50.69	0.000836	1.17	1.77	24.48	0.00033
Perry Reach	1994 Cross Section	3000	50.69	0.001482	1.58	1.87	17.16	0.00033
Perry Reach	1994 Cross Section	2000	50.69	0.000366	0.81	1.86	33.65	0.00033
Perry Reach	1994 Cross Section	1500	50.69	0.00026	0.77	2.29	28.75	0.00033
Perry Reach	1994 Cross Section	1302	50.69	0.00019	0.69	2.5	29.39	0.00033
Perry Reach	1994 Cross Section	1100	50.69	0.00086	1.16	1.7	25.70	0.00033
Perry Reach	1994 Cross Section	1000	50.69	0.001033	1.26	1.67	24.09	0.00033
Perry Reach	1994 Cross Section	500	50.69	0.001508	1.38	1.42	25.87	0.00033
Perry Reach	1995 Cross Section	10000	50.69	0.005013	2.25	1.27	17.74	0.00033
Perry Reach	1995 Cross Section	9500	50.69	0.003493	2.22	1.65	13.84	0.00033
Perry Reach	1995 Cross Section	9200	50.69	0.002259	1.94	1.96	13.33	0.00033
Perry Reach	1995 Cross Section	9002	50.69	0.000915	1.36	2.23	16.71	0.00033
Perry Reach	1995 Cross Section	8800	50.69	0.001577	1.68	2	15.09	0.00033
Perry Reach	1995 Cross Section	8500	50.69	0.001559	1.68	2.01	15.01	0.00033
Perry Reach	1995 Cross Section	8000	50.69	0.00208	1.86	1.98	13.76	0.00033
Perry Reach	1995 Cross Section	7500	50.69	0.002675	2.07	1.93	12.69	0.00033
Perry Reach	1995 Cross Section	7000	50.69	0.001493	1.61	1.98	15.90	0.00033
Perry Reach	1995 Cross Section	6500	50.69	0.002036	1.88	2	13.48	0.00033
Perry Reach	1995 Cross Section	6000	50.69	0.00197	1.76	1.82	15.82	0.00033
Perry Reach	1995 Cross Section	5700	50.69	0.002099	1.86	1.87	14.57	0.00033
Perry Reach	1995 Cross Section	5502	50.69	0.002738	2.04	1.75	14.20	0.00033
Perry Reach	1995 Cross Section	5300	50.69	0.001877	1.75	2	14.48	0.00033
Perry Reach	1995 Cross Section	5000	50.69	0.002109	1.82	1.94	14.36	0.00033
Perry Reach	1995 Cross Section	4500	50.69	0.001459	1.56	1.91	17.01	0.00033
Perry Reach	1995 Cross Section	4000	50.69	0.001669	1.73	2.09	14.02	0.00033
Perry Reach	1995 Cross Section	3000	50.69	0.001482	1.56	1.84	17.66	0.00033
Perry Reach	1995 Cross Section	2000	50.69	0.000495	0.89	1.69	33.70	0.00033
Perry Reach	1995 Cross Section	1500	50.69	0.000404	0.91	2.04	27.31	0.00033
Perry Reach	1995 Cross Section	1302	50.69	0.000333	0.85	2.14	27.87	0.00033
Perry Reach	1995 Cross Section	1100	50.69	0.001064	1.23	1.58	26.08	0.00033
Perry Reach	1995 Cross Section	1000	50.69	0.001147	1.28	1.59	24.91	0.00033
Perry Reach	1995 Cross Section	500	50.69	0.001427	1.34	1.44	26.27	0.00033

River/Creek	Reach	River Station	Q_2 Total (m^3/s)	Energy Slope (m/m)	Velocity Channel (m/s)	Hydr. Depth (m)	Width (m)	d_{50} (m)
Perry Reach	1997 Cross Section	10000	50.69	0.005314	2.33	1.27	17.13	0.00033
Perry Reach	1997 Cross Section	9500	50.69	0.003485	2.26	1.8	12.46	0.00033
Perry Reach	1997 Cross Section	9200	50.69	0.002195	1.92	1.97	13.40	0.00033
Perry Reach	1997 Cross Section	9002	50.69	0.000912	1.36	2.23	16.71	0.00033
Perry Reach	1997 Cross Section	8800	50.69	0.002461	1.96	1.85	13.98	0.00033
Perry Reach	1997 Cross Section	8500	50.69	0.002629	2.01	1.82	13.86	0.00033
Perry Reach	1997 Cross Section	8000	50.69	0.00081	1.29	2.19	17.94	0.00033
Perry Reach	1997 Cross Section	7500	50.69	0.002952	2.1	1.87	12.91	0.00033
Perry Reach	1997 Cross Section	7000	50.69	0.001736	1.67	1.84	16.50	0.00033
Perry Reach	1997 Cross Section	6500	50.69	0.002438	2.03	1.97	12.68	0.00033
Perry Reach	1997 Cross Section	6000	50.69	0.002186	1.86	1.9	14.34	0.00033
Perry Reach	1997 Cross Section	5700	50.69	0.002062	1.84	1.89	14.58	0.00033
Perry Reach	1997 Cross Section	5502	50.69	0.001754	1.74	1.97	14.79	0.00033
Perry Reach	1997 Cross Section	5300	50.69	0.001676	1.66	1.97	15.50	0.00033
Perry Reach	1997 Cross Section	5000	50.69	0.001848	1.72	1.92	15.35	0.00033
Perry Reach	1997 Cross Section	4500	50.69	0.001299	1.5	2.01	16.81	0.00033
Perry Reach	1997 Cross Section	4000	50.69	0.001285	1.54	2.36	13.95	0.00033
Perry Reach	1997 Cross Section	3000	50.69	0.001353	1.49	1.83	18.59	0.00033
Perry Reach	1997 Cross Section	2500	50.69	0.000455	0.76	1.45	46.00	0.00033
Perry Reach	1997 Cross Section	2000	50.69	0.000503	0.89	1.69	33.70	0.00033
Perry Reach	1997 Cross Section	1500	50.69	0.000484	0.91	1.83	30.44	0.00033
Pery Reach	1997 Cross Section	1302	50.69	0.000471	0.91	1.85	30.11	0.00033
Perry Reach	1997 Cross Section	1100	50.69	0.001055	1.33	1.83	20.83	0.00033
Perry Reach	1997 Cross Section	1000	50.69	0.00095	1.28	1.88	21.06	0.00033
Perry Reach	1997 Cross Section	500	50.69	0.001499	1.49	1.66	20.49	0.00033

Table C.2: Abiaca River (1996) station data.

Station	Flow Discharge Q (m^3/s)	Flow Velocity V (m/s)	Top Width W (m)	Flow depth d
1000	2.86	0.41	24.2	0.29
	5.72	0.5	24.58	0.46
	8.58	0.57	24.88	0.60
	11.44	0.63	25.14	0.72
	14.3	0.69	25.37	0.82
	17.16	0.73	25.59	0.92
	20.02	0.77	25.79	1.01
	22.88	0.81	25.98	1.09
	25.74	0.85	26.15	1.16
	28.6	0.88	26.32	1.24
	31.46	0.91	26.49	1.31
	34.32	0.94	26.64	1.37
	37.18	0.96	26.79	1.44
	40.04	0.99	26.94	1.50
	42.9	1.01	27.09	1.56
	45.76	1.04	27.29	1.62
	48.62	1.06	27.55	1.67
	51.48	1.08	27.89	1.72
	54.34	1.09	28.28	1.76
	57.2	1.11	28.65	1.80
1500	2.86	0.45	21.39	0.30
	5.72	0.58	23.09	0.43
	8.58	0.66	23.76	0.55
	11.44	0.72	24.13	0.66
	14.3	0.78	24.24	0.76
	17.16	0.82	24.35	0.85
	20.02	0.87	24.45	0.94
	22.88	0.91	24.55	1.03
	25.74	0.94	24.64	1.11
	28.6	0.98	24.72	1.18
	31.46	1.01	24.8	1.25
	34.32	1.04	24.88	1.32
	37.18	1.07	24.96	1.39
	40.04	1.1	25.03	1.46
	42.9	1.12	25.11	1.52
	45.76	1.15	25.18	1.58
	48.62	1.17	25.25	1.65
	51.48	1.19	25.35	1.70
	54.34	1.21	25.47	1.76
	57.2	1.23	25.66	1.81

Station	Flow Discharge Q (m^3/s)	Flow Velocity V (m/s)	Top Width W (m)	Flow depth d
2000	2.86	0.45	18.57	0.34
	5.72	0.59	20.66	0.47
	8.58	0.68	21.79	0.58
	11.44	0.76	22.51	0.67
	14.3	0.83	22.62	0.77
	17.16	0.88	22.73	0.86
	20.02	0.93	22.82	0.94
	22.88	0.98	22.92	1.02
	25.74	1.02	23.01	1.10
	28.6	1.06	23.12	1.17
	31.46	1.09	23.27	1.23
	34.32	1.13	23.41	1.30
	37.18	1.16	23.56	1.36
	40.04	1.19	23.69	1.42
	42.9	1.22	23.83	1.48
	45.76	1.24	23.96	1.54
	48.62	1.27	24.09	1.60
	51.48	1.29	24.22	1.65
	54.34	1.31	24.34	1.70
	57.2	1.33	24.47	1.76
2500	2.86	0.31	20.53	0.45
	5.72	0.42	22.9	0.59
	8.58	0.51	23.15	0.73
	11.44	0.58	23.37	0.84
	14.3	0.65	23.56	0.94
	17.16	0.7	23.74	1.03
	20.02	0.75	23.9	1.11
	22.88	0.8	24.06	1.19
	25.74	0.84	24.21	1.27
	28.6	0.88	24.35	1.34
	31.46	0.91	24.5	1.41
	34.32	0.95	24.73	1.47
	37.18	0.98	24.94	1.53
	40.04	1.01	25.15	1.58
	42.9	1.03	25.36	1.64
	45.76	1.06	25.57	1.69
	48.62	1.08	25.85	1.74
	51.48	1.11	26.12	1.78
	54.34	1.12	27.66	1.75
	57.2	1.14	29.34	1.71

Station	**Flow Discharge** ***Q*** **(m^3/s)**	**Flow Velocity** ***V*** **(m/s)**	**Top Width** ***W*** **(m)**	**Flow depth** ***d***
3000	2.86	0.94	17.19	0.18
	5.72	0.84	19.01	0.36
	8.58	0.9	19.27	0.49
	11.44	0.96	19.5	0.61
	14.3	1.02	19.69	0.71
	17.16	1.08	19.88	0.80
	20.02	1.13	20.05	0.89
	22.88	1.17	20.21	0.97
	25.74	1.21	20.36	1.04
	28.6	1.25	20.55	1.11
	31.46	1.29	20.81	1.17
	34.32	1.32	21.05	1.23
	37.18	1.36	21.29	1.29
	40.04	1.38	21.52	1.34
	42.9	1.41	21.75	1.40
	45.76	1.44	21.97	1.45
	48.62	1.46	22.19	1.50
	51.48	1.49	22.4	1.55
	54.34	1.5	22.85	1.59
	57.2	1.5	23.93	1.59
3500	2.86	0.4	22.48	0.32
	5.72	0.56	22.64	0.45
	8.58	0.67	22.78	0.56
	11.44	0.75	22.92	0.66
	14.3	0.82	23.04	0.76
	17.16	0.87	23.15	0.85
	20.02	0.92	23.3	0.93
	22.88	0.97	23.45	1.01
	25.74	1.01	23.6	1.08
	28.6	1.05	23.74	1.15
	31.46	1.08	23.88	1.22
	34.32	1.11	24.01	1.28
	37.18	1.14	24.14	1.35
	40.04	1.17	24.26	1.41
	42.9	1.2	24.39	1.47
	45.76	1.22	24.55	1.52
	48.62	1.25	24.71	1.58
	51.48	1.27	24.87	1.63
	54.34	1.29	25.04	1.68
	57.2	1.3	25.69	1.71

Station	**Flow Discharge** *Q* **(m^3/s)**	**Flow Velocity** *V* **(m/s)**	**Top Width** *W* **(m)**	**Flow depth** *d*
4000	2.86	0.3	29.73	0.32
	5.72	0.39	36.2	0.41
	8.58	0.43	41.38	0.48
	11.44	0.47	43.82	0.56
	14.3	0.5	44.41	0.65
	17.16	0.52	45.92	0.72
	20.02	0.54	47.7	0.78
	22.88	0.56	49.42	0.83
	25.74	0.57	51.05	0.89
	28.6	0.58	52.63	0.94
	31.46	0.59	54.16	0.99
	34.32	0.6	54.92	1.04
	37.18	0.61	55.44	1.10
	40.04	0.62	55.95	1.16
	42.9	0.62	56.45	1.22
	45.76	0.63	56.94	1.27
	48.62	0.64	57.42	1.33
	51.48	0.64	57.89	1.38
	54.34	0.65	59.42	1.41
	57.2	0.65	61.66	1.43

APPENDIX D
NATURAL STREAMS DATA (KODOATIE, 2000) TO DEVELOP THE EQUATIONS

Table D.1: Toffaletti (1968) data – Atchafalaya River.

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Transported Sediment Concen. (ppm)
12/18/53	382.32	304.80	6.10	0.21	0.124	0.000002	31	1
03/19/54	637.20	307.85	6.22	0.33	0.161	0.000010	29	6
03/24/54	651.36	307.85	6.22	0.34	0.091	0.000004	29	9
12/10/53	719.33	307.85	6.25	0.37	0.153	0.000006	29	8
12/03/53	1073.33	313.94	6.89	0.50	0.138	0.000010	26	4
04/24/55	1084.66	313.94	6.28	0.55	0.091	0.000009	18	18
05/01/55	1138.46	313.94	6.22	0.58	0.091	0.000010	15	23
03/10/54	1169.62	313.94	6.83	0.55	0.157	0.000011	28	6
01/28/55	1200.77	316.99	6.46	0.59	0.138	0.000010	19	19
01/21/55	1214.93	316.99	6.40	0.60	0.130	0.000011	18	25
06/25/54	1237.58	313.94	6.74	0.59	0.123	0.000011	30	19
07/06/54	1237.58	316.99	6.80	0.57	0.132	0.000011	28	15
03/31/54	1240.42	313.94	6.80	0.58	0.155	0.000011	29	17
10/08/54	1263.07	316.99	6.61	0.60	0.123	0.000011	26	17
03/05/54	1376.35	316.99	7.19	0.60	0.151	0.000010	29	36
09/24/54	1393.34	316.99	6.89	0.64	0.119	0.000011	30	38
10/15/54	1449.98	316.99	6.92	0.66	0.141	0.000014	26	42
11/26/53	1707.70	323.09	7.59	0.70	0.169	0.000014	27	23
12/31/54	1770.00	323.09	7.04	0.78	0.144	0.000016	24	62
04/07/45	2044.70	321.56	9.97	0.64	0.189	0.000023	28	14
11/01/17	2143.82	328.27	9.85	0.66	0.223	0.000015	28	23
01/12/46	2155.15	321.87	10.30	0.65	0.195	0.000017	13	16
10/05/45	2177.81	322.48	10.24	0.66	0.241	0.000017	19	20
11/15/17	2279.76	331.01	9.94	0.69	0.209	0.000015	25	15
06/12/25	2282.59	333.76	9.94	0.69	0.201	0.000022	6	13
12/17/44	2288.26	327.96	10.18	0.69	0.208	0.000020	31	26
03/24/45	2288.26	327.66	9.88	0.71	0.213	0.000018	29	21
09/10/70	2327.90	334.37	9.20	0.76	0.148	0.000018	6	136
11/16/26	2359.06	338.33	8.90	0.78	0.261	0.000024	29	23
10/20/45	2415.70	327.36	10.58	0.70	0.226	0.000019	14	37
05/05/17	2421.36	334.98	9.91	0.73	0.223	0.000017	29	44
11/03/00	2475.17	335.89	10.52	0.70	0.215	0.000024	8	155
12/31/44	2500.66	329.18	10.45	0.73	0.189	0.000019	29	29
01/01/00	2554.46	348.08	9.91	0.74	0.200	0.000027	29	16
09/04/53	2730.05	344.42	8.23	0.96	0.177	0.000019	25	67
07/07/00	2766.86	349.30	10.49	0.76	0.227	0.000026	17	33
08/19/81	3086.88	374.90	9.48	0.87	0.153	0.000027	27	49
01/05/55	3285.12	350.52	7.86	1.19	0.103	0.000015	21	225
12/05/72	3398.40	373.08	10.52	0.87	0.308	0.000029	19	44
08/28/53	3483.36	350.52	9.30	1.07	0.177	0.000020	22	61
08/17/55	3540.00	365.76	8.32	1.16	0.130	0.000023	9	208
08/05/81	3624.96	390.14	10.09	0.92	0.153	0.000032	34	57
12/06/79	3624.96	368.81	8.11	1.21	0.154	0.000024	9	174
01/25/46	3851.52	340.46	10.85	1.04	0.305	0.000020	8	122
07/22/81	4163.04	396.24	10.55	1.00	0.153	0.000031	33	33

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Transported Sediment Concen. (ppm)
03/12/80	4616.16	390.14	9.05	1.31	0.171	0.000028	5	232
07/31/55	4984.32	387.10	9.42	1.37	0.143	0.000028	8	252
04/15/81	5380.80	405.38	10.88	1.22	0.232	0.000035	26	74
04/29/81	5494.08	408.43	11.25	1.20	0.153	0.000036	34	120
09/11/44	6598.56	393.19	12.86	1.30	0.211	0.000034	29	146
12/20/79	6853.44	402.34	11.00	1.55	0.172	0.000034	7	183
01/06/81	7788.00	411.48	10.88	1.74	0.179	0.000038	8	102
01/27/81	7986.24	438.91	11.86	1.53	0.188	0.000038	8	207
10/29/71	8042.88	406.30	13.62	1.45	0.192	0.000037	26	222
06/01/53	8354.40	414.53	12.07	1.67	0.221	0.000043	18	194
03/26/80	8439.36	408.43	11.64	1.77	0.169	0.000039	9	404
01/13/81	8524.32	435.86	12.80	1.53	0.175	0.000038	8	179
04/18/26	8524.32	412.39	13.81	1.50	0.181	0.000040	10	237
01/19/81	8665.92	435.86	12.95	1.53	0.286	0.000041	22	156
09/03/53	9175.68	417.58	13.38	1.64	0.193	0.000042	12	387
01/12/81	9543.84	448.06	13.87	1.54	0.235	0.000045	20	60
09/30/80	10223.52	451.10	13.23	1.71	0.199	0.000044	12	343
10/06/80	11243.04	454.15	13.17	1.88	0.197	0.000048	15	333
01/05/81	11497.92	454.15	13.29	1.91	0.260	0.000050	18	567
04/10/71	11639.52	468.78	14.75	1.68	0.274	0.000045	16	232
07/16/71	11781.12	469.70	14.54	1.73	0.289	0.000045	21	260
10/20/80	12007.68	457.20	13.41	1.96	0.229	0.000051	18	178
10/13/80	12149.28	457.20	13.75	1.93	0.235	0.000051	17	280
07/22/71	12574.08	476.10	14.20	1.86	0.183	0.000047	21	365
10/11/71	13848.48	483.72	14.11	2.03	0.181	0.000050	21	474
08/17/98	14188.32	503.22	14.72	1.92	0.193	0.000049	15	501

Table D.2: Simons (1957) data – American canal (canal data in Colorado), Nebraska and Wyoming.

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Transported Sediment Concen. (ppm)
-	1.22	3.19	0.80	0.47	0.229	0.000294	21	406
-	1.56	3.49	0.80	0.56	0.173	0.000253	21	249
-	3.20	3.96	1.32	0.61	0.349	0.000110	26	44
-	4.14	9.33	1.07	0.41	0.318	0.000135	25	254
-	4.83	10.73	0.89	0.51	0.465	0.000237	26	52
-	5.01	7.62	0.89	0.74	0.580	0.000330	26	448
-	5.62	7.59	1.01	0.73	0.715	0.000302	23	123
-	6.42	12.56	1.01	0.50	0.446	0.000218	28	100
-	10.47	6.92	1.60	0.95	0.360	0.000114	26	131
-	12.59	11.73	1.83	0.59	0.096	0.000063	23	370
-	29.18	22.19	2.53	0.52	0.253	0.000058	22	115
-	29.4037	14.813	2.591	0.8	0.311	0.00012	21.67	185

Table D.3: Chitale (1966) data – India canal.

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Transported Sediment Concen. (ppm)
-	1.15	4.35	0.67	0.39	0.048	0.000145	20	1,031
-	1.29	4.31	0.79	0.38	0.064	0.000165	20	760
-	2.02	5.34	0.94	0.40	0.042	0.000115	20	1,417
-	3.00	5.78	1.10	0.47	0.046	0.000115	20	3,132
-	13.19	10.70	1.94	0.64	0.051	0.000100	20	671
-	13.41	10.58	1.97	0.65	0.050	0.000100	20	981
-	14.03	14.66	1.72	0.56	0.037	0.000080	20	4,230
-	14.11	13.49	1.85	0.57	0.036	0.000080	20	1,894
-	14.81	13.55	1.86	0.59	0.043	0.000080	20	2,467
-	15.84	17.31	1.57	0.58	0.070	0.000120	20	726
-	15.87	17.34	1.57	0.58	0.056	0.000120	20	596
-	19.22	15.95	2.37	0.51	0.048	0.000088	20	512
-	19.45	16.03	2.38	0.51	0.044	0.000088	20	624
-	24.59	18.07	2.24	0.61	0.046	0.000120	20	2,517
-	27.50	17.89	2.51	0.61	0.039	0.000070	20	822
-	27.67	17.98	2.52	0.61	0.033	0.000070	20	831
-	27.89	18.17	2.17	0.71	0.050	0.000112	20	2,601
-	30.86	20.57	2.37	0.63	0.064	0.000080	20	918
-	33.74	20.58	2.38	0.69	0.043	0.000080	20	797
-	59.16	25.49	2.44	0.95	0.021	0.000084	20	5,759
-	60.72	25.56	2.49	0.95	0.025	0.000084	20	5,182
-	68.82	25.77	2.55	1.05	0.031	0.000110	20	3,557
-	68.92	25.68	2.55	1.05	0.033	0.000110	20	3,508
-	131.39	51.51	3.29	0.77	0.066	0.000065	20	1,593
-	132.80	51.90	3.29	0.78	0.064	0.000065	20	1,976
-	153.25	56.02	3.37	0.81	0.024	0.000060	20	2,887
-	156.05	56.27	3.39	0.82	0.020	0.000060	20	2,601
-	157.41	56.47	3.35	0.83	0.030	0.000070	20	2,316
-	158.37	56.61	3.35	0.83	0.039	0.000070	20	2,175
-	163.72	66.55	3.39	0.73	0.082	0.000057	20	1,519
-	166.36	66.54	3.41	0.73	0.080	0.000057	20	1,425
-	242.19	79.10	3.56	0.86	0.057	0.000064	20	1,490

Table D.4: Williams and Rosgen (1989) data – Chippewa River.

