Utah State University
DigitalCommons@USU

Reports | Utah Water Research Laboratory

January 1994

The Study of Resistance and Stability of Vegetation in Flood Channels

William Rahmeyer

David Werth

Rob Cleere

Follow this and additional works at: https://digitalcommons.usu.edu/water_rep

Part of the Civil and Environmental Engineering Commons, and the Water Resource Management Commons

Recommended Citation

Rahmeyer, William; Werth, David; and Cleere, Rob, "The Study of Resistance and Stability of Vegetation in Flood Channels" (1994). *Reports.* Paper 147.
https://digitalcommons.usu.edu/water_rep/147

This Report is brought to you for free and open access by the Utah Water Research Laboratory at DigitalCommons@USU. It has been accepted for inclusion in Reports by an authorized administrator of DigitalCommons@USU. For more information, please contact digitalcommons@usu.edu.

UtahStateUniversity
MERRILL-CAZIER LIBRARY

UWRL Archives

The Study Of Resistance And Stability Of Vegetation In Flood Channels

by
William Rahmeyer P.E. PhD.
Professor of Civil and
Environmental Engineering,

David Werth
Research Assistant,

Rob Cleere
Research Assistant

Utah State University

Lab Report No. USU-376

December 1994

prepared for the

U.S. Army Engineers Waterways Experiment Station,
Vicksburg, MS.

Federal Contract No - DACW39-94-K-0009.

UTAH STATE UNIVERSITY

UTAH WATER RESEARCH LAB
DR. WILLIAM RAHMEYER
LOGAN, UTAH 84322-8200
(801) 797-3180

129960

THE STUDY OF RESISTANCE AND STABILITY OF VEGETATION IN FLOOD CHANNELS

PREFACE

The following report was prepared by the Utah Water Research Laboratory of Utah State University in Logan, Utah. The report contains the data and conclusions of flow tests conducted with different types of shrubs and woody vegetation in the hydraulics flumes of Utah State University. The funding agency for this project was the U.S. Army Engineers Waterways Experiment Station, Vicksburg, MS.; Project Name - Flood Control Channels; Work Unit Title - Stability of Vegetative Cover in Flood Control Channels; Work Unit No - 337A3; Federal Contract No - DACW39-94-K-0009. The study was the result of a proposal submitted in response to the U.S. Army Engineer Waterways Experiment Station Broad Agency Announcement, Open Channel Flow, HL-3. The study was conducted under the supervision of Dr. William Rahmeyer of Utah State University, and was aided by Dave Werth and Rob Cleere of Utah State University. The project was coordinated with Dave Derrick,. Craig Fischenich, and Gary Freeman of the U.S. Army Engineers Waterways Experiment Station. Appreciation is also expressed to Ron Copeland and Brad Hall of the U.S. Army Engineers Waterways Experiment Station for their review of the project report and results.

NOMENCLATURE

The following symbols and units were used in this report:

A	Cross sectional area of flow, ft^2.
A_i	Frontal area of vegetation blocking flow, ft^2.
b	Bed width, ft.
C	Chezy resistance coefficient, $ft^{1/2}$/sec.
C_d	Drag coefficient of vegetation, dimensionless.
dy/dx	Unit change in slope of water surface, dimensionless.
D_S	Stem diameter, ft.
d_{84}	Bed material size that equals or exceeds 84% of particles sizes, ft.
E	Modulus of elasticity of the vegetation, psf or Pascal.
f	Friction factor, dimensionless.
F_B	Total force on channel bottom produced by vegetation, lbs.
Fr	Froude number, dimensionless.
g	Gravitational constant = 32.2 ft/s^2.
H	Total plant height, ft.
H'	Effective plant height, ft.
H_{CL}	Plant height to center of leaf mass, ft.
h	Undeflected vegetation height, ft.
I	Second moment of inertia of cross section of plant stem, ft^4 or m^4.
k	Deflected roughness height, ft.
L	Length of channel reach, ft.
M	Relative plant density, dimensionless.
m	Correction factor for channel meandering, dimensionless.
n	Manning's resistance coefficient, dimensionless.
n_b	Manning's resistance coefficient for bed roughness and vegetation, dimensionless.
n_{base}	Manning's resistance coefficient for bed roughness, dimensionless.
n_{veg}	Manning's resistance coefficient for vegetation, dimensionless.
P	Wetted perimeter of channel, ft.
P_d	Plant density, # of plants / unit ft^2.
P_S	Plant spacing (average of lateral and longitudinal distances between stems), ft.
Q	Flow rate or discharge, cfs.
R	Hydraulic radius (R=A/P), ft.
R	Gross hydraulic radius, ft.

R_b	Hydraulic radius due to resistance of bed and vegetation, ft.
R_w	Hydraulic radius due to resistance of flume walls, ft.
Re	Reynold's number, dimensionless.
S	Bed or energy slope, dimensionless.
S_f	Energy grade line slope, dimensionless.
S_o	Bed slope, dimensionless.
V	Mean channel velocity, fps.
V_P	Plant approach velocity at center of plant, fps.
V*	Shear velocity ($V^*=[gRS]^{1/2}$), fps.
Y_O	Flow depth, ft.
y_n	Normal flow depth, ft.
W_P	Plant width, ft.
γ	Specific weight of water, lbs/ft^3 or $Newtons/m^3$.
τ_o	Shear stress on channel bottom ($\tau_o=\gamma RS$), lbs/ft^2

CONVERSION FACTORS

The following report is written exclusively in the EI (English) systems of units. The units can be converted to the SI(Metric) systems with the following conversions:

1 foot = 0.3048 meters
1 square foot = .092903 $meters^2$
1 cubic foot = 0.028317 $meters^3$
1 pound force = 4.44822 Newtons
1 psf = 47.88026 Pascal

The following conversions can be used to convert the Manning's resistance coefficient n, note that units are based on the English system:

$$n = (8g)^{1/2} \cdot 1.486 \cdot R^{1/6} / C$$
$$n = f^{2} \cdot 1.486 \cdot R^{1/6}$$
$$n = (8)^{1/2} \cdot 1.486 \cdot R^{1/6} \cdot V^*/V$$

Table of Contents

List of Figures

Figure | Page

List of Tables

Table | Page

section 1 INTRODUCTION

1-1 To calculate the stage discharge relationship of a stream or river, it is necessary to accurately determine the flow resistance of the channel bed and sides. Past research has made considerable progress in predicting the roughness of uniform channels based on both theoretical and experimental investigations. However, to determine the flow resistance associated with flood plains and over-bank flooding, the effects of emergent vegetation on the flood plains must be considered. Over-bank flow onto the flood plains typically submerges many types of shrubs and woody vegetation.

1-2 Research has been conducted on vegetation such as dense layered grasses and on the rigid blockage of cylindrical tree trunks. Very little has been studied on the resistance effects of shrubs and woody vegetation that are submerged by turbulent flows. The flexible stems and varying shapes of the plant's leaf mass, greatly complicate the understanding of resistance. Resistance of flexible stems and plant shapes can not be adequately explained with either a boundary roughness or a form drag approach.

1-3 The purpose of this study was to investigate the effect of woody vegetation, particularly ground cover plants and shrubs, on flow resistance. The primary objective was to determine the head loss and resistance coefficients from the laboratory testing of plants in conditions as close to in situ as possible. The following investigation required the testing of numerous plants and plant densities in both a large laboratory flume and in a smaller sectional flume.

1-4 The study also included a number of secondary objectives:

1) The effects of flow velocity and depth on the Manning's resistance coefficient *n*;
2) The effects of the geometry and characteristics of plants on the drag forces produced by the plants;
3) The relationship of drag force with the bed shear stress and the flow resistance of the channel;
4) The overall effect of flow variables and plant characteristics on the Manning's coefficient *n*;
5) The maximum velocity limits for stem breakage and leaf detachment;
6) Observations of plant distortion and bending during submerged flow conditions;
7) Observations of sediment transport and of the scour of bed material during testing;
8) Considerations of the effect of vegetation on determining resistance and flow depth in compound flood channels.

1-5 The following report includes: chapters on background material; test setup; test plants; test procedures; test results of resistance and drag forces; data analysis and methodology; and a summary of conclusions and recommendations. Observations of plant and sediment movement were recorded on 35mm color slides and on 8mm videotape. The methodology and equations to predict resistance for woody types of vegetation will be presented along with a discussion of the application of vegetated resistance with compound flood channels.

section 2 FLOW RESISTANCE

2-2 The resistance to flow in waterways can be characterized by a roughness or resistance coefficient. The most commonly used equation for flow resistance is the Manning's equation (Equation 1), where the Manning's coefficient or Manning's *n* represents the resistance. This report will focus on Manning's coefficient since most methodologies and applications such as HEC-2 use Manning's *n* exclusively. Other resistance equations do use different resistance coefficients such as the Chezy *C* or the Darcy friction factor *f*. However, the conversions from Manning's *n* are straight forward and the following equations can easily be converted to either *C* or *f*.

$$V = \frac{1.486}{n} R^{2/3} S^{1/2} \tag{1}$$

Where, V is the mean velocity of flow in feet per second; R is hydraulic radius, in feet; S is slope of the energy grade line, in feet per feet; *n* is Manning's resistance coefficient; and 1.486 is a unit conversion for English units, in $ft^{1/3}$/sec.

2-2 A critical misunderstanding concerning Manning's *n* is the assumption that *n* is an independent variable, and remains constant for changes in flow variables such as velocity and depth. Chow (1959) recognized that *n* will vary with variables of geometry that include: surface roughness, vegetation, channel irregularity, channel alignment, silting and scouring, obstructions, and channel shape. The range of Manning's *n* published by Chow for vegetation was from 0.001 to 0.05 for moderately tall vegetation and from 0.05 to 0.10 for very tall and dense vegetation. Chow (1959) was also one of the first to publish that Manning' *n* could vary with the flow variables of depth and discharge.

2-3 Cowan (1956) formulated the first additive or linearization of n (Equation 2) that was basically the summarization of the effects of the primary flow geometries.

$$n = \left(n_o + n_1 + n_2 + n_3 + n_4\right) \cdot m_5 \tag{2}$$

Where, n_o is a base n value for straight, uniform, and smooth channels in natural materials; n_1 is an additive value to n_o which accounts for surface irregularities; n_2 is an additive value which accounts for variations in channel geometry in a cross section; n_3 is an additive value which accounts for obstructions; n_4 is an additive value which accounts for vegetation; and m_5 is a correction factor for the meandering or sinuosity of the channel.

2-4 Detailed tables of base and additive values can be found in publications by Chow (1959), Benson and Dalrymple (1967), Barnes (1967), and others. The derivation of Cowan's additive equation (Equation 2) is based in part on the assumption that velocity, slope, and depth are constant across the flow channel. This assumption restricts the application of Equation 2 to uniform channels or uniform sub-sections, and prevents the use of the equation to determine an average channel resistance coefficient for situations such as over-bank flooding.

2-5 Limerinos(1970) recognized that Manning's base n_0 was not just a function of relative roughness, but varied with depth or hydraulic radius. From the analysis of 11 different streams he formulated Equation 3.

$$n_0 = \frac{.0926 \cdot R^{1/6}}{1.16 + 2 \cdot Log\left(\frac{R}{d_{84}}\right)} \quad (3)$$

Where d_{84} is the bed material size that equals or exceeds 84% of the particle sizes. The limitations of Equation 3 include that the equation can only be applied to a narrow range of natural channels, and that the particle size data must be known. Limerinos' equation does not account for the effects of vegetation.

2-6 Jarrett (1984, 1985) recognized that Manning's *n* varied with hydraulic radius, and stated that Manning's *n* should vary with the slope of the energy grade line. Jarrett did his work analyzing high mountain streams, and derived Equation 4.

$$n_0 = 0.39 \cdot S^{0.38} \cdot R^{-0.16} \quad (4)$$

Jarrett's analysis had an average standard error of 28% for Equation 4, and the equation is limited to stream slopes from .002 to as high as .052. In three of the streams he analyzed, the flow was affected by bank vegetation, which created additional turbulence and resistance. However, he did not include this data in the development of Equation 4, and therefor an additive method similar to the methods presented by Cowan (1956) or Arcement and Schneider (1989), would be needed along with Equation 4 to determine the overall roughness when vegetation is present.

2-7 Abdelsalam et al. (1992) analyzed 4 wide, vegetated canals in Egypt. They modified Manning's equation to provide Equation 5 which then accounted for resistance in wide canals with submerged, grassy, vegetation.

$$V = \frac{1.486}{n} \cdot Y_O^{1.62} \cdot S^{0.5} \tag{5}$$

The limitations associated with this equation are that it only applies to vegetation growing within the main channel, and that the vegetation needs to be submerged. Also, the vegetation is confined to plant types similar to grasses and not to shrubs or woody types of vegetation.

2-8 Recent studies on flow resistance with grasses include the research by Kouwen and Li (1980). Their work provides a means of determining Manning's *n* by comparing grasses to flow tests of artificial plastic strips. They show that grasses behave similarly to artificial plastic strips, and that Manning's *n* (Equation 6) is basically a function of the relative roughness, k/y_n, where k is the deflected roughness height and y_n is the normal depth.

$$n_o = \frac{y_n^{1/6}}{\sqrt{8g\left[a + b \cdot \log\left(\frac{y_n}{k}\right)\right]}} \tag{6}$$

Where, a and b are regression constants dependent on shear velocity and the critical shear velocity. Because there are no experiments with natural vegetation that publish values for the parameter k, Kouwen and Li (1980) have proposed a method utilizing

Equation 7 as a means of determining k based on physical parameters of the vegetation.

$$k = 0.14 \cdot h \cdot \left(\frac{\left(\frac{M\,E\,I}{\gamma\, y_n\, S} \right)^{0.25}}{h} \right)^{1.59} \tag{7}$$

Where E is the modulus of elasticity of the vegetative material in Pascals; I is the second moment of the cross-sectional area of the plant stems in meters to the fourth power; M is the relative density defined as the ratio of the stem count to a reference number of stems per unit area; h is the un-deflected vegetation height; and γ = the weight density of water in Newtons per cubic meter. Their method first assumes a value for the product of MEI and a value for the flow depth of the channel. Then, through an iterative process, MEI is optimized.

2-9 Since this method applies to densely packed grasses, it cannot be directly applied to flood plains where vegetation includes other types of vegetation. It has to be assumed that the above method predicts a base value of resistance, n_o, since the densely spaced grass completely covers the soil or base material. Shrubs and woody vegetation would be much more difficult to model using artificial roughness because the MEI would have to be experimentally determined for each plant species, plant size, and plant spacing. Equation 7 also does not account for the separate effects of velocity and flow depth on any distortion or change in shape of a plant.

2-10 Research by Thompson and Roberson (1976) did include the study of vegetation that deformed or distorted with velocity. They recognized that plants such as shrubs contributed to flow resistance from the flow blockage of the plants, while the channel bottom added to the total resistance from the roughness of the unoccupied channel bed. They also recognized that resistance of plants depends upon the plant size, plant shape, flexibility of the plant, the concentration or spacing of the plants, and the extent of the submergence of the plant. However, their studies were limited to tests with artificial, plastic rods. They included no actual plant data in their analysis, and they also did not publish any definitive equations or methods to determine resistance.

2-11 Ree and Crow (1977) tested actual plants for flow roughness but their work was limited to planted rows of crop types of plants such as wheat, sorghum, and grasses. Their tests were conducted in fields with very small slopes. While they did publish their results as graphical relationships of resistance versus velocity times hydraulic radius (n vs. VR), their test results were essentially independent of energy slope. Their results did show that flow resistance of plants would decrease with increased velocity due to the bending of the plants. Frentyl (1962) also studied a crop type of plant, alfalfa, for shallow flows and noted the decrease of resistance with increased velocity. He attempted to relate resistance to flow parameters and ratios of plant characteristics.

2-12 One of the most recent works on blockage and drag forces was published by Kadlec (1990). His work focuses on determining energy slope for wetland types of plants, especially grassy types of plants, and on wetland flows that are laminar to transitional in Reynold's number. Since his study was limited to fairly low velocities, his analysis was based on flow blockage of rigid plant stems and a small range of shallow flow depths. He did acknowledge that the determination of Manning's resistance coefficient n would require flow data for different depths and would be quite difficult. Kadlec proposed that flow resistance could be based on the summation of drag forces from individual plants.