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Transported Sediment Concen. (ppm)
04/13/77	117	185	1.4	0.5	0.980	0.00013	11.5	8
11/16/77	141	185	1.4	0.5	1.100	0.00015	8.5	3
04/14/78	374	231	2	0.8	1.990	0.00025	6.5	27
05/10/77	51.8	176	0.99	0.3	3.000	0.00011	17	6
06/06/78	172	200	1.5	0.6	3.200	0.00019	22	13
07/06/77	337	209	2.2	0.8	3.330	0.00023	26	23
11/17/76	32	132	1	0.2	3.500	9.3E-05	4.5	5
10/12/77	433	231	2.2	0.9	4.650	0.00025	13	22
10/18/76	30.6	124	1.1	0.2	5.000	0.00011	7	4
04/05/78	320	225	1.8	0.8	5.800	0.00023	4.5	19
04/17/79	620	245	2.5	1.0	6.000	0.00025	4.5	17
10/31/78	123	190	1.3	0.5	7.600	0.00017	10.5	5
09/13/77	255	204	1.8	0.7	7.660	0.00021	19	11
07/06/78	348	226	1.9	0.8	7.900	0.00025	21	19
04/23/79	779	247	2.8	1.1	15.500	0.00025	8	38
05/10/77	132	188	1	0.7	0.550	0.00033	17.5	47
03/17/77	219	215	1.3	0.8	0.570	0.00032	3	68
09/13/77	279	223	1.5	0.9	0.580	0.00034	19	176
07/06/77	377	225	1.8	0.9	0.600	0.00036	26	101
04/13/77	139	187	1.1	0.7	0.610	0.00034	15	60
11/16/77	198	199	1.3	0.8	0.630	0.00031	5	47
04/17/79	739	239	2.9	1.1	0.640	0.00031	5	75
11/16/76	51.5	153	0.62	0.6	0.650	0.00032	3	16
06/06/78	247	224	1.6	0.7	0.680	0.00035	22	19
10/12/77	479	227	2.2	1.0	0.710	0.00032	13	70
07/06/78	473	233	2	1.0	0.740	0.00029	24	77
10/18/76	50.7	160	0.61	0.5	0.870	0.00029	6	28
08/24/77	53.8	160	0.68	0.5	0.880	0.00032	20	48
04/23/79	884	244	3.2	1.1	1.300	0.00032	9.5	99
05/11/77	110	243	0.95	0.5	0.400	0.00032	18.5	33
04/14/77	155	241	1.1	0.6	0.440	0.00041	15	194
03/16/77	257	265	1.5	0.7	0.460	0.00045	4.5	201
07/24/79	140	247	0.85	0.7	0.475	0.00029	24.5	33
07/07/77	399	273	1.6	0.9	0.480	0.00037	25.5	357
04/06/78	391	276	1.8	0.8	0.480	0.00028	5	99
05/30/79	219	242	1.4	0.7	0.480	0.00017	20.5	58

Date of Measurement	**Water Discharge** *Q* **(m^3/s)**	**Channel Width** *W* **(m)**	**Flow Depth** *d* **(m)**	**Flow Velocity** *V* **(m/s)**	**Mean bed Diameter** d_s **(mm)**	**Water Surface Slope** *S* **(m/m)**	**Water Temp. (°C)**	**Transported Sediment Concen. (ppm)**
09/11/79	118	229	0.76	0.7	0.480	0.00025	18.5	69
09/14/77	295	274	1.3	0.9	0.490	0.00037	18.5	85
06/07/78	217	264	1.1	0.7	0.510	0.00024	22.5	63
10/19/76	72.5	171	0.75	0.6	0.540	0.00036	6	64
09/20/78	320	277	1.5	0.8	0.540	0.00033	19	81
11/17/76	70	171	0.76	0.5	0.560	0.00058	4	73
11/01/78	187	246	1.2	0.6	0.560	0.00029	7.5	58
09/20/76	70.5	171	0.8	0.5	0.580	0.00039	16	102
05/16/78	170	261	0.97	0.7	0.600	0.00025	16.5	59
09/01/76	76.2	195	0.88	0.5	0.620	0.00039	19	41
11/17/77	210	270	1.4	0.6	0.710	0.00036	3.5	70

Table D.5: USBR (1958) data – Colorado River.

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Transported Sediment Concen. (ppm)
-	77.53	103.08	1.13	0.66	0.310	0.000207	11	86
-	92.03	130.54	1.49	0.47	0.313	0.000073	11	23
-	96.79	95.73	1.91	0.53	0.280	0.000133	13	23
-	105.34	130.54	1.51	0.53	0.290	0.000060	11	312
-	105.34	106.35	1.40	0.71	0.310	0.000233	13	133
-	108.23	106.99	1.37	0.74	0.315	0.000253	10	113
-	109.16	95.17	1.55	0.74	0.280	0.000277	9	365
-	111.65	96.29	1.99	0.58	0.260	0.000147	10	18
-	115.25	136.14	1.37	0.62	0.310	0.000176	12	62
-	118.19	99.95	2.01	0.59	0.280	0.000113	13	21
-	121.11	107.59	1.48	0.76	0.273	0.000333	12	152
-	121.76	108.15	1.59	0.71	0.300	0.000220	11	105
-	127.71	132.52	1.68	0.57	0.285	0.000100	10	139
-	128.90	106.77	1.51	0.80	0.330	0.000233	11	239
-	131.45	107.54	1.57	0.78	0.288	0.000260	12	225
-	132.24	136.11	1.45	0.67	0.315	0.000389	12	172
-	134.00	136.72	1.47	0.67	0.285	0.000183	11	176
-	135.92	106.43	1.67	0.76	0.315	0.000220	9	195
-	137.87	92.64	1.93	0.77	0.236	0.000196	13	113
-	154.47	110.11	1.86	0.76	0.293	0.000207	15	198
-	155.52	109.93	1.93	0.73	0.325	0.000167	20	200
-	157.36	134.74	1.94	0.60	0.260	0.000200	11	177
-	158.40	110.32	1.91	0.75	0.300	0.000173	16	193
-	166.08	134.58	1.91	0.65	0.285	0.000100	14	193
-	169.90	137.42	1.59	0.78	0.320	0.000107	14	143
-	173.16	102.77	2.04	0.83	0.250	0.000153	8	289
-	175.59	102.43	2.06	0.83	0.335	0.000407	10	316
-	178.11	100.97	2.08	0.85	0.340	0.000127	11	73
-	181.17	110.67	2.15	0.76	0.340	0.000177	22	304
-	181.65	109.79	1.93	0.86	0.315	0.000213	11	413
-	183.78	136.17	2.01	0.67	0.270	0.000157	16	68
-	184.20	102.43	1.91	0.94	0.300	0.000267	8	230
-	187.60	110.69	2.18	0.78	0.360	0.000173	24	276
-	191.93	104.83	2.26	0.81	0.430	0.000140	11	192
-	194.90	101.49	2.29	0.84	0.290	0.000173	11	112
-	196.07	110.06	2.04	0.87	0.300	0.000260	11	78

Date of Measurement	Water Discharge *Q* (m³/s)	Channel Width *W* (m)	Flow Depth *d* (m)	Flow Velocity *V* (m/s)	Mean bed Diameter d_s (mm)	Water Surface Slope *S* (m/m)	Water Temp. (°C)	Transported Sediment Concen. (ppm)
-	198.90	103.28	2.25	0.85	0.295	0.000277	9	474
-	203.12	151.82	2.25	0.60	0.245	0.000100	10	262
-	209.80	110.90	2.24	0.84	0.345	0.000227	22	212
-	210.28	104.23	2.06	0.98	0.310	0.000067	9	604
-	216.91	146.03	2.03	0.73	0.220	0.000100	12	145
-	217.08	110.92	2.22	0.88	0.330	0.000216	17	242
-	219.12	107.58	2.53	0.81	0.270	0.000267	17	316
-	219.80	110.59	2.06	0.97	0.340	0.000193	14	160
-	220.31	109.44	2.87	0.70	0.315	0.000213	9	182
-	221.49	103.95	2.31	0.92	0.320	0.000220	14	325
-	221.72	104.27	2.47	0.86	0.285	0.000240	15	477
-	223.62	112.22	2.49	0.80	0.355	0.000173	20	109
-	226.53	139.33	2.44	0.67	0.290	0.000080	22	164
-	228.94	146.62	2.70	0.58	0.230	0.000146	14	189
-	234.49	153.28	2.64	0.58	0.155	0.000080	14	94
-	239.11	140.22	2.43	0.70	0.205	0.000127	23	253
-	240.07	111.68	2.22	0.97	0.370	0.000187	22	151
-	241.83	143.79	2.99	0.56	0.200	0.000346	20	264
-	243.52	103.01	2.57	0.92	0.300	0.000177	18	283
-	245.76	105.79	2.40	0.97	0.280	0.000110	18	178
-	254.20	247.28	1.46	0.70	0.270	0.000167	11	394
-	269.94	112.79	2.68	0.89	0.340	0.000224	19	148
-	272.78	108.45	2.68	0.94	0.695	0.000103	15	178
-	274.22	112.51	2.65	0.92	0.370	0.000206	22	255
-	279.77	142.12	2.62	0.75	0.200	0.000153	27	168
-	279.77	112.77	2.72	0.91	0.400	0.000147	27	202
-	288.83	142.10	2.58	0.79	0.225	0.000067	24	181
-	293.28	112.23	3.12	0.84	0.280	0.000193	13	573
-	293.50	110.28	3.05	0.87	0.275	0.000150	21	159
-	294.44	158.25	2.76	0.67	0.210	0.000100	20	106
-	296.76	112.78	2.80	0.94	0.395	0.000233	26	87
-	301.86	139.97	2.54	0.85	0.395	0.000147	22	230
-	303.92	113.05	2.83	0.95	0.320	0.000207	15	328
-	307.10	113.61	2.87	0.94	0.295	0.000216	26	199
-	308.65	139.54	2.64	0.84	0.320	0.000120	18	90
-	310.61	113.09	2.90	0.95	0.350	0.000193	24	166
-	315.73	114.01	2.78	1.00	0.335	0.000233	26	302
-	324.23	144.34	2.96	0.76	0.265	0.000166	17	264

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Transported Sediment Concen. (ppm)
-	324.62	140.97	2.67	0.86	0.400	0.000153	22	193
-	324.79	141.75	2.92	0.78	0.240	0.000087	26	111
-	328.48	146.97	2.91	0.77	0.200	0.000073	27	228
-	330.71	147.69	3.14	0.71	0.230	0.000069	19	152
-	334.14	109.06	2.63	1.16	0.240	0.000283	19	160
-	335.84	146.54	2.85	0.80	0.225	0.000060	26	233
-	343.65	157.90	2.82	0.77	0.195	0.000144	20	338
-	344.62	144.79	2.62	0.91	0.320	0.000113	21	140
-	344.90	146.37	2.70	0.87	0.340	0.000160	22	115
-	345.44	114.35	3.07	0.99	0.360	0.000227	27	201
-	348.30	159.88	3.89	0.56	0.180	0.000037	17	57
-	348.75	111.59	3.34	0.94	0.260	0.000196	23	172
-	358.77	110.15	3.37	0.97	0.250	0.000220	18	355
-	359.20	146.21	2.96	0.83	0.270	0.000127	25	83
-	359.99	116.81	3.09	1.00	0.270	0.000127	16	209
-	360.50	114.73	3.14	1.00	0.375	0.000257	27	213
-	362.46	117.03	2.83	1.09	0.300	0.000187	13	131
-	370.61	111.64	2.62	1.27	0.275	0.000160	20	36
-	387.66	149.09	3.08	0.84	0.280	0.000207	26	114
-	389.58	114.91	3.63	0.93	0.230	0.000200	20	212
-	403.57	253.10	2.30	0.69	0.310	0.000140	19	32
-	408.39	112.77	2.87	1.26	0.248	0.000310	18	347
-	413.43	148.29	3.37	0.83	0.240	0.000177	17	119
-	443.16	162.43	3.59	0.76	0.195	0.000134	19	48
-	454.32	160.67	3.31	0.85	0.175	0.000170	17	284
-	500.16	254.55	2.19	0.90	0.360	0.000180	19	769

Table D.6: Shiohara and Tsubaki (1959) data – Hii River.

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. °C	Transported Sediment Concen. (ppm)
-	0.00094	0.35	0.02	0.14	0.210	0.008090	20	925
-	0.00145	0.35	0.02	0.19	0.210	0.011300	20	1,955
-	0.00199	0.35	0.02	0.23	0.210	0.010700	20	3,316
-	0.00168	0.35	0.03	0.19	0.210	0.009750	20	2,347
-	0.00244	0.35	0.03	0.25	0.210	0.009270	20	1,728
-	0.00303	0.35	0.03	0.28	0.210	0.008040	20	4,878
-	0.00448	0.35	0.03	0.40	0.210	0.007280	20	4,274
-	0.00542	0.35	0.03	0.46	0.210	0.008390	20	5,639
-	0.00440	0.35	0.04	0.35	0.210	0.007080	20	3,546
-	0.00651	0.35	0.04	0.51	0.210	0.006690	20	3,261
-	0.00745	0.35	0.04	0.56	0.210	0.006440	20	4,323
-	0.00367	0.35	0.03	0.31	0.210	0.005820	20	1,249
-	0.00513	0.35	0.04	0.35	0.210	0.005820	20	1,325
-	0.00437	0.35	0.04	0.29	0.210	0.007690	20	1,702
-	0.00775	0.35	0.04	0.50	0.210	0.005150	20	2,342
-	1.78047	8.00	0.31	0.73	1.440	0.000840	20	121
-	2.35603	8.00	0.40	0.74	1.440	0.001060	20	167
-	2.42392	8.00	0.42	0.71	1.440	0.000850	20	116
-	2.76436	8.00	0.49	0.70	1.440	0.000860	20	117
-	3.49857	8.00	0.59	0.74	1.440	0.000880	20	299
-	4.85132	8.00	0.65	0.93	1.440	0.001480	20	271
-	4.47922	8.00	0.70	0.80	1.440	0.001010	20	154
-	4.72729	8.00	0.73	0.81	1.440	0.001530	20	191
-	1.13182	8.00	0.20	0.70	1.330	0.001660	20	553
-	2.23740	8.00	0.37	0.75	1.330	0.001380	20	207
-	1.95124	8.00	0.39	0.63	1.330	0.000890	20	136
-	2.91789	8.00	0.45	0.80	1.330	0.001420	20	167
-	0.18104	2.00	0.16	0.58	1.260	0.001690	20	296
-	0.24806	2.00	0.20	0.63	1.260	0.001610	20	284
-	0.34433	2.00	0.26	0.67	1.260	0.001610	20	275
-	0.42868	2.00	0.29	0.73	1.260	0.001670	20	283
-	0.52172	2.00	0.34	0.76	1.260	0.001660	20	243
-	0.71449	2.00	0.47	0.76	1.260	0.001660	20	242
-	0.04740	0.80	0.11	0.55	1.260	0.001690	20	225
-	0.07000	0.80	0.15	0.60	1.260	0.001720	20	127
-	0.39008	2.00	0.30	0.66	1.460	0.001370	20	222
-	0.49427	2.00	0.36	0.69	1.460	0.001400	20	210
-	0.53144	2.00	0.36	0.74	1.460	0.001460	20	270

Table D.7: Hubble and Matejka (1959) data – Middle Loup River.

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Transported Sediment Concen. (ppm)
09/03/25	9.34	44.81	0.33	0.62	0.282	0.001420	31	648
03/15/26	9.46	45.42	0.31	0.67	0.351	0.001288	20	884
03/25/97	10.22	44.20	0.33	0.70	0.339	0.001345	10	1,044
08/10/70	10.31	43.89	0.32	0.73	0.317	0.001458	24	455
03/28/26	10.36	45.11	0.33	0.69	0.274	0.001307	18	816
04/25/98	10.39	44.81	0.37	0.62	0.383	0.001288	31	411
11/18/70	10.45	43.28	0.36	0.68	0.424	0.001250	22	481
12/07/25	10.93	45.11	0.33	0.74	0.334	0.001326	26	494
08/17/99	11.30	37.49	0.33	0.92	0.351	0.001174	1	1,637
05/05/70	11.30	44.20	0.34	0.75	0.382	0.001250	16	871
10/29/69	11.61	42.98	0.29	0.93	0.292	0.001439	4	1,831
02/10/70	11.72	44.20	0.30	0.88	0.335	0.001023	11	1,110
02/24/99	12.09	46.33	0.31	0.83	0.351	0.001307	4	1,345
10/09/69	12.23	43.89	0.30	0.94	0.278	0.000928	4	1,618
12/25/71	12.54	45.11	0.25	1.13	0.219	0.001345	3	1,023

Table D.8: Posada Garcia (1995) and Toffaletti (1968) data – Mississippi River.

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Transported Sediment Concent. (ppm)
03/23/89	1900.00	380.00	7.08	0.71	0.299	0.000059	12	6
06/19/89	3590.00	391.00	7.19	1.28	0.290	0.000105	25	154
06/07/90	1230.00	221.00	6.20	0.90	0.480	0.000040	10	15
05/16/88	332.00	228.00	3.61	0.40	0.180	0.000028	22	2
03/09/89	1480.00	270.00	4.52	1.21	0.381	0.000172	7	187
05/19/88	1480.00	350.00	4.31	0.98	0.386	0.000173	22	104
06/07/89	1760.00	270.00	5.18	1.26	0.389	0.000172	23	154
07/20/87	2640.00	377.00	5.65	1.24	0.379	0.000170	27	212
12/02/87	2810.00	428.00	5.30	1.24	0.370	0.000177	6	353
05/23/88	3230.00	945.00	5.85	0.58	0.454	0.000029	22	3
12/06/87	4200.00	974.00	7.82	0.55	0.393	0.000017	9	1
06/11/89	8760.00	1008.00	9.31	0.93	0.606	0.000026	24	4
06/14/90	9550.00	1046.00	11.80	0.78	0.570	0.000016	22	7
03/03/90	16100.00	1080.00	12.50	1.20	0.659	0.000042	6	12
03/16/89	20400.00	1070.00	13.70	1.39	0.556	0.000051	9	34
03/01/90	6620.00	761.00	9.84	0.88	0.889	0.000031	6	4
12/17/87	1830.00	525.00	5.54	0.63	0.340	0.000060	9	6
08/06/87	2050.00	519.00	4.08	0.97	0.350	0.000045	31	48
06/04/88	2150.00	515.00	4.06	1.03	0.292	0.000079	25	87
06/25/89	4880.00	562.00	9.62	0.90	0.246	0.000040	26	77
03/29/89	6150.00	556.00	11.10	1.00	0.307	0.000042	13	25
02/28/90	2340.00	355.00	6.11	1.08	0.798	0.000093	3	46
07/31/87	332.00	168.00	2.92	0.68	0.378	0.000150	31	15
05/29/88	438.00	164.00	3.17	0.84	0.334	0.000050	22	25
12/12/87	519.00	177.00	4.02	0.73	0.393	0.000052	11	101
06/18/89	860.00	195.00	8.98	0.49	0.373	0.000050	23	3
03/22/89	1500.00	200.00	10.30	0.73	0.392	0.000053	12	2
06/22/89	1070.00	165.00	9.19	0.71	0.561	0.000021	26	7
06/22/90	1250.00	200.00	9.75	0.64	0.222	0.000016	28	4
03/26/89	1500.00	182.00	10.40	0.79	0.450	0.000037	15	22
08/02/87	7630.00	850.00	11.50	0.78	0.284	0.000064	31	17
05/30/88	8160.00	838.00	11.00	0.89	0.286	0.000060	24	17
12/13/87	9920.00	904.00	11.00	1.00	0.398	0.000066	9	314

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Transported Sediment Concent. (ppm)
06/20/89	23300.00	990.00	15.10	1.56	0.286	0.000069	25	114
03/24/89	26800.00	1035.00	15.90	1.63	0.321	0.000066	11	119
05/26/88	7170.00	805.00	8.36	1.07	0.380	0.000104	22	34
12/08/87	9470.00	844.00	9.67	1.16	0.846	0.000101	9	370
06/14/89	15300.00	902.00	11.50	1.47	0.469	0.000098	24	61
07/30/87	6850.00	701.00	6.75	1.45	0.370	0.000094	30	85
05/28/88	7050.00	754.00	7.36	1.27	0.394	0.000096	23	83
12/11/87	8770.00	750.00	7.96	1.47	0.334	0.000095	9	152
06/17/89	16900.00	897.00	13.10	1.44	0.441	0.000094	24	84
03/07/90	23300.00	855.00	17.30	1.58	0.365	0.000082	7	84
03/21/89	25900.00	913.00	16.50	1.72	0.681	0.000085	9	102
05/20/88	3350.00	487.00	6.75	1.02	0.386	0.000085	23	36
07/22/87	3830.00	482.00	7.35	1.08	0.324	0.000085	28	74
03/13/89	3940.00	490.00	6.90	1.17	0.389	0.000085	6	120
06/08/89	4760.00	508.00	7.66	1.22	0.443	0.000092	25	83
01/15/79	1512.29	455.98	4.94	0.67	0.235	0.000079	3	13
09/14/70	1512.29	457.20	4.66	0.71	0.505	0.000072	2	25
04/01/36	1560.43	460.25	4.82	0.70	0.296	0.000134	14	26
03/16/09	1634.06	459.64	5.18	0.69	0.328	0.000103	2	45
05/25/51	1755.84	470.61	6.00	0.62	0.544	0.000072	5	14
05/20/54	1767.17	462.69	5.39	0.71	0.268	0.000056	7	21
05/26/51	1806.82	470.92	6.10	0.63	0.573	0.000057	5	14
11/17/53	1886.11	463.91	5.55	0.73	0.287	0.000052	18	12
01/28/27	1886.11	471.53	6.16	0.65	0.598	0.000057	2	21
01/27/27	1911.60	472.14	6.19	0.65	0.572	0.000052	2	23
08/19/53	2005.06	467.26	5.61	0.77	0.293	0.000052	21	14
07/04/26	2064.53	471.83	6.34	0.69	1.152	0.000046	11	15
05/12/63	2095.68	464.52	5.64	0.80	0.386	0.000103	17	44
04/02/26	2115.50	474.88	6.52	0.68	0.642	0.000052	21	7
07/22/81	2208.96	465.43	6.07	0.78	0.299	0.000072	6	30
01/24/46	2271.26	469.39	5.97	0.81	0.574	0.000072	2	67
11/23/79	2279.76	470.92	6.04	0.80	0.224	0.000072	6	37
11/23/79	2279.76	470.92	6.04	0.80	0.224	0.000093	6	36
08/28/63	2299.58	470.61	5.55	0.88	0.625	0.000098	9	51

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (^{o}C)	Transported Sediment Concent. (ppm)
08/04/53	2486.50	471.22	6.40	0.82	0.274	0.000056	22	19
09/02/18	2628.10	469.39	5.94	0.94	0.549	0.000093	2	70
07/12/45	2633.76	469.39	6.64	0.84	0.641	0.000062	18	14
04/13/07	2789.52	469.39	6.95	0.86	0.306	0.000069	23	21
12/26/80	2832.00	477.62	6.95	0.85	0.299	0.000065	21	31
03/31/90	2888.64	472.44	6.95	0.88	0.472	0.000077	25	37
09/21/90	2916.96	477.62	6.40	0.95	0.429	0.000062	18	49
05/05/17	3001.92	474.88	6.83	0.93	0.511	0.000077	26	48
03/15/26	3030.24	480.06	7.74	0.82	0.579	0.000031	24	24
05/27/89	3086.88	477.93	6.74	0.96	0.377	0.000093	22	61
10/16/45	3115.20	478.54	7.32	0.89	0.646	0.000061	8	27
06/14/80	3256.80	472.74	7.35	0.94	0.310	0.000060	27	24
07/19/81	3256.80	472.74	7.35	0.94	0.310	0.000062	27	23
01/18/91	3398.40	480.97	7.35	0.96	0.350	0.000067	13	70
12/15/44	3426.72	478.54	7.99	0.90	0.741	0.000042	28	15
01/09/26	3568.32	479.15	6.58	1.13	0.187	0.000079	17	201
04/05/00	3624.96	486.16	7.47	1.00	0.429	0.000049	18	37
06/21/90	3624.96	475.49	7.53	1.01	0.443	0.000072	26	59
04/14/17	3681.60	481.28	7.65	1.00	0.555	0.000077	27	41
03/23/45	3766.56	480.97	7.77	1.01	0.643	0.000031	29	17
02/26/89	3823.20	486.46	7.56	1.04	0.354	0.000093	13	100
01/16/62	3851.52	484.02	7.47	1.07	0.229	0.000108	8	202
04/08/00	3851.52	484.63	7.74	1.03	0.469	0.000052	20	36
08/12/79	3908.16	481.89	7.77	1.04	0.225	0.000072	16	79
08/12/79	3908.16	481.89	7.77	1.04	0.225	0.000088	16	78
01/17/17	3993.12	480.36	8.02	1.04	0.500	0.000077	24	62
05/02/53	4021.44	480.36	7.99	1.05	0.225	0.000063	24	40
09/16/99	4049.76	480.36	8.02	1.05	0.467	0.000046	26	31
09/30/16	4134.72	485.24	8.08	1.05	0.447	0.000103	21	67
05/01/72	4191.36	482.80	8.35	1.04	0.604	0.000047	28	38
04/20/07	4389.60	483.11	7.99	1.14	0.216	0.000075	6	126
04/21/53	4502.88	486.16	8.41	1.10	0.208	0.000066	26	59
01/23/53	4531.20	486.16	8.50	1.10	0.220	0.000062	29	69
12/02/25	4559.52	496.82	9.63	0.95	0.519	0.000026	26	32