2-13 Usually the larger vegetation such as shrubs and trees are found in the flood plains adjacent to the main channel. This type of vegetation is a major influence on flow depth and resistance during situations such as over-bank flooding. Since the larger types of vegetation constitute much of the resistance within flood plains, Petryk and Bosmajian (1975) proposed a method to calculate flow resistance based on the drag forces created by the larger plants. They derived Equation 8 for Manning's n by summing the forces in the longitudinal direction. The forces include pressure forces, the gravitational force, shear forces, and the drag forces.

$$n = n_b \cdot \sqrt{1 + \left(\frac{C_d \ \Sigma A_i}{2gA\,L}\right) \cdot \left(\frac{1.486}{n_b}\right)^2 \cdot \left(\frac{A}{P}\right)^{4/3}} \qquad \textbf{(8)}$$

Where n is the total roughness coefficient, n_b is the total boundary roughness, C_d is the effective drag coefficient for the vegetation the direction of the flow, A = the cross-sectional area of the flow, in square feet, ΣA_i = the total frontal area of vegetation blocking the flow in the reach, in square feet, L = the length of the channel reach being considered, in feet, and g = the gravitational constant, in feet per square second.

2-14 The expression $C_d\Sigma A/(AL)$ represents the vegetation blockage, or the density of vegetation in the flood plain. This expression must be either directly or indirectly measured as a total blockage of flow . The total additive base n_b is determined by Cowan's additive method (Equation 2), except that the additive resistance n_4 for other types of vegetation is excluded.

2-15 There are several limitations to using Petryk and Bosmajian's Equation 8. The channel velocity must be small enough to prevent bending or distortion of the shape of the vegetation, and large variations in velocity can not occur across the channel. . Vegetation such as grasses and shrubs are then excluded Vegetation must also be distributed relatively uniformly in the lateral direction. Finally, the flow depth must be less than or equal to the maximum vegetation height (Petryk, 1989). In channels during flooding, the velocities over the flood plains can be relatively high and large degrees of bending and distortion of vegetation will occur. Vegetation can also vary widely across a flood plain, and depths often submerge vegetation. However, when tree trunks dominate sections of a flood plain, this method can be used for predicting the total resistance coefficient.

2-16 Arcement and Schneider (1989) further developed Petryk's method by stating that the portion of the vegetation which cannot be measured directly or calculated as rigid flow blockage, should be included in Cowan's formula as n_V (Equation 9).

$$n_b = n_o + n_1 + n_2 + n_3 + n_V \tag{9}$$

Where, n_V accounts for vegetation , such as shrubs and grass, on the flood plain that cannot be measured directly or calculated as a flow blockage. Equation 8, as defined by Petryk, accounts only for rigid and measurable vegetation such as tree trunks.

2-17 It should then be possible to use Equations 8 and 9 to include the effects of trees, grasses, and shrubs in calculating the total resistance of a vegetated channel. The total base resistance n_b of Equation 9 can be determined from either a base n_o or a grass base resistance (Equation 6). The total resistance n is calculated from correcting the total base resistance n_b for the effects of trees by Equation 8. The additive resistance coefficient n_V in Equation 9 is due to the effects of vegetation such as shrubs and woody vegetation. The main purpose of this study is to develop a data base and methodology to determine n_V.

section 3 FLOW IN COMPOUND FLOOD CHANNELS

3-1 Cowan's additive equation (Equations 2) and the equations to predict resistance from vegetation (Equations 6, 7, 8, 9) are all based on the assumption of constant velocity, energy slope, and flow depth across the channel. Many flood channels such as those with over-bank flooding do not have uniform cross sections with uniform flow resistance. Special considerations must be taken to calculate the flow depths and flow resistance of these compound channels, especially when vegetation is present.

3-2 Chow (1959) and Cowan (1956) have shown that there are many factors which affect the boundary roughness and flow resistance. Even within the main flow section of a compound flood channel, these factors can vary. However, the roughness and flow resistance will significantly vary from subsection to subsection for compound channels with flood plains and over-bank flooding. Main flow channels which have different roughness along sections of the wetted perimeter can be referred to as composite channels. Determining the total discharge for a compound channel that includes a composite main channel can be complicated. Currently, there are two different methods used; a flow conveyance method, and an equivalent flow resistance method.

3-3 The <u>flow conveyance method</u> is a more mathematically rigorous method for compound channels, and has been assumed by most researchers to be the most fundamentally correct and accurate. Masterman and Thorne (1992) apply the law of continuity when they state that the total discharge is equal to the sum of the discharges of the main channel and its flood plains. This is possible when the assumption is made that the flow in all parts or sections of the channel is caused by the same energy grade line, that is, the energy grade line is the same everywhere in the compound channel.

3-4 With the assumption of constant energy slope, the discharge of each section can be solved for iteratively, section by section, and by checking to ensure that the water-surface elevation is the same for each section. The total discharge of the compound flood channel is then the sum of the discharges of each channel section.

3-5 The <u>equivalent resistance method</u> applies Manning's formula to the entire compound flood channel. It is necessary to compute a compound roughness, or an equivalent resistance, for the entire channel. Chow (1959) presented three equations for determining an equivalent resistance. The development of these equations are based on applying a weighting factor to each section of the compound channel and then combining them appropriately.

3-6 All three equations are based on a constant water surface elevation. To determine the equivalent roughness, the total area is subdivided into N parts, of which the wetted perimeters P_1, P_2, ..., P_N and the roughness coefficients n_1, n_2, ..., n_N for each section are known.

3-7 The most widely used equivalent resistance equation is based on the assumption that each section of the total area of the channel has the same mean velocity. The equation was intended for use with composite channels with variable roughness and not for use with compound channels. However, the equation is sometimes used for compound channels even though large errors can occur. Using this assumption, the equivalent roughness may be determined by the following equation:

$$n = \left(\frac{\Sigma \left(P_N \cdot n_N^{1.5} \right)}{\Sigma P_N} \right)^{2/3} \qquad (10)$$

3-8 Dracos and Hardegger (1987) have suggested using this equation for compound flood channel with subsections of fairly low flow resistance and smooth boundaries. Sections with vegetation, typically have rough boundaries and high resistance, and would not be suitable for use with this equation.

3-9 The second equivalent resistance equation presented by Chow for determining an equivalent roughness is based on the assumption that the total force resisting the flow, KV^2PL, is equal to the sum of the forces resisting the flow in each section of the cross section. This equation also uses the assumption that each part of the total area has the same mean velocity.

$$n = \left(\frac{\Sigma \left(P_N \cdot n_N^{2} \right)}{\Sigma P_N} \right)^{1/2} \qquad (11)$$

3-10 The third equation given by Chow for determining an equivalent roughness is based on the assumption that the total discharge of the flow is equal to sum of the discharges for each area within the total area (Lotter, 1933).

$$n = \frac{\left(\Sigma P_N \cdot \Sigma R_N^{5/3}\right)}{\Sigma\left(\frac{P_N \cdot R_N^{5/3}}{n_N}\right)} \tag{12}$$

Where $R_1, R_{2,} \ldots, R_N$ are the hydraulic radii of each section. Equation 12 is actually a flow conveyance equation since the velocity does not have to be constant throughout the cross section.

3-11 The flow conveyance method and Equation 12 will yield the same results for a compound flood channel. The equivalent resistance method and Equations 10 and 11 will yield questionable results for compound channels with vegetation if the assumption of equal velocity is made. It is inherent that the resistance of channel sections with vegetation will be larger than the resistance for the main channel, and will then experience lower velocities than the main channel. The assumption of constant velocity is invalid and the use of the equivalent resistance method is questionable for vegetated flood plains. The difference in results between the two methods will, in part, depend on the magnitude of the resistance of the vegetation.

3-12 Both the flow conveyance method and Equation 12 utilize an iterative solution to solve for the flow depth or total discharge. The advantage of Equations 10 and 11 of the equivalent resistance method is a direct solution for depth or discharge. However, if the flow resistance should vary with velocity and or depth, the solution by either method will become more complicated and iterative. The equations and methods of the previous section on flow resistance were limited to flow sections of uniform resistance and velocity. However, these equations (Equations 1 through 9) can be applied to each individual sub-section of the compound flood channel and used with either the flow conveyance or equivalent flow resistance methods. Additional information on flow resistance and compound flood channels can be found in very comprehensive literature review by Craig Fischenich (1994).

section 4 SEDIMENT TRANSPORT WITH VEGETATION

4-1 It is common knowledge that the presence of vegetation in a channel or flood plain will effect the sediment transport and the scour or erosion of the channel bottom and sides. Vegetation will certainly reinforce and strengthen the soil surfaces through the development of root systems. The effective soil boundary is then more resistant to soil movement and erosion. Vegetation can also impede the movement of the contact portion of the bed load (ASCE 1960), and prevent or stabilize bed forms.

4-2 Another common belief is that the presence of vegetation increases flow resistance and then results in the reduction of flow velocity from increased depth. The reduced velocity will then reduce the sediment transport of the channel and reduce the forces necessary to cause scour and erosion. Li and Shen (1973) have developed the theory to explain how the retarding flow rate is the result of the drag forces on tall vegetation, and developed the methodology to predict the reduction of sediment load.

4-3 The limitations of Li and Shen's (1976) study include the exclusion of the effects of the leaves and branches of vegetation. Also, their investigations only studied cylinders, and relied on the assumption of uniformly distributed bed shear. The development of their theory was based on a horizontal, 2 dimensional flow field around multiple cylinders. Tests of actual vegetation was not available for their study, and the 2 dimensional analysis precluded the consideration of vertical velocity components. The blockage produced by plant leaves and branches could produce vertical velocity components that would then create flow vortices and local scour. Local scour immediately upstream of bridge piers (Richardson, Simons, et al 1975) is a classical example of this type of phenomena. Another effect of the plant foliage would be the formation of a layer or blanket that would divert flow beneath the foliage. Flow diverted beneath the foliage blanket could result in increased velocities along the channel bottom.

section 5 TEST FACILITY

5-1 The Utah Water Research Laboratory is a facility of Utah State University and is the water research center for the state of Utah. The laboratory was built in the late 1960's and has been involved both nationally and internationally in all areas of water engineering. The laboratory serves both the Environmental Engineering Division and the Water Division of the department of Civil Engineering at Utah State University. Over 20 professional faculty and engineers and approximately 60 graduate students are assigned to the Water Division at the laboratory. Part of the Utah Water Research Laboratory is the hydraulic's laboratory. The hydraulic's lab is one of the largest laboratories (outside of WEST) that is available for physical modeling and testing. Over 50,000 square feet of lab space and flows in excess of 150 cfs are available for the different models and flumes in the lab. The lab includes calibration facilities for NBS traceable calibrations of flow meters and velocity meters. Permanent support staff are available for construction and fabrication of the models.

5-2 Two flumes were used for the plant tests of this study. The large flume of the hydraulic's laboratory was used for multiple plant tests. The large flume is a 8 foot wide by 6 foot deep by 500 foot long rectangular flume with a horizontal floor. A sectional flume was constructed from one of the laboratory's 3 foot wide by 3 foot deep return flow channels.

section 6 TEST PLANTS

6-1 There were four different groups of plants tested in the large laboratory flume and ten groups of plants tested in the sectional flume. All of the plants tested were broadleaf deciduous, woody vegetation, and found in most USDA zones. The plants tested in the larger flume were placed in staggered rows along the 50 length of the test section. The spacing selected for the plants was based on the typical spacing (Kadlec 1990) of 1½ to 2 plant diameters for emergent plants The plants tested in the sectional flume were placed in a single row of 4 to 5 plants along the centerline of the flume. A single plant was instrumented for determining drag force in each flume. The test plant in the larger flume was located in the center of the 50 foot by 8 foot test section. The test plant for the sectional flume was the last plant, with 4 plants located upstream.

6-2 With the exception of the plants used to test for drag forces, all of the plants in the large flume were placed intact, with root structure and original soil, into a 8-inch deep test bed of clay. The plants were anchored through the clay by wiring the plant stem to a section of chain link fencing placed flat on the concrete bottom of the flume. The test plants in the section flume and the drag force plant of the larger flume, were cantilevered into test platform and load cell. The roots of the cantilevered plants had to be removed.

6-3 The four plants tested in the large flume were:

1) 20-inch Yellow Twig Dogwood (Cornus stolonifera Flaviramea);
2) 28-inch Berried Elderberry (Sambucus Racemosa);
3) 8-inch Purpleleaf Euonymus (Euonymus Fortunei Colorata);
4) 38-inch Red Twig Dogwood (Cornus Sericea).

6-4 The ten plants tested in the sectional flume were:

1) 20-inch Yellow Twig Dogwood (Cornus Stolonifera Flaviramea);
2) 8-inch Purpleleaf Euonymus (Euonymus Fortunei Colorata);
3) 22-inch Arctic Blue Willow (Salix Purpurea Nana)
4) 28-inch Maple (Acer Platenoides)
5) 32-inch Common Privet (Ligustrum Vulgare)
6) 21-inch Blue Elderberry (Sambucus Canadensis)
7) 36-inch French Pink Pussywillow (Salix Caprea Pendula)
8) 36-inch Sycamore (Platenus Acer Ifolia)
9) 29-inch Western Sand Cherry (Prunis Besseyi)
10) 30-inch Staghorn Sumac (Rhus Typhina)

6-5 Table 1 and Figure 1 show the plant heights, spacings, and numbers of plants tested in the large flume tests. Table 2 and Figure 2 show the average dimensions and plant characteristics of the plants tested in the large flume. Table 3 shows the average dimensions and characteristics of the plants tested in the sectional flume. The range of heights of individual plants varied from the average height characteristics in Table 3 with a variation of 3 inches, the plant widths varied by 4 inches, and the diameters of the stems varied by one sixteenth of an inch.

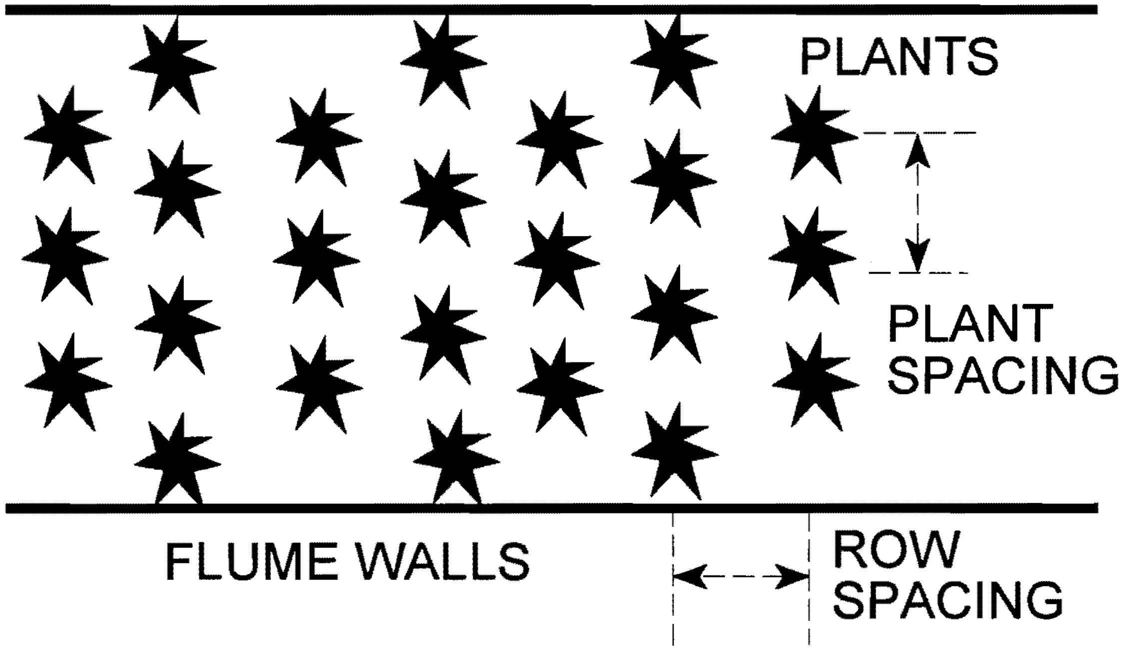


Figure 1 Large Flume Test Plant Spacings

Table 1 Large Flume Test Plant Heights, Numbers, and Spacing

PLANT Plant/Runs	PLANT HEIGHT	ROW SPACING	PLANT DENSITY	NO. OF PLANTS
Dogwood Runs 1-1 to 1-9	20"	16"	.4983 / ft^2	192
Dogwood Runs 2-1 to 2-4	20"	25"	.2215 / ft^2	96
Elderberry Runs 3-1 to 3-10	28"	18"	.2500 / ft^2	117
Euonymus Runs 4-1 to 4-7	8"	10"	1.190 /ft^2	480
Euonymus Runs 5-1 to 5-3	8"	16"	.5289 / ft^2	280
Dogwood Runs 6-1 to 6-8	38"	36"	.1111 / ft^2	45
Dogwood Runs 7-1 to 7-2	38"	54"	.0494 / ft^2	23