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Transported Sediment Concent. (ppm)
08/20/79	4616.16	486.16	8.38	1.13	0.226	0.000072	18	108
10/18/52	4701.12	492.25	8.35	1.14	0.243	0.000065	28	81
12/13/25	4729.44	497.74	9.24	1.03	0.624	0.000031	26	34
02/10/99	4814.40	493.78	9.66	1.01	0.733	0.000025	17	92
02/11/89	4871.04	494.39	8.50	1.16	0.306	0.000103	8	106
12/28/61	4871.04	497.43	8.56	1.14	0.307	0.000098	19	70
06/12/99	4899.36	486.77	8.90	1.13	0.567	0.000046	28	31
10/13/71	4956.00	491.95	9.05	1.11	0.472	0.000067	23	39
10/03/52	4984.32	491.03	8.50	1.19	0.211	0.000066	27	98
07/11/52	5040.96	492.25	8.53	1.20	0.191	0.000062	23	103
09/09/25	5040.96	499.87	9.81	1.03	0.610	0.000042	28	25
07/10/52	5069.28	492.86	8.56	1.20	0.191	0.000079	21	101
09/15/51	5267.52	499.57	9.45	1.12	0.313	0.000053	4	86
01/15/53	5324.16	495.30	8.99	1.20	0.225	0.000065	26	72
10/26/71	5437.44	497.74	9.33	1.17	0.610	0.000046	23	60
01/14/53	5579.04	498.35	9.17	1.22	0.225	0.000072	25	91
05/27/25	5607.36	502.92	10.12	1.10	0.697	0.000036	27	45
08/16/99	5720.64	499.87	9.66	1.18	0.176	0.000042	6	182
08/25/25	5947.20	502.92	10.49	1.13	0.680	0.000042	27	52
04/02/81	6060.48	494.39	9.54	1.28	0.324	0.000088	14	112
04/02/81	6060.48	494.39	9.51	1.29	0.334	0.000073	16	86
04/05/62	6071.81	511.45	9.72	1.22	0.334	0.000108	22	105
05/17/99	6202.08	501.70	10.21	1.21	0.345	0.000026	8	167
04/28/62	6230.40	501.09	10.06	1.24	0.356	0.000108	25	77
03/31/52	6258.72	501.70	9.78	1.28	0.176	0.000063	12	119
04/10/71	6258.72	499.87	9.60	1.30	0.417	0.000082	11	106
07/03/52	6258.72	504.14	9.97	1.25	0.463	0.000055	9	106
04/10/71	6400.32	499.87	9.57	1.34	0.399	0.000086	11	108
02/03/99	6626.88	505.97	10.97	1.19	0.733	0.000025	17	132
12/02/89	6711.84	499.26	9.48	1.42	0.399	0.000108	26	137
10/07/16	6796.80	508.41	9.88	1.35	0.435	0.000098	19	105
11/11/98	6796.80	504.75	11.22	1.20	0.723	0.000036	20	86
11/28/98	6825.12	505.36	10.00	1.35	0.592	0.000072	21	68
10/19/16	6881.76	505.97	9.33	1.46	0.356	0.000118	8	226

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Transported Sediment Concent. (ppm)
11/26/72	6910.08	507.19	10.27	1.33	0.239	0.000057	17	112
04/08/71	6910.08	495.00	9.88	1.41	0.399	0.000089	11	121
09/21/61	7323.55	515.72	9.81	1.45	0.221	0.000118	9	320
04/07/71	7363.20	498.65	10.12	1.46	0.399	0.000078	10	128
06/18/06	7788.00	507.19	10.21	1.50	0.250	0.000076	2	239
03/15/52	7872.96	510.84	11.09	1.39	0.520	0.000060	10	131
06/24/16	8127.84	518.16	10.73	1.46	0.427	0.000113	11	104
02/16/80	8184.48	514.50	10.42	1.53	0.233	0.000069	19	187
06/17/06	8241.12	509.63	10.36	1.56	0.260	0.000093	2	233
01/11/62	8411.04	502.92	11.06	1.51	0.295	0.000103	18	175
08/30/98	8411.04	495.00	10.85	1.57	0.496	0.000082	13	110
02/27/99	8524.32	513.89	10.94	1.52	0.485	0.000072	22	132
08/29/98	8524.32	507.80	10.64	1.58	0.496	0.000095	13	104
09/02/89	8779.20	510.84	10.67	1.61	0.350	0.000108	23	232
08/24/98	9912.00	508.71	11.40	1.71	0.431	0.000105	9	145
10/04/97	10166.88	516.64	12.25	1.61	0.632	0.000088	21	214
08/22/98	10280.16	513.59	11.40	1.76	0.419	0.000082	9	178

Table D.9: Posada Garcia (1995) data – Amazon River.

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Transported Sediment Concent. (ppm)
02/06/87	300.00	135.00	2.47	0.90	0.364	0.000145	29	56
05/21/86	1290.00	218.00	5.26	1.12	0.298	0.000146	29	166
05/19/86	1430.00	263.00	4.95	1.10	0.378	0.000089	29	236
02/08/87	252.00	151.00	2.23	0.75	0.584	0.000139	29	34
03/16/83	235.00	237.00	1.98	0.50	0.273	0.000030	29	5
02/14/87	324.00	244.00	2.38	0.56	0.444	0.000118	29	23
05/15/86	800.00	266.00	3.81	0.79	0.296	0.000057	30	65
06/06/85	874.00	266.00	4.90	0.67	0.308	0.000030	29	15
11/29/82	1040.00	260.00	4.71	0.85	0.227	0.000030	27	72
10/10/84	2400.00	233.00	8.73	1.18	0.273	0.000030	29	130
02/10/87	322.00	235.50	2.71	0.51	0.542	0.000139	29	13
02/02/87	134.00	106.00	2.11	0.60	0.279	0.000218	29	68
02/05/87	293.00	186.00	1.85	0.85	0.896	0.000238	29	43
05/22/86	1190.00	214.00	4.35	1.28	0.438	0.000182	29	220
02/11/87	32.40	67.00	2.40	0.20	0.220	0.000118	29	10
02/02/87	106.00	136.00	1.42	0.55	0.767	0.000225	29	38
05/23/86	308.00	140.00	2.45	0.90	0.370	0.000225	29	136
02/09/87	22.10	31.50	1.23	0.57	0.519	0.000139	29	15
02/09/87	52.10	102.50	1.51	0.34	0.424	0.000139	29	8
02/15/87	185.00	104.00	4.33	0.41	0.185	0.000076	29	46
12/11/82	23100.00	1010.00	19.90	1.15	0.089	0.000060	27	89
07/11/83	24700.00	1040.00	23.70	1.00	0.196	0.000045	27	11
02/04/87	8.60	23.00	1.13	0.33	0.282	0.000238	29	39
05/22/86	52.00	49.50	1.46	0.72	0.296	0.000182	29	194
03/09/83	4030.00	1315.00	3.74	0.82	0.532	0.000059	32	6
05/30/85	12100.00	2170.00	6.50	0.86	0.492	0.000064	28	15
11/19/82	14000.00	2181.00	6.85	0.94	0.487	0.000058	29	17
11/18/82	14400.00	2172.00	6.99	0.95	0.499	0.000058	29	17
10/15/84	22600.00	2501.00	9.05	1.00	0.493	0.000065	28	24
08/18/82	59900.00	2560.00	16.50	1.42	0.374	0.000047	29	61
08/19/82	57300.00	2195.00	17.40	1.50	0.396	0.000058	28	60
06/05/85	22100.00	2890.00	7.21	1.06	0.217	0.000044	28	80
10/11/84	34600.00	3270.00	11.00	0.96	0.342	0.000035	29	30

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (^{o}C)	Transported Sediment Concent. (ppm)
08/17/82	47100.00	3338.00	12.60	1.12	0.375	0.000033	28	37
12/05/82	23800.00	2215.00	10.90	0.99	0.428	0.000047	28	8
06/24/82	50900.00	2650.00	16.30	1.18	0.350	0.000041	28	59
08/22/82	65000.00	2680.00	17.20	1.41	0.431	0.000042	29	82
12/06/82	23000.00	1905.00	15.50	0.78	0.378	0.000039	28	4
06/25/82	49600.00	1910.00	19.60	1.33	0.495	0.000043	28	72
08/23/82	67100.00	2040.00	21.40	1.54	0.426	0.000048	30	75
08/15/82	30800.00	2505.00	11.40	1.08	0.404	0.000062	27	29
12/03/82	25400.00	1275.00	18.80	1.06	0.489	0.000046	28	16
06/22/82	52000.00	1208.00	26.20	1.64	0.338	0.000055	27	82
08/20/82	70700.00	1310.00	28.00	1.93	0.499	0.000058	30	58
11/21/82	17300.00	1227.00	13.80	1.02	0.410	0.000058	29	11
10/13/84	27300.00	1150.00	17.20	1.38	0.426	0.000058	28	45
08/16/82	43700.00	1333.00	17.80	1.84	0.436	0.000061	27	102
05/26/85	2650.00	849.00	3.76	0.83	0.699	0.000037	30	21
10/18/84	5260.00	840.00	6.73	0.93	0.911	0.000037	30	8
02/04/87	17.50	22.50	1.10	0.71	0.427	0.000238	29	262
02/11/87	152.00	67.50	4.66	0.48	0.418	0.000139	29	25
05/18/86	317.00	77.50	6.14	0.67	0.211	0.000089	29	11
01/30/87	133.00	170.00	1.16	0.68	0.349	0.000400	29	255
05/25/86	272.00	167.50	1.68	0.97	0.211	0.000272	29	851
12/06/82	75700.00	1819.00	21.80	1.84	0.331	0.000026	27	140
11/30/82	66600.00	1720.00	21.80	1.78	0.212	0.000064	27	167
07/08/76	38100.00	970.00	23.00	1.71	0.255	0.000069	26	78
05/20/77	43600.00	1080.00	23.80	1.70	0.220	0.000069	27	159
12/03/82	71300.00	3020.00	16.90	1.40	0.192	0.000045	27	164
05/28/77	133000.00	3130.00	27.60	1.54	0.216	0.000033	28	69
06/22/76	140000.00	3100.00	28.10	1.61	0.244	0.000033	26	86
11/29/82	65400.00	2160.00	19.00	1.59	0.244	0.000064	27	128
05/22/77	83700.00	2129.00	22.00	1.79	0.198	0.000056	27	125
06/29/76	86100.00	2100.00	21.90	1.87	0.238	0.000056	26	63
05/22/77	63600.00	1400.00	23.70	1.92	0.233	0.000058	27	120
11/27/82	57100.00	1360.00	22.70	1.85	0.196	0.000064	27	174
12/05/82	80800.00	1400.00	36.10	1.60	0.154	0.000045	27	110

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Transported Sediment Concent. (ppm)
02/22/84	85200.00	1418.00	37.30	1.61	0.120	0.000034	27	78
05/26/77	151000.00	1000.00	62.30	2.42	0.409	0.000037	27	47
12/01/82	62700.00	1530.00	23.90	1.71	0.343	0.000045	27	175
12/12/82	120000.00	2300.00	38.90	1.34	0.141	0.000014	27	23
06/11/77	155000.00	2400.00	45.00	1.44	0.171	0.000019	27	43
12/13/82	123000.00	2200.00	46.20	1.21	0.135	0.000014	27	17
03/04/84	177000.00	2250.00	48.50	1.62	0.122	0.000014	28	49
06/02/77	230000.00	2340.00	55.80	1.76	0.237	0.000020	27	52
06/14/76	235000.00	2600.00	48.90	1.85	0.243	0.000020	26	85
06/02/77	139.00	1.00	65.00	2.14	0.149	0.000020	27	62
06/02/77	128.00	1.00	68.00	1.88	0.149	0.000020	27	49
06/02/77	111.00	1.00	63.00	1.76	0.371	0.000020	27	29
06/02/77	118.00	1.00	65.00	1.81	0.376	0.000020	27	36
06/02/77	139.00	1.00	63.00	2.20	0.124	0.000020	27	78
12/10/82	90600.00	1510.00	44.60	1.35	0.259	0.000014	27	18

APPENDIX E

NATURAL STREAMS DATA (KODOATIE, 2000) TO VERIFY THE NEW EQUATIONS

Table E.1: Colby and Hembree (1955) data – Niabrara River.

Date of Measurement	**Water Discharge Q (m^3/s)**	**Channel Width W (m)**	**Flow Depth d (m)**	**Flow Velocity V (m/s)**	**Mean Bed Diameter d_s (mm)**	**Water Surface Slope S (m/m)**	**Water Temp. °C**	**Transported Sediment Concen. (ppm)**
12/23/25	5.86	21.34	0.44	0.62	0.349	0.001212	23	257
09/16/25	5.91	21.03	0.42	0.67	0.320	0.001250	28	278
09/05/25	6.57	21.34	0.43	0.72	0.280	0.001136	24	372
05/27/25	6.62	21.34	0.47	0.65	0.285	0.001250	21	566
08/17/70	6.65	21.49	0.44	0.71	0.292	0.001288	23	608
03/30/26	6.65	21.18	0.47	0.67	0.300	0.001136	16	567
11/21/70	7.16	21.18	0.46	0.73	0.337	0.001288	22	637
02/22/71	7.22	21.34	0.44	0.77	0.306	0.001174	17	740
12/10/25	7.53	21.34	0.49	0.72	0.299	0.001155	22	550
07/10/43	7.56	21.49	0.47	0.75	0.304	0.001345	24	825
08/11/70	7.64	21.34	0.48	0.75	0.286	0.001269	18	577
08/20/25	7.78	21.34	0.49	0.74	0.314	0.001288	23	747
01/09/27	9.40	21.34	0.43	1.01	0.334	0.001610	1	940
06/20/71	9.42	21.03	0.48	0.94	0.327	0.001402	16	1,118
03/22/71	9.74	21.34	0.47	0.98	0.262	0.001420	16	1,069
10/11/69	11.35	21.34	0.49	1.09	0.307	0.001705	5	1,267
01/30/70	11.72	21.64	0.49	1.10	0.286	0.001705	7	1,600
06/30/97	12.88	21.64	0.53	1.13	0.314	0.001686	14	1,293
05/07/70	16.05	21.95	0.58	1.27	0.215	0.001799	12	1,488

Table E.2: Einstein (1955) data – Mountain Creek.

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Transported Sediment Concen. (ppm)
-	0.06	3.92	0.04	0.41	0.286	0.003150	20	1,046
-	0.08	3.29	0.06	0.37	0.899	0.001510	20	54
-	0.09	3.92	0.05	0.50	0.286	0.003110	20	584
-	0.09	3.92	0.05	0.50	0.286	0.003110	20	360
-	0.09	3.92	0.05	0.50	0.286	0.003090	20	360
-	0.09	3.51	0.07	0.39	0.899	0.001610	22	70
-	0.10	3.55	0.07	0.40	0.899	0.001520	25	73
-	0.10	3.92	0.05	0.53	0.286	0.003090	20	520
-	0.11	3.92	0.05	0.55	0.286	0.003090	20	689
-	0.12	3.76	0.08	0.42	0.899	0.001580	22	41
-	0.12	3.92	0.05	0.57	0.286	0.003060	20	656
-	0.13	3.92	0.06	0.59	0.286	0.003060	20	603
-	0.13	3.92	0.06	0.59	0.286	0.003070	20	573
-	0.15	3.92	0.06	0.61	0.286	0.003020	20	1,029
-	0.15	3.92	0.09	0.45	0.899	0.001370	25	79
-	0.15	3.92	0.09	0.45	0.899	0.001400	25	79
-	0.16	3.92	0.06	0.63	0.286	0.003020	20	1,092
-	0.16	3.95	0.09	0.45	0.899	0.001390	25	74
-	0.16	3.95	0.09	0.45	0.899	0.001370	25	74
-	0.17	3.98	0.09	0.46	0.899	0.001390	25	83
-	0.17	3.92	0.07	0.63	0.286	0.002480	20	418
-	0.18	4.02	0.10	0.47	0.899	0.001600	26	200
-	0.18	4.02	0.10	0.47	0.899	0.001590	26	178
-	0.18	4.02	0.10	0.47	0.899	0.001590	26	200
-	0.18	4.02	0.10	0.47	0.899	0.001590	26	178
-	0.18	3.92	0.07	0.67	0.286	0.002960	20	1,120
-	0.19	4.02	0.10	0.47	0.899	0.001480	22	82
-	0.19	4.02	0.10	0.47	0.899	0.001510	22	109
-	0.19	4.04	0.10	0.47	0.899	0.001580	26	215
-	0.19	4.04	0.10	0.47	0.899	0.001580	26	172
-	0.19	4.04	0.10	0.47	0.899	0.001490	22	85
-	0.19	4.04	0.10	0.47	0.899	0.001520	22	106
-	0.19	4.04	0.10	0.47	0.899	0.001550	22	132
-	0.19	4.04	0.10	0.47	0.899	0.001560	22	95
-	0.19	4.04	0.10	0.47	0.899	0.001570	22	116
-	0.20	4.06	0.10	0.48	0.899	0.001480	24	123

Date of Measurement	Water Discharge *Q* (m^3/s)	Channel Width *W* (m)	Flow Depth *d* (m)	Flow Velocity *V* (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope *S* (m/m)	Water Temp. (°C)	Transported Sediment Concen. (ppm)
-	0.20	4.08	0.10	0.48	0.899	0.001480	24	119
-	0.21	4.22	0.13	0.38	0.899	0.001640	20	74
-	0.21	4.10	0.11	0.48	0.899	0.001480	24	113
-	0.22	4.12	0.11	0.49	0.899	0.001490	24	92
-	0.23	4.30	0.14	0.37	0.899	0.001630	25	27
-	0.23	4.13	0.11	0.49	0.899	0.001490	24	105
-	0.24	4.15	0.12	0.50	0.899	0.001500	24	136
-	0.24	4.15	0.12	0.50	0.899	0.001560	26	186
-	0.24	3.92	0.08	0.75	0.286	0.002910	20	2,601
-	0.25	4.16	0.12	0.50	0.899	0.001490	24	146
-	0.26	4.18	0.12	0.51	0.899	0.001510	24	111
-	0.27	4.21	0.12	0.52	0.899	0.001510	24	135
-	0.29	4.33	0.17	0.40	0.899	0.001630	25	42
-	0.30	4.25	0.13	0.53	0.899	0.001490	24	108
-	0.30	4.25	0.13	0.53	0.899	0.001570	15	169
-	0.30	4.25	0.13	0.53	0.899	0.001560	15	161
-	0.31	4.26	0.14	0.53	0.899	0.001500	24	172
-	0.31	4.26	0.14	0.53	0.899	0.001570	26	159
-	0.31	4.26	0.14	0.53	0.899	0.001550	15	178
-	0.32	4.27	0.14	0.54	0.899	0.001550	25	686
-	0.32	4.27	0.14	0.54	0.899	0.001570	26	229
-	0.32	4.27	0.14	0.54	0.899	0.001550	15	216
-	0.33	4.28	0.14	0.54	0.899	0.001530	15	193
-	0.33	4.28	0.14	0.54	0.899	0.001550	15	193
-	0.33	3.92	0.10	0.85	0.286	0.002850	20	620
-	0.34	4.30	0.14	0.54	0.899	0.001590	26	204
-	0.35	4.28	0.14	0.57	0.899	0.001360	20	264
-	0.35	3.92	0.10	0.85	0.286	0.002760	20	508
-	0.35	4.31	0.15	0.55	0.899	0.001630	26	139
-	0.35	4.31	0.15	0.55	0.899	0.001560	26	183
-	0.35	4.31	0.15	0.55	0.899	0.001560	26	171
-	0.39	4.33	0.16	0.56	0.899	0.001580	26	195
-	0.39	4.33	0.16	0.56	0.899	0.001580	26	195
-	0.41	4.33	0.17	0.57	0.899	0.001570	26	169
-	0.42	4.33	0.20	0.48	0.899	0.001650	25	29
-	0.43	4.33	0.17	0.58	0.899	0.001590	26	234
-	0.44	4.33	0.18	0.58	0.899	0.001610	26	258
-	0.45	4.33	0.18	0.58	0.899	0.001610	26	181

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Transported Sediment Concen. (ppm)
-	0.45	4.33	0.18	0.58	0.899	0.001630	26	181
-	0.46	4.33	0.21	0.49	0.899	0.001730	20	146
-	0.46	3.92	0.12	0.99	0.286	0.002760	20	853
-	0.65	3.92	0.15	1.13	0.286	0.002750	20	931
-	0.65	4.33	0.26	0.57	0.899	0.001790	20	149
-	0.68	4.33	0.27	0.58	0.899	0.001710	25	71
-	0.70	4.33	0.25	0.65	0.899	0.001600	20	345
-	0.76	4.33	0.29	0.61	0.899	0.001790	20	208
-	0.81	4.33	0.30	0.62	0.899	0.001790	20	112
-	0.85	4.33	0.31	0.63	0.899	0.001770	20	179
-	0.88	4.33	0.30	0.69	0.899	0.001750	20	317
-	0.90	4.33	0.32	0.65	0.899	0.001790	20	351
-	0.93	4.33	0.33	0.66	0.899	0.001790	20	195
-	0.96	4.33	0.32	0.70	0.899	0.001790	20	384
-	1.00	3.92	0.19	1.35	0.286	0.002690	20	758
-	1.01	4.33	0.33	0.71	0.899	0.001770	20	259
-	1.02	4.33	0.33	0.71	0.899	0.001790	25	573
-	1.02	4.33	0.33	0.71	0.899	0.001810	20	239
-	1.02	4.33	0.33	0.71	0.899	0.001800	20	406
-	1.02	4.33	0.33	0.71	0.899	0.001800	20	239
-	1.04	4.33	0.35	0.68	0.899	0.001840	25	140
-	1.35	4.33	0.41	0.77	0.899	0.001870	25	230
-	1.39	4.33	0.41	0.77	0.899	0.001850	25	491
-	1.46	4.33	0.43	0.78	0.899	0.001880	25	431
-	1.48	4.33	0.44	0.78	0.899	0.001920	25	209
-	1.49	4.33	0.44	0.79	0.899	0.001830	25	277

Table E.3: Toffaletti (1968) data – Red River.

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Transported Sediment Concen. (ppm)
-	27.52	23.77	1.68	0.69	0.200	0.000086	29	286
-	109.58	57.91	2.68	0.71	0.110	0.000080	24	146
-	112.41	57.30	2.32	0.85	0.200	0.000134	24	595
-	114.96	57.91	2.35	0.85	0.300	0.000140	17	236
-	120.91	55.47	2.44	0.89	0.100	0.000200	20	181
-	122.04	53.65	2.38	0.96	0.300	0.000185	11	302
-	138.47	66.14	2.29	0.92	0.300	0.000165	15	395
-	138.47	59.44	2.38	0.98	0.300	0.000179	11	150
-	139.03	57.91	2.44	0.98	0.311	0.000176	22	198
-	143.85	63.40	2.47	0.92	0.300	0.000238	23	197
-	146.11	55.78	2.62	1.00	0.290	0.000182	27	244
-	146.68	67.67	2.68	0.81	0.120	0.000232	24	473
-	153.47	58.52	2.71	0.97	0.290	0.000165	24	261
-	166.75	67.67	2.56	0.96	0.190	0.000051	27	116
-	172.44	112.78	1.31	1.17	0.090	0.000194	16	232
-	209.26	71.63	3.32	0.88	0.210	0.000127	22	484
-	226.53	109.42	2.29	0.91	0.311	0.000185	19	388
-	233.61	118.26	2.47	0.80	0.110	0.000214	15	148
-	255.41	112.17	2.56	0.89	0.290	0.000207	12	305
-	322.80	120.40	2.68	1.00	0.200	0.000196	22	526
-	328.47	97.54	3.32	1.01	0.210	0.000188	19	432
-	334.13	110.34	2.47	1.23	0.210	0.000159	20	428
-	342.62	116.74	3.11	0.94	0.210	0.000254	22	620
-	351.12	112.17	2.13	1.47	0.130	0.000124	18	706
-	359.61	111.25	2.10	1.54	0.120	0.000116	23	531
-	362.44	99.06	3.08	1.19	0.120	0.000118	29	464
-	362.44	118.26	2.99	1.03	0.200	0.000161	18	663
-	376.60	115.82	2.35	1.39	0.210	0.000141	21	702
-	393.59	99.67	3.38	1.17	0.200	0.000181	17	299
-	399.26	112.78	3.41	1.04	0.311	0.000178	17	1,317
-	413.41	110.64	2.44	1.53	0.200	0.000115	18	1,297
-	424.74	111.86	2.38	1.60	0.140	0.000155	19	1,153
-	427.57	121.62	3.17	1.11	0.210	0.000202	16	1,217

Table E.4: Culbertson (1972) data – Rio Grande Convey Canal.