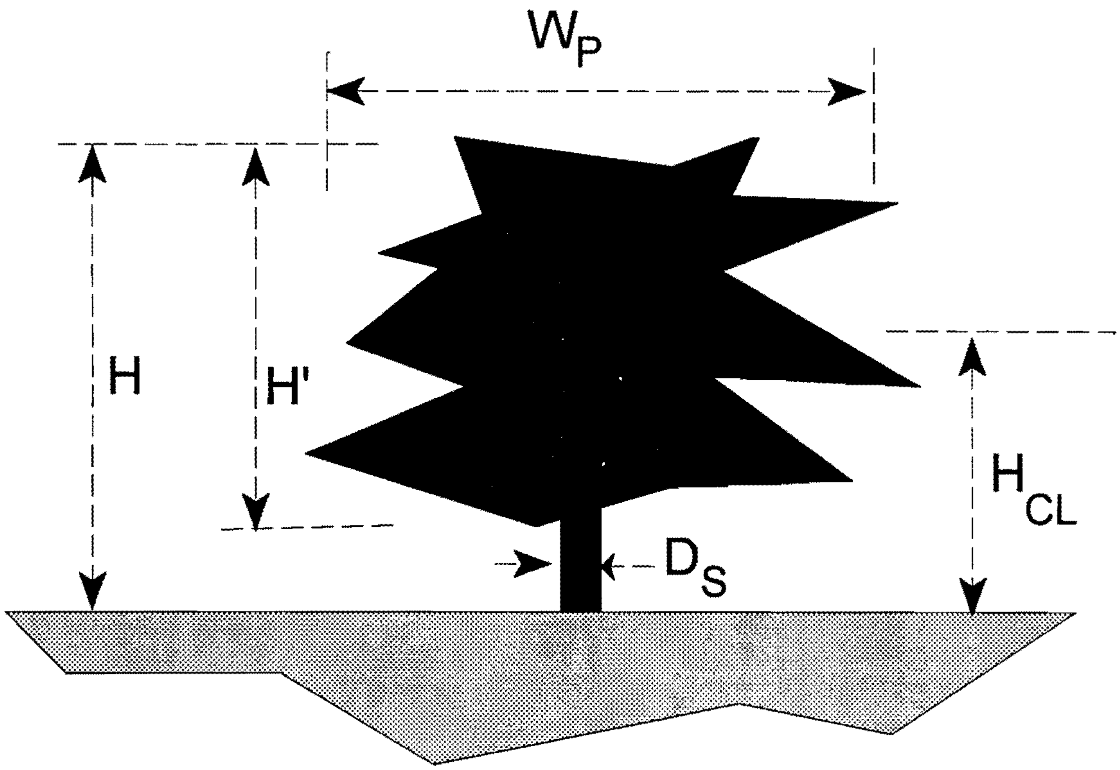


Figure 2 Dimensions and Characteristics of Plants in Large Flume

Table 2 Dimensions and Characteristics of Plants in Large Flume

Plant/Runs	H	W_P	D_S	H'	H_{CL}	NO. OF BRANCHES	NO. OF LEAVES	LEAF SIZE
Dogwood	20"	9"	3/8" one stem	13"	12"	6	50	3" long ½" w
Dogwood	20"	9"	3/8" one stem	13"	12"	6	50	3" long ½" w
Elderberry	28"	14"	3/8" one stem	20"	14"	5	40	2" long 1" w
Euonymus	8"	10"	1/4" two stems	8"	4"	9	90	2" long ½" w
Euonymus Runs 5-1 to 5-3	8"	10"	1/4" two stems	8"	4"	9	90	2" long ½" w
Dogwood Runs 6-1 to 6-8	38"	26"	1" two stems	30"	17"	8	160	3" long 1.5" w
Dogwood Runs 7-1 to 7-2	38"	26"	1" two stems	30"	17"	8	160	3" long 1.5" w

Table 3 Dimensions and Characteristics of Plants in Sectional Flume

Plant/Runs	H	W_P	D_S	H'	H_{CL}	NO. OF BRANCHES	NO. OF LEAVES	LEAF SIZE
Dogwood	20"	9"	3/8"	13"	12"	6	50	3" long ½" w
Euonymus	8"	10"	1/4" 2ea.	8"	4"	9	90	2" long ½" w
Arctic Blue Willow	22"	12"	½"	20"	24"	5	140	2" long ½" w
Norway Maple	28"	12"	½"	12"	24"	5	140	2" long ½" w
Common Privet	32"	10"	½"	27"	16"	6	275	1.3 " l 3/8" w
Blue Elderberry	21"	18"	1"	16"	12"	3	175	2.5" l 3/4" w
Pink Pussywillow	36"	10"	3/4"	10"	20"	4	90	1.5" l ½" w
Sycamore	36"	8"	0.4"	33"	19"	3	23	6" long 6" w
Western Sand Cherry	29"	6"	1/3"	20"	19"	7	100	2" long 1" w
Staghorn Sumac	30"	10"	½"	12"	24"	12	140	2" long ½" w

section 7 LARGE FLUME (RESISTANCE) TEST SETUP

7-1 The concrete floor under the test section of the large flume (Figure 3) was covered with a layer of chain link fence which extended across the width of the channel and along 90 feet of the flume. The fencing was necessary so that each individual plant could be anchored, by wire, to prevent their removal by the force of flowing water. The upstream end of the fencing was attached to a beam fixed to the bottom of the flume. The fence also helped stabilize the test bed and prevent lateral movement of the test bed during testing. A clay bed approximately 8 inches deep was placed and compacted in place on top of the chain link fence. Finally, a one inch layer of topsoil was laid and compacted in place on top of the clay. A 4 inch diameter drain pipe was buried along one side of the clay and soil bed to drain water from the test bed during periods between test series. The test section was located in the large flume so that the 24 foot view section of the flumes west wall was adjacent to the downstream reach of the test section.

7-2 The test reach was a length of 50 feet of the clay and soil bed, and was preceded by a 30 foot length of approach bed. Cement blocks were placed on the approach bed to create a turbulent layer and to establish a fully developed velocity distribution before the test reach. To ensure that the blocks created the necessary velocity distribution, tests were conducted with velocity profiles at different locations to verify the spacing of the cinder blocks. The remaining 10 feet of the clay and soil bed was placed at the end of the test section.

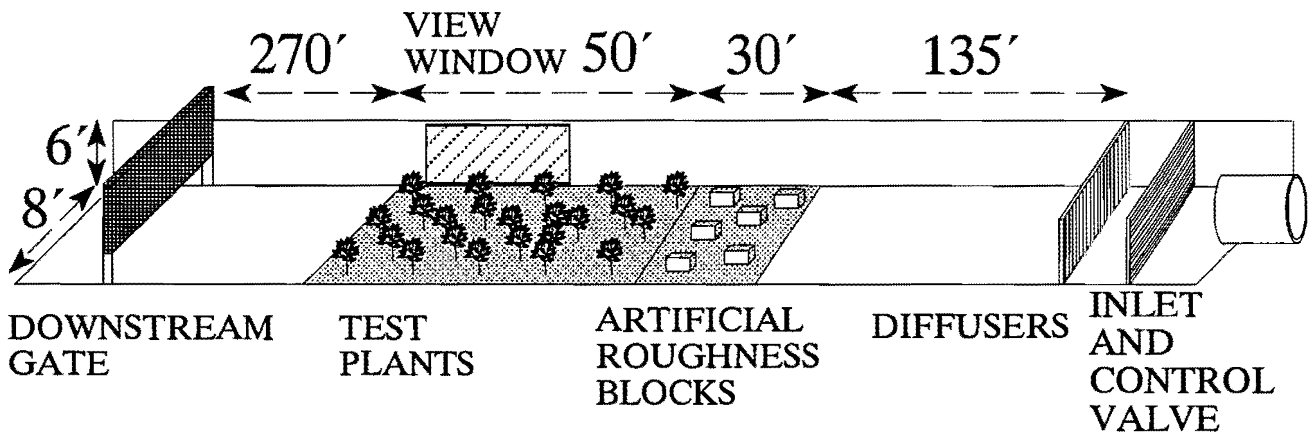


Figure 3 Sketch of the Large Test Flume

7-3 At the downstream end of the clay bed, stop logs were inserted into the flume and removed as necessary to slowly fill the flume. This was done to prevent the test plants during filling. It was found that several layers of stop logs had to be left in during testing, especially with low water depths, to maintain a constant velocity profile throughout the test section. At downstream end of the flume, 300 feet downstream of the test section, a hydraulic gate was used to control flow depth.

7-4 Water entered the upstream end of the flume, 165 feet upstream of the test section, from a 48 inch diameter pipe. A remote controlled butterfly valve in the 48 inch pipeline was used to control the flow rate. A Mapco sonic meter was used to measure the flow rate in the 48 inch pipeline. A series of vertical and horizontal distribution vanes were placed downstream of the 48 inch inlet pipe to dissipate the jet from the pipe exit.

7-5 To take depth and velocity measurements, a wheeled platfrom that moved on tracks adjacent to the flume sides, was positioned at 5 foot intervals of length to facilitate measurements. Water surface elevations were measured with the help of a stationary transit and a measuring rod. Flow velocities were taken with a Marsh Mcbirney Model 201 Portable Water Current Meter. Depth and water surface elevations were taken along the centerline of the flume. Velocity measurements were made at depth intervals of 3 inches and at stations #5, #25, and #45. Station #0 was the upstream end of the test section, station #25 was at the middle of the test section, and station #50 was at the downstream end of the 50 foot long test section.

7-6 A single plant, in the centerline of the flume and at station #25, was selected as the test plant to determine drag force. An average sized test plant was selected and inserted into a platform to measure drag force. The test platform was a shallow metal box with ball bearings in the bottom and a metal plate resting upon the ball bearings. The test plant, with its roots removed, was attached and cantilevered from the plate. A load cell was then attached to the tail end of the plate to measure the drag force on the plant, as a compression force. Using a Vishay Instrument Model P-350 Strain Indicator, the drag force produced by the individual test plant was then able to be determined. The platform was covered with a section of drain cloth to prevent soil from interfering with the ball bearings and movement of the plate. Elastic bands were used to position the plate within the platform's shallow box. The strain gage was zeroed at the start of each series of runs, and the sensitivity of the strain gage was 200 micro-inches per inch per pound. Measurements were taken to the nearest micro-inch. The following section 9 of this report explains the mounting of the test plant in detail.

section 8 PROCEDURES FOR RESISTANCE TESTS

8-1 Prior to beginning each series of tests, the test bed was leveled and a layer of topsoil placed and compacted on top of the clay bed. The test plants were then placed in the test flume just prior to testing. The flume was slowly filled with water with the stop logs in place and the downstream gate closed. With the flume filled and no flow, the strain gage for drag force was zeroed. Flow and depth were controlled with the downstream gate and the 48 inch inlet butterfly valve. Time was allowed for the flume to reach equilibrium before beginning each test run.

8-2 Typically, nine test runs were made for each test series. The first three runs were made at high depths, with the flume nearly full, and at three different velocities. The next three runs were made at a medium depth, and the last three runs were made at a low depth. The test plants were submerged, even at low depths, because the flow forces were adequate to bend the plants with the flow.

8-3 The first measurements taken for each test were the water surface elevations at 5 foot intervals along the centerline of the test section. Velocity measurements were taken next. Velocity measurements were taken at 3 inch intervals of depth at stations #5, #25, and #45. The local velocity at the plant (plant approach velocity) was measured 2 inches upstream of the leaf mass of the test plant used to measure drag force. The plant approach velocity was measured 2 inches upstream of the test plant to avoid making a measurement in a possible stagnation region of the upstream face of the plant. Measurements taken in the plant mass and at the upstream face of the plant were inconclusive because of the interference of individual leaves, but the measurements did show that there was still substantial velocity and flow through the plant mass and through the stagnation region. The strain on the load cell was measured for each test run. As the depths and velocities were varied, the test plants and soil were observed through the view window for soil movement, plant distortion, and plant failure.

8-4 The procedure to calculate the Manning's coefficient *n* for the plant resistance, involved an initial estimate of a total Manning's roughness coefficient to best fit the gradually varied backwater curve of water surface elevations along the test section. The gradually varied backwater curve was the result of the energy loss due to the flow resistance of the vegetation and the roughness of the test bed and flume walls. Equation 13 was the equation used to fit the backwater curve.

$$\frac{dy}{dx} = \left(\frac{S_o - S_f}{1 - Fr^2} \right) \tag{13}$$

Where dy/dx is the unit change in slope of the water surface; S_o is the slope of the bed; S_f is the slope of the energy line; and F_r is the Froude number. S_f is calculated from the Manning's equation (Equation 1) for the estimate of Manning's *n*, the mean velocity V calculated from continuity, and the hydraulic radius R. The Froude number was calculated from Equation 14.

$$F_r = \frac{V}{\sqrt{g \cdot R}} \tag{14}$$

The total Manning's *n* was then iteratively solved using a trial and error process until the shape of the backwater curve predicted by Equation 13 was the same as the measured curve of the actual water surface. Figure 4 is an example of the backwater curve fit for test run 1-7 with a total Manning's *n* of 0.048.

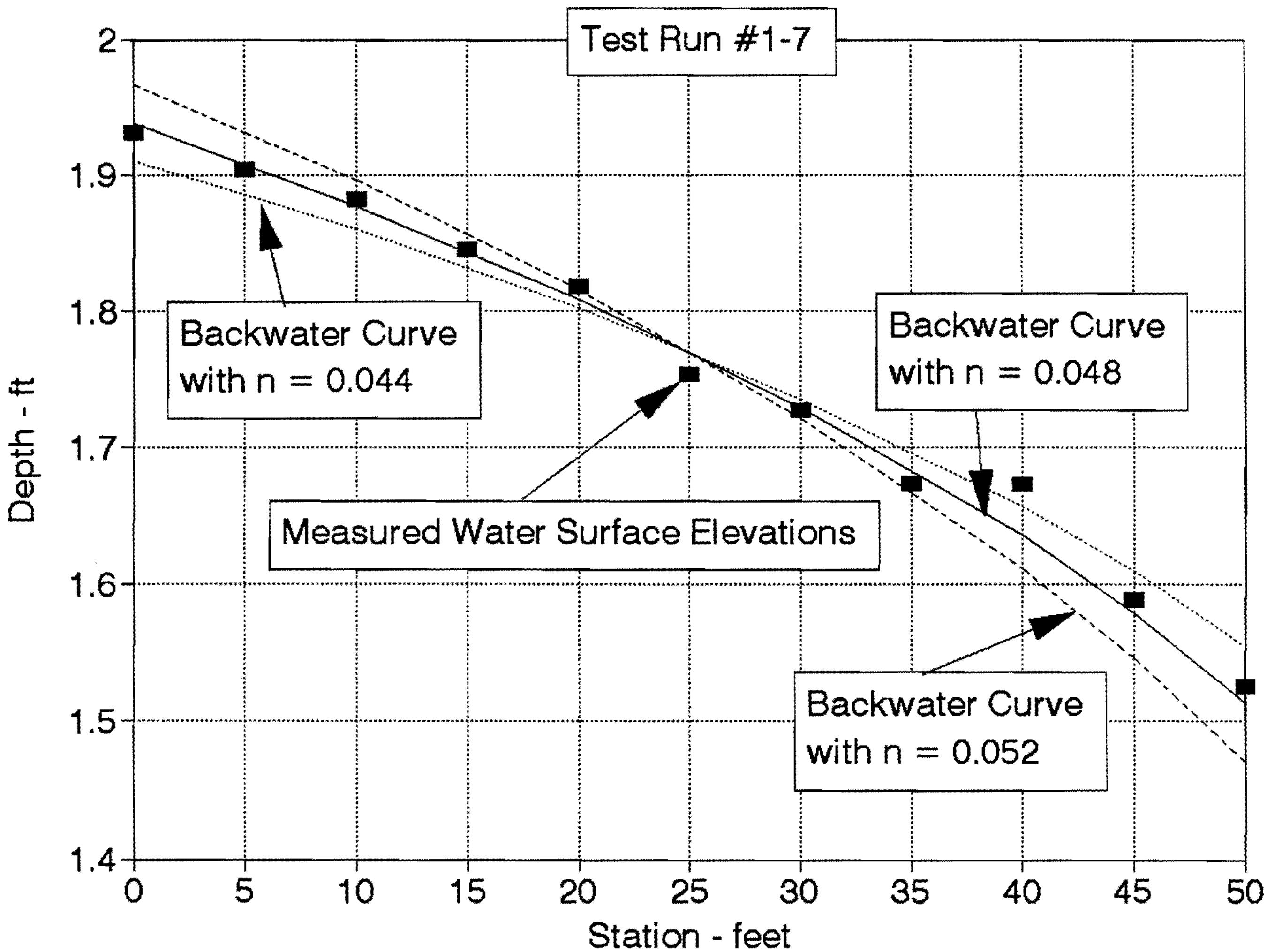


Figure 4 Example of the Fit of Backwater Curve to Deterimine n

8-5 From the total Manning's n, the value of n for the bed roughness and plant resistance was determined. This was done through a number of steps. First, the total n was converted to a Darcy-Weisbach friction factor, f, by Equation 15.