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Transported Sediment Concen. (ppm)
01/13/81	25.75	21.34	1.30	0.93	0.270	0.000650	15	1,025
01/13/81	25.75	22.86	1.37	0.82	0.280	0.000650	15	1,025
01/14/81	25.19	22.86	1.50	0.74	0.210	0.000650	15	906
01/14/81	25.19	20.12	1.25	1.00	0.230	0.000650	15	906
04/13/81	33.68	22.56	0.89	1.67	0.200	0.000730	17	1,348
05/24/08	36.22	21.34	1.02	1.66	0.210	0.001110	18	2,475
04/14/81	36.51	27.43	0.89	1.50	0.180	0.000520	17	985
09/22/82	35.38	22.56	1.10	1.43	0.180	0.000660	4	2,486
09/23/82	35.38	22.56	1.11	1.42	0.180	0.000590	3	3,049

Table E.5: Toffaletti (1968) data – Rio Grande River.

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. °C	Transported Sediment Concen. (ppm)
03/05/44	35.12	40.54	1.05	0.83	0.302	0.000830	18	783
03/05/44	35.12	139.90	0.40	0.62	0.302	0.000830	18	463
06/11/44	57.49	81.69	0.89	0.79	0.281	0.000820	23	598
06/11/44	57.49	108.81	0.44	1.20	0.281	0.000820	23	867
09/09/25	57.49	176.78	0.48	0.68	0.338	0.000800	27	596
09/09/25	58.34	82.30	0.82	0.86	0.272	0.000800	24	924
11/08/43	59.47	81.99	0.78	0.93	0.317	0.000830	15	1,000
11/08/43	59.47	192.63	0.33	0.93	0.317	0.000830	17	1,117
11/14/24	77.31	82.91	0.75	1.24	0.230	0.000890	14	2,517
06/03/25	78.16	81.99	0.84	1.13	0.312	0.000760	21	1,113
06/03/25	80.71	112.78	0.73	0.97	0.318	0.000760	21	724
11/14/24	82.41	195.07	0.36	1.17	0.306	0.000890	18	2,917
07/01/71	95.16	82.30	0.95	1.22	0.223	0.000830	19	1,724
07/01/71	110.16	194.46	0.53	1.06	0.214	0.000830	18	1,635
09/03/89	113.28	81.38	0.90	1.54	0.308	0.000760	19	3,653
08/29/89	122.91	81.08	0.81	1.86	0.308	0.000760	17	2,978
08/29/89	124.04	151.79	0.58	1.40	0.308	0.000760	19	2,881
05/28/25	133.67	106.68	0.75	1.68	0.330	0.000790	23	2,118
09/03/89	133.95	157.89	0.69	1.22	0.308	0.000760	22	3,621
05/28/25	136.79	82.91	1.06	1.55	0.328	0.000790	22	1,849
08/26/89	154.34	158.50	0.65	1.50	0.308	0.000740	21	2,791
08/26/89	164.26	82.30	1.05	1.91	0.308	0.000740	18	3,588
09/10/89	168.79	162.15	0.64	1.63	0.308	0.000800	25	2,819
09/10/89	171.05	83.21	1.04	1.98	0.308	0.000800	23	4,530
05/25/25	172.75	149.05	0.66	1.74	0.317	0.000830	23	2,415
05/25/25	173.88	82.91	1.16	1.82	0.293	0.000830	21	2,139
02/09/25	180.96	173.74	0.63	1.65	0.347	0.000840	18	2,869
02/09/25	183.80	82.91	1.11	2.00	0.387	0.000840	17	2,517
05/16/89	190.59	169.77	0.66	1.71	0.308	0.000800	16	4,337
05/16/89	194.28	82.30	1.12	2.10	0.308	0.000800	14	3,203
08/20/89	220.61	154.84	0.83	1.72	0.308	0.000830	22	2,768
08/20/89	231.09	82.91	1.32	2.11	0.308	0.000830	19	2,343
05/21/89	235.34	164.90	0.78	1.84	0.308	0.000800	17	3,830
05/21/89	235.62	82.60	1.36	2.10	0.308	0.000800	16	2,989
05/29/89	245.82	82.30	1.25	2.38	0.308	0.000790	19	2,818
05/29/89	246.38	196.60	0.67	1.88	0.308	0.000790	20	3,766
06/04/89	282.35	194.16	0.80	1.81	0.308	0.000800	20	3,164
06/04/89	286.03	83.21	1.46	2.35	0.308	0.000800	23	2,449

Table E.6: Chaudry et al. (1970) data – West Pakistan (CHOP) Canal.

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Transported Sediment Concen. (ppm)
-	27.52	23.77	1.68	0.69	0.200	0.000086	29	286
-	109.58	57.91	2.68	0.71	0.110	0.000080	24	146
-	112.41	57.30	2.32	0.85	0.200	0.000134	24	595
-	114.96	57.91	2.35	0.85	0.300	0.000140	17	236
-	120.91	55.47	2.44	0.89	0.100	0.000200	20	181
-	122.04	53.65	2.38	0.96	0.300	0.000185	11	302
-	138.47	66.14	2.29	0.92	0.300	0.000165	15	395
-	138.47	59.44	2.38	0.98	0.300	0.000179	11	150
-	139.03	57.91	2.44	0.98	0.311	0.000176	22	198
-	143.85	63.40	2.47	0.92	0.300	0.000238	23	197
-	146.11	55.78	2.62	1.00	0.290	0.000182	27	244
-	146.68	67.67	2.68	0.81	0.120	0.000232	24	473
-	153.47	58.52	2.71	0.97	0.290	0.000165	24	261
-	166.75	67.67	2.56	0.96	0.190	0.000051	27	116
-	172.44	112.78	1.31	1.17	0.090	0.000194	16	232
-	209.26	71.63	3.32	0.88	0.210	0.000127	22	484
-	226.53	109.42	2.29	0.91	0.311	0.000185	19	388
-	233.61	118.26	2.47	0.80	0.110	0.000214	15	148
-	255.41	112.17	2.56	0.89	0.290	0.000207	12	305
-	322.80	120.40	2.68	1.00	0.200	0.000196	22	526
-	328.47	97.54	3.32	1.01	0.210	0.000188	19	432
-	334.13	110.34	2.47	1.23	0.210	0.000159	20	428
-	342.62	116.74	3.11	0.94	0.210	0.000254	22	620
-	351.12	112.17	2.13	1.47	0.130	0.000124	18	706
-	359.61	111.25	2.10	1.54	0.120	0.000116	23	531
-	362.44	99.06	3.08	1.19	0.120	0.000118	29	464
-	362.44	118.26	2.99	1.03	0.200	0.000161	18	663
-	376.60	115.82	2.35	1.39	0.210	0.000141	21	702
-	393.59	99.67	3.38	1.17	0.200	0.000181	17	299
-	399.26	112.78	3.41	1.04	0.311	0.000178	17	1,317
-	413.41	110.64	2.44	1.53	0.200	0.000115	18	1,297
-	424.74	111.86	2.38	1.60	0.140	0.000155	19	1,153
-	427.57	121.62	3.17	1.11	0.210	0.000202	16	1,217

Table E.7: Williams and Rosgen (1989) data – Wisconsin River.

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Transported Sediment Concen. (ppm)
05/08/78	195	299	1.2	0.5	0.400	0.00033	13.5	56
07/11/78	714	310	2.6	0.9	0.400	0.00037	22	49
06/06/78	368	306	1.6	0.8	0.425	0.00035	22.5	50
10/18/77	289	302	1.3	0.7	0.430	0.00031	10	83
04/17/78	456	309	2	0.8	0.430	0.00031	9	22
08/15/78	145	292	1	0.5	0.430	0.00029	26	75
03/24/77	149	283	0.88	0.6	0.440	0.00032	7.5	110
08/24/77	86.9	219	0.85	0.5	0.440	0.00028	22	29
05/16/77	118	278	0.82	0.5	0.490	0.00041	25	27

Table E.8: Mahmood et al. (1989) data – Pakistan (Acop) Canal.

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. °C	Transported Sediment Concen. (ppm)
	27.50	86.26	0.91	0.35	0.128	0.000142	18	15
	28.77	85.65	0.91	0.37	0.154	0.000124	18	13
	29.48	93.27	0.76	0.41	0.152	0.000088	17	16
	29.59	35.66	1.68	0.49	0.085	0.000085	31	103
	44.00	48.77	1.34	0.67	0.177	0.000145	31	94
	47.83	46.33	1.80	0.57	0.169	0.000108	32	215
	48.62	35.66	2.32	0.59	0.116	0.000072	23	32
	49.64	46.63	1.68	0.63	0.147	0.000110	30	36
	50.60	35.66	2.23	0.64	0.128	0.000074	24	54
	51.42	35.66	2.32	0.62	0.114	0.000070	23	76
-	51.88	35.36	2.19	0.67	0.123	0.000086	17	422
-	51.90	35.66	2.19	0.66	0.136	0.000086	18	386
	52.13	35.66	2.29	0.64	0.110	0.000075	32	156
	52.13	49.07	1.43	0.74	0.140	0.000148	31	445
	52.27	35.36	2.26	0.66	0.121	0.000073	23	58
	52.41	35.66	2.53	0.58	0.117	0.000076	28	128
	52.47	35.36	2.29	0.65	0.123	0.000088	24	869
-	52.92	35.36	2.16	0.69	0.132	0.000085	18	153
	54.14	35.36	2.26	0.68	0.112	0.000067	21	61
-	54.37	35.36	2.19	0.70	0.129	0.000085	18	367
-	54.74	35.66	2.19	0.70	0.124	0.000089	16	560
-	55.16	35.97	2.23	0.69	0.112	0.000085	22	289
-	55.64	35.66	2.35	0.66	0.113	0.000077	28	511
-	56.29	35.97	2.29	0.68	0.138	0.000076	24	184
	56.80	46.33	1.92	0.64	0.144	0.000109	30	225
	58.33	35.97	2.47	0.66	0.122	0.000087	29	166
	61.73	35.66	2.53	0.68	0.127	0.000074	29	79
	63.77	47.55	2.16	0.62	0.156	0.000150	16	110
	65.92	46.63	2.16	0.65	0.151	0.000107	25	290
	67.11	46.94	2.13	0.67	0.152	0.000112	30	54
	67.71	46.63	2.16	0.67	0.147	0.000110	36	372
	67.85	46.63	2.13	0.68	0.159	0.000124	25	146
	68.13	46.03	2.07	0.71	0.149	0.000127	21	529
	68.78	47.24	2.23	0.65	0.155	0.000147	16	845
	68.84	47.85	2.19	0.66	0.152	0.000148	15	410
	68.92	124.97	1.46	0.38	0.195	0.000045	19	5
	69.18	46.94	2.16	0.68	0.164	0.000102	25	262

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. °C	Transported Sediment Concen. (ppm)
	70.03	47.24	2.16	0.68	0.153	0.000116	30	48
	70.40	46.63	2.16	0.70	0.142	0.000101	25	346
-	70.40	46.63	2.32	0.65	0.144	0.000116	29	323
	70.42	46.63	2.19	0.69	0.143	0.000115	30	82
	70.71	46.63	2.16	0.70	0.146	0.000099	25	366
	71.30	46.63	2.10	0.73	0.211	0.000104	24	79
-	71.92	46.63	2.32	0.67	0.148	0.000112	28	796
-	72.66	46.63	2.32	0.67	0.150	0.000116	25	142
	72.66	46.63	2.35	0.66	0.156	0.000112	29	310
	73.60	46.63	2.26	0.70	0.145	0.000111	31	335
	74.11	46.63	2.23	0.71	0.142	0.000116	32	233
	74.22	46.63	2.29	0.70	0.155	0.000114	28	333
	74.30	94.79	1.49	0.52	0.146	0.000142	26	77
-	74.84	46.63	2.29	0.70	0.152	0.000107	28	304
	75.32	46.33	2.29	0.71	0.161	0.000104	28	240
	75.69	49.07	2.16	0.71	0.193	0.000148	34	98
	75.86	46.63	2.32	0.70	0.148	0.000115	31	351
	76.94	69.49	1.83	0.61	0.108	0.000132	27	125
	77.11	46.33	2.26	0.74	0.149	0.000108	31	289
	77.28	46.63	2.26	0.73	0.147	0.000109	31	577
	78.55	46.63	2.32	0.73	0.149	0.000107	32	385
	78.92	99.67	1.34	0.59	0.167	0.000104	26	88
-	79.17	46.94	2.44	0.69	0.142	0.000095	21	383
	79.60	50.60	2.13	0.74	0.191	0.000154	16	279
	80.19	49.07	2.04	0.80	0.178	0.000148	25	69
-	81.52	49.07	2.13	0.78	0.182	0.000152	20	399
	83.31	49.07	2.07	0.82	0.179	0.000145	32	122
	84.02	49.38	2.16	0.79	0.167	0.000146	31	56
-	85.21	47.85	2.10	0.85	0.168	0.000132	21	322
	85.29	88.39	1.46	0.66	0.164	0.000129	26	132
	86.25	49.68	2.23	0.78	0.186	0.000154	17	167
-	86.34	49.38	2.16	0.81	0.170	0.000147	29	1,007
	86.54	49.68	2.16	0.80	0.207	0.000154	17	71
	87.50	49.38	2.19	0.81	0.176	0.000144	32	328
	89.48	49.68	2.16	0.83	0.185	0.000154	16	104
-	90.42	49.38	2.13	0.86	0.173	0.000153	21	517
	90.53	88.39	1.52	0.67	0.148	0.000137	28	183
	92.79	100.89	1.40	0.66	0.154	0.000106	27	106
	94.27	88.39	1.46	0.73	0.084	0.000137	28	190

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. °C	Transported Sediment Concen. (ppm)
	96.59	86.56	1.62	0.69	0.131	0.000139	26	331
	97.44	70.41	2.10	0.66	0.147	0.000134	26	164
	98.94	86.56	1.65	0.69	0.167	0.000127	26	232
	99.48	86.56	1.65	0.70	0.192	0.000129	26	289
	110.12	125.58	1.86	0.47	0.241	0.000086	17	19
	110.72	71.02	2.16	0.72	0.179	0.000137	26	481
	130.46	70.41	2.35	0.79	0.125	0.000129	25	297
	136.32	127.41	1.77	0.61	0.133	0.000086	28	34
	137.82	69.19	2.38	0.84	0.132	0.000133	28	607
	138.04	70.41	2.41	0.81	0.118	0.000149	26	563
	139.74	71.93	2.23	0.87	0.149	0.000107	25	391
	140.14	70.10	2.35	0.85	0.126	0.000134	28	564
	146.62	126.49	1.71	0.68	0.198	0.000087	30	48
	151.24	90.22	1.89	0.89	0.116	0.000152	29	188
	153.31	70.71	2.10	1.03	0.174	0.000135	30	419
	153.82	71.63	2.35	0.91	0.144	0.000166	26	584
	156.48	72.24	2.41	0.90	0.161	0.000149	27	228
	158.09	118.87	2.23	0.60	0.083	0.000070	28	369
	166.87	90.53	1.89	0.98	0.179	0.000113	28	319
	169.08	72.24	2.47	0.95	0.162	0.000121	28	169
	169.67	70.71	1.89	1.27	0.164	0.000134	30	872
	179.56	124.36	2.04	0.71	0.223	0.000112	21	52
	183.83	91.14	2.19	0.92	0.173	0.000138	26	373
	207.62	126.19	2.16	0.76	0.273	0.000099	14	49
	222.09	128.02	2.26	0.77	0.226	0.000104	12	97
	224.44	120.70	2.50	0.74	0.195	0.000082	31	65
	233.10	140.21	2.07	0.80	0.206	0.000098	12	268
	267.65	117.35	2.80	0.81	0.313	0.000112	18	65
	279.80	135.94	2.32	0.89	0.293	0.000112	28	123
	291.27	128.63	2.59	0.87	0.176	0.000100	23	115
	297.16	128.32	2.56	0.90	0.154	0.000097	25	2,083
	297.41	129.24	2.62	0.88	0.187	0.000098	19	229
	321.51	119.79	3.41	0.79	0.169	0.000088	14	138
	337.28	116.43	3.20	0.91	0.289	0.000112	14	39
	342.95	110.95	3.29	0.94	0.250	0.000119	16	33
	346.71	110.64	3.32	0.94	0.252	0.000123	14	71
	349.46	111.56	3.41	0.92	0.230	0.000121	15	44
	349.97	112.17	3.47	0.90	0.205	0.000112	13	106
	355.72	116.74	3.26	0.93	0.299	0.000109	14	42

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. °C	Transported Sediment Concen. (ppm)
	357.76	111.25	3.54	0.91	0.201	0.000125	15	162
	362.91	120.09	3.57	0.85	0.272	0.000112	14	116
	363.33	128.02	2.77	1.02	0.260	0.000093	26	265
	363.64	110.95	3.44	0.95	0.275	0.000120	16	103
	371.80	113.39	3.51	0.94	0.234	0.000120	15	493
	375.65	125.88	3.81	0.78	0.268	0.000116	-1	17
	380.58	101.50	2.90	1.29	0.182	0.000105	30	57
	387.69	122.23	3.72	0.85	0.279	0.000107	15	32
	388.05	121.92	3.66	0.87	0.331	0.000108	-1	18
	391.06	92.05	3.66	1.16	0.157	0.000150	30	342
	392.70	119.79	3.57	0.92	0.275	0.000112	14	94
	393.21	111.86	3.57	0.99	0.242	0.000121	24	108
	394.77	117.65	3.54	0.95	0.279	0.000113	16	44
	395.13	113.08	3.81	0.92	0.222	0.000061	27	89
	404.62	114.30	3.57	0.99	0.197	0.000119	14	614
	412.04	111.86	3.63	1.02	0.170	0.000119	25	216
	412.29	118.26	3.63	0.96	0.233	0.000120	23	106
	412.72	118.26	3.60	0.97	0.220	0.000121	21	57
	414.47	111.56	3.69	1.01	0.214	0.000121	23	86
	417.42	112.47	3.66	1.01	0.202	0.000117	25	114
	423.25	118.26	3.63	0.99	0.258	0.000121	24	59
	428.15	114.00	3.69	1.02	0.210	0.000122	13	54
	441.29	120.40	4.08	0.90	0.208	0.000093	23	181
	451.40	121.92	4.24	0.87	0.202	0.000098	27	67
	481.92	123.44	4.30	0.91	0.364	0.000079	18	29
	486.82	123.44	4.27	0.92	0.199	0.000103	29	205
	528.68	123.44	3.72	1.15	0.113	0.000055	23	95

Table E.9: Posada Garcia (1995) and Toffaletti (1968) data – Mississippi River.

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Transported Sediment Concent. (ppm)
11/28/43	10761.60	518.16	11.95	1.74	0.561	0.000108	17	97
11/02/98	10959.84	523.04	13.72	1.53	0.758	0.000046	21	236
02/14/25	11639.52	505.97	12.07	1.91	0.188	0.000082	4	511
04/29/98	13253.76	532.18	15.24	1.63	0.664	0.000077	28	118
01/29/25	19087.68	575.46	13.69	2.42	0.475	0.000113	18	329
04/15/98	19937.28	548.64	16.76	2.17	0.696	0.000118	25	185
04/21/98	21608.16	542.54	17.28	2.30	0.664	0.000134	27	188
01/26/55	4248.00	896.11	7.59	0.62	0.297	0.000018	18	12
04/12/55	4276.32	896.11	7.53	0.63	0.287	0.000022	17	15
04/20/55	4332.96	896.11	7.53	0.64	0.307	0.000022	17	12
07/01/54	4502.88	908.30	7.68	0.65	0.282	0.000020	28	12
04/27/55	4531.20	899.16	7.50	0.67	0.304	0.000022	18	13
06/23/54	4616.16	908.30	7.77	0.65	0.292	0.000020	31	31
10/20/54	4701.12	908.30	7.59	0.68	0.327	0.000020	24	12
10/13/54	4814.40	911.35	7.83	0.67	0.301	0.000023	26	15
09/22/54	4899.36	908.30	7.83	0.69	0.305	0.000022	29	16
01/19/55	4956.00	905.26	8.11	0.68	0.293	0.000020	18	33
09/30/54	5097.60	911.35	7.92	0.71	0.300	0.000023	28	15
11/22/81	5125.92	908.30	6.74	0.84	0.199	0.000036	34	70
06/18/54	5324.16	914.40	8.23	0.71	0.292	0.000020	31	16
02/13/82	5494.08	914.40	6.92	0.87	0.198	0.000037	32	49
01/07/55	6456.96	938.78	8.84	0.78	0.302	0.000023	21	34
04/03/54	6541.92	972.31	8.60	0.78	0.292	0.000027	29	20
03/26/54	6938.40	978.41	8.56	0.83	0.292	0.000023	29	22
12/16/53	7448.16	987.55	9.17	0.82	0.292	0.000028	29	21
03/18/54	7504.80	987.55	8.93	0.85	0.292	0.000027	28	29
12/09/53	8042.88	993.65	9.54	0.85	0.294	0.000022	27	20
08/03/81	9827.04	1002.79	8.93	1.10	0.199	0.000041	34	110
03/12/54	10506.72	1033.27	10.61	0.96	0.292	0.000028	29	49
04/13/81	10563.36	1008.89	9.20	1.14	0.188	0.000037	25	97
12/02/53	10591.68	1024.13	10.58	0.98	0.284	0.000032	24	45
03/10/80	10704.96	1014.98	10.27	1.03	0.210	0.000032	6	140
11/25/53	10903.20	1045.46	10.70	0.97	0.253	0.000027	24	33

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Transported Sediment Concent. (ppm)
08/02/55	11639.52	1027.18	14.48	0.78	0.292	0.000032	19	153
12/24/53	11752.80	1042.42	11.13	1.01	0.292	0.000033	28	46
04/27/81	12205.92	1033.27	9.57	1.23	0.179	0.000043	26	106
12/25/79	13933.44	1051.56	11.77	1.13	0.183	0.000035	7	26
12/13/79	14216.64	1054.61	11.46	1.18	0.200	0.000027	8	194
03/24/80	15179.52	1066.80	11.52	1.24	0.198	0.000036	7	151
05/01/81	16340.64	1072.90	12.56	1.21	0.206	0.000033	6	207
01/11/81	16935.36	1085.09	12.37	1.26	0.209	0.000037	6	167
01/18/81	17020.32	1091.18	12.13	1.29	0.205	0.000038	22	262
01/25/81	17416.80	1085.09	12.56	1.28	0.233	0.000033	8	105
01/04/81	18124.80	1088.14	12.89	1.29	0.212	0.000033	7	137
01/15/81	18492.96	1097.28	12.53	1.35	0.199	0.000040	20	204
09/28/80	21013.44	1100.33	12.98	1.47	0.188	0.000032	10	216
01/11/81	21211.68	1100.33	13.23	1.46	0.188	0.000038	19	144
05/30/53	22032.96	1097.28	14.63	1.37	0.188	0.000037	17	59
10/02/80	22061.28	1103.38	13.81	1.45	0.199	0.000035	12	186
01/08/81	22656.00	1103.38	13.44	1.53	0.199	0.000038	18	244
09/05/53	22854.24	1100.33	15.45	1.34	0.290	0.000042	26	77
01/04/81	24298.56	1103.38	14.45	1.52	0.196	0.000037	18	193
10/23/80	24298.56	1103.38	14.69	1.50	0.199	0.000033	17	167
10/09/80	24468.48	1103.38	14.42	1.54	0.199	0.000037	15	136
10/12/80	25969.44	1103.38	14.81	1.59	0.210	0.000035	17	189
06/03/53	26026.08	1103.38	14.97	1.58	0.178	0.000035	18	165
09/10/53	26082.72	1097.28	15.06	1.58	0.282	0.000038	11	199
10/16/80	26309.28	1103.38	14.81	1.61	0.199	0.000036	17	160
05/09/53	26564.16	1097.28	15.67	1.55	0.322	0.000035	11	94
08/29/53	28829.76	1109.47	16.40	1.58	0.299	0.000038	21	101
05/22/88	3590.00	525.00	6.13	1.12	0.334	0.000114	23	68
03/15/89	4890.00	602.00	7.29	1.11	0.377	0.000128	8	77
12/05/87	5190.00	574.00	6.62	1.37	0.378	0.000130	6	209
06/10/89	5220.00	609.00	6.60	1.30	0.431	0.000127	25	107
06/13/90	12600.00	623.00	11.40	1.77	0.572	0.000109	22	179
06/20/90	25500.00	1055.00	15.00	1.61	0.357	0.000080	26	85
06/07/88	5570.00	778.00	19.30	0.37	0.172	0.000003	26	0

Date of Measurement	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (^{o}C)	Transported Sediment Concent. (ppm)
12/20/87	9560.00	776.00	20.30	0.61	0.182	0.000006	13	3
06/28/89	20100.00	813.00	21.80	1.13	0.208	0.000020	26	51
04/01/89	22500.00	800.00	21.50	1.31	0.224	0.000022	14	93
03/14/90	26700.00	881.00	21.20	1.43	0.323	0.000027	13	94
03/05/90	22800.00	1260.00	12.10	1.49	0.543	0.000088	8	138
03/19/89	24800.00	1337.00	12.10	1.53	0.412	0.000093	9	142
06/11/90	5040.00	941.00	6.44	0.83	0.448	0.000036	22	21
07/28/87	6270.00	995.00	6.11	1.03	0.479	0.000065	30	19
05/24/88	6790.00	991.00	6.54	1.05	0.385	0.000066	22	34
12/07/87	8820.00	1008.00	7.91	1.11	0.444	0.000066	8	70
06/12/89	14100.00	1135.00	9.38	1.32	0.408	0.000079	25	46
03/04/90	21000.00	1153.00	12.00	1.51	0.993	0.000078	6	79
03/17/89	24700.00	1165.00	12.80	1.65	0.686	0.000084	10	120
06/18/90	20800.00	1002.00	14.10	1.47	0.457	0.000087	26	61
08/04/87	7750.00	1131.00	7.14	0.96	0.381	0.000067	30	21
06/02/88	7950.00	1129.00	6.81	1.03	0.377	0.000067	25	30
12/15/87	10400.00	1153.00	8.29	1.09	0.321	0.000064	9	91
06/23/89	24800.00	1222.00	13.20	1.53	0.374	0.000064	25	98
03/27/89	26600.00	1210.00	14.50	1.52	0.314	0.000027	12	128
06/23/90	27300.00	1255.00	14.90	1.46	0.392	0.000055	27	58
03/10/90	34100.00	1308.00	15.20	1.72	0.251	0.000060	11	153
07/23/87	4250.00	591.00	6.46	1.11	0.345	0.000089	29	57
06/05/88	5700.00	900.00	7.59	0.83	0.259	0.000028	25	12
08/07/87	6190.00	983.00	7.59	0.83	0.266	0.000029	30	14
12/18/87	8180.00	970.00	9.04	0.93	0.249	0.000031	9	58
06/26/89	19000.00	1020.00	14.30	1.31	0.244	0.000041	26	77
03/30/89	23100.00	1010.00	15.60	1.47	0.212	0.000040	14	112
06/25/90	23200.00	1025.00	15.90	1.42	0.252	0.000040	27	76
03/12/90	26300.00	1013.00	16.80	1.55	0.267	0.000039	13	115
06/05/89	2320.00	562.00	6.16	0.67	0.498	0.000039	24	4

APPENDIX F
LABORATORY DATA (KODOATIE, 2000)

Table F.1: Kodoatie (2000) laboratory data.