$$f^2 = \frac{n\sqrt{8g}}{1.486 \cdot R^{1/6}} \tag{15}$$

The coefficient of friction for the bed and plants, f_b, was determined using a correction for the effects of the flume walls and an assumption that the channel was rectangular. The coefficient of friction for the walls, f_w, was determined from Equation 16 regressed for this study to fit the correction figure presented in the ASCE Sedimentation Engineering Manual (1977).

$$f_w = 0.274367\left(\frac{Re}{f}\right)^{-0.175092} \tag{16}$$

Where Re is the Reynold's number. Equation 16 was a power fit regression with an r^2 of .9998. The friction factor for the bed, f_b, was then calculated with Equation 17.

$$f_b = f + \frac{2Y_o}{b}\left(f - f_w\right) \tag{17}$$

Where, b is the width of the channel, and Y_o is the flow depth. Manning's resistance coefficient for the bed roughness and plant resistance was calculated from the hydraulic radius R_b determined by Equation 18.

$$\frac{R_b}{f_b} = \frac{R_w}{f_w} = \frac{R}{f} \tag{18}$$

Where R_b is the hydraulic radius for the bed and plants; R_w is the hydraulic radius for the walls; and R is the gross hydraulic radius. Equations 17 and 18 are from the ASCE Sedimentation Engineering manual (1977) on side wall corrections. Finally, the Manning's coefficient n_b for the bed roughness and vegetation was converted from R_b from the Manning's equation (Equation 1).

8-6 The coefficient n_b is the resistance of both the bed roughness and the vegetation. Equation 19 was used to calculate the resistance coefficient n_{veg} for the net resistance of the vegetation.

$$n_{veg} = n_b - n_{base} \tag{19}$$

Where, n_{veg} is the Manning's coefficient for vegetation; n_b is the bed and vegetation resistance; and n_{base} is the base value of only the bed roughness. The value for n_{base} was determined by testing only the soil and clay base.

section 9 SECTIONAL FLUME (DRAG FORCE) TEST SETUP

9-1 A smaller sectional flume was used to study the drag forces developed on single plants. The tests were carried out in a horizontal 3 foot wide by 3 foot high smooth sided steel flume. To produce higher velocities, a false plywood wall was built in the flume, narrowing the width to 18 inches. Water was supplied by a 3 ft. by 3 ft. channel running perpendicular to the flume entrance. A baffle was placed at the entrance of the flume to straighten the incoming flow. A plexiglass observation window was also installed in the side of the flume.

9-2 Since the bottom of the flume consisted of smooth steel, it was necessary to devise a method by which to attach the plants. This was accomplished by building a 1 ½ in. thick false deck out of smooth, painted plywood. The deck was bolted through the bottom of the flume and sealed with silicon caulk. Several one inch holes were drilled through the plywood to the steel bottom. These holes were placed upstream of the test plant. They were designed to hold plants which would create a flow regime around the test plant similar to that of the test plant used in the large flume testing.

9-3 To attach the plants to the bottom, a beveled rubber grommet and wide flanged washers were used. The roots of the plants were cut of at the base of the stem, and then the stem was inserted through the washer and into the grommet. The rubber grommet was used to protect the base of the stem. When the plant was inserted into the grommet and the grommet was compressed, the grommet acted as a cantilevered connection (see Figure 5). Without the grommet, the plant tended to break at the base when subjected to high velocities. The rubber would give a slight bit, thus allowing the plant to bend a small amount at the base rather than shear off against the sharp edges of the plywood floor. This is similar to the conditions that the plant experiences in the field with soil around its base. The wide flanged washers had two holes which allowed the grommet to be attached to the plywood floor with the use of screws. Since the beveled grommet was slightly larger than the holes, the screws had to draw the grommet down into the hole, compressing the rubber.

9-4 The test plant used to measure drag force had the same rubber grommet method, but was attached to a smooth aluminum plate (Figure 5) rather than the plywood floor. The plate was 6 inches wide by 12 inches long and 1 in. thick. The plate provided a platform by which to measure the drag force produced on the plant. A hole was drilled into the plate and a shorter grommet had to be used because the plate was not as thick as the false deck. The plant was inserted through the washer and the grommet then screwed to the plate in the same method as the other plants.

9-5 To assimilate the plate into the deck, a 6 ½ in. by 12 ½ in. rectangle was cut in the center of the floor along the centerline of the flume. Since the floor was 1 ½ in. thick, ½ in. diameter ball bearings were placed directly on the smooth steel floor where the plywood was removed. This allowed the plate to move smoothly on the steel deck and it also raised the top of the plate up to 1 ½ in. so it was exactly flush with the rest of the floor. This prevented the water from striking the face of the plate and adding to the measured drag force.

9-6 The strain gauge (0 to 10 pound range) used to measure drag force was the same gauge used in the large flume tests. The strain gauge was placed and centered directly behind the aluminum plate to measure the drag force as compression on the gauge. While the gauge was a commercially available and waterproof model, the gauge and connections were still sealed in waterproof bags.

The strain gauge was temperature compensating and always zeroed in place and under water. The calibration of the gauge was checked before each test series.

9-7 Elastic bands were was attached to both the plate and the plywood floor immediately downstream and to the sides of the plate. This held the plate firmly in contact with the strain gauge and centered in the floor cavity. A sketch of this setup is shown in Figure 5.

9-8 Velocity measurements were made from a propeller type Ott Velocity Meter. Velocity measurements were taken just upstream of the test plant used to measure drag force. Measurements were taken at different depths, and the plant velocity was taken at the depth of the center of the leaf mass.

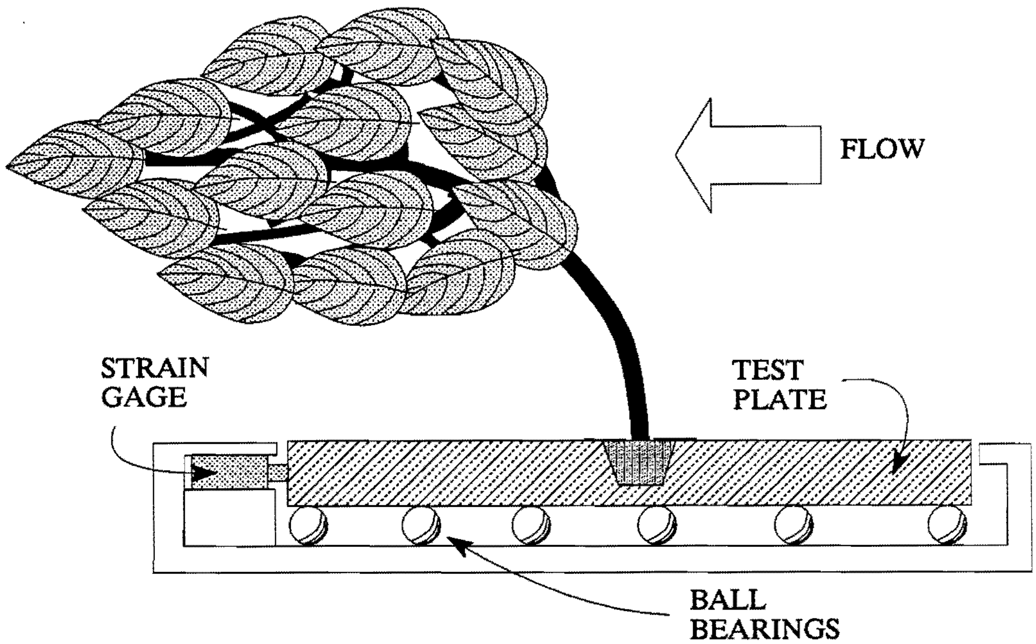


Figure 5 Test Setup for Determining Plant Drag Force

section 10 PROCEDURES FOR DRAG FORCE TESTS

10-1 Before each test series, measurements were made of plant dimensions and plant characteristics. Plant height, width, leaf size and stem height were measured, and the number of branches, stems and leaves were counted. The diameter of stems and branches was recorded, and the bending characteristics were also measured. The forces required to bend the plant 45 degrees and horizontal were determined. The strain gauge was first attached to the top of the plant. After the bending forces and deflection were determined there, the gauge was hooked to the center of the plant and the bending forces were again measured.

10-2 The roots of the test plant were then removed and the plant was attached to the aluminum plate. When the plate was in place, stop-logs were placed at the downstream end of the flume. The logs were placed to a height of 3 ft. This allowed the flume to be completely filled and the strain gauge set to zero to compensate for any buoyancy effects.

10-3 The intent of the test plan was to make almost all of the tests with the plants completely submerged. Because some plants did not bend very far enough to completely submerge at the highest velocities and lowest flow depths, it was necessary to use stop logs to provide downstream control of the depth. When used, they were evenly spaced so that a uniform velocity profile occurred.

10-4 Each plant was subjected to a series of 10 runs. Each run was at an increasing velocity, ranging from approximately 0.25 to 8 ft/sec. During each run, the velocity directly upstream of the plant and the compression on the strain gauge were recorded. This velocity was taken at the centerline of the effective leaf area. As velocity increased, the velocity probe was lowered to compensate for plant bending. This insured that the velocity of each run was being recorded at the centerline. The angle that the plant deflected was determined from marks drawn on the sidewall of the flume. Video tapes were taken to allow for more detailed observation of the plants at a later time.

10-5 After the plant was subjected to 10 different velocities, all of the leaves were removed. The plant was then immediately subjected to 10 more runs. Velocity, drag and deflection data were recorded in the same fashion.

section 11 RESULTS FOR THE RESISTANCE TESTS

11-1 There were eight different test series completed in the large flume using different plants types, plant heights, and plant spacings. The first series was performed on only the bed, without vegetation, to determine the bed roughness. A Manning's n (corrected for wall effects) of approximately 0.02 was found for the soil bed. Tables 1 and 2 list the test series with the plant dimensions and plant spacings. The second and third series were performed using Yellow Twig Dogwood plants, and for the third series, 50% of the Dogwoods were removed in a uniform manner. The fourth series utilized Elderberry plants. Euonymus plants were used for the fifth series and sixth series, and 45% of the Euonymus plants were removed for the sixth series. The seventh and eighth series were completed using larger Red Twig Dogwoods, and the eighth series used the same Red Twig Dogwoods thinned to 50%.

11-2 The following tables (Table 4) summarize the test results and calculations of the 8 series of tests completed in the large flume. The data sheets and backwater curve fits for each test run are in Appendix A.

11-3 Table 4 shows that Manning's n_{veg} varied with plant type, size, and spacing. The range of Manning's n_{veg} for the resistance of vegetation was from 0.02 to 0.13. Figure 6 shows that Manning's n_{veg} was not constant with flow characteristics and varied with the hydraulic radius. Figure 7 shows a more linear relationship of Manning's n_{veg} with the parameter RS. Figure 8 shows a definite linear relationship of Manning's n_{veg} with average channel velocity. Figures 7 and 8 show that Manning's n_{veg} decreased with increased RS or velocity.

11-4 Table 4 also shows the tabulated values for the measured drag force on the test plants in the large flume. The tables show a definite relationship between Manning's n_{veg} and the drag force, and a relationship between the bed shear stress $\tau_o = \gamma RS$.

11-5 Figure 9 is an example of the velocity profile measured for test run 6-3. The profile demonstrates the effect of the leaf mass on the velocities. The plant approach velocity is the velocity that occurred upstream at the centerline of the leaf mass of the plant. It is important to note that the velocity significantly increases below the leaf mass. The mean velocity calculated from continuity was about the same as would be predicted using the Einstein-Prantl velocity profile equation with a roughness height equal to the height of the plant. The velocity profiles also indicate the possibility of using a linear relationship of the surface velocity to plant height to estimate the plant approach velocity.

11-6 The test runs were both video taped and photographed. It was obvious that the flow resistance was influenced by the flow blockage and roughness of the leaf mass of the shrubs. A very important observation was that the plant easily bent with the flow, and the leaf mass trailed downstream forming a streamlined, almost teardrop shaped, profile. The leaf mass changed with velocity and became more streamlined with increased velocity. This observation confirms the decreasing trend of Manning's n_{veg} with velocity in Figure 8. It was obvious that the shrub's leaf mass can not be considered a rigid area of blockage.

11-7 Average channel velocities from 3 to 4 fps were necessary to cause either the leaves to pull off of the plants or for the stems to break. Table 4 lists the observed velocity limits. The velocities were much greater than expected. It should also be noted that the velocities required to break stems and leaves, also caused significant movement of bed material. It is likely that some, if not all, of the leaf and stem failures may have been due to impact of large bed material, i.e. gravel, that was being transported by the flow.

11-8 One of the most significant observations was that the layer of plant foliage diverted flow beneath the plants. Velocities beneath the plants were measured at levels approaching surface velocities. Measurable scour was observed beneath the plants, and even the clay bed was eroded. The velocities were sufficient to transport and move the largest sizes of gravel.

11-9 The Euonymus plants were a ground cover type of plant, with leaves extending to the soil bed. However, with the typical spacings of the plants, there were areas of channel bottom directly exposed to flow. Measurable scour was observed in these open areas between plants for all of the tests. The test series had to be stopped for the Euonymus plants, when it was observed that the plant's root systems were failing. Local scour of the roots and bed directly upstream of the plant stems caused the removal of the bed material anchoring the plants. Only the wires attached to the plant stems kept the plants from washing downstream. Observations showed that local scour was occurring from 3 dimensional flow vortices in front of the plant stems. The vortices appeared to be similar to those reported in the literature for bridge pier scour.