Data Source	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Trans-ported Sediment Concent. (ppm)
LABORATORY DATA								
Barton and Lin (1955)	0.126	1.219	0.238	0.435	0.18	0.000880	14.3	551
Barton and Lin (1955)	0.085	1.219	0.171	0.408	0.18	0.000860	23.3	27
Barton and Lin (1955)	0.099	1.219	0.192	0.423	0.18	0.000866	20.4	480
Barton and Lin (1955)	0.113	1.219	0.210	0.442	0.18	0.000880	17.9	544
Barton and Lin (1955)	0.156	1.219	0.256	0.499	0.18	0.000880	22.9	629
Barton and Lin (1955)	0.088	1.219	0.198	0.363	0.18	0.000810	21.3	233
Barton and Lin (1955)	0.057	1.219	0.155	0.299	0.18	0.000880	19.0	256
Barton and Lin (1955)	0.042	1.219	0.140	0.249	0.18	0.000870	20.3	65
Barton and Lin (1955)	0.056	1.219	0.201	0.226	0.18	0.000440	22.3	19
Barton and Lin (1955)	0.043	1.219	0.165	0.216	0.18	0.000450	22.4	279
Barton and Lin (1955)	0.076	1.219	0.137	0.457	0.18	0.001500	20.8	1,221
Barton and Lin (1955)	0.054	1.219	0.122	0.362	0.18	0.001580	21.6	573
Barton and Lin (1955)	0.038	1.219	0.110	0.284	0.18	0.001610	19.3	304
Barton and Lin (1955)	0.025	1.219	0.091	0.229	0.18	0.001600	22.9	112
Barton and Lin (1955)	0.059	1.219	0.122	0.400	0.18	0.001350	24.3	1,006
Barton and Lin (1955)	0.075	1.219	0.146	0.419	0.18	0.001160	23.4	904
Barton and Lin (1955)	0.118	1.219	0223	0.433	0.18	0.000820	26.0	559
Barton and Lin (1955)	0.204	1.219	0.314	0.533	0.18	0.000610	26.5	560
Barton and Lin (1955)	0.251	1.219	0.421	0.489	0.18	0.000650	25.4	333
Barton and Lin (1955)	0.210	1.219	0.210	0.817	0.18	0.001560	22.8	1,939
Barton and Lin (1955)	0.255	1.219	0.229	0.915	0.18	0.001670	21.8	1,826
Barton and Lin (1955)	0.190	1.219	0.186	0.837	0.18	0.001660	22.5	1,922
Barton and Lin (1955)	0.258	1.219	0.232	0.912	0.18	0.001700	20.2	1,741
Barton and Lin (1955)	0.210	1.219	0.198	0.868	0.18	0.001830	26.2	1,704
Barton and Lin (1955)	0.229	1.219	0.238	0.791	0.18	0.001240	24.6	1,606
Barton and Lin (1955)	0.201	1.219	0.210	0.784	0.18	0.001250	24.7	1,409
Barton and Lin (1955)	0.164	1.219	0.183	0.737	0.18	0.001210	25.3	1,060
Barton and Lin (1955)	0.119	1.219	0.125	0.781	0.18	0.001290	26.4	1,638
Barton and Lin (1955)	0.204	1.219	0.171	0.980	0.18	0.001600	25.7	2,472
Barton and Lin (1955)	0.215	1.219	0.162	1.093	0.18	0.002100	26.1	3,764
Brooks (1957)	0.008	0.267	0.075	0.405	0.145	0.002600	27.5	1,099
Brooks (1957)	0.006	0.267	0.076	0.279	0.145	0.002000	24.0	200
Brooks (1957)	0.010	0.267	0.091	0.430	0.145	0.002200	26.0	720
Brooks (1957)	0.006	0.267	0.060	0.380	0.145	0.003500	26.5	1,199
Brooks (1957)	0.008	0.267	0.069	0.409	0.088	0.002800	25.0	3,990
Brooks (1957)	0.006	0.267	0.057	0.373	0.088	0.003300	25.0	5,283
Brooks (1957)	0.006	0.267	0.085	0.250	0.088	0.001300	25.0	190
Brooks (1957)	0.006	0.267	0.070	0.302	0.088	0.002350	25.0	1,349
Brooks (1957)	0.009	0.267	0.087	0.405	0.088	0.002400	25.0	3,592
Brooks (1957)	0.008	0.267	0.086	0.329	0.088	0.002150	25.0	1,748
Brooks (1957)	0.008	0.267	0.055	0.542	0.145	0.003100	26.0	1,898
Brooks (1957)	0.011	0.267	0.073	0.544	0.145	0.002300	27.5	1,499
Brooks (1957)	0.006	0.267	0.047	0.461	0.145	0.003300	26.0	2,696

Data Source	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Trans-ported Sediment Concent. (ppm)
Brooks (1957)	0.012	0.267	0.074	0.624	0.145	0.002500	22.0	1,948
Brooks (1957)	0.012	0.267	0.072	0.635	0.145	0.002400	12.5	2,446
Brooks (1957)	0.010	0.267	0.059	0.616	0.145	0.002400	21.0	2,446
Brooks (1957)	0.012	0.267	0.074	0.624	0.145	0.002100	31.5	2,147
Brooks (1957)	0.012	0.267	0.072	0.642	0.088	0.002250	25.0	4,835
Brooks (1957)	0.012	0.267	0.072	0.642	0.088	0.002200	25.0	4,885
Brooks (1957)	0.009	0.267	0.058	0.599	0.088	0.002450	25.0	5,084
Brooks (1957)	0.015	0.267	0.085	0.647	0.088	0.001850	25.0	3,443
Guy et al. (1966)	0.301	2.438	0.311	0.397	0.18989	0.000430	18.1	29
Guy et al. (1966)	0.359	2.438	0.314	0.469	0.195072	0.000580	16.4	120
Guy et al. (1966)	0.127	2.438	0.165	0.317	0.18989	0.000790	18.0	34
Guy et al. (1966)	0.144	2.438	0.171	0.346	0.195986	0.000840	19.1	58
Guy et al. (1966)	0.147	2.438	0.168	0.360	0.200863	0.000920	12.3	84
Guy et al. (1966)	0.279	2.438	0.302	0.380	0.270967	0.000460	16.0	12
Guy et al. (1966)	0.347	2.438	0.287	0.497	0.249936	0.000650	16.0	98
Guy et al. (1966)	0.145	2.438	0.146	0.406	0.289865	0.001260	13.9	93
Guy et al. (1966)	0.304	2.438	0.305	0.409	0.300228	0.000450	16.5	12
Guy et al. (1966)	0.381	2.438	0.305	0.513	0.289255	0.000630	16.4	75
Guy et al. (1966)	0.304	2.438	0.262	0.475	0.27493	0.000690	14.6	51
Guy et al. (1966)	0.139	2.438	0.180	0.318	0.289865	0.000730	14.9	20
Guy et al. (1966)	0.204	2.438	0.174	0.481	0.270053	0.001080	16.0	150
Guy et al. (1966)	0.224	2.438	0.250	0.367	0.41148	0.000360	11.0	9
Guy et al. (1966)	0.224	2.438	0.259	0.354	0.451104	0.000390	11.5	10
Guy et al. (1966)	0.222	2.438	0.244	0.374	0.438912	0.000420	9.0	23
Guy et al. (1966)	0.225	2.438	0.229	0.403	0.463296	0.000470	11.0	27
Guy et al. (1966)	0.055	2.438	0.107	0.212	0.445008	0.000490	11.5	5
Guy et al. (1966)	0.108	2.438	0.155	0.286	0.423672	0.000600	12.0	8
Guy et al. (1966)	0.110	2.438	0.140	0.323	0.499872	0.000880	9.5	42
Guy et al. (1966)	0.055	2.438	0.101	0.225	0.469392	0.000880	10.5	16
Guy et al. (1966)	0.201	2.438	0.238	0.347	0.45781	0.000470	12.7	6
Guy et al. (1966)	0.197	2.438	0.183	0.443	0.413004	0.000530	17.1	37
Guy et al. (1966)	0.201	2.438	0.183	0.450	0.459943	0.000650	18.5	31
Guy et al. (1966)	0.037	0.610	0.165	0.370	0.260299	0.000860	27.8	61
Guy et al. (1966)	0.044	0.610	0.174	0.417	0.311201	0.001100	14.5	91
Guy et al. (1966)	0.028	0.610	0.152	0.305	0.319735	0.000870	20.0	7
Guy et al. (1966)	0.032	0.610	0.149	0.348	0.32766	0.000880	20.0	47
Guy et al. (1966)	0.030	0.610	0.155	0.317	0.28956	0.000470	22.5	12
Guy et al. (1966)	0.041	0.610	0.158	0.428	0.33528	0.000630	22.6	85
Guy et al. (1966)	0.045	0.610	0.180	0.411	0.465125	0.000380	18.0	17
Guy et al. (1966)	0.386	2.438	0.290	0.547	0.197815	0.000660	18.2	281
Guy et al. (1966)	0.419	2.438	0.283	0.607	0.192024	0.000700	18.3	519
Guy et al. (1966)	0.472	2.438	0.323	0.599	0.199949	0.000830	17.4	836
Guy et al. (1966)	0.580	2.438	0.332	0.716	0.177698	0.000990	18.9	1,300
Guy et al. (1966)	0.198	2.438	0.158	0.513	0.199034	0.001270	16.6	503
Guy et al. (1966)	0.622	2.438	0.311	0.820	0.180746	0.001300	19.7	1,270
Guy et al. (1966)	0.231	2.438	0.186	0.508	0.188976	0.001300	15.3	861
Guy et al. (1966)	0.274	2.438	0.207	0.541	0.187147	0.001400	18.0	1,240

Data Source	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Trans-ported Sediment Concent. (ppm)
Guy et al. (1966)	0.213	2.438	0.158	0.551	0.199949	0.001470	18.5	999
Guy et al. (1966)	0.233	2.438	0.149	0.639	0.18989	0.001940	18.6	1,210
Guy et al. (1966)	0.386	2.438	0.283	0.558	0.284988	0.000840	18.3	200
Guy et al. (1966)	0.441	2.438	0.311	0.582	0.27493	0.001080	16.9	358
Guy et al. (1966)	0.314	2.438	0.229	0.563	0.25085	0.001260	15.3	550
Guy et al. (1966)	0.504	2.438	0.329	0.628	0.270053	0.001300	18.1	639
Guy et al. (1966)	0.545	2.438	0.344	0.648	0.277978	0.001400	17.4	931
Guy et al. (1966)	0.610	2.438	0.314	0.797	0.260909	0.001630	16.8	833
Guy et al. (1966)	0.444	2.438	0.287	0.636	0.255118	0.001670	14.8	704
Guy et al. (1966)	0.191	2.438	0.140	0.559	0.27493	0.001850	14.2	753
Guy et al. (1966)	0.446	2.438	0.323	0.566	0.259994	0.000900	17.6	330
Guy et al. (1966)	0.360	2.438	0.268	0.550	0.324307	0.001000	16.7	405
Guy et al. (1966)	0.244	2.438	0.189	0.529	0.259994	0.001160	15.6	298
Guy et al. (1966)	0.514	2.438	0.320	0.658	0.282854	0.001200	15.6	506
Guy et al. (1966)	0.430	2.438	0.280	0.629	0.279806	0.001310	15.8	664
Guy et al. (1966)	0.577	2.438	0.326	0.726	0.263957	0.001310	16.5	732
Guy et al. (1966)	0.280	2.438	0.198	0.580	0.265176	0.001340	14.9	563
Guy et al. (1966)	0.488	2.438	0.311	0.644	0.249936	0.001340	15.8	549
Guy et al. (1966)	0.283	2.438	0.198	0.587	0.271882	0.001360	14.7	505
Guy et al. (1966)	0.433	2.438	0.268	0.662	0.256946	0.001360	15.2	733
Guy et al. (1966)	0.339	2.438	0.186	0.747	0.248107	0.001410	14.7	1,040
Guy et al. (1966)	0.156	2.438	0.134	0.476	0.289865	0.001500	14.1	480
Guy et al. (1966)	0.364	2.438	0.229	0.654	0.255118	0.001580	13.0	789
Guy et al. (1966)	0.225	2.438	0.210	0.438	0.460248	0.000570	10.0	92
Guy et al. (1966)	0.226	2.438	0.213	0.434	0.445008	0.000780	11.5	268
Guy et al. (1966)	0.120	2.438	0.125	0.394	0.478536	0.001120	18.0	208
Guy et al. (1966)	0.343	2.438	0.293	0.481	0.414528	0.001140	16.0	380
Guy et al. (1966)	0.383	2.438	0.305	0.516	0.381	0.001240	15.7	554
Guy et al. (1966)	0.139	2.438	0.128	0.445	0.4572	0.001890	17.0	378
Guy et al. (1966)	0.231	2.438	0.186	0.508	0.490728	0.001930	16.4	508
Guy et al. (1966)	0.378	2.438	0.198	0.782	0.42672	0.002470	16.0	856
Guy et al. (1966)	0.247	2.438	0.189	0.537	0.374904	0.002890	17.0	917
Guy et al. (1966)	0.606	2.438	0.247	1.007	0.429768	0.003010	19.0	2,460
Guy et al. (1966)	0.129	2.438	0.091	0.577	0.451104	0.003690	17.4	1,850
Guy et al. (1966)	0.204	2.438	0.189	0.443	0.530962	0.000720	14.7	99
Guy et al. (1966)	0.202	2.438	0.192	0.432	0.493471	0.000900	18.5	106
Guy et al. (1966)	0.202	2.438	0.177	0.468	0.490728	0.001170	18.0	195
Guy et al. (1966)	0.436	2.438	0.244	0.733	0.539801	0.001800	18.7	1,640
Guy et al. (1966)	0.248	2.438	0.198	0.514	0.481889	0.001990	19.1	639
Guy et al. (1966)	0.441	2.438	0.277	0.652	0.497738	0.002000	16.2	588
Guy et al. (1966)	0.235	2.438	0.162	0.597	0.484022	0.002010	18.6	761
Guy et al. (1966)	0.240	2.438	0.192	0.514	0.443789	0.002030	20.0	463
Guy et al. (1966)	0.233	2.438	0.195	0.491	0.439826	0.002040	21.2	625
Guy et al. (1966)	0.232	2.438	0.198	0.480	0.49591	0.002150	21.0	534
Guy et al. (1966)	0.227	2.438	0.168	0.555	0.431902	0.002220	16.0	578
Guy et al. (1966)	0.232	2.438	0.186	0.512	0.477012	0.002220	20.7	662
Guy et al. (1966)	0.433	2.438	0.274	0.647	0.467868	0.002330	20.1	807

Data Source	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Trans-ported Sediment Concent. (ppm)
Guy et al. (1966)	0.227	2.438	0.174	0.535	0.476707	0.002350	17.2	571
Guy et al. (1966)	0.435	2.438	0.287	0.623	0.515722	0.002370	18.5	765
Guy et al. (1966)	0.320	2.438	0.247	0.532	0.494995	0.002370	13.5	480
Guy et al. (1966)	0.435	2.438	0.280	0.636	0.447751	0.002400	16.6	657
Guy et al. (1966)	0.231	2.438	0.195	0.486	0.511759	0.002480	23.2	429
Guy et al. (1966)	0.436	2.438	0.265	0.674	0.462686	0.002590	21.3	761
Guy et al. (1966)	0.326	2.438	0.219	0.610	0.442874	0.003200	20.3	1,510
Guy et al. (1966)	0.411	2.438	0.317	0.532	0.920496	0.000370	20.7	28
Guy et al. (1966)	0.380	2.438	0.308	0.506	0.96012	0.000370	18.0	21
Guy et al. (1966)	0.460	2.438	0.320	0.590	0.999744	0.000590	19.7	65
Guy et al. (1966)	0.210	2.438	0.177	0.487	0.9906	0.000710	17.4	63
Guy et al. (1966)	0.201	2.438	0.165	0.500	0.859536	0.000800	19.5	73
Guy et al. (1966)	0.477	2.438	0.317	0.617	0.969264	0.001120	19.4	140
Guy et al. (1966)	0.216	2.438	0.162	0.549	0.920496	0.001300	17.1	201
Guy et al. (1966)	0.477	2.438	0.305	0.641	0.938784	0.001360	19.2	211
Guy et al. (1966)	0.232	2.438	0.171	0.557	0.911352	0.001450	19.0	253
Guy et al. (1966)	0.465	2.438	0.283	0.672	0.908304	0.001830	17.5	308
Guy et al. (1966)	0.195	2.438	0.140	0.572	0.981456	0.001920	19.0	450
Guy et al. (1966)	0.639	2.438	0.338	0.775	0.740664	0.002750	18.0	601
Guy et al. (1966)	0.254	2.438	0.168	0.621	0.935736	0.003040	17.3	519
Guy et al. (1966)	0.632	2.438	0.317	0.817	0.890016	0.003130	19.1	537
Guy et al. (1966)	0.286	2.438	0.180	0.652	1.030224	0.003390	18.3	822
Guy et al. (1966)	0.643	2.438	0.311	0.848	0.755904	0.003560	18.9	1,080
Guy et al. (1966)	0.629	2.438	0.280	0.920	0.96012	0.003930	18.3	1,180
Guy et al. (1966)	0.628	2.438	0.271	0.950	0.920496	0.004370	18.5	1,900
Guy et al. (1966)	0.044	0.610	0.171	0.427	0.310591	0.001030	33.8	117
Guy et al. (1966)	0.053	0.610	0.180	0.486	0.260299	0.001180	27.2	168
Guy et al. (1966)	0.053	0.610	0.171	0.512	0.255118	0.001390	10.2	226
Guy et al. (1966)	0.065	0.610	0.177	0.599	0.316382	0.001470	14.3	455
Guy et al. (1966)	0.076	0.610	0.216	0.573	0.326441	0.002010	13.1	854
Guy et al. (1966)	0.075	0.610	0.201	0.610	0.310591	0.002100	33.1	719
Guy et al. (1966)	0.065	0.610	0.192	0.554	0.315468	0.002140	34.3	787
Guy et al. (1966)	0.040	0.610	0.158	0.413	0.354482	0.001020	20.1	142
Guy et al. (1966)	0.048	0.610	0.149	0.526	0.354482	0.002130	20.0	460
Guy et al. (1966)	0.056	0.610	0.158	0.574	0.309677	0.002400	20.0	732
Guy et al. (1966)	0.074	0.610	0.158	0.768	0.329794	0.003200	19.8	1,960
Guy et al. (1966)	0.055	0.610	0.152	0.594	0.32004	0.000970	22.1	507
Guy et al. (1966)	0.048	0.610	0.146	0.537	0.356616	0.001170	23.4	452
Guy et al. (1966)	0.060	0.610	0.155	0.631	0.440436	0.001200	24.1	1,030
Guy et al. (1966)	0.066	0.610	0.162	0.667	0.429158	0.001630	23.2	1,220
Guy et al. (1966)	0.069	0.610	0.219	0.519	0.499872	0.001700	18.6	387
Guy et al. (1966)	0.088	0.610	0.247	0.587	0.48006	0.002010	19.2	408
Guy et al. (1966)	0.105	0.610	0.268	0.639	0.599846	0.002480	23.3	720
Guy et al. (1966)	0.109	0.610	0.259	0.689	0.594055	0.002930	21.5	904
Guy et al. (1966)	0.108	0.610	0.262	0.679	0.540106	0.002940	22.4	1,100
Guy et al. (1966)	0.108	0.610	0.256	0.693	0.517855	0.003310	18.7	1,050
Guy et al. (1966)	0.108	0.610	0.238	0.746	0.580034	0.003510	18.9	1,200