Table 4 Summary of Large Flume (Resistance) Test Results

Run	Yo ft	avg V fps	n flume	Fd lbs	R flume	Sf	R net	n net	C net
Runs 1-1 to 1-9 were with 192 Dogwood plants on 16-inch centers and 17" spacing between rows.									
1-1	4.17	1.20	0.046	0.250	2.042	0.0005	3.956	0.0715	26.14
1-2	4.12	2.00	0.042	0.300	2.030	0.0012	3.896	0.0649	28.73
1-3	3.68	2.46	0.040	0.375	1.917	0.0018	3.484	0.0596	30.71
1-4	3.09	1.58	0.047	0.375	1.743	0.0012	2.967	0.0670	26.59
1-5	3.35	1.93	0.043	0.375	1.823	0.0014	3.194	0.0625	28.86
1-6	3.44	2.26	0.040	0.500	1.849	0.0016	3.261	0.0584	31.00
1-7	1.76	2.88	0.045	0.775	1.222	0.0058	1.714	0.0564	28.83
1-8	2.35	3.25	0.041	0.875	1.480	0.0048	2.264	0.0544	31.29
1-9	2.91	3.58	0.038	0.750	1.685	0.0042	2.773	0.0530	33.25
Runs 2-1 to 2-4 were with 50 % of Dogwood plants removed in a uniform pattern.									
2-1	4.45	2.51	0.031	0.275	2.107	0.0010	4.051	0.0479	39.14
2-2	3.77	3.03	0.031	1.075	1.941	0.0017	3.471	0.0457	40.03
2-3	1.69	3.47	0.040	0.875	1.188	0.0069	1.640	0.0496	32.54
2-4	1.3	2.46	0.042	1.075	0.981	0.0050	1.269	0.0499	31.01
Runs 3-1 to 3-10 26" to 30" Elderberry, 18" centers and 24" rows									
3-1	3.96	0.96	0.042		1.990	0.0003	3.720	0.0637	29.02
3-2	3.23	1.57	0.035		1.785	0.0006	3.011	0.0496	36.01
3-3	3.49	1.93	0.034		1.864	0.0009	3.244	0.0492	36.75
3-4	3.13	1.00	0.045	0.450	1.754	0.0004	2.979	0.0641	27.83
3-5	2.32	1.70	0.040	0.550	1.467	0.0013	2.219	0.0527	32.20
3-6	2.57	2.01	0.033		1.563	0.0011	2.410	0.0440	39.07
3-7	2.79	2.27	0.032	0.650	1.643	0.0012	2.603	0.0435	40.07
3-8	2.68	2.52	0.033	1.200	1.603	0.0017	2.516	0.0446	38.89
3-9	2.45	2.83	0.031	0.895	1.521	0.0020	2.303	0.0409	41.77
3-10	3.002	3.102	0.030		1.715	0.0019	2.784	0.0414	42.54

Table 4 Summary of Large Flume (Resistance) Test Results

Run	Yo ft	avg V fps	n flume	Fd lbs	R flume	Sf	R net	n net	C net
Runs 4-1 to 4-7 with 8" Euonymus, 10" CENTERS and 11" rows (480 plants)									
4-1	3.878	1.048	0.045	0.05	1.969	0.0004	3.675	0.0682	27.06
4-2	3.921	1.377	0.04	0.06	1.980	0.0006	3.681	0.0605	30.53
4-3	3.673	2.195	0.038	0.12	1.915	0.0016	3.456	0.0563	29.62
4-4	2.762	2.172	0.045	0.15	1.634	0.0022	2.658	0.0622	28.10
4-5	2.911	2.512	0.042	0.16	1.685	0.0025	2.787	0.0587	30.01
4-6	2.563	3.195	0.041	0.25	1.562	0.00429	2.463	0.0555	31.09
4-7	1.61	2.679	0.042	0.25	1.148	0.0048	1.566	0.0517	31.00
Runs 5-1 to 5-3 with 8" Euonymus, 10" CENTERS and 11" rows 45% removed (280 plants)									
5-1	3.385	1.348	0.038	0.09	1.833	0.0005	3.177	0.0548	32.86
5-2	3.394	2.074	0.035	0.15	1.836	0.0011	3.172	0.0504	35.74
5-3	2.32	3.158	0.035	0.15	1.468	0.0033	2.210	0.0460	36.90
Runs 6-1 to 6-8 were with 36"to 40" Dogwoods on 3' centers and 3'rows (45 plants), plants subm									
6-1	4.143	1.059	0.075	2.55	2.035	0.0011	4.046	0.1186	15.82
6-2	4.145	1.574	0.07	3.40	2.036	0.0021	4.044	0.1106	16.96
6-3	4.253	2.004	0.062	5.80	2.061	0.0027	4.130	0.0985	19.10
Runs 6-4 to 6-6 were with water surface at top of plant									
6-4	3.085	1.139	0.085	2.30	1.742	0.0020	3.036	0.1231	14.52
6-5	2.472	2.007	0.07	6.15	1.528	0.0051	2.430	0.0954	18.07
6-6	2.719	3.127	0.05		1.619	0.0058	2.639	0.0693	25.22
Run 6-7 with plants half submerged									
6-7	1.776	2.224	0.07	8.30	1.230	0.0083	1.753	0.0886	18.41
6-8	3.067	3.154	0.05	7.10	1.736	0.0054	2.970	0.0715	24.91
Runs 7-1 to 7-2 were with 36"to 40" Dogwoods on 3' centers and 3'rows thinned by 50% (23 plant									
7-1	3.885	1.142	0.07	3.18	1.971	0.0012	3.788	0.1082	17.15
Run 7-2 was with water surface at top of plant									
7-2	2.685	1.653	0.07	8.60	1.607	0.0032	2.635	0.0973	17.94

Table 4 Summary of Large Flume (Resistance) Test Results

Run	Yo ft	avg V fps	R veg.	n veg.	C veg.	YRS	plant density	plant V fps	V/V*	Reynolds
Runs 1-1 to 1-9 were with 192 Dogwood plants on 16-inch centers and 17" spacing between rows.										
1-1	4.17	1.20	2.408	0.051	33.50	0.132	0.4983	0.70	2.408	1.36E+06
1-2	4.12	2.00	2.233	0.045	37.96	0.302	0.4983	1.30	4.014	2.23E+06
1-3	3.68	2.46	1.879	0.040	41.82	0.400	0.4983	1.80	4.937	2.45E+06
1-4	3.09	1.58	1.736	0.047	34.76	0.220	0.4983	1.20	3.171	1.34E+06
1-5	3.35	1.93	1.783	0.042	38.62	0.279	0.4983	1.20	3.873	1.76E+06
1-6	3.44	2.26	1.731	0.038	42.54	0.332	0.4983	1.80	4.536	2.11E+06
1-7	1.76	2.88	0.885	0.036	40.13	0.623	0.4983	3.00	5.780	1.41E+06
1-8	2.35	3.25	1.134	0.034	44.20	0.673	0.4983	3.20	6.523	2.10E+06
1-9	2.91	3.58	1.356	0.033	47.54	0.724	0.4983	3.00	7.185	2.84E+06
Runs 2-1 to 2-4 were with 50 % of Dogwood plants removed in a uniform pattern.										
2-1	4.45	2.51	1.795	0.028	58.79	0.257	0.2215	2.50	11.334	2.91E+06
2-2	3.77	3.03	1.457	0.026	61.79	0.357	0.2215	2.90	13.682	3.00E+06
2-3	1.69	3.47	0.753	0.030	48.03	0.710	0.2215	4.40	15.669	1.63E+06
2-4	1.30	2.46	0.586	0.030	45.63	0.393	0.2215	3.20	11.108	8.92E+05
Runs 3-1 to 3-10 26" to 30" Elderberry, 18" centers and 24" rows										
3-1	3.96	0.96	2.106	0.044	38.57	0.069	0.2500	0.60	3.852	1.02E+06
3-2	3.23	1.57	1.382	0.030	53.15	0.119	0.2500	1.20	6.280	1.35E+06
3-3	3.49	1.93	1.477	0.029	54.46	0.173	0.2500		7.736	1.79E+06
3-4	3.13	1.00	1.692	0.044	36.92	0.080	0.2500	0.60	3.984	8.48E+05
3-5	2.32	1.70	1.080	0.033	46.15	0.174	0.2500	1.80	6.796	1.08E+06
3-6	2.57	2.01	0.968	0.024	61.64	0.166	0.2500	1.50	8.052	1.39E+06
3-7	2.79	2.27	1.030	0.024	63.71	0.200	0.2500	2.00	9.080	1.69E+06
3-8	2.68	2.52	1.025	0.025	60.92	0.262	0.2500	2.40	10.088	1.81E+06
3-9	2.45	2.83	0.837	0.021	69.28	0.286	0.2500	2.60	11.308	1.86E+06
3-10	3.00	3.10	1.031	0.021	69.88	0.332	0.2500	2.50	12.408	2.47E+06

Table 4 Summary of Large Flume (Resistance) Test Results

Run	Yo ft	avg V fps	R veg.	n veg.	C veg.	YRS	plant density	plant V fps	V/V*	Reynolds
Runs 4-1 to 4-7 with 8" Euonymus, 10" CENTERS and 11" rows (480 plants)										
4-1	3.88	1.05	2.175	0.048	35.18	0.094	1.1901	0.40	0.881	1.10E+06
4-2	3.92	1.38	2.008	0.040	41.34	0.127	1.1901	0.40	1.157	1.45E+06
4-3	3.67	2.20	1.556	0.036	44.15	0.343	1.1901	0.70	1.844	2.17E+06
4-4	2.76	2.17	1.480	0.042	37.65	0.373	1.1901	0.90	1.825	1.65E+06
4-5	2.91	2.51	1.487	0.039	41.08	0.437	1.1901	1.60	2.111	2.00E+06
4-6	2.56	3.20	1.256	0.036	43.54	0.659	1.1901	1.20	2.685	2.25E+06
4-7	1.61	2.68	0.748	0.032	44.85	0.466	1.1901	1.20	2.251	1.20E+06
Runs 5-1 to 5-3 with 8" Euonymus, 10" CENTERS and 11" rows 45% removed (280 plants)										
5-1	3.39	1.35	1.602	0.035	46.28	0.105	0.5289	0.60	2.549	1.22E+06
5-2	3.39	2.07	1.480	0.030	52.33	0.210	0.5289	1.00	3.921	1.88E+06
5-3	2.32	3.16	0.935	0.026	56.74	0.457	0.5289	1.90	5.971	1.99E+06
Runs 6-1 to 6-8 were with 36"to 40" Dogwoods on 3' centers and 3'rows (45 plants), plants submerged										
6-1	4.14	1.06	3.054	0.099	18.21	0.280	0.1111	0.40	9.531	1.22E+06
6-2	4.15	1.57	2.986	0.091	19.73	0.538	0.1111	0.60	14.166	1.82E+06
6-3	4.25	2.00	2.926	0.079	22.69	0.687	0.1111	0.80	18.036	2.36E+06
Runs 6-4 to 6-6 were with water surface at top of plant										
6-4	3.09	1.14	2.318	0.103	16.62	0.384	0.1111	0.50	10.251	9.88E+05
6-5	2.47	2.01	1.700	0.075	21.60	0.770	0.1111	1.40	18.063	1.39E+06
6-6	2.72	3.13	1.577	0.049	32.63	0.959	0.1111	0.70	28.143	2.36E+06
Run 6-7 with plants half submerged										
6-7	1.78	2.22	1.189	0.069	22.34	0.911	0.1111	1.00	20.016	1.11E+06
6-8	3.07	3.15	1.809	0.052	31.92	1.000	0.1111	2.00	28.386	2.68E+06
Runs 7-1 to 7-2 were with 36"to 40" Dogwoods on 3' centers and 3'rows thinned by 50% (23 plants)										
7-1	3.89	1.14	2.777	0.088	20.03	0.277	0.0494	0.70	23.126	1.24E+06
Run 7-2 was with water surface at top of plant										
7-2	2.69	1.65	1.859	0.077	21.36	0.530	0.0494	1.80	33.473	1.24E+06

Table 4 Summary of Large Flume (Resistance) Test Results

Run 3-6 soil moving
Run 3-7 Gravel moving
Run 3-9 leaves and stems breaking
Run 4-3 few leaves lost, soil beginning to move
Run 6-2 some soil moving
Run 6-3 sand and small gravel moving
Run 6-8 few leaves pulling off

Note: plants were placed in stagered rows so that plant rows alternated
ie. row 1 (6 plants), row 2 (5 plants), row 3 (6 plants), etc
plant density is plants per square foot

Yo - average depth (feet)
V - average velocity (fps)
n - Mannings
Fd - drag force (lbs)
C - Chezy coefficient
f - friction factor
Rh - hydraulic radius (feet)
Sf - energy slope

YRS - shear stress (psf)
V* - shear velocity (fps)
VYRS - stream power (lb/sec ft)
V/V* - Prandtl coefficient
Reynolds - based on V and Rh
n net (etc) based on correction for effect of flume walls
n veg. (etc) based on subtracting bed loss

n(veg.) = n(net) - n(bed) where n(bed)=0.02

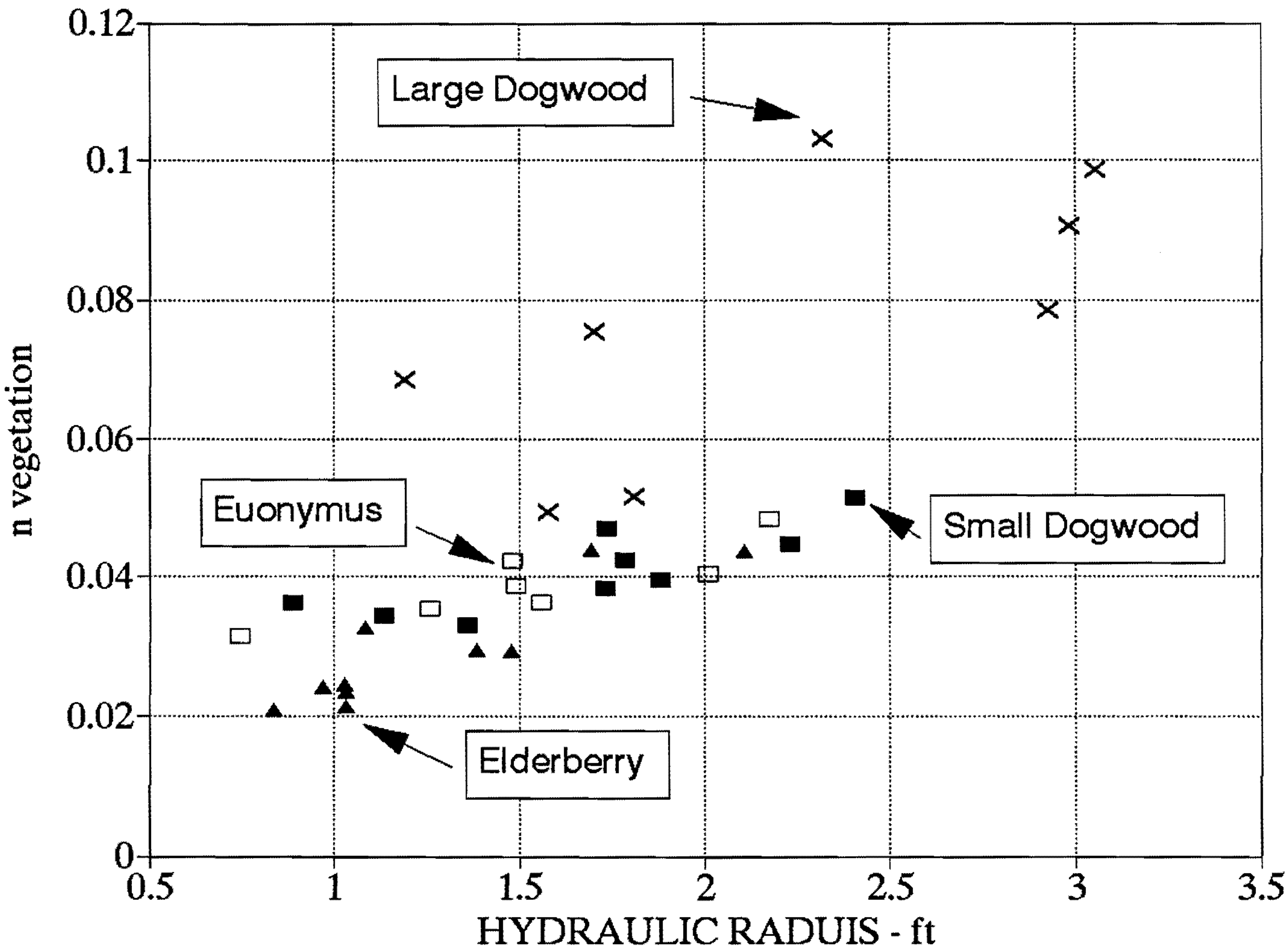


Figure 6 Manning's n_{veg} vs. Hydraulic Radius

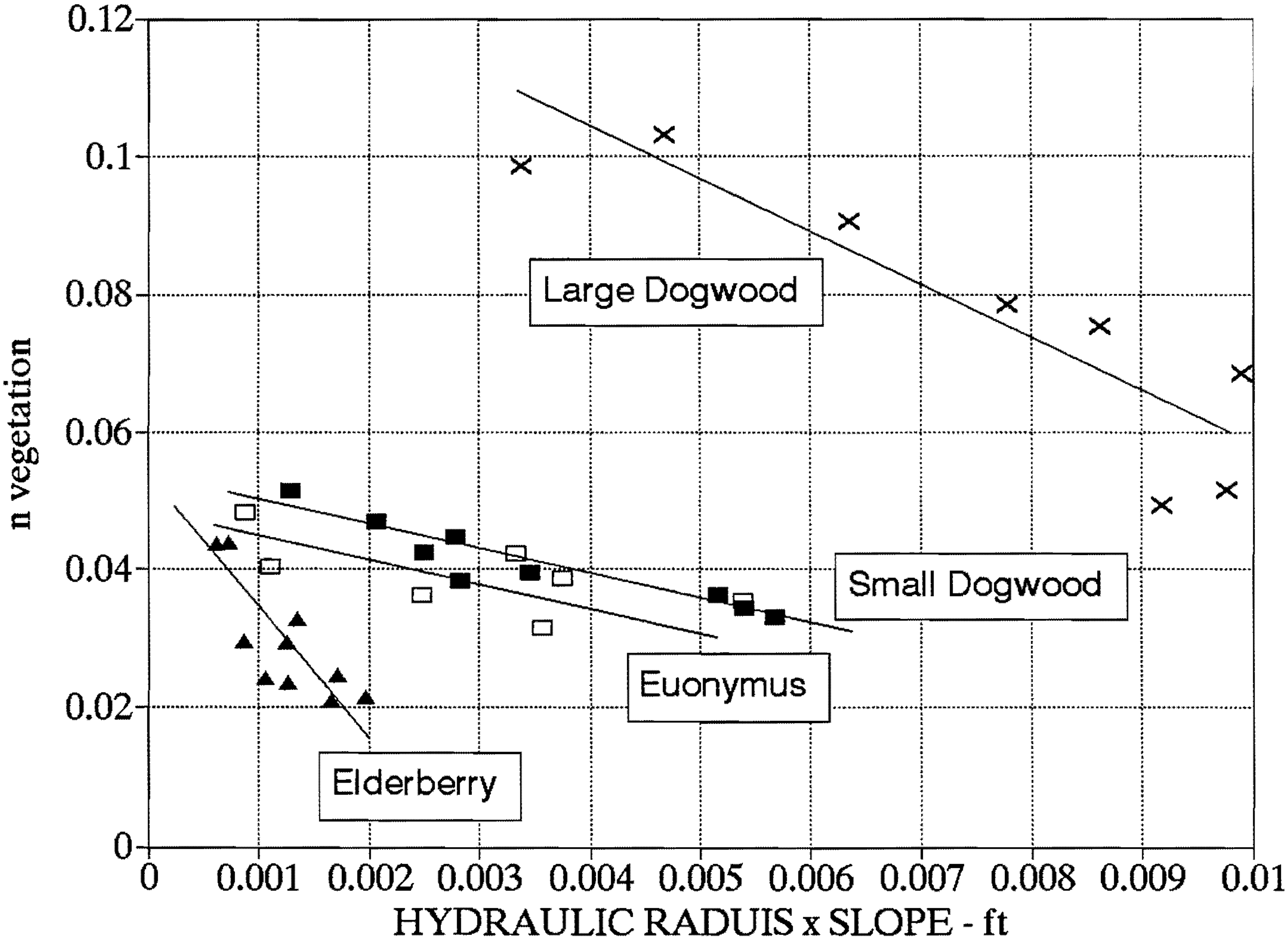


Figure 7 Manning's n_{veg} vs. RS

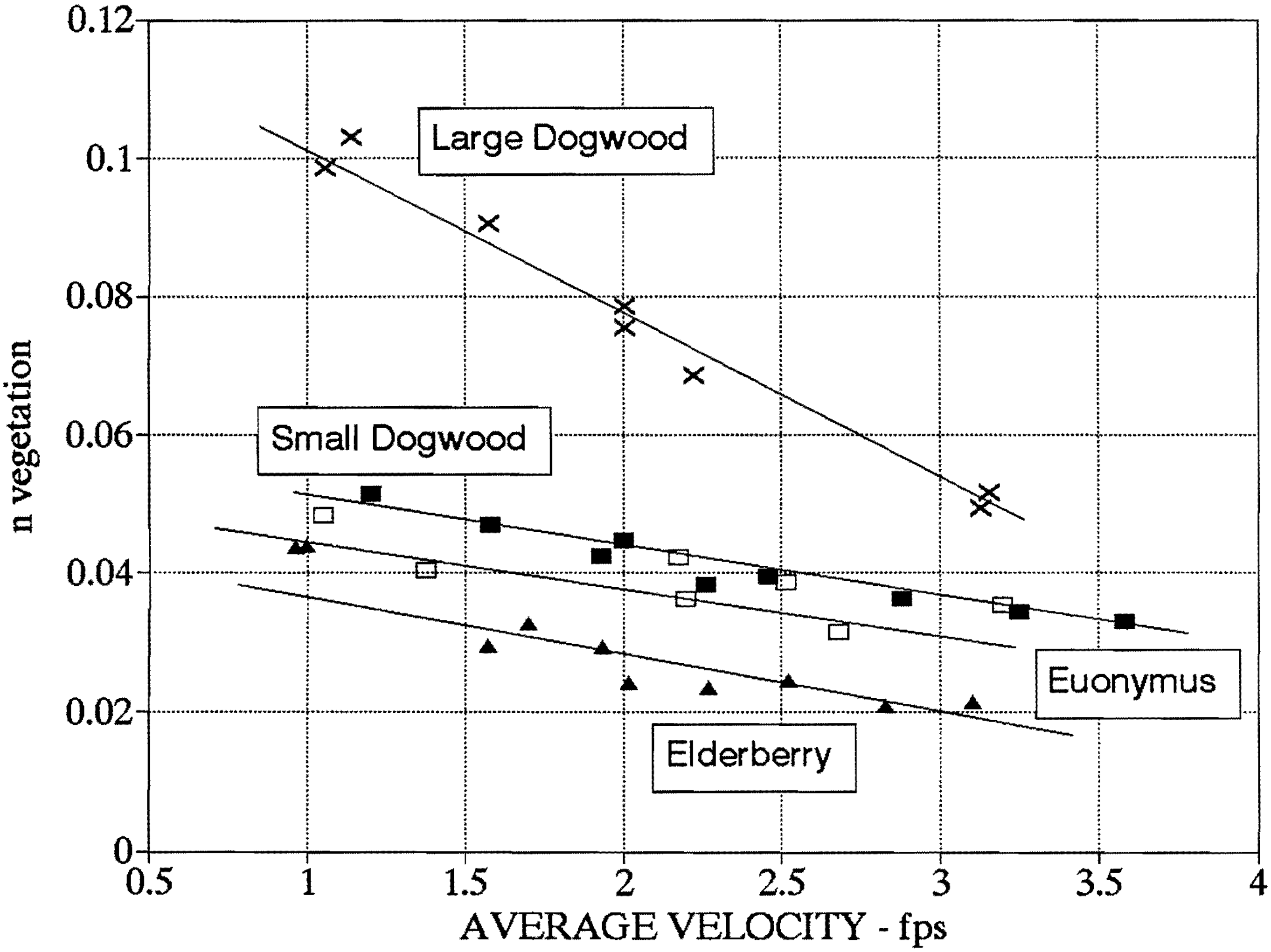


Figure 8 Manning's n_{veg} vs. Velocity

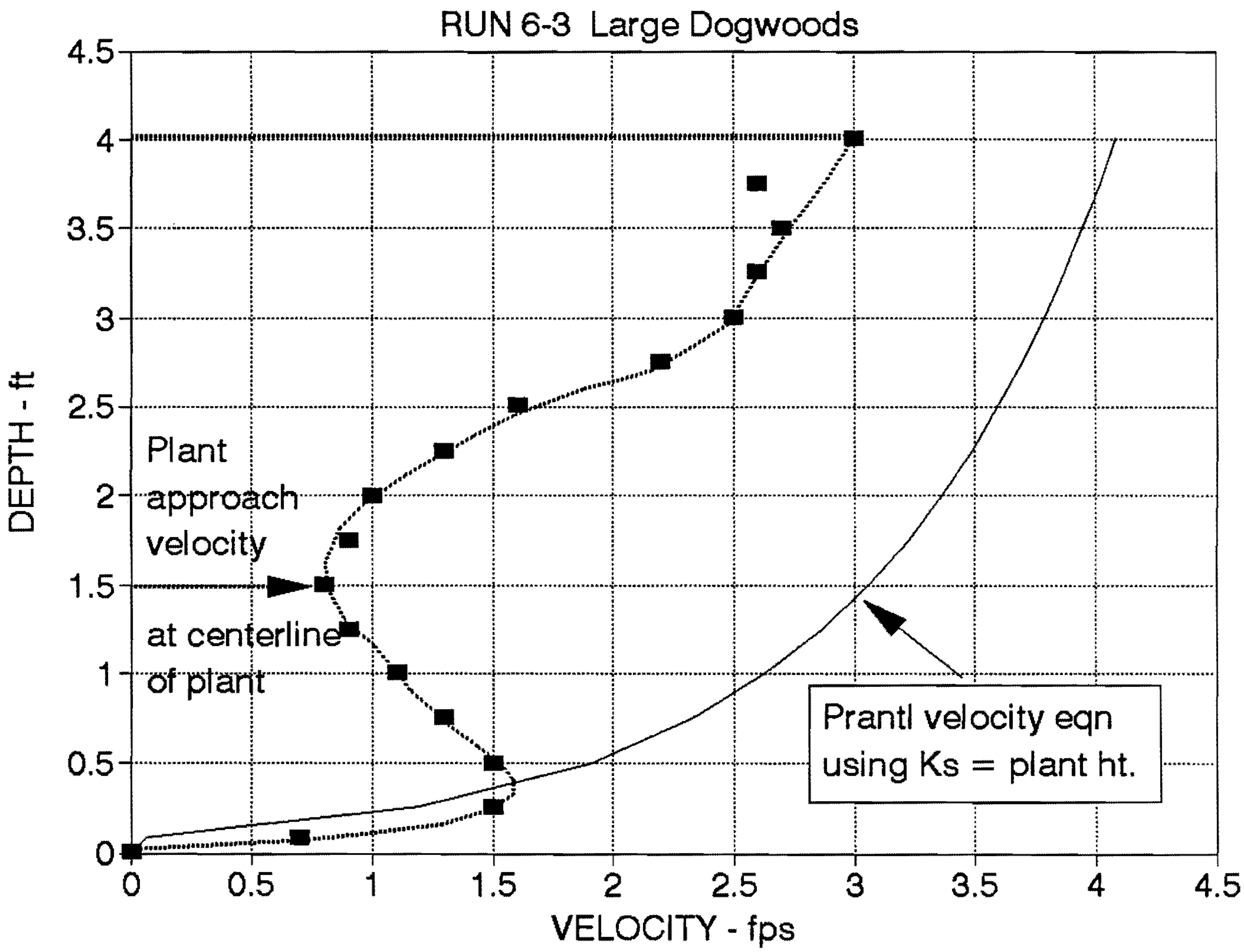


Figure 9 Example Velocity Profile for Test Run 6-3

section 12 RESULTS FOR THE DRAG FORCE TESTS

12-1 Table 5 summarizes the test data for the drag force measurements made in both the large and sectional flumes. A reference plant velocity of 2 fps was selected for comparison between plant types. Appendix B contains the data for the drag force tests in the sectional flume.

12-2 Figure 10 demonstrates the repeatability of drag force measurements between the large and sectional flumes. This is important because it shows that test data from the sectional flume can be directly compared to the plants and resistance coefficients determined in the large flume tests.

12-3 Figure 10 also shows a linear relationship between drag force and plant velocity. Test data from four different Dogwood plants are included in Figure 10. It is important to note because the plants deformed or changed shape with an increase in velocity, the drag force varied linearly with velocity instead of velocity squared.

Table 5 Summary of Drag Force Results

Plant Type	Drag Force w/ leaves	Drag Force w/o leaves	Plant Velocity
20" Dogwood* n_{veg} = 0.037	0.28 lbs	---	2 fps
28" Elderberry* n_{veg} = 0.024	0.65 lbs	---	2 fps
8" Euonymus* n_{veg} = 0.036	0.20 lbs	---	2 fps
38" Red Twig Dogwood* n_{veg} = 0.052	3.55 lbs	---	2 fps
Dogwood (series 1)	0.20 lbs	0.21 lbs	2 fps
Dogwood (series 2)	0.22 lbs	0.16 lbs	2 fps
Dogwood (series 3)	0.26 lbs	0.14 lbs	2 fps
Arctic Blue Willow	0.40 lbs	0.18 lbs	2 fps
8" Euonymus	0.25 lbs	0.20 lbs	2 fps
Norway Maple	0.22 lbs	0.06 lbs	2 fps
Common Privet	0.63 lbs	0.30 lbs	2 fps
Blue Elderberry	0.80 lbs	0.21 lbs	2 fps
French Pink Pussywillow	0.63 lbs	0.32 lbs	2 fps
Sycamore	0.36 lbs	0.11 lbs	2 fps
Western Sand Cherry	0.13 lbs	0.07 lbs	2 fps
Staghorn Sumac	0.28 lbs	0.10 lbs	2 fps

* Data from large flume tests

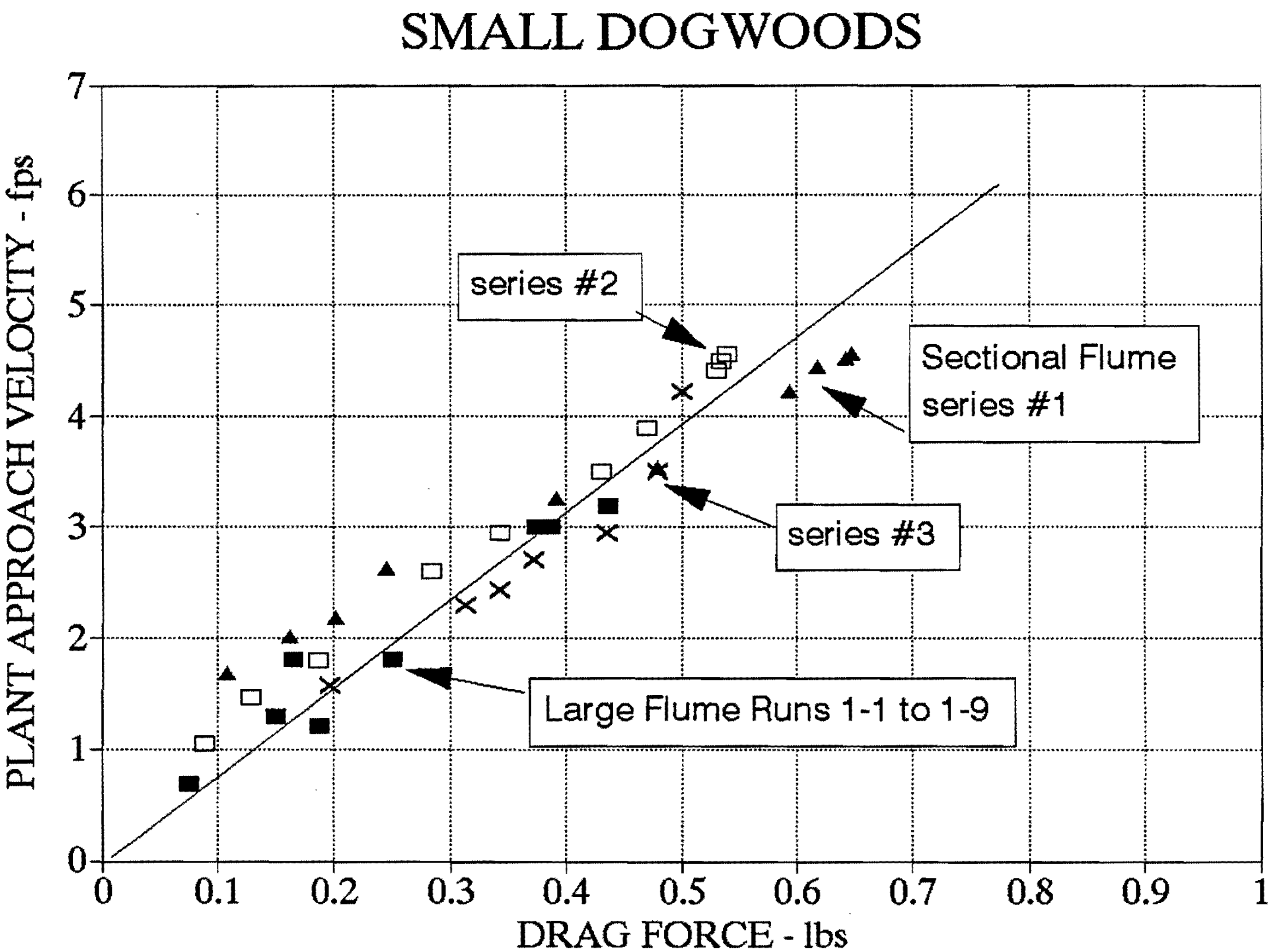


Figure 10 Plant Approach Velocity vs. Drag Force; Large and Sectional Flume Data

section 13 ANALYSIS OF VEGETATION RESISTANCE

13-1 Kadlec (1990) presented a hypothesis that the flow resistance from vegetation can be thought of as the result of the total forces, F_B, produced by vegetation on the channel bottom. The net bottom vegetation force is then equal to the sum of the drag forces from each plant and can be equated to the net bottom shear force (Equation 20) produced by the plants. The plant density P_d can be calculated by Equation 21 and be equated to the average plant spacing P_S as shown in Equation 21. The net vegetation shear stress ($\tau_o = \gamma RS$) is also equivalent to total drag forces divided by the area of channel bottom, and is equivalent to the average drag force times the plant density (Equation 22).

$$\tau_o \cdot AREA_{bottom} = \sum F_D = \#_{plants} \cdot F_D \tag{20}$$

$$P_d = \frac{\#_{plants}}{AREA_{bottom}} = \frac{1}{P_S^{\,2}} \tag{21}$$

$$F_D \cdot P_d = \tau_o = \gamma \cdot R \cdot S \tag{22}$$

Where τ_o is the plant shear stress on the channel bottom, P_d is the plant density in numbers of plants per unit square foot, and P_S is the plant spacing or average lateral and longitudinal distance between plant stems.

$$R = \frac{F_D \cdot P_d}{\gamma \cdot S} \tag{23}$$

13-2 Equation 23 can be used to the hydraulic radius to drag force, plant density, and slope. Manning's equation can then be modified to the form of Equation 24, and re-arranged to show the relationship of Manning's n with drag force, plant density, and slope as in Equation 25.

$$V = \frac{1.486}{n} \left(\frac{F_D \cdot P_d}{\gamma \cdot S} \right)^{2/3} S^{1/2} \tag{24}$$

$$n = \frac{1.486}{V} \left(\frac{F_D \cdot P_d}{\gamma} \right)^{2/3} S^{-1/6} \tag{25}$$

13-3 Figure 11 shows a plot of Manning's *n* calculated from the measured drag force with Equation 25 against the actual measured values of Manning's *n*. The plot indicates a 1:1 correlation and therefor the validity of the initial assumption of Equations 20, 22 and 25. The large degree of scatter is due to the limited measurement of a single drag force from a single plant for each test series. It was not possible to instrument all of the test plants to determine an average drag force.