Data Source	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Trans-ported Sediment Concent. (ppm)
Guy et al. (1966)	0.097	0.610	0.219	0.724	0.549859	0.003880	20.6	1,250
Guy et al. (1966)	0.622	2.438	0.271	0.941	0.179832	0.001000	19.3	1,240
Guy et al. (1966)	0.626	2.438	0.262	0.980	0.171907	0.001060	19.4	1,490
Guy et al. (1966)	0.619	2.438	0.256	0.991	0.289865	0.001380	17.8	1,270
Guy et al. (1966)	0.624	2.438	0.277	0.922	0.303886	0.001340	15.6	1,230
Guy et al. (1966)	0.444	2.438	0.195	0.934	0.29718	0.001420	14.5	1,370
Guy et al. (1966)	0.622	2.438	0.250	1.021	0.274015	0.001720	15.7	2,350
Guy et al. (1966)	0.224	2.438	0.101	0.913	0.505968	0.004360	18.0	4,100
Guy et al. (1966)	0.089	2.438	0.058	0.632	0.4572	0.004460	19.0	1,370
Guy et al. (1966)	0.151	2.438	0.082	0.752	0.478536	0.004920	17.2	3,550
Guy et al. (1966)	0.158	2.438	0.076	0.850	0.521208	0.004940	17.0	4,610
Guy et al. (1966)	0.534	2.438	0.131	1.672	0.50292	0.006200	18.5	5,570
Guy et al. (1966)	0.435	2.438	0.198	0.900	0.467868	0.003260	21.7	2,920
Guy et al. (1966)	0.626	2.438	0.250	1.026	0.920496	0.005870	18.4	2,750
Guy et al. (1966)	0.321	2.438	0.149	0.880	0.966216	0.006000	18.5	2,620
Guy et al. (1966)	0.466	2.438	0.183	1.045	0.938784	0.006500	17.3	3,110
Guy et al. (1966)	0.632	2.438	0.207	1.251	0.999744	0.007100	19.3	4,020
Guy et al. (1966)	0.625	2.438	0.162	1.587	0.920496	0.009200	18.2	6,140
Guy et al. (1966)	0.443	2.438	0.155	1.169	0.938784	0.009400	18.0	5,090
Guy et al. (1966)	0.444	2.438	0.134	1.357	1.039368	0.011200	21.7	9,480
Guy et al. (1966)	0.089	0.610	0.195	0.745	0.320345	0.001660	33.9	1,150
Guy et al. (1966)	0.099	0.610	0.226	0.717	0.295351	0.001720	12.1	706
Guy et al. (1966)	0.089	0.610	0.177	0.823	0.315468	0.001840	12.4	907
Guy et al. (1966)	0.099	0.610	0.183	0.884	0.28956	0.001890	11.9	1,410
Guy et al. (1966)	0.099	0.610	0.219	0.741	0.305714	0.001940	26.9	1,820
Guy et al. (1966)	0.099	0.610	0.223	0.727	0.279197	0.002610	32.8	1,150
Guy et al. (1966)	0.093	0.610	0.149	1.023	0.310896	0.002700	20.0	2,210
Guy et al. (1966)	0.074	0.610	0.158	0.768	0.338328	0.001880	22.1	2,790
Guy et al. (1966)	0.095	0.610	0.158	0.979	0.309677	0.003430	21.9	4,320
Guy et al. (1966)	0.107	0.610	0.219	0.798	0.519989	0.001980	25.0	521
Guy et al. (1966)	0.135	0.610	0.250	0.888	0.559918	0.003660	24.3	1,970
Guy et al. (1966)	0.136	0.610	0.265	0.841	0.559918	0.003770	22.2	1,950
Guy et al. (1966)	0.135	0.610	0.271	0.817	0.580034	0.003990	19.3	1,790
Guy et al. (1966)	0.108	0.610	0.232	0.766	0.544982	0.004080	21.5	1,200
Guy et al. (1966)	0.118	0.610	0.219	0.881	0.472135	0.004330	17.7	1,520
Guy et al. (1966)	0.619	2.438	0.241	1.053	0.178003	0.001120	19.3	2,000
Guy et al. (1966)	0.331	2.438	0.155	0.873	0.178918	0.001700	19.1	2,480
Guy et al. (1966)	0.616	2.438	0.226	1.120	0.25207	0.001670	18.5	1,670
Guy et al. (1966)	0.423	2.438	0.183	0.948	0.289865	0.001530	12.7	1,540
Guy et al. (1966)	0.619	2.438	0.219	1.156	0.314249	0.001990	14.7	2,710
Guy et al. (1966)	0.445	2.438	0.168	1.089	0.26609	0.002290	15.1	2,760
Guy et al. (1966)	0.445	2.438	0.158	1.150	0.283159	0.002780	15.4	3,120
Guy et al. (1966)	0.605	2.438	0.189	1.312	0.499872	0.003420	21.1	3,290
Guy et al. (1966)	0.604	2.438	0.186	1.332	0.524866	0.003550	23.2	3,390
Guy et al. (1966)	0.233	2.438	0.098	0.979	0.50993	0.005310	21.4	5,250
Guy et al. (1966)	0.234	2.438	0.098	0.984	0.484022	0.005500	20.2	5,680
Guy et al. (1966)	0.231	2.438	0.091	1.034	0.461772	0.006400	20.2	6,310

Data Source	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Trans-ported Sediment Concent. (ppm)
Guy et al. (1966)	0.607	2.438	0.155	1.600	0.475793	0.007900	13.3	8,440
Guy et al. (1966)	0.177	2.438	0.158	0.458	0.908304	0.000640	16.7	26
Guy et al. (1966)	0.129	0.610	0.171	1.238	0.298399	0.004170	28.4	4,340
Guy et al. (1966)	0.151	0.610	0.204	1.210	0.320345	0.004560	7.9	3,960
Guy et al. (1966)	0.114	0.610	0.155	1.198	0.339852	0.002900	20.0	3,090
Guy et al. (1966)	0.063	0.610	0.155	0.669	0.359664	0.003500	20.0	3,280
Guy et al. (1966)	0.113	0.610	0.155	1.195	0.28956	0.004330	21.8	5,100
Guy et al. (1966)	0.151	0.610	0.195	1.269	0.555955	0.004860	20.3	2,690
Guy et al. (1966)	0.421	2.438	0.134	1.286	0.481584	0.004320	17.5	4,750
Guy et al. (1966)	0.612	2.438	0.165	1.526	0.347472	0.004660	18.7	4,340
Guy et al. (1966)	0.239	2.438	0.085	1.149	0.399288	0.005460	17.5	5,960
Guy et al. (1966)	0.284	2.438	0.082	1.414	0.384048	0.006070	16.0	6,810
Guy et al. (1966)	0.605	2.438	0.152	1.629	0.414528	0.006190	19.0	6,230
Guy et al. (1966)	0.605	2.438	0.168	1.479	0.482803	0.006340	10.7	4,480
Guy et al. (1966)	0.601	2.438	0.165	1.498	0.502006	0.006220	24.5	4,490
Guy et al. (1966)	0.591	2.438	0.162	1.500	0.493776	0.006460	22.7	4,390
Guy et al. (1966)	0.603	2.438	0.168	1.476	0.413004	0.006510	21.0	5,760
Guy et al. (1966)	0.593	2.438	0.162	1.505	0.529742	0.007400	23.5	6,760
Guy et al. (1966)	0.579	2.438	0.134	1.770	0.810768	0.011600	20.4	7,320
Guy et al. (1966)	0.440	2.438	0.116	1.557	0.829056	0.012300	19.6	10,200
Guy et al. (1966)	0.584	2.438	0.134	1.787	0.758952	0.012600	21.0	7,000
Guy et al. (1966)	0.591	2.438	0.131	1.850	1.02108	0.012800	20.5	7,010
Guy et al. (1966)	0.130	0.610	0.149	1.431	0.300228	0.004470	21.6	7,900
Guy et al. (1966)	0.197	0.610	0.226	1.429	0.527914	0.005510	21.7	3,330
Guy et al. (1966)	0.198	0.610	0.229	1.421	0.565099	0.005500	22.5	4,350
Guy et al. (1966)	0.197	0.610	0.229	1.414	0.559918	0.005370	23.7	4,710
Guy et al. (1966)	0.198	0.610	0.223	1.459	0.524866	0.006280	24.0	7,640
Guy et al. (1966)	0.180	0.610	0.219	1.348	0.522122	0.005650	18.1	3,350
Guy et al. (1966)	0.212	0.610	0.201	1.727	0.459943	0.007680	19.9	5,690
Guy et al. (1966)	0.216	0.610	0.216	1.636	0.569976	0.005200	22.6	3,330
Guy et al. (1966)	0.214	0.610	0.232	1.518	0.559918	0.005080	22.5	3,400
Guy et al. (1966)	0.215	0.610	0.210	1.677	0.559918	0.007900	23.3	9,730
Guy et al. (1966)	0.628	2.438	0.204	1.262	0.170993	0.001960	19.1	4,650
Guy et al. (1966)	0.628	2.438	0.195	1.319	0.181966	0.003000	18.9	9,240
Guy et al. (1966)	0.628	2.438	0.195	1.321	0.171907	0.003500	18.7	12,900
Guy et al. (1966)	0.632	2.438	0.186	1.395	0.150876	0.003900	18.8	16,200
Guy et al. (1966)	0.628	2.438	0.183	1.408	0.179832	0.004600	18.5	23,900
Guy et al. (1966)	0.617	2.438	0.192	1.318	0.263042	0.002800	13.6	4,760
Guy et al. (1966)	0.614	2.438	0.180	1.401	0.260909	0.004930	15.9	9,080
Guy et al. (1966)	0.615	2.438	0.168	1.504	0.239878	0.008130	10.2	28,700
Guy et al. (1966)	0.439	2.438	0.152	1.182	0.270053	0.003280	15.0	5,060
Guy et al. (1966)	0.616	2.438	0.177	1.430	0.257861	0.004700	10.8	10,500
Guy et al. (1966)	0.438	2.438	0.131	1.371	0.279197	0.005330	15.1	11,500
Guy et al. (1966)	0.604	2.438	0.171	1.452	0.276149	0.005930	10.2	13,000
Guy et al. (1966)	0.604	2.438	0.165	1.505	0.275234	0.008150	10.9	27,600
Guy et al. (1966)	0.236	2.438	0.091	1.059	0.284988	0.008200	11.6	19,900
Guy et al. (1966)	0.424	2.438	0.113	1.541	0.41148	0.006560	18.0	6,180

Data Source	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Trans-ported Sediment Concent. (ppm)
Guy et al. (1966)	0.158	2.438	0.085	0.759	0.405384	0.008620	18.9	9,630
Guy et al. (1966)	0.307	2.438	0.085	1.474	0.530352	0.008980	19.4	4,160
Guy et al. (1966)	0.380	2.438	0.094	1.651	0.39624	0.009860	20.0	11,400
Guy et al. (1966)	0.607	2.438	0.131	1.898	0.478536	0.010100	18.5	11,500
Guy et al. (1966)	0.439	2.438	0.131	1.374	0.467868	0.005700	21.2	5,360
Guy et al. (1966)	0.442	2.438	0.125	1.451	0.487985	0.005780	21.2	5,480
Guy et al. (1966)	0.442	2.438	0.128	1.415	0.459029	0.005710	21.6	5,160
Guy et al. (1966)	0.440	2.438	0.137	1.314	0.465125	0.005750	23.0	5,130
Guy et al. (1966)	0.432	2.438	0.119	1.492	0.485851	0.006430	21.8	7,140
Guy et al. (1966)	0.435	2.438	0.125	1.428	0.499872	0.007400	15.0	7,100
Guy et al. (1966)	0.440	2.438	0.131	1.377	0.435864	0.007340	22.4	8,280
Guy et al. (1966)	0.447	2.438	0.134	1.368	0.438912	0.008210	19.0	17,700
Guy et al. (1966)	0.602	2.438	0.152	1.621	0.454762	0.008060	19.6	16,100
Guy et al. (1966)	0.340	2.438	0.113	1.237	0.486766	0.009600	19.5	8,960
Guy et al. (1966)	0.129	0.610	0.168	1.261	0.305105	0.005660	12.7	5,600
Guy et al. (1966)	0.135	0.610	0.180	1.235	0.305105	0.007100	7.0	5,180
Guy et al. (1966)	0.135	0.610	0.171	1.301	0.284988	0.004930	23.5	5,530
Guy et al. (1966)	0.150	0.610	0.183	1.346	0.320345	0.004080	23.8	5,250
Guy et al. (1966)	0.161	0.610	0.183	1.448	0.370332	0.008650	12.5	12,300
Guy et al. (1966)	0.161	0.610	0.183	1.448	0.319735	0.007300	31.7	8,780
Guy et al. (1966)	0.188	0.610	0.192	1.604	0.353568	0.008350	11.4	26,100
Guy et al. (1966)	0.188	0.610	0.189	1.632	0.46543	0.006350	26.7	21,000
Guy et al. (1966)	0.192	0.610	0.189	1.669	0.336194	0.009700	12.9	29,600
Guy et al. (1966)	0.193	0.610	0.186	1.704	0.375209	0.006560	27.9	20,800
Guy et al. (1966)	0.125	0.610	0.152	1.347	0.341376	0.006200	20.3	4,990
Guy et al. (1966)	0.132	0.610	0.152	1.421	0.309677	0.008000	20.0	7,110
Guy et al. (1966)	0.153	0.610	0.158	1.583	0.319735	0.009100	20.3	18,400
Guy et al. (1966)	0.171	0.610	0.158	1.770	0.329794	0.011400	19.9	18,400
Guy et al. (1966)	0.152	0.610	0.149	1.673	0.280111	0.006950	19.6	15,100
Guy et al. (1966)	0.183	0.610	0.158	1.893	0.329794	0.009100	19.6	22,500
Guy et al. (1966)	0.171	0.610	0.155	1.805	0.349606	0.009800	19.6	14,600
Guy et al. (1966)	0.215	0.610	0.213	1.653	0.584911	0.009000	23.7	22,300
Guy et al. (1966)	0.222	0.610	0.201	1.811	0.522122	0.010750	25.0	10,300
Guy et al. (1966)	0.223	0.610	0.198	1.843	0.559918	0.013050	25.1	15,800
Guy et al. (1966)	0.223	0.610	0.198	1.850	0.515112	0.011750	22.5	9,180
Guy et al. (1966)	0.222	0.610	0.198	1.836	0.559918	0.013650	22.3	21,800
Guy et al. (1966)	0.223	0.610	0.207	1.762	0.64008	0.019280	24.0	50,000
Guy et al. (1966)	0.222	0.610	0.195	1.867	0.562966	0.014380	16.9	26,000
Guy et al. (1966)	0.440	2.438	0.155	1.161	0.206045	0.008450	16.8	35,500
Guy et al. (1966)	0.619	2.438	0.198	1.280	0.210007	0.009500	17.3	47,300
Guy et al. (1966)	0.436	2.438	0.137	1.305	0.291084	0.009520	11.0	7,920
Guy et al. (1966)	0.605	2.438	0.183	1.356	0.314858	0.010220	10.8	35,800
Guy et al. (1966)	0.432	2.438	0.122	1.454	0.277978	0.009300	11.1	36,100
Guy et al. (1966)	0.605	2.438	0.174	1.429	0.299923	0.010070	11.5	42,400
Kennedy and Brooks (1963)	0.040	0.851	0.168	0.277	0.142	0.000560	19.5	14
Kennedy and Brooks (1963)	0.040	0.851	0.134	0.348	0.142	0.001450	18.4	390
Kennedy and Brooks (1963)	0.040	0.851	0.114	0.412	0.142	0.002060	18.4	1,419

Data Source	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Trans-ported Sediment Concent. (ppm)
Kennedy and Brooks (1963)	0.040	0.851	0.105	0.442	0.142	0.001980	25.1	1,129
Kennedy and Brooks (1963)	0.040	0.851	0.104	0.448	0.142	0.001600	25.3	979
Kennedy and Brooks (1963)	0.040	0.851	0.077	0.600	0.142	0.002500	25.3	1,708
Kennedy and Brooks (1963)	0.040	0.851	0.072	0.650	0.142	0.001980	25.7	1,568
Kennedy and Brooks (1963)	0.040	0.851	0.071	0.655	0.142	0.002070	25.2	1,409
Kennedy and Brooks (1963)	0.040	0.851	0.069	0.674	0.142	0.002100	25.4	1,738
Laursen (1958)	0.081	0.914	0.171	0.515	0.11	0.001220	20.6	2,247
Laursen (1958)	0.087	0.914	0.229	0.415	0.11	0.000550	21.8	290
Laursen (1958)	0.105	0.914	0.283	0.405	0.11	0.000430	22.8	140
Laursen (1958)	0.182	0.914	0.283	0.704	0.11	0.001010	24.0	2,696
Laursen (1958)	0.084	0.914	0.157	0.585	0.11	0.001520	21.3	4,239
Laursen (1958)	0.075	0.914	0.158	0.518	0.11	0.001440	21.6	3,134
Laursen (1958)	0.060	0.914	0.162	0.402	0.11	0.001060	23.3	660
Laursen (1958)	0.111	0.914	0.230	0.527	0.11	0.000920	21.6	1,559
Laursen (1958)	0.134	0.914	0.303	0.485	0.11	0.000580	26.5	610
Laursen (1958)	0.050	0.914	0.116	0.472	0.11	0.001860	24.9	2,715
Laursen (1958)	0.028	0.914	0.095	0.326	0.11	0.001600	26.4	550
Laursen (1958)	0.042	0.914	0.116	0.390	0.11	0.001500	21.5	1,029
Laursen (1958)	0.104	0.914	0.221	0.515	0.11	0.000800	23.7	1,309
Laursen (1958)	0.024	0.914	0.076	0.351	0.11	0.002100	19.8	1,429
Laursen (1958)	0.135	0.914	0.144	1.024	0.11	0.001200	22.8	5,153
Laursen (1958)	0.133	0.914	0.216	0.671	0.11	0.001070	23.2	3,054
Laursen (1958)	0.090	0.914	0.173	0.570	0.04	0.001000	22.9	83,402
Laursen (1958)	0.068	0.914	0.141	0.530	0.04	0.001170	22.9	81,998
Laursen (1958)	0.109	0.914	0.205	0.582	0.04	0.000860	22.9	58,397
Laursen (1958)	0.057	0.914	0.165	0.375	0.04	0.000810	22.9	30,298
Laursen (1958)	0.027	0.914	0.116	0.259	0.04	0.000780	22.9	7,297
Laursen (1958)	0.087	0.914	0.146	0.649	0.04	0.001070	22.9	97,004
Laursen (1958)	0.125	0.914	0.172	0.796	0.04	0.001140	22.9	83,402
Laursen (1958)	0.136	0.914	0.202	0.738	0.04	0.001000	22.9	98,098
Nomicos	0.005	0.267	0.073	0.246	0.152	0.002000	26.0	183
Nomicos	0.005	0.267	0.073	0.260	0.152	0.002100	25.6	348
Nomicos	0.005	0.267	0.073	0.279	0.152	0.002400	25.5	459
Nomicos	0.006	0.267	0.073	0.299	0.152	0.002600	25.0	662
Nomicos	0.006	0.267	0.073	0.317	0.152	0.002750	25.0	882
Nomicos	0.007	0.267	0.073	0.366	0.152	0.002700	25.0	1,249
Nomicos	0.008	0.267	0.073	0.422	0.152	0.002400	25.0	1,766
Nomicos	0.011	0.267	0.073	0.559	0.152	0.002000	25.0	1,918
Nomicos	0.012	0.267	0.073	0.629	0.152	0.002250	25.0	2,173
Nomicos	0.016	0.267	0.073	0.811	0.152	0.003900	25.0	5,386
Nomicos	0.009	0.267	0.073	0.473	0.152	0.002250	25.0	1,565
Nomicos	0.010	0.267	0.073	0.518	0.152	0.002100	25.0	1,945
Nomicos	0.008	0.267	0.074	0.387	0.145	0.002700	25.0	1,199
Nomicos	0.005	0.267	0.073	0.279	0.145	0.002100	25.0	230
Nomicos	0.005	0.267	0.073	0.246	0.152	0.002000	26.0	300
Nomicos	0.005	0.267	0.073	0.260	0.152	0.002100	25.6	590
Nomicos	0.005	0.267	0.073	0.279	0.152	0.002400	25.5	820

Data Source	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Trans-ported Sediment Concent. (ppm)
Nomicos	0.006	0.267	0.073	0.299	0.152	0.002600	25.0	1,149
Nomicos	0.006	0.267	0.073	0.317	0.152	0.002750	25.0	1,798
Nomicos	0.007	0.267	0.073	0.366	0.152	0.002700	25.0	2,496
Nomicos	0.008	0.267	0.073	0.422	0.152	0.002400	25.0	3,393
Nomicos	0.005	0.267	0.074	0.278	0.152	0.002350	15.0	310
Nomicos	0.005	0.267	0.073	0.279	0.152	0.002100	25.0	230
Nomicos	0.005	0.267	0.073	0.279	0.152	0.002100	25.0	220
Nomicos	0.005	0.267	0.073	0.280	0.152	0.001900	35.6	110
Nomicos	0.012	0.267	0.073	0.629	0.145	0.002100	25.0	1,848
Nomicos	0.012	0.267	0.071	0.652	0.137	0.002500	24.3	2,297
Nomicos	0.011	0.267	0.068	0.605	0.137	0.002250	24.0	3,293
Nomicos	0.011	0.267	0.073	0.559	0.152	0.002000	25.0	3,194
Nomicos	0.012	0.267	0.073	0.629	0.152	0.002250	25.0	3,393
Nomicos	0.016	0.267	0.073	0.811	0.152	0.003900	25.0	5,581
Nomicos	0.012	0.267	0.073	0.631	0.152	0.002400	15.3	3,233
Nomicos	0.012	0.267	0.073	0.629	0.152	0.002100	25.0	1,868
Nomicos	0.012	0.267	0.073	0.629	0.152	0.002300	25.0	2,137
Nomicos	0.012	0.267	0.074	0.626	0.152	0.002200	38.0	1,658
Nomicos	0.008	0.267	0.072	0.431	0.137	0.002750	24.1	1,998
Nomicos	0.009	0.267	0.073	0.473	0.152	0.002250	25.0	2,895
Nomicos	0.010	0.267	0.073	0.518	0.152	0.002100	25.0	3,293
Onishi et al. (1976)	0.034	0.914	0.102	0.369	0.25	0.001540	28.4	67
Onishi et al. (1976)	0.046	0.914	0.101	0.495	0.25	0.001935	20.0	744
Onishi et al. (1976)	0.040	0.914	0.108	0.402	0.25	0.001630	25.5	196
Onishi et al. (1976)	0.039	0.914	0.100	0.430	0.25	0.001840	21.0	485
Onishi et al. (1976)	0.030	0.914	0.081	0.405	0.25	0.002540	21.0	311
Onishi et al. (1976)	0.030	0.914	0.075	0.439	0.25	0.002560	21.0	524
Onishi et al. (1976)	0.027	0.914	0.077	0.384	0.25	0.002670	21.0	314
Onishi et al. (1976)	0.024	0.914	0.076	0.349	0.25	0.002560	24.0	282
Onishi et al. (1976)	0.053	0.914	0.123	0.476	0.25	0.001465	24.0	406
Onishi et al. (1976)	0.050	0.914	0.133	0.412	0.25	0.001220	26.0	98
Onishi et al. (1976)	0.039	0.914	0.127	0.338	0.25	0.001090	25.0	66
Onishi et al. (1976)	0.065	0.914	0.135	0.527	0.25	0.001560	25.0	688
Onishi et al. (1976)	0.052	0.914	0.096	0.585	0.25	0.001650	21.8	1,063
Onishi et al. (1976)	0.052	0.914	0.096	0.585	0.25	0.001650	21.8	3,348
Stein (1965)	0.152	1.219	0.183	0.681	0.4	0.003520	21.1	2,089
Stein (1965)	0.115	1.219	0.183	0.514	0.4	0.002850	20.6	1,028
Stein (1965)	0.200	1.219	0.183	0.897	0.4	0.003210	22.2	3,034
Stein (1965)	0.156	1.219	0.305	0.421	0.4	0.000610	22.8	93
Stein (1965)	0.198	1.219	0.305	0.533	0.4	0.001680	21.7	476
Stein (1965)	0.240	1.219	0.305	0.647	0.4	0.002600	22.8	943
Stein (1965)	0.282	1.219	0.305	0.759	0.4	0.002900	20.0	1,767
Stein (1965)	0.283	1.219	0.305	0.761	0.4	0.002980	20.6	1,506
Stein (1965)	0.326	1.219	0.299	0.894	0.4	0.003000	24.4	1,881
Stein (1965)	0.329	1.219	0.311	0.867	0.4	0.003010	21.1	1,958
Stein (1965)	0.368	1.219	0.305	0.991	0.4	0.003270	22.2	2,254
Stein (1965)	0.411	1.219	0.302	1.116	0.4	0.003280	22.2	2,823