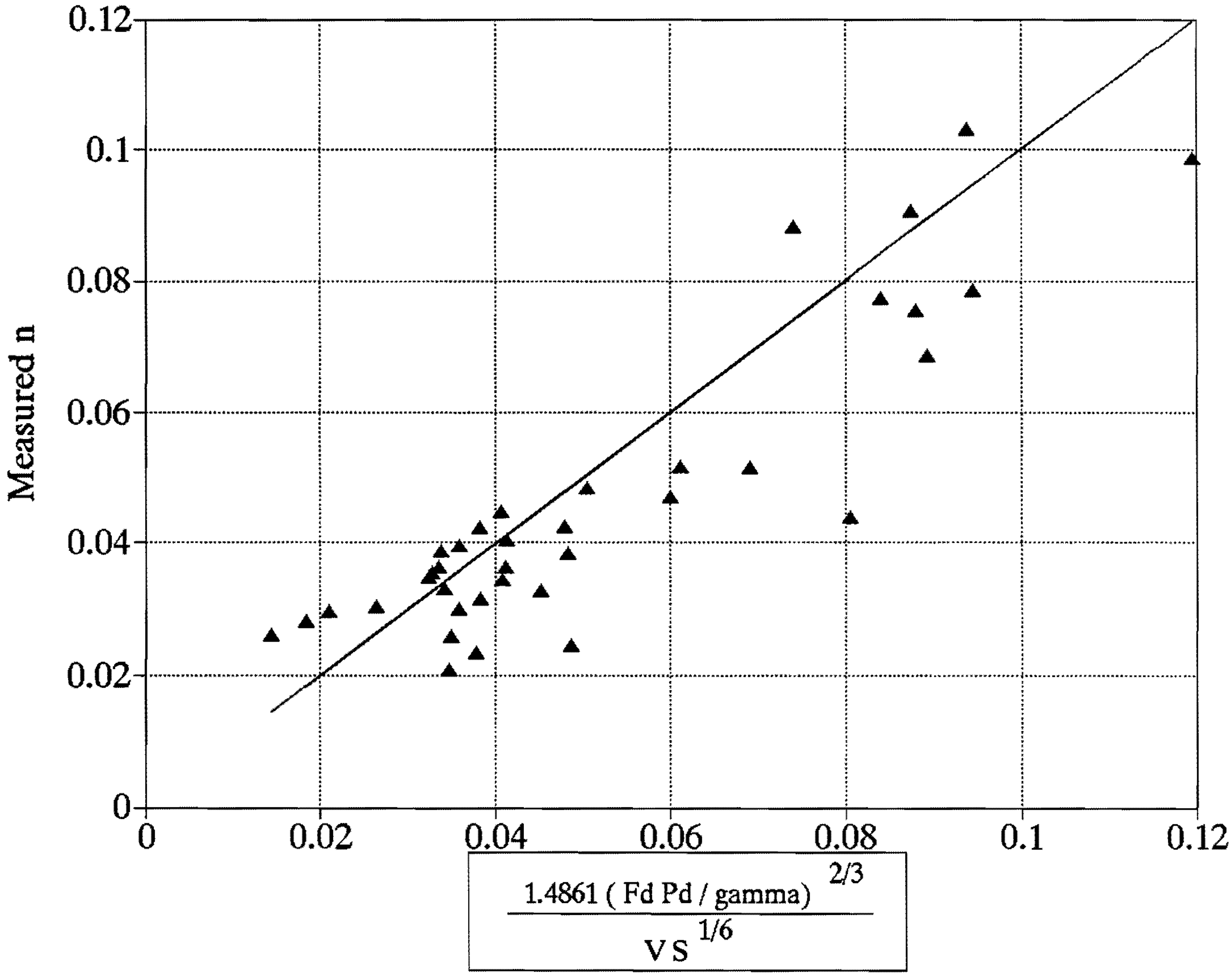


Figure 11 Relationship of Manning's n with Manning's n Calculated from Drag Force

13-4 From observations of the test plants as they distorted and changed shape, it was hypothesized that resistance or drag force will be the combination of form drag and boundary roughness of the distorted leaf mass. Figures 6, 7, and 8 (previous section on test results) demonstrated that Manning's n_{veg} and F_D were not a constant, and varied with both flow and plant characteristics. Dimensional analysis was then used to formulate a relationship of Manning's n with plant and flow characteristics. The independent variables that influence n are: Yo(average flow depth); V(average velocity); R(hydraulic radius); V_P(plant approach velocity); S(energy slope); H(plant height); H'(effective plant height that produced flow blockage); W_P(plant width); D_S(stem diameter); P_d(plant density); L_C(length to center of mass of leaves); number of branches; number of leaves; leaf size; force to deflect/bend center of leaf mass a distance Δ; and deflection Δ.

13-5 By eliminating redundant relationships of variables, the variables are reduced to the relationship of Equation 26. The stem diameter D_S is a measure of the plant flexibility, and plant density P_d accounts for blockage or disturbance of plants upstream. The repeating independent variables were selected as ρ(density), V(average velocity), and H'(effective plant height).

$$n = f\left(\rho, V, Y_o, S, D_S, H, H', P_d, P_W\right) \qquad (26)$$

13-6 A multiple regression analysis was performed on the dimensionless π terms from the dimensional analysis, and the relationship of Equation 27 was derived.

$$n_{veg} = 4.26 \left(\frac{gH'}{V^2}\right)^{0.34} \left(P_d H'^2\right)^{1.33} \left(\frac{D_S}{H'}\right)^{0.22} (S)^{0.09} \qquad (27)$$

The regression analysis showed that variables Y_o, W_S, and H were redundant and had very little effect in the relationship.

13-7 The parameter gH'/V^2 is a plant Froude number, D_S/H' is a slenderness ratio, and $P_dH'^2$ is a plant density ratio. Slope S was needed as a parameter because it reduced the scatter of data to curve fit from 20% to 13%. Equation 27 shows that *n* will increase with an increase of P_d, D_S, and S, and *n* will decrease with an increase in V and H'. Increasing plant height without increasing stem diameter made the plant more flexible therefor reducing *n*. The parameters were similar to those initially proposed by Fenzl (1962) for a study of flow resistance of alfalfa. The relationship of Equation 27 had regression fit of data of R^2=97%, and a data scatter to equation of ±13%. This is an acceptable curve fit because the accuracy of the measurements to determine resistance and drag force was about 10%. Figure 12 demonstrates the regression fit of Equation 27 with test data.

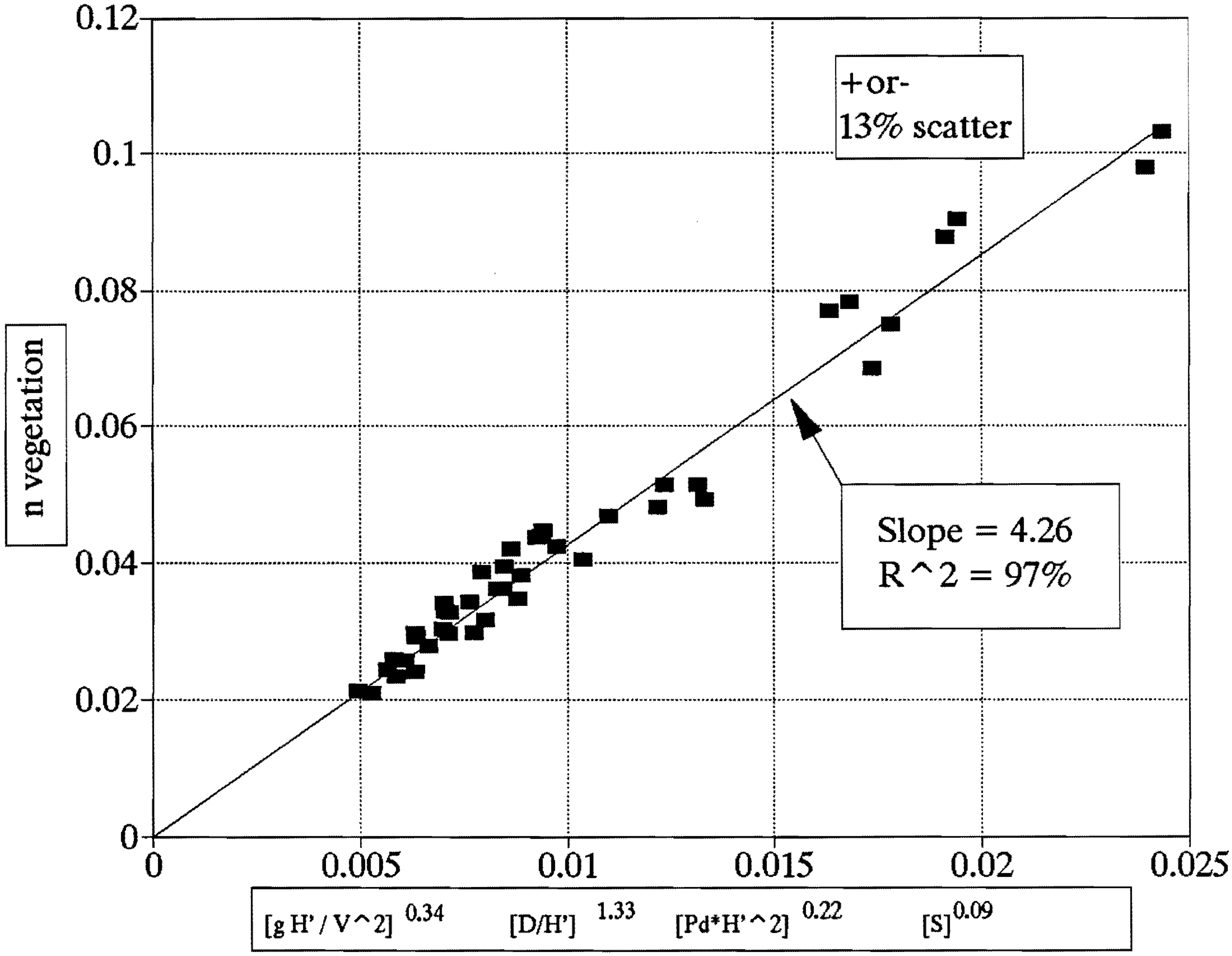


Figure 12 Regression Fit of Flow Resistance Data of Large Flume

13-8 By combining Equations 25 and 27, Equation 28 can then be used to calculate drag force F_D from the flow and plant variables of Equation 27.

$$F_D = \frac{1737\ V^{0.5}\ S^{0.38}\ D_S^{2.0}}{H'^{0.83}\ P_d^{0.68}} \tag{28}$$

Equation 28 is not dimensionally correct. Drag force F_D is in the units of lbs, velocity V is in units of fps, stem diameter D_S and effective plant height H' are in units of feet, and the plant density P_d is in units of plants per unit ft^2.

Section 14 SUMMARY AND CONCLUSIONS

CONCLUSIONS:

1. Four different groups of shrubs (woody vegetation) were tested in a large flume to determine the flow resistance and drag forces produced by the vegetation. An additional 8 different plants (for a total of 10) were tested in a sectional flume to determine drag force on a single plant. The plants were tested with varying velocities, flow depths, and plant spacing (density). Tables 4 and 5 are the summary of the test results.

2. Flow resistance, Manning's n_{veg}, was found to decrease with velocity. An important observation of the submerged plants was that the plants were flexible and the leaf mass formed a streamlined (teardrop) shape that reduced the flow forces on the plants. The teardrop shape also protected the leaves from being pulled off the plant stems, and reduced breakage of the smaller plant stems. Maximum plant velocity limits of 3 to 4 fps were observed for leaf failure. However, failure of leaves and stems will also occur at these velocities due to the impact with bed material being transported by the high velocities. Figures 13, 14, 15, 16, 17, and 18 demonstrate the distortion of the test plants at different flows.

3. Another important observation during the testing was that the leaf mass or layer of foliage diverted flow beneath the foliage layer (Figure 15). The flow resulted in significant velocities along the channel bottom which caused general scour (Figure 16) and increased sediment transport (Figure 17). Even the clay

test bed suffered significant erosion at channel velocities of 4 fps. The ground cover plants prevented channel bottom velocities, but the plants and exposed bed between plants experienced local scour from 3 dimensional vortices formed from the flow above the plants (Figure 18).

4. Table 5 lists the drag forces for each of the plants at a relative plant velocity of 2 fps. Data shows a definite linear relationship between drag force and velocity, and between drag force and flow resistance. Equation 25 was derived to show the theoretical relationship between Manning's n_{veg} and drag force.

5. Test data also showed that drag force and flow resistance could be related to both flow and plant characteristics. A regression analysis developed a relationship (Equation 27) between n and the parameters of gH'/V^2 (Plant Froude number), D_s/H' (slenderness ratio or plant flexibility), $P_dH'^2$ (plant density ratio), and S (bed or energy slope). Equation 28 was derived for the relationship of drag force F_D and the variables of velocity, plant spacing, stem diameter, slope, flow depth, and plant height.

6. The prototype plant tests found values of Manning's n_{veg} that exceeded 0.10 for average height and density of woody vegetation. An analysis (Appendix C) was made of the two methods for calculating flow depths and equivalent resistance in a compound flood channel. The equivalent resistance method (Equation 10) was found to result in a channel flow that was significantly less

than the flow calculated by the conveyance method (Equation 12). The equivalent resistance method under predicts flow because it assumes constant velocity throughout the entire flood channel and therefore proportions too large of flow in the vegetated subsections and too small of flow in the main flow channel.

RECOMMENDATIONS:

1) It is recommended to use the conveyance method to calculate equivalent Manning's n for use with the left and right flood plains of HEC-2. However, Manning's n_{veg} is not constant with flow parameters, and this will complicate the use of programs such as HEC-2. The methodology for using n_{veg} with HEC-2 will have to be developed.

2) Only 4 plant groups were tested in the large flume. It is recommended that other types of plants still need to be tested in a prototype large flume environment. The application of drag force data from sectional flume testing and field measurements will probably require the use of plant velocity. More testing is needed with large flumes to develop the methods to predict plant velocities in fully developed channel flows.