Data Source	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Trans-ported Sediment Concent. (ppm)
Stein (1965)	0.283	1.219	0.302	0.768	0.4	0.002900	22.2	1,552
Stein (1965)	0.156	1.219	0.244	0.526	0.4	0.002010	21.1	638
Stein (1965)	0.199	1.219	0.244	0.668	0.4	0.002980	21.1	1,461
Stein (1965)	0.241	1.219	0.244	0.811	0.4	0.002970	21.1	1,955
Stein (1965)	0.283	1.219	0.244	0.952	0.4	0.002850	21.1	2,165
Stein (1965)	0.326	1.219	0.244	1.095	0.4	0.002690	24.4	2,792
Stein (1965)	0.303	1.219	0.244	1.019	0.4	0.002860	22.2	2,702
Stein (1965)	0.264	1.219	0.247	0.877	0.4	0.002490	22.2	2,231
Stein (1965)	0.178	1.219	0.244	0.598	0.4	0.002670	22.2	1,040
Stein (1965)	0.084	1.219	0.122	0.568	0.4	0.003470	23.3	479
Stein (1965)	0.115	1.219	0.125	0.753	0.4	0.003870	22.2	2,527
Stein (1965)	0.312	1.219	0.366	0.699	0.4	0.002540	26.7	943
Stein (1965)	0.286	1.219	0.335	0.700	0.4	0.002560	26.7	1,014
Stein (1965)	0.234	1.219	0.274	0.699	0.4	0.003100	26.1	1,457
Stein (1965)	0.182	1.219	0.210	0.709	0.4	0.003480	26.7	1,894
Stein (1965)	0.156	1.219	0.180	0.713	0.4	0.003950	28.3	2,202
Stein (1965)	0.131	1.219	0.152	0.703	0.4	0.003870	25.6	2,387
Stein (1965)	0.078	1.219	0.091	0.701	0.4	0.004030	25.6	2,549
Stein (1965)	0.240	1.219	0.183	1.078	0.4	0.003310	23.3	3,990
Stein (1965)	0.453	1.219	0.305	1.219	0.4	0.002260	22.2	2,686
Stein (1965)	0.481	1.219	0.305	1.296	0.4	0.002510	23.3	2,934
Stein (1965)	0.368	1.219	0.244	1.238	0.4	0.002610	23.3	3,344
Stein (1965)	0.141	1.219	0.122	0.947	0.4	0.003700	22.2	3,499
Stein (1965)	0.111	1.219	0.098	0.936	0.4	0.003980	26.7	4,227
Stein (1965)	0.430	1.219	0.210	1.679	0.4	0.007050	25.0	16,932
Stein (1965)	0.320	1.219	0.216	1.213	0.4	0.003040	26.7	3,733
Stein (1965)	0.453	1.219	0.305	1.219	0.4	0.002590	28.9	3,037
Stein (1965)	0.284	1.219	0.183	1.274	0.4	0.005080	23.9	7,059
Stein (1965)	0.329	1.219	0.183	1.473	0.4	0.007360	23.3	13,364
Stein (1965)	0.368	1.219	0.183	1.651	0.4	0.010790	22.8	23,887
Stein (1965)	0.411	1.219	0.247	1.364	0.4	0.003270	22.8	4,406
Stein (1965)	0.453	1.219	0.244	1.524	0.4	0.004170	22.2	7,294
Stein (1965)	0.481	1.219	0.247	1.599	0.4	0.005240	22.2	9,553
Stein (1965)	0.169	1.219	0.122	1.139	0.4	0.004270	25.0	4,892
Stein (1965)	0.200	1.219	0.122	1.347	0.4	0.006610	24.4	7,145
Stein (1965)	0.226	1.219	0.122	1.522	0.4	0.010130	23.9	18,155
Stein (1965)	0.255	1.219	0.122	1.713	0.4	0.013030	23.9	28,628
Stein (1965)	0.281	1.219	0.125	1.842	0.4	0.016950	25.6	38,368
Stein (1965)	0.394	1.219	0.213	1.513	0.4	0.005530	26.7	8,619
Stein (1965)	0.314	1.219	0.183	1.410	0.4	0.005240	27.2	7,983
Stein (1965)	0.238	1.219	0.149	1.310	0.4	0.005290	27.2	7,535
Stein (1965)	0.134	1.219	0.091	1.199	0.4	0.004910	26.7	6,112
Stein (1965)	0.282	1.219	0.149	1.551	0.4	0.009800	26.7	19,175
Stein (1965)	0.262	1.219	0.149	1.437	0.4	0.006790	25.6	12,248
Stein (1965)	0.357	1.219	0.216	1.352	0.4	0.003650	26.7	4,604
Straub (1954, 1958)	0.008	0.305	0.063	0.417	0.191	0.002980	20.0	745
Straub (1954, 1958)	0.008	0.305	0.074	0.356	0.191	0.002536	20.0	423

Data Source	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Trans-ported Sediment Concent. (ppm)
Straub (1954, 1958)	0.008	0.305	0.076	0.345	0.191	0.002642	20.0	417
Straub (1954, 1958)	0.008	0.305	0.047	0.560	0.191	0.003439	20.0	1,743
Straub (1954, 1958)	0.014	0.305	0.075	0.622	0.163	0.002350	30.0	1,408
Straub (1954, 1958)	0.014	0.305	0.073	0.640	0.163	0.002560	23.9	2,003
Straub (1954, 1958)	0.014	0.305	0.071	0.657	0.163	0.002820	17.2	2,297
Straub (1954, 1958)	0.014	0.305	0.070	0.660	0.163	0.003240	11.1	2,817
Straub (1954, 1958)	0.014	0.305	0.069	0.677	0.163	0.003260	5.8	3,612
Straub (1954, 1958)	0.014	0.305	0.068	0.683	0.163	0.003620	1.7	4,784
Straub (1954, 1958)	0.008	0.305	0.043	0.612	0.191	0.004043	20.0	3,138
Straub (1954, 1958)	0.008	0.305	0.040	0.664	0.191	0.005890	20.0	4,937
Straub (1954, 1958)	0.008	0.305	0.037	0.713	0.191	0.006309	20.0	6,950
Straub (1954, 1958)	0.008	0.305	0.035	0.757	0.191	0.007347	20.0	8,740
Straub (1954, 1958)	0.008	0.305	0.043	0.616	0.191	0.006574	20.0	12,479
Straub (1954, 1958)	0.024	0.914	0.048	0.546	0.191	0.004620	20.0	6,264
Straub (1954, 1958)	0.057	0.914	0.088	0.701	0.191	0.002370	20.0	2,664
Straub (1954, 1958)	0.113	0.914	0.169	0.732	0.191	0.001080	20.0	1,337
Straub (1954, 1958)	0.142	0.914	0.203	0.764	0.191	0.000950	20.0	1,065
Straub (1954, 1958)	0.170	0.914	0.235	0.790	0.191	0.000560	20.0	889
Straub (1954, 1958)	0.170	0.914	0.223	0.835	0.191	0.001024	20.0	889
Straub (1954, 1958)	0.024	0.914	0.042	0.630	0.191	0.004440	20.0	6,264
Straub (1954, 1958)	0.113	0.914	0.172	0.720	0.191	0.001160	20.0	1,337
Straub (1954, 1958)	0.170	0.914	0.239	0.779	0.191	0.000780	20.0	889
Taylor	0.048	0.852	0.081	0.692	0.228	0.002050	23.0	1,211
Taylor	0.047	0.852	0.079	0.707	0.228	0.002080	38.0	1,250
Taylor	0.084	0.852	0.114	0.866	0.228	0.001980	24.5	2,001
Taylor	0.084	0.852	0.112	0.878	0.228	0.001990	38.9	2,131
Taylor	0.012	0.267	0.078	0.585	0.138	0.001870	48.0	2,892
Taylor	0.012	0.267	0.078	0.585	0.138	0.001910	33.0	2,772
Vanoni and Brooks (1957)	0.014	0.851	0.073	0.234	0.137	0.001410	23.4	37
Vanoni and Brooks (1957)	0.017	0.851	0.074	0.276	0.137	0.002040	24.5	240
Vanoni and Brooks (1957)	0.020	0.851	0.073	0.325	0.137	0.002800	25.2	1,149
Vanoni and Brooks (1957)	0.024	0.851	0.073	0.389	0.137	0.002780	25.5	1,898
Vanoni and Brooks (1957)	0.026	0.851	0.072	0.428	0.137	0.002770	22.4	2,197
Vanoni and Brooks (1957)	0.028	0.851	0.076	0.439	0.137	0.002460	27.4	1,399
Vanoni and Brooks (1957)	0.033	0.851	0.092	0.423	0.137	0.002010	18.9	2,197
Vanoni and Brooks (1957)	0.034	0.851	0.165	0.244	0.137	0.000390	24.6	3
Vanoni and Brooks (1957)	0.044	0.851	0.161	0.318	0.137	0.000700	23.4	68
Vanoni and Brooks (1957)	0.053	0.851	0.167	0.372	0.137	0.001050	21.9	210
Vanoni and Brooks (1957)	0.063	0.851	0.163	0.454	0.137	0.001220	25.2	670
Vanoni and Brooks (1957)	0.075	0.851	0.169	0.523	0.137	0.001020	20.7	1,449
Vanoni and Brooks (1957)	0.033	0.851	0.062	0.629	0.137	0.002760	18.9	2,994
Vanoni and Brooks (1957)	0.039	0.851	0.071	0.647	0.137	0.002050	23.5	2,496
Vanoni and Brooks (1957)	0.109	0.851	0.166	0.771	0.137	0.001070	24.9	1,149
Vanoni and Hwang (1967)	0.006	0.267	0.076	0.274	0.23	0.002300	22.0	120
Vanoni and Hwang (1967)	0.005	0.267	0.074	0.246	0.23	0.002000	21.2	62
Vanoni and Hwang (1967)	0.004	0.267	0.073	0.188	0.23	0.001200	22.0	1
Vanoni and Hwang (1967)	0.007	0.267	0.073	0.376	0.23	0.002800	22.6	488

Data Source	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Transported Sediment Concent. (ppm)
Vanoni and Hwang (1967)	0.006	0.267	0.074	0.291	0.23	0.000700	25.5	265
Vanoni and Hwang (1967)	0.007	0.267	0.073	0.335	0.23	0.002900	21.7	417
Vanoni and Hwang (1967)	0.008	0.267	0.071	0.426	0.23	0.002700	21.9	619
Vanoni and Hwang (1967)	0.004	0.267	0.070	0.229	0.23	0.001590	21.0	7
Vanoni and Hwang (1967)	0.007	0.267	0.073	0.380	0.23	0.002860	20.9	448
Vanoni and Hwang (1967)	0.064	1.100	0.182	0.319	0.206	0.000642	19.8	31
Vanoni and Hwang (1967)	0.088	1.100	0.180	0.443	0.206	0.001055	20.1	180
Vanoni and Hwang (1967)	0.108	1.100	0.176	0.558	0.206	0.001303	20.7	1,489
Vanoni and Hwang (1967)	0.091	1.100	0.180	0.462	0.206	0.001116	21.0	380
Vanoni and Hwang (1967)	0.095	1.100	0.184	0.472	0.206	0.001100	19.2	410
Vanoni and Hwang (1967)	0.122	1.100	0.238	0.466	0.206	0.000809	18.8	261
Vanoni and Hwang (1967)	0.185	1.100	0.371	0.455	0.206	0.000455	20.0	61
Williams (1970)	0.012	0.305	0.096	0.425	1.35	0.001210	22.8	11
Williams (1970)	0.012	0.305	0.090	0.451	1.35	0.001620	18.6	39
Williams (1970)	0.013	0.305	0.090	0.467	1.35	0.001820	16.6	60
Williams (1970)	0.013	0.305	0.091	0.479	1.35	0.002000	18.4	87
Williams (1970)	0.014	0.305	0.092	0.502	1.35	0.002100	17.2	116
Williams (1970)	0.014	0.305	0.093	0.503	1.35	0.002110	17.8	119
Williams (1970)	0.015	0.305	0.090	0.529	1.35	0.002360	17.2	183
Williams (1970)	0.015	0.305	0.090	0.547	1.35	0.002720	17.8	280
Williams (1970)	0.016	0.305	0.088	0.582	1.35	0.003180	16.2	316
Williams (1970)	0.016	0.305	0.088	0.602	1.35	0.003970	16.2	449
Williams (1970)	0.018	0.305	0.088	0.686	1.35	0.005090	15.8	778
Williams (1970)	0.021	0.305	0.090	0.764	1.35	0.005570	12.4	828
Williams (1970)	0.023	0.305	0.095	0.777	1.35	0.006430	15.6	967
Williams (1970)	0.022	0.305	0.153	0.467	1.35	0.001060	19.0	9
Williams (1970)	0.024	0.305	0.155	0.507	1.35	0.001370	21.0	38
Williams (1970)	0.023	0.305	0.148	0.499	1.35	0.001330	26.0	42
Williams (1970)	0.025	0.305	0.154	0.522	1.35	0.001440	22.8	53
Williams (1970)	0.026	0.305	0.158	0.532	1.35	0.001720	23.6	85
Williams (1970)	0.027	0.305	0.156	0.572	1.35	0.001840	23.2	102
Williams (1970)	0.027	0.305	0.154	0.578	1.35	0.002160	17.8	120
Williams (1970)	0.030	0.305	0.158	0.618	1.35	0.002510	18.8	172
Williams (1970)	0.031	0.305	0.154	0.664	1.35	0.003140	20.8	287
Williams (1970)	0.037	0.305	0.155	0.791	1.35	0.004160	20.8	404
Williams (1970)	0.033	0.305	0.212	0.512	1.35	0.000810	22.0	6
Williams (1970)	0.035	0.305	0.217	0.531	1.35	0.000790	16.0	18
Williams (1970)	0.037	0.305	0.214	0.573	1.35	0.001310	21.6	39
Williams (1970)	0.040	0.305	0.218	0.606	1.35	0.001780	20.6	66
Williams (1970)	0.046	0.305	0.216	0.706	1.35	0.002720	19.0	196
Williams (1970)	0.007	0.610	0.030	0.373	1.35	0.004890	26.6	226
Williams (1970)	0.008	0.610	0.028	0.486	1.35	0.005690	25.6	387
Williams (1970)	0.010	0.610	0.028	0.579	1.35	0.008160	25.0	1,092
Williams (1970)	0.024	0.610	0.087	0.457	1.35	0.001180	24.0	25
Williams (1970)	0.025	0.610	0.090	0.464	1.35	0.001540	25.6	43
Williams (1970)	0.028	0.610	0.088	0.527	1.35	0.002100	28.2	135
Williams (1970)	0.033	0.610	0.088	0.623	1.35	0.003300	28.2	338

Data Source	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Trans-ported Sediment Concent. (ppm)
Williams (1970)	0.044	0.610	0.146	0.496	1.35	0.001060	23.6	15
Williams (1970)	0.048	0.610	0.150	0.529	1.35	0.000970	26.4	25
Williams (1970)	0.050	0.610	0.152	0.538	1.35	0.001370	26.8	55
Williams (1970)	0.063	0.610	0.152	0.679	1.35	0.002810	24.8	203
Williams (1970)	0.073	0.610	0.148	0.809	1.35	0.004450	26.0	450
Williams (1970)	0.063	0.610	0.211	0.493	1.35	0.000600	22.4	84
Williams (1970)	0.073	0.610	0.208	0.574	1.35	0.000800	26.6	19
Williams (1970)	0.078	0.610	0.216	0.589	1.35	0.001470	25.2	48
Williams (1970)	0.080	0.610	0.215	0.607	1.35	0.001720	27.8	83
Williams (1970)	0.102	0.610	0.215	0.778	1.35	0.002800	27.8	263
Williams (1970)	0.143	1.190	0.225	0.532	1.35	0.000960	28.0	19
Williams (1970)	0.142	1.190	0.215	0.553	1.35	0.000910	25.0	26
Williams (1970)	0.150	1.190	0.215	0.588	1.35	0.001150	28.6	43
Williams (1970)	0.158	1.190	0.210	0.632	1.35	0.001910	27.6	93
Williams (1970)	0.163	1.190	0.205	0.666	1.35	0.002140	26.2	122
Williams (1970)	0.003	0.305	0.028	0.379	1.35	0.004070	13.8	76
Williams (1970)	0.004	0.305	0.030	0.393	1.35	0.004110	18.6	183
Williams (1970)	0.004	0.305	0.030	0.440	1.35	0.004950	19.2	328
Williams (1970)	0.004	0.305	0.032	0.456	1.35	0.005900	21.0	604
Williams (1970)	0.011	0.305	0.030	1.240	1.35	0.033100	19.2	19,753
Williams (1970)	0.011	0.305	0.091	0.413	1.35	0.001100	21.4	10
Williams (1970)	0.012	0.305	0.096	0.425	1.35	0.001360	19.8	20
Williams (1970)	0.056	0.305	0.098	1.867	1.35	0.016200	19.8	8,815
Williams (1970)	0.018	0.610	0.030	0.993	1.35	0.023400	26.0	9,341
Williams (1970)	0.004	0.305	0.030	0.480	1.35	0.007510	12.6	965
Williams (1970)	0.005	0.305	0.030	0.513	1.35	0.010800	11.8	1,913
Williams (1970)	0.005	0.305	0.030	0.593	1.35	0.012800	17.6	2,871
Williams (1970)	0.006	0.305	0.030	0.680	1.35	0.015100	15.6	4,200
Williams (1970)	0.007	0.305	0.030	0.720	1.35	0.019900	23.6	7,694
Williams (1970)	0.008	0.305	0.030	0.907	1.35	0.022200	24.8	9,139
Williams (1970)	0.022	0.305	0.090	0.784	1.35	0.005940	20.4	914
Williams (1970)	0.022	0.305	0.090	0.784	1.35	0.005920	22.0	1,001
Williams (1970)	0.024	0.305	0.095	0.840	1.35	0.007210	21.8	1,277
Williams (1970)	0.030	0.305	0.100	0.976	1.35	0.008240	23.6	1,484
Williams (1970)	0.032	0.305	0.100	1.040	1.35	0.010900	25.0	2,333
Williams (1970)	0.037	0.305	0.100	1.208	1.35	0.012900	20.4	3,848
Williams (1970)	0.046	0.305	0.150	1.016	1.35	0.008420	18.8	1,318
Williams (1970)	0.053	0.305	0.145	1.199	1.35	0.011800	18.8	2,751
Williams (1970)	0.071	0.305	0.145	1.596	1.35	0.011300	19.0	3,880
Williams (1970)	0.064	0.305	0.210	1.000	1.35	0.004540	18.8	571
Williams (1970)	0.079	0.305	0.200	1.296	1.35	0.009550	20.0	1,761
Williams (1970)	0.010	0.610	0.027	0.622	1.35	0.011700	26.8	2,407
Williams (1970)	0.015	0.610	0.028	0.864	1.35	0.017200	26.8	4,738
Williams (1970)	0.048	0.610	0.090	0.873	1.35	0.007140	28.4	1,322
Williams (1970)	0.063	0.610	0.090	1.140	1.35	0.011300	24.8	2,783
Williams (1970)	0.091	0.610	0.150	0.995	1.35	0.006430	26.8	998
Williams (1970)	0.097	0.610	0.140	1.134	1.35	0.008770	26.2	1,843

Data Source	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Trans-ported Sediment Concent. (ppm)
Williams (1970)	0.130	0.610	0.200	1.064	1.35	0.005600	27.2	813
Willis et al. (1972)	0.197	1.219	0.274	0.589	0.1	0.000962	21.7	2,096
Willis et al. (1972)	0.197	1.219	0.335	0.482	0.1	0.000519	20.6	580
Willis et al. (1972)	0.170	1.219	0.335	0.416	0.1	0.000442	22.2	196
Willis et al. (1972)	0.227	1.219	0.320	0.581	0.1	0.000654	23.3	1,264
Willis et al. (1972)	0.255	1.219	0.305	0.686	0.1	0.000500	22.2	1,728
Willis et al. (1972)	0.283	1.219	0.320	0.726	0.1	0.000481	25.0	1,357
Willis et al. (1972)	0.255	1.219	0.366	0.572	0.1	0.000519	26.7	904
Willis et al. (1972)	0.228	1.219	0.375	0.498	0.1	0.000538	26.9	575
Willis et al. (1972)	0.194	1.219	0.378	0.420	0.1	0.000346	27.8	158
Willis et al. (1972)	0.142	1.219	0.305	0.381	0.1	0.000308	26.7	87
Willis et al. (1972)	0.170	1.219	0.317	0.440	0.1	0.000462	26.7	291
Willis et al. (1972)	0.194	1.219	0.314	0.506	0.1	0.000635	25.3	735
Willis et al. (1972)	0.198	1.219	0.314	0.518	0.1	0.000615	25.8	779
Willis et al. (1972)	0.227	1.219	0.299	0.622	0.1	0.000769	23.9	1,424
Willis et al. (1972)	0.254	1.219	0.262	0.794	0.1	0.000750	25.0	1,629
Willis et al. (1972)	0.227	1.219	0.238	0.782	0.1	0.000538	20.8	2,702
Willis et al. (1972)	0.170	1.219	0.287	0.486	0.1	0.000730	21.9	640
Willis et al. (1972)	0.199	1.219	0.287	0.571	0.1	0.000884	22.2	1,736
Willis et al. (1972)	0.227	1.219	0.247	0.753	0.1	0.000788	19.4	2,056
Willis et al. (1972)	0.142	1.219	0.290	0.401	0.1	0.000712	20.8	213
Willis et al. (1972)	0.114	1.219	0.262	0.358	0.1	0.000269	21.1	101
Willis et al. (1972)	0.142	1.219	0.259	0.448	0.1	0.000711	21.4	459
Willis et al. (1972)	0.170	1.219	0.259	0.538	0.1	0.001000	23.1	1,372
Willis et al. (1972)	0.227	1.219	0.229	0.813	0.1	0.000980	26.4	2,032
Willis et al. (1972)	0.213	1.219	0.229	0.764	0.1	0.000576	25.6	1,745
Willis et al. (1972)	0.113	1.219	0.198	0.469	0.1	0.000808	23.6	996
Willis et al. (1972)	0.127	1.219	0.195	0.533	0.1	0.000962	23.9	1,514
Willis et al. (1972)	0.078	1.219	0.146	0.438	0.1	0.001210	26.1	993
Willis et al. (1972)	0.084	1.219	0.143	0.480	0.1	0.001320	24.4	1,345
Willis et al. (1972)	0.085	1.219	0.143	0.486	0.1	0.001380	22.5	1,091
Willis et al. (1972)	0.085	1.219	0.168	0.416	0.1	0.000981	22.5	478
Willis et al. (1972)	0.113	1.219	0.232	0.401	0.1	0.000577	22.2	240
Willis et al. (1972)	0.142	1.219	0.232	0.501	0.1	0.000865	22.2	1,076
Willis et al. (1972)	0.156	1.219	0.229	0.561	0.1	0.000865	21.1	1,507
Willis et al. (1972)	0.198	1.219	0.207	0.784	0.1	0.000615	22.2	1,883
Willis et al. (1972)	0.227	1.219	0.213	0.871	0.1	0.000750	21.7	2,359
Willis et al. (1972)	0.340	1.219	0.256	1.089	0.1	0.001480	30.0	3,681
Willis et al. (1972)	0.340	1.219	0.302	0.924	0.1	0.000923	30.6	1,941
Willis et al. (1972)	0.340	1.219	0.305	0.915	0.1	0.000692	28.3	2,181
Willis et al. (1972)	0.199	1.219	0.195	0.838	0.1	0.001020	28.3	2,807
Willis et al. (1972)	0.283	1.219	0.283	0.819	0.1	0.000654	22.8	1,709
Willis et al. (1972)	0.312	1.219	0.287	0.892	0.1	0.000692	24.2	2,013
Willis et al. (1972)	0.368	1.219	0.290	1.043	0.1	0.000885	23.9	3,374
Willis et al. (1972)	0.396	1.219	0.290	1.123	0.1	0.001150	23.1	4,973
Willis et al. (1972)	0.425	1.219	0.280	1.243	0.1	0.001870	25.6	6,720
Willis et al. (1972)	0.453	1.219	0.277	1.340	0.1	0.001100	26.1	8,286

Data Source	Water Discharge Q (m^3/s)	Channel Width W (m)	Flow Depth d (m)	Flow Velocity V (m/s)	Mean Bed Diameter d_s (mm)	Water Surface Slope S (m/m)	Water Temp. (°C)	Trans-ported Sediment Concent. (ppm)
Willis et al. (1972)	0.453	1.219	0.305	1.219	0.1	0.001190	22.8	5,427
Willis et al. (1972)	0.425	1.219	0.305	1.143	0.1	0.000827	25.8	3,945
Willis et al. (1972)	0.396	1.219	0.317	1.026	0.1	0.000712	25.0	2,905
Willis et al. (1972)	0.368	1.219	0.308	0.981	0.1	0.000442	24.4	2,239
Willis et al. (1972)	0.340	1.219	0.308	0.905	0.1	0.000462	25.8	1,579
Willis et al. (1972)	0.312	1.219	0.305	0.838	0.1	0.000538	26.1	1,286
Willis et al. (1972)	0.283	1.219	0.271	0.856	0.1	0.000673	25.6	1,690
Willis et al. (1972)	0.312	1.219	0.274	0.931	0.1	0.000788	26.4	3,075
Willis et al. (1972)	0.340	1.219	0.274	1.016	0.1	0.000808	24.7	3,691
Willis et al. (1972)	0.368	1.219	0.271	1.113	0.1	0.000981	23.3	4,859
Willis et al. (1972)	0.396	1.219	0.274	1.185	0.1	0.001130	23.9	5,836
Willis et al. (1972)	0.425	1.219	0.271	1.284	0.1	0.001980	24.2	6,551
Willis et al. (1972)	0.453	1.219	0.268	1.386	0.1	0.001290	21.1	11,174
Willis et al. (1972)	0.480	1.219	0.290	1.361	0.1	0.001500	22.2	11,626
Willis et al. (1972)	0.479	1.219	0.250	1.572	0.1	0.001380	23.1	19,119
Willis et al. (1972)	0.423	1.219	0.238	1.458	0.1	0.001210	24.4	13,962
Willis et al. (1972)	0.396	1.219	0.241	1.351	0.1	0.001400	17.5	13,207
Willis et al. (1972)	0.367	1.219	0.244	1.235	0.1	0.001130	21.9	8,067
Willis et al. (1972)	0.339	1.219	0.247	1.125	0.1	0.001080	21.7	6,296
Willis et al. (1972)	0.312	1.219	0.244	1.048	0.1	0.001120	22.2	4,634
Willis et al. (1972)	0.283	1.219	0.244	0.953	0.1	0.000807	21.4	3,216
Willis et al. (1972)	0.255	1.219	0.238	0.879	0.1	0.000538	21.7	2,353
Willis et al. (1972)	0.255	1.219	0.241	0.868	0.1	0.000826	25.6	2,332
Willis et al. (1972)	0.283	1.219	0.232	1.003	0.1	0.000846	26.1	3,120
Willis et al. (1972)	0.312	1.219	0.235	1.089	0.1	0.001100	25.3	4,125
Willis et al. (1972)	0.340	1.219	0.232	1.203	0.1	0.001290	21.1	5,798
Willis et al. (1972)	0.170	1.219	0.177	0.788	0.1	0.000827	23.9	2,271
Willis et al. (1972)	0.127	1.219	0.137	0.759	0.1	0.001270	24.2	3,154
Willis et al. (1972)	0.100	1.219	0.119	0.688	0.1	0.001330	23.9	3,415
Willis et al. (1972)	0.170	1.219	0.162	0.863	0.1	0.001080	21.1	3,261
Willis et al. (1972)	0.212	1.219	0.189	0.919	0.1	0.001060	22.2	3,436
Willis et al. (1972)	0.255	1.219	0.210	0.994	0.1	0.000808	22.5	3,459
Willis et al. (1972)	0.283	1.219	0.210	1.104	0.1	0.000981	22.8	4,861
Willis et al. (1972)	0.340	1.219	0.210	1.325	0.1	0.001440	30.0	13,867
Willis et al. (1972)	0.447	1.219	0.244	1.505	0.1	0.001670	24.4	18,320
Willis et al. (1972)	0.142	1.219	0.128	0.907	0.1	0.001020	24.2	4,358
Willis et al. (1972)	0.170	1.219	0.131	1.063	0.1	0.001760	25.0	10,924
Willis et al. (1972)	0.127	1.219	0.104	1.004	0.1	0.001750	25.6	10,513
Willis et al. (1972)	0.113	1.219	0.110	0.847	0.1	0.001420	24.7	5,761
Willis et al. (1972)	0.184	1.219	0.158	0.950	0.1	0.001120	21.1	4,447
Willis et al. (1972)	0.198	1.219	0.149	1.089	0.1	0.001120	21.7	6,808
Willis et al. (1972)	0.212	1.219	0.152	1.140	0.1	0.001120	21.7	9,070
Willis et al. (1972)	0.227	1.219	0.183	1.016	0.1	0.001100	22.2	4,632
Willis et al. (1972)	0.240	1.219	0.186	1.059	0.1	0.001190	22.2	5,564
Willis et al. (1972)	0.255	1.219	0.183	1.143	0.1	0.001540	23.1	7,793
Willis et al. (1972)	0.270	1.219	0.177	1.251	0.1	0.001230	21.7	10,032
Willis et al. (1972)	0.283	1.219	0.180	1.292	0.1	0.001440	21.7	13,469
Willis et al. (1972)	0.312	1.219	0.210	1.215	0.1	0.001810	22.8	9,898
Willis et al. (1972)	0.312	1.219	0.204	1.251	0.1	0.001210	23.1	7,998
Willis et al. (1972)	0.340	1.219	0.213	1.306	0.1	0.002040	24.2	12,344

APPENDIX G
FLUME DATA SETS (GESSLER ET AL., 1994)

Table G.1: Flume data set (Gessler et al., 1994).

Run	Discharge (cfs)	Depth ft)	Grain Size d_{95} (mm)	Slope (ft/ft)	Bottom Width (ft)	Absolute Wall Roughness (ft)	Bank Angle (H:V)
1	0.320	0.293	0.280	0.002546	0.813	0.183	1:1
2	0.469	0.349	0.280	0.002546	0.872	0.183	1:1
3	0.724	0.446	0.280	0.002546	0.854	0.183	1:1
4	0.302	0.281	0.280	0.002431	0.820	0.027	1:1
5	0.492	0.315	0.280	0.002778	0.853	0.027	1:1
6	0.713	0.384	0.280	0.002315	0.885	0.027	1:1
7	0.316	0.271	0.280	0.002315	0.874	0.051	1:1
8	0.475	0.274	0.280	0.002778	0.902	0.051	1:1
9	0.636	0.336	0.280	0.002662	0.921	0.051	1:1
22	0.319	0.315	0.280	0.002546	0.697	0.320	1:1
23	0.521	0.414	0.280	0.002546	0.740	0.320	1:1
24	0.681	0.458	0.280	0.002662	0.682	0.320	1:1
10	0.299	0.286	0.954	0.002431	0.504	0.183	1:1
11	0.514	0.396	0.954	0.002315	0.325	0.183	1:1
12	0.718	0.416	0.954	0.002546	0.531	0.183	1:1
13	0.318	0.217	0.954	0.002662	0.842	0.027	1:1
14	0.467	0.250	0.954	0.002662	1.138	0.027	1:1
15	0.689	0.322	0.954	0.002431	1.030	0.027	1:1
16	0.285	0.211	0.954	0.002431	1.419	0.051	1:1
17	0.505	0.296	0.954	0.002546	1.380	0.051	1:1
18	0.692	0.350	0.954	0.002662	1.610	0.051	1:1
19	0.317	0.299	0.954	0.002546	0.925	0.320	1:1
20	0.508	0.390	0.954	0.002315	0.954	0.320	1:1
21	0.730	0.516	0.954	0.002431	0.724	0.320	1:1
25	0.303	0.279	0.934	0.002546	0.811	0.183	1:1
26	0.510	0.355	0.934	0.002546	0.822	0.183	1:1
27	0.735	0.431	0.934	0.002546	0.840	0.183	1:1
28	0.265	0.188	0.934	0.002546	0.769	0.027	1:1
29	0.488	0.261	0.934	0.002546	0.777	0.027	1:1
30	0.652	0.317	0.934	0.002546	0.768	0.027	1:1
31	0.269	0.215	0.934	0.002546	0.771	0.051	1:1
32	0.475	0.270	0.934	0.002546	0.811	0.051	1:1
33	0.654	0.341	0.934	0.002546	0.829	0.051	1:1
34	0.300	0.274	0.934	0.002546	0.919	0.320	1:1
35	0.516	0.413	0.934	0.002546	0.829	0.320	1:1
36	0.711	0.480	0.934	0.002546	0.847	0.320	1:1
37	0.292	0.245	0.280	0.002546	1.024	0.183	2:1
38	0.482	0.280	0.280	0.002662	1.136	0.183	2:1
39	0.657	0.331	0.280	0.002546	1.145	0.183	2:1
40	0.263	0.191	0.280	0.002546	1.005	0.027	2:1
41	0.440	0.201	0.280	0.002546	1.011	0.027	2:1
42	0.612	0.252	0.280	0.002546	1.000	0.027	2:1
43	0.267	0.219	0.280	0.002315	0.946	0.051	2:1

Run	Discharge (cfs)	Depth ft)	Grain Size d_{95} (mm)	Slope (ft/ft)	Bottom Width (ft)	Absolute Wall Roughness (ft)	Bank Angle (H:V)
44	0.515	0.228	0.280	0.002546	1.083	0.051	2:1
45	0.623	0.267	0.280	0.002546	1.043	0.051	2:1
46	0.298	0.258	0.280	0.002546	0.992	0.320	2:1
47	0.485	0.335	0.280	0.002546	1.002	0.320	2:1
48	0.708	0.395	0.280	0.002546	1.053	0.320	2:1
49	0.287	0.236	0.954	0.002315	0.998	0.183	2:1
50	0.490	0.288	0.954	0.002431	1.091	0.183	2:1
51	0.708	0.335	0.954	0.002546	1.127	0.183	2:1
52	0.261	0.171	0.954	0.002431	0.950	0.027	2:1
53	0.448	0.193	0.954	0.002546	1.179	0.027	2:1
54	0.707	0.251	0.954	0.002546	1.080	0.027	2:1
55	0.294	0.189	0.954	0.002778	1.008	0.051	2:1
56	0.535	0.280	0.954	0.002315	0.879	0.051	2:1
57	0.655	0.283	0.954	0.002431	1.067	0.051	2:1
58	0.298	0.265	0.954	0.002315	0.995	0.320	2:1
59	0.423	0.299	0.954	0.002546	1.118	0.320	2:1
60	0.639	0.347	0.954	0.002662	1.217	0.320	2:1
61	0.267	0.228	0.934	0.002546	0.991	0.183	2:1
62	0.483	0.292	0.934	0.002662	1.005	0.183	2:1
63	0.712	0.357	0.934	0.002431	1.040	0.183	2:1
64	0.292	0.183	0.934	0.002431	0.918	0.027	2:1
65	0.480	0.227	0.934	0.002546	0.960	0.027	2:1
66	0.695	0.283	0.934	0.002546	0.922	0.027	2:1
67	0.271	0.207	0.934	0.002315	0.871	0.051	2:1
68	0.480	0.239	0.934	0.002546	0.961	0.051	2:1
69	0.713	0.310	0.934	0.002662	0.886	0.051	2:1
70	0.279	0.245	0.934	0.002546	1.028	0.320	2:1
71	0.478	0.332	0.934	0.002546	0.963	0.320	2:1
72	0.634	0.344	0.934	0.002778	1.140	0.320	2:1
73	0.282	0.217	0.280	0.002546	1.238	0.183	3:1
74	0.443	0.255	0.280	0.002894	1.306	0.183	3:1
75	0.523	0.277	0.280	0.003241	1.270	0.183	3:1
76	0.275	0.197	0.280	0.002315	1.165	0.027	3:1
77	0.427	0.175	0.280	0.002431	1.275	0.027	3:1
78	0.677	0.236	0.280	0.002315	1.178	0.027	3:1
79	0.260	0.186	0.280	0.002315	1.324	0.051	3:1
80	0.464	0.197	0.280	0.002662	1.267	0.051	3:1
81	0.686	0.230	0.280	0.002894	1.327	0.051	3:1
82	0.292	0.239	0.280	0.002778	1.157	0.320	3:1
83	0.437	0.287	0.280	0.003125	1.184	0.320	3:1
84	0.360	0.264	0.280	0.002894	1.166	0.320	3:1
85	0.278	0.206	0.954	0.002546	1.227	0.183	3:1
86	0.476	0.262	0.954	0.002778	1.264	0.183	3:1
87	0.526	0.298	0.954	0.002546	1.156	0.183	3:1
88	0.280	0.167	0.954	0.002546	1.110	0.027	3:1

Run	Discharge (cfs)	Depth ft)	Grain Size d_{95} (mm)	Slope (ft/ft)	Bottom Width (ft)	Absolute Wall Roughness (ft)	Bank Angle (H:V)
89	0.464	0.198	0.954	0.002546	1.280	0.027	3:1
90	0.574	0.210	0.954	0.002662	1.394	0.027	3:1
91	0.277	0.178	0.954	0.002546	1.191	0.051	3:1
92	0.448	0.210	0.954	0.002546	1.332	0.051	3:1
93	0.619	0.236	0.954	0.002546	1.436	0.051	3:1
94	0.281	0.233	0.954	0.002662	1.194	0.320	3:1
95	0.489	0.314	0.954	0.002546	1.093	0.320	3:1
96	0.378	0.277	0.954	0.002546	1.147	0.320	3:1
97	0.273	0.222	0.934	0.002662	1.131	0.183	3:1
98	0.472	0.269	0.934	0.002315	1.200	0.183	3:1
99	0.378	0.257	0.934	0.002431	1.167	0.183	3:1
100	0.274	0.170	0.934	0.001736	1.161	0.027	3:1
101	0.455	0.179	0.934	0.002662	1.245	0.027	3:1
102	0.711	0.232	0.934	0.002546	1.162	0.027	3:1
103	0.282	0.168	0.934	0.002546	1.252	0.051	3:1
104	0.467	0.199	0.934	0.002315	1.313	0.051	3:1
105	0.688	0.238	0.934	0.002315	1.357	0.051	3:1
106	0.279	0.230	0.934	0.002662	1.245	0.320	3:1
107	0.393	0.288	0.934	0.002546	1.230	0.320	3:1
108	0.357	0.261	0.934	0.002662	1.152	0.320	3:1

Table G.2: Flume data set (Gessler et al., 1994).

Run #	Actual Discharge (cfs)	Mid. Velocity (ft/sec)	Side Velocity (ft/sec)	Total Roughness *f*	Wall Roughness f_w	Bed Roughness f_b	Total Load (mg/sec)	Suspended Load Over Side (mg/sec)	Suspended Concentration Side (mg/l)	Suspended Concentration Mid. (mg/l)
1	0.320	1.310	0.449	0.133	0.182	0.112	2,230	167.5	2171.5	4501.0
2	0.469	1.612	0.530	0.125	0.170	0.088	5,201	374.6	2901.5	6551.6
3	0.724	1.652	0.737	0.107	0.127	0.107	8,756	694.1	2367.2	6487.8
4	0.302	1.103	0.534	0.127	0.116	0.144	6,351	791.0	9386.9	20504.4
5	0.492	1.695	0.676	0.085	0.098	0.078	10,958	1348.0	10054.3	12365.0
6	0.713	1.817	0.827	0.069	0.073	0.069	19,745	2212.5	9071.4	17951.2
7	0.316	1.244	0.498	0.110	0.120	0.104	2,746	105.0	1436.2	4721.7
8	0.475	1.850	0.669	0.064	0.081	0.057	11,455	418.2	4162.0	8884.8
9	0.636	1.892	0.768	0.069	0.080	0.064	10,771	558.0	3218.4	5192.1
22	0.319	1.146	0.427	0.184	0.225	0.157	845	30.9	365.0	1216.8
23	0.521	1.358	0.539	0.172	0.212	0.147	3,028	144.5	781.5	3026.7
24	0.681	1.519	0.602	0.175	0.207	0.136	4,608	253.0	1001.7	3462.6
10	0.299	1.204	0.425	0.139	0.187	0.123	754	6.2	89.9	63.9
11	0.514	1.528	0.571	0.128	0.161	0.101	1,039	6.2	34.4	455.2
12	0.718	1.833	0.781	0.090	0.102	0.081	5,217	7.0	26.0	172.7
13	0.318	1.741	0.592	0.055	0.070	0.049	2,963	10.2	182.2	167.9
14	0.467	2.048	0.706	0.046	0.061	0.041	6,262	9.9	112.0	245.5
15	0.689	2.124	0.933	0.045	0.046	0.045	2,639	37.3	193.0	130.9
16	0.285	1.534	0.495	0.064	0.087	0.056	996	2.4	55.3	74.5
17	0.505	1.825	0.717	0.063	0.073	0.058	3,906	5.5	44.1	97.6
18	0.692	2.155	0.809	0.063	0.077	0.052	7,435	17.6	88.7	453.7
19	0.317	1.322	0.418	0.158	0.217	0.112	1,120	2.2	29.4	51.8
20	0.508	1.589	0.522	0.143	0.188	0.092	1,206	6.0	37.6	47.3
21	0.730	1.390	0.652	0.167	0.193	0.167	788	13.5	38.9	70.0
25	0.303	1.272	0.477	0.127	0.150	0.113	736	12.9	173.3	596.7
26	0.510	1.727	0.611	0.102	0.131	0.078	1,676	52.2	338.8	862.4
27	0.735	1.822	0.775	0.097	0.109	0.085	4,228	157.9	548.1	1334.4
28	0.265	1.755	0.614	0.042	0.050	0.040	4,248	51.0	1174.9	2614.5
29	0.488	2.067	0.926	0.036	0.036	0.040	12,586	323.7	2565.2	6733.5
30	0.652	2.224	1.043	0.038	0.038	0.042	16,579	869.2	4146.9	7157.9
31	0.269	1.678	0.493	0.063	0.095	0.050	3,469	77.6	1702.0	1631.8
32	0.475	2.005	0.776	0.046	0.054	0.044	7,922	270.2	2389.5	2992.4
33	0.654	2.204	0.842	0.054	0.065	0.046	10,386	517.5	2641.8	3701.7
34	0.300	1.184	0.389	0.151	0.219	0.128	302	6.6	112.3	313.8
35	0.516	1.361	0.561	0.168	0.195	0.146	1,171	23.3	121.5	345.7
36	0.711	1.509	0.667	0.152	0.173	0.138	1,870	48.0	156.2	505.5
37	0.292	0.998	0.407	0.186	0.277	0.161	1,711	70.7	723.5	2853.7
38	0.482	1.249	0.557	0.133	0.189	0.123	5,844	245.3	1405.1	6641.4
39	0.657	1.437	0.642	0.124	0.175	0.105	9,343	729.7	2595.4	8998.1
40	0.263	1.108	0.533	0.096	0.111	0.102	4,803	433.0	5564.4	11525.0
41	0.440	1.771	0.802	0.041	0.053	0.042	14,661	535.1	4129.5	8909.4
42	0.612	1.959	0.933	0.045	0.055	0.043	20,923	857.0	3617.5	10074.8
43	0.267	1.136	0.436	0.122	0.185	0.101	2,370	90.2	1077.7	3876.8
44	0.515	1.783	1.134	0.054	0.032	0.047	13,403	648.4	2749.1	9507.0
45	0.623	1.834	0.845	0.057	0.073	0.052	18,406	967.3	4012.3	11087.6

Run #	**Actual Discharge (cfs)**	**Mid. Velocity (ft/sec)**	**Side Velocity (ft/sec)**	**Total Roughness *f***	**Wall Roughness f_w**	**Bed Roughness f_b**	**Total Load (mg/sec)**	**Suspended Load Over Side (mg/sec)**	**Suspended Concentration Side (mg/l)**	**Suspended Concentration Mid. (mg/l)**
46	0.298	1.025	0.382	0.203	0.340	0.161	1,231	38.1	375.3	2642.1
47	0.485	1.150	0.507	0.197	0.285	0.166	2,697	238.6	1047.9	3497.8
48	0.708	1.292	0.620	0.181	0.244	0.155	4,136	378.2	976.9	4723.6
49	0.287	0.995	0.414	0.149	0.230	0.142	722	0.4	4.4	151.5
50	0.490	1.349	0.562	0.122	0.177	0.099	1,958	2.5	13.2	27.7
51	0.708	1.646	0.671	0.109	0.163	0.081	4,520	12.7	42.3	107.7
52	0.261	1.407	0.524	0.059	0.093	0.054	2,354	67.4	1098.9	462.5
53	0.448	1.695	0.692	0.046	0.067	0.044	9,074	5.8	55.9	94.7
54	0.707	2.232	0.956	0.038	0.052	0.033	15,891	16.4	68.2	276.6
55	0.294	1.316	0.523	0.081	0.124	0.078	2,227	2.3	31.1	76.2
56	0.535	1.653	0.783	0.064	0.083	0.061	5,099	69.7	283.9	504.4
57	0.655	1.794	0.819	0.062	0.081	0.055	8,252	3.0	11.4	105.0
58	0.298	1.036	0.337	0.204	0.413	0.147	898	0.8	8.7	26.0
59	0.423	1.247	0.347	0.202	0.514	0.126	1,377	4.3	34.6	59.1
60	0.639	1.413	0.477	0.177	0.355	0.119	2,197	21.9	95.5	176.4
61	0.267	1.033	0.380	0.166	0.285	0.140	865	11.0	138.8	885.6
62	0.483	1.466	0.564	0.127	0.196	0.093	4,427	82.2	427.4	1067.5
63	0.712	1.517	0.698	0.116	0.158	0.097	4,444	168.1	472.3	1273.0
64	0.292	1.456	0.610	0.055	0.076	0.054	3,659	82.4	1009.2	1639.6
65	0.480	1.818	0.826	0.048	0.060	0.045	11,468	454.7	2672.2	5046.4
66	0.695	2.030	1.008	0.047	0.056	0.045	22,382	1040.5	3221.2	5761.2
67	0.271	1.309	0.528	0.083	0.116	0.072	2,475	27.4	302.8	896.6
68	0.480	1.787	0.734	0.058	0.082	0.049	9,731	184.9	1102.3	3580.9
69	0.713	1.947	0.935	0.061	0.078	0.056	19,499	794.3	2209.1	4274.8
70	0.279	1.008	0.364	0.205	0.346	0.158	795	10.1	115.0	889.1
71	0.478	1.298	0.490	0.185	0.301	0.129	2,050	48.4	223.8	767.3
72	0.634	1.482	0.528	0.166	0.299	0.112	3,721	62.2	249.0	831.3
73	0.282	0.909	0.339	0.219	0.431	0.172	1,113	27.5	286.8	2096.1
74	0.443	1.121	0.463	0.193	0.336	0.151	6,017	197.6	1094.6	6885.3
75	0.523	1.183	0.499	0.201	0.366	0.165	8,584	470.3	2046.8	8842.9
76	0.275	0.925	0.519	0.136	0.145	0.137	2,255	160.3	1326.0	5155.7
77	0.427	1.697	0.681	0.045	0.074	0.038	13,590	376.4	3007.0	7394.7
78	0.677	1.976	0.843	0.043	0.072	0.036	25,464	1127.0	3998.9	9702.6
79	0.260	0.913	0.403	0.152	0.221	0.133	1,176	22.6	270.0	2345.6
80	0.464	1.581	0.670	0.062	0.100	0.054	14,985	548.1	3512.5	13713.6
81	0.686	1.889	0.818	0.057	0.092	0.048	29,762	997.6	3841.4	13710.9
82	0.292	0.881	0.347	0.284	0.520	0.220	1,104	22.5	189.1	2199.3
83	0.437	1.038	0.370	0.285	0.677	0.214	3,907	139.9	764.9	4736.4
84	0.360	0.939	0.367	0.281	0.561	0.223	2,013	84.8	551.7	3609.0
85	0.278	0.945	0.355	0.186	0.364	0.151	968	5.8	63.7	199.3
86	0.476	1.200	0.472	0.169	0.322	0.130	1,900	5.1	26.4	158.2
87	0.526	1.094	0.554	0.179	0.260	0.163	2,730	55.6	188.2	51.1
88	0.280	1.318	0.520	0.076	0.124	0.063	2,423	1.3	14.8	106.8
89	0.464	1.550	0.671	0.062	0.096	0.054	6,323	8.1	51.2	176.2
90	0.574	1.696	0.718	0.059	0.096	0.050	11,098	6.6	34.8	222.5
91	0.277	1.132	0.469	0.107	0.168	0.091	795	2.9	32.7	78.3
92	0.448	1.412	0.560	0.087	0.151	0.069	4,906	3.4	23.1	108.9

Run #	Actual Discharge (cfs)	Mid. Velocity (ft/sec)	Side Velocity (ft/sec)	Total Roughness f	Wall Roughness f_w	Bed Roughness f_b	Total Load (mg/sec)	Suspended Load Over Side (mg/sec)	Suspended Concentration Side (mg/l)	Suspended Concentration Mid. (mg/l)
93	0.619	1.530	0.685	0.076	0.120	0.066	9,970	3.2	14.1	144.5
94	0.281	0.919	0.305	0.281	0.622	0.189	423	4.3	43.1	91.1
95	0.489	1.221	0.457	0.235	0.414	0.138	1,596	5.0	18.5	95.9
96	0.378	0.886	0.386	0.262	0.481	0.231	1,301	6.0	33.7	112.5
97	0.273	0.994	0.295	0.231	0.617	0.154	1,471	31.1	356.4	1334.1
98	0.472	1.155	0.470	0.147	0.282	0.120	3,396	65.5	320.9	1712.2
99	0.378	0.984	0.436	0.194	0.321	0.166	1,417	22.0	127.4	671.2
100	0.274	1.197	0.495	0.062	0.096	0.053	1,862	26.7	311.6	855.2
101	0.455	1.796	0.706	0.046	0.078	0.038	14,818	193.4	1424.4	5990.4
102	0.711	2.084	0.965	0.040	0.059	0.035	23,331	699.2	2244.4	5140.6
103	0.282	1.219	0.466	0.092	0.156	0.074	2,354	22.2	282.0	1156.0
104	0.467	1.555	0.653	0.059	0.093	0.049	9,179	127.5	821.9	2899.2
105	0.688	1.906	0.724	0.053	0.099	0.039	14,284	352.5	1433.1	5745.0
106	0.279	0.866	0.300	0.289	0.631	0.210	1,072	16.8	176.1	1343.5
107	0.393	0.939	0.312	0.306	0.779	0.214	1,719	23.3	149.8	948.9
108	0.357	1.025	0.329	0.248	0.633	0.170	1,980	22.3	165.9	725.2