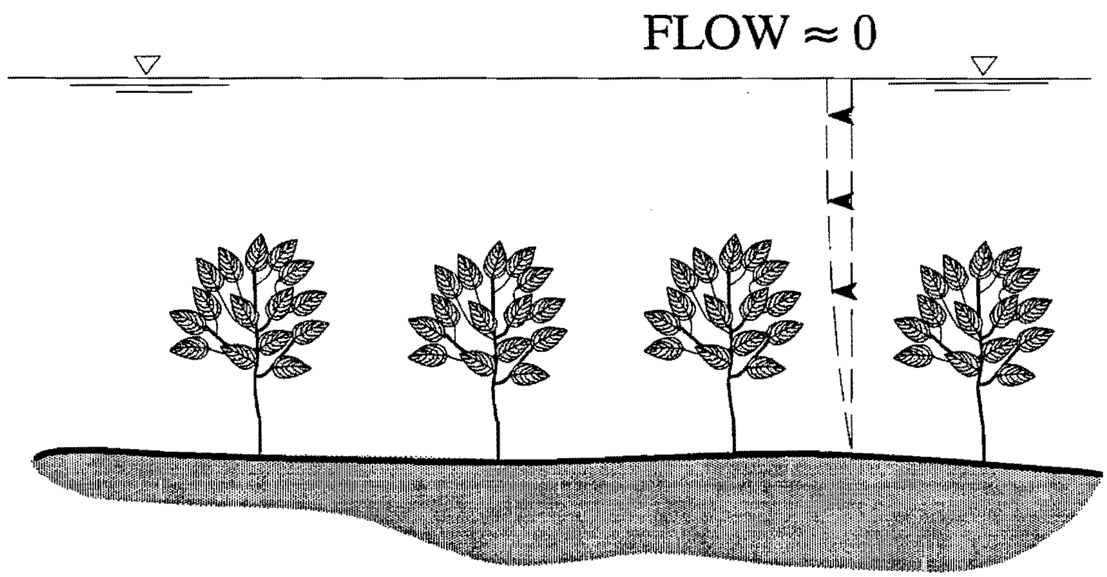


Figure 13 Test Plants at Zero Flow

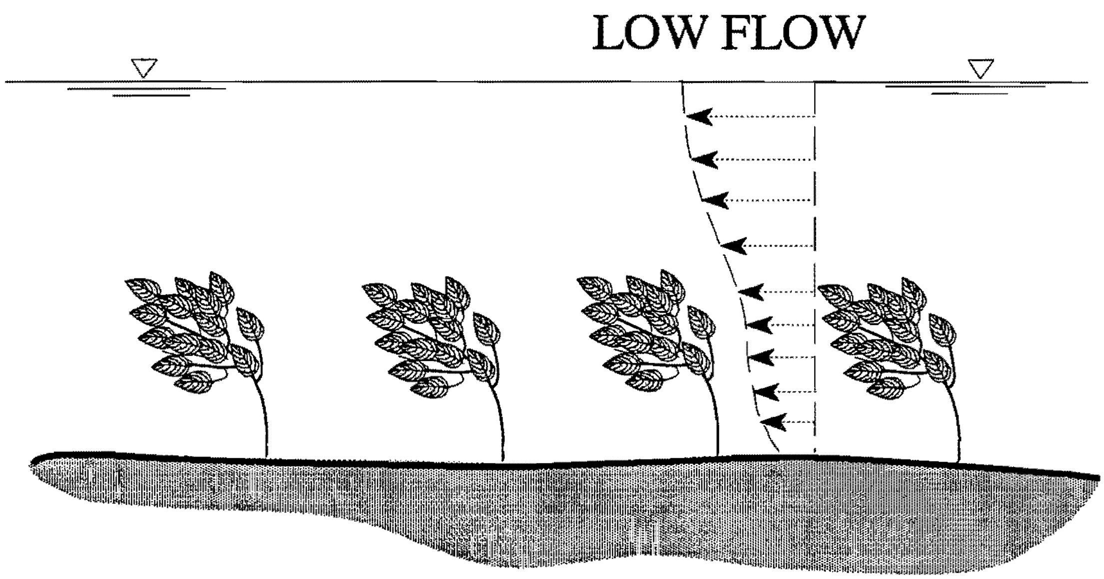


Figure 14 Test Plants at Low Flow

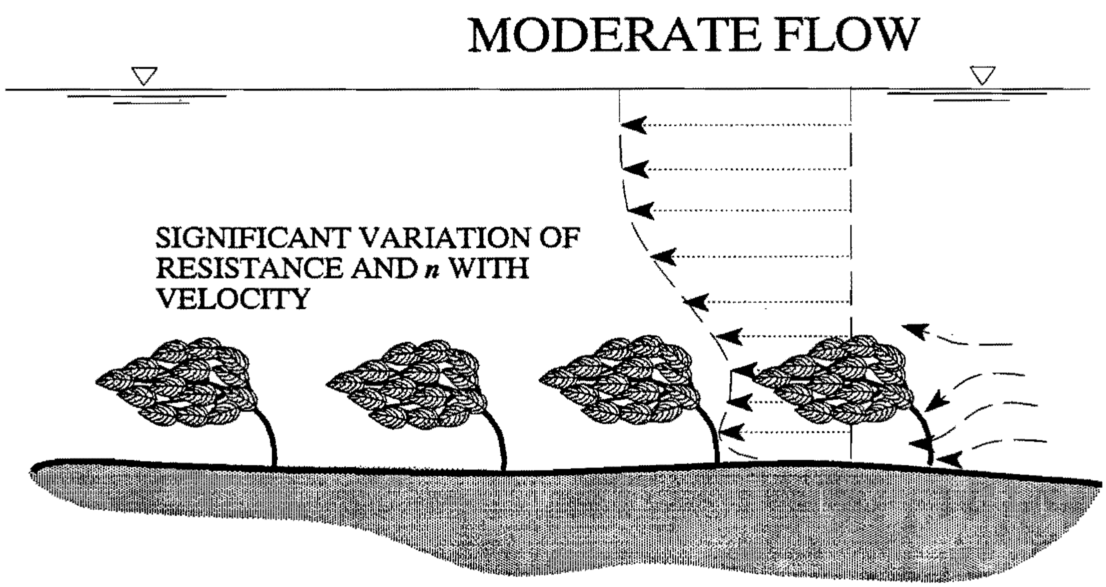


Figure 15 Test Plants at Moderate Flow

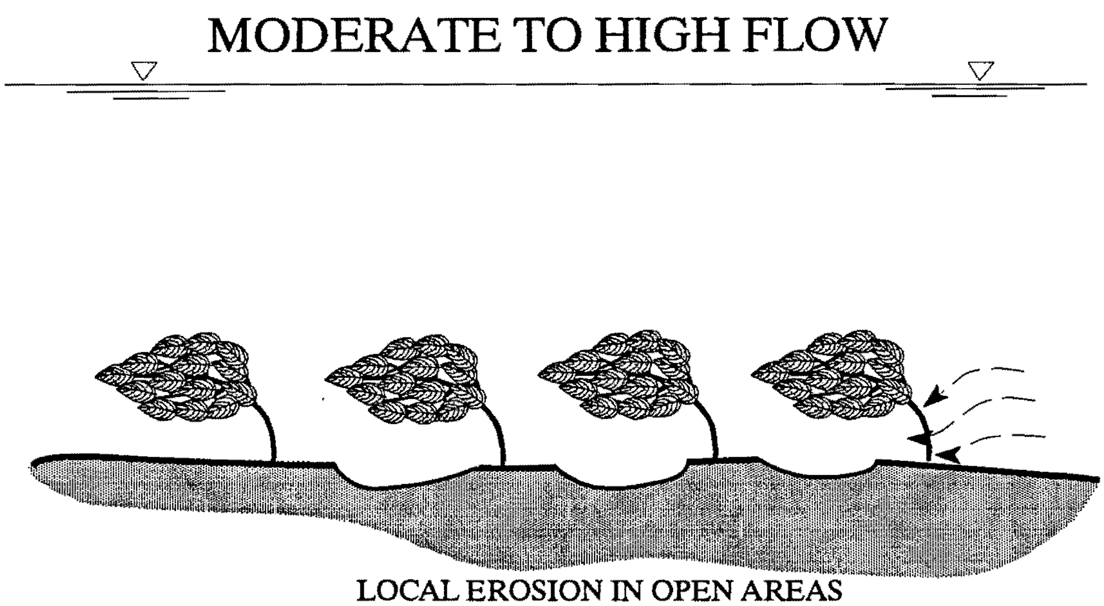


Figure 16 Test Plants with Local Erosion

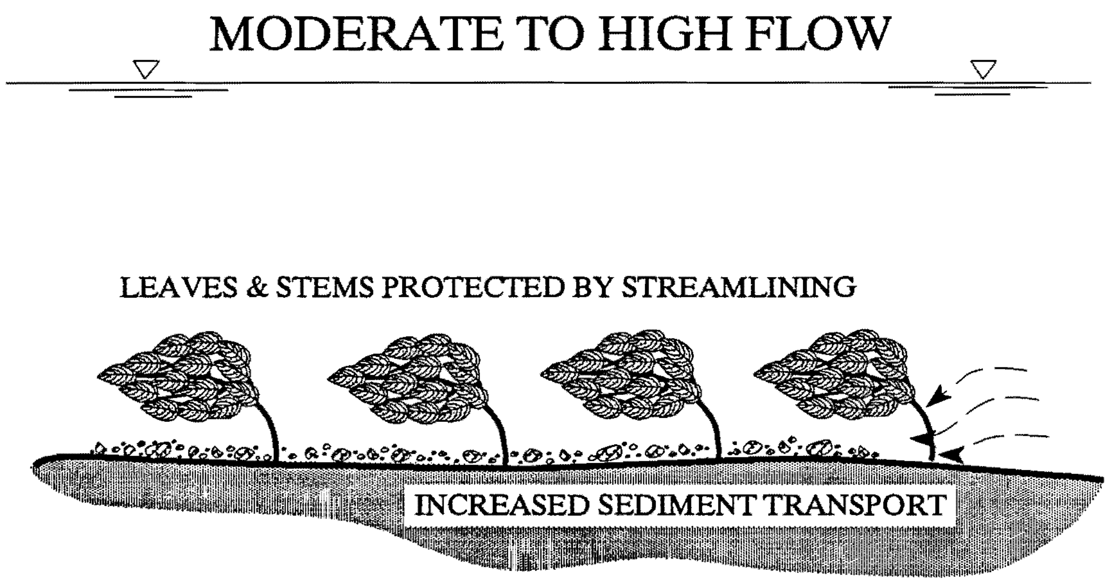


Figure 17   Test Plants with Sediment Transport

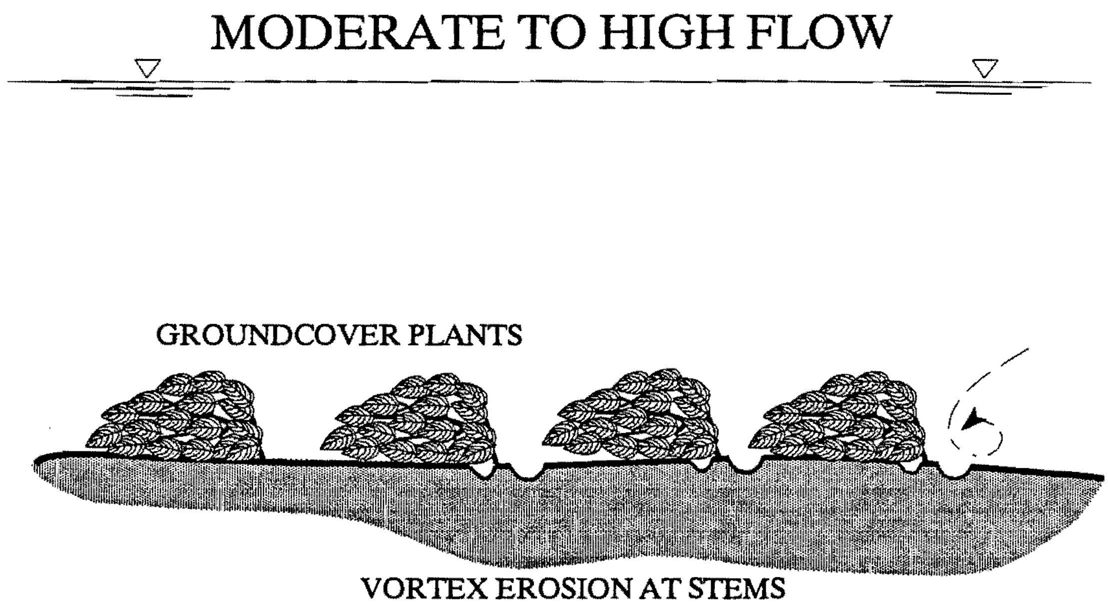


Figure 18   Test Plants with Stem Erosion

REFERENCES

Abdelsalam, M.W., Khattab, A.F., Khalifa, A.A., and Bakry, M.F., 1992, "Flow Capacity Through Wide and Submerged Vegetal Channels", Journal of Irrigation and Drainage Engineering, American Society of Civil Engineers, v. 118, no. 5, September/October, pp. 724 - 732.

ASCE, 1977, Sedimentation Engineering, American Society of Civil Engineering-Manuals and Reports on Engineering Practice- No.54, 1977, pp. 152-154.
Barnes, H.H., Jr., 1967, "Roughness Characteristics of Natural Channels", U.S. Geological Survey Water-Supply Paper 1849, p. 213.

Benson, M.A., and Dalrymple, T., 1967, "General Field and Office Procedures for Indirect Office Procedures", U.S. Geological Survey Techniques of Water Resources Investigations, Book 3, Chapter A1, p. 30.

Chow, V.T., 1959, Open-Channel Hydraulics, New York, McGraw-Hill Book Co.

Cowan, W.L., 1956, "Estimating Hydraulic Roughness Coefficients", Agricultural Engineering, v. 37, no. 7, pp. 473-475.

Dracos, T., and Hardegger, P., 1987, "Steady Uniform Flow in Prismatic Channels with Flood Plains", Journal of Hydraulic Research, v. 25, no. 2, pp. 169 - 185.

Fishenich, J.C., 1994, "Flow Resistance in Vegetated Channels; Summary of the Literature", Technical Report HL-94-xx, U.S. Army Engineers Waterways Experiment Station, Vicksburg, MS.

Jarrett, R.D., 1984, "Hydraulics of High-Gradient Streams", American Society of Civil Engineers, Journal of Hydraulic Engineering, v. 110, no. HY11.

Jarrett, R.D., 1985, "Determination of Roughness Coefficients for Streams in Colorado", U.S. Geological Survey Water-Resources Investigations Report 85-4004.

Jarrett, R.D., 1990, "Hydrologic and Hydraulic Research in Mountain Rivers", Water Resources Bulletin, American Water Resources Association, 26:3, June, pp. 419-429.

Kadlec, R.H., 1990, "Overland Flow in Wetlands: Vegetation Resistance", American Society of Civil Engineering, Journal of Hydraulic Engineering, v. 116, no. 5, May 1990, pp. 691-706.

Li, R.M., and Shen, H.W., 1973, "The Effect of Tall Vegetation on Flow and Sediment", Journal of Hydraulics, American Society of Civil Engineers, v. 99, no. HY5, May 1973, pp. 793-815.

Limerinos, J.T., 1970, "Determination of the Manning Coefficient from Measured Bed Roughness in Natural Channels", U.S. Geological Survey Water-Supply Paper 1898-B, p. 47.

Masterman, R., and Thorne, C.R., 1992, "Predicting Influence of Bank Vegetation on Channel Capacity", Journal of Hydraulic Engineering, American Society of Civil Engineers, v. 118, no. 7, July, pp. 1052 - 1058.

Petryk, S., and Bosmajian, G., 1975, "Analysis of Flow Through Vegetation", Proceedings, American Society of Civil Engineers, Journal of the Hydraulics Division, v. 101, no. HY7, pp. 871-884.

Ree, W.O. and Crow, F.R., 1977, "Friction Factors for Vegetated Waterways of Small Slope", U.S. Department of Agriculture, Agricultural Research Service, Publication S-151.

Richardson, E.V., Simons, D.B., Karaki, S., Mahmood, K, and Stevens, M.A., 1975, "Highways in the River Environment: Hydraulic and Environmental Design Consideration", Federal Highway Administration Training and Design Manual, May 1975.

Thompson, G.T. and Roberson, 1976, "A Theory of Flow Resistance for Vegetated Channels", Transactions of the ASAE, Soil and Water Division, January 1976, pp. 288-293.

APPENDIX A

RESISTANCE TEST DATA AND BACKWATER CURVES

C.O.E. Large Flume Project RUN #: 1-1
Date: 4-22-94
Plants: Dogwoods at 16" spacing

FLOW =	40	cfs			
dP =	1.5	inches between taps			
Drag =	10	micro inches	calibr=	40	micro-in / lbs
Drag =	0.25	lbs			

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		

Bottom elevations by transit reading (inches)

124.1875	124.6250	125.0000	124.8750	123.2500	122.6250	123.2500	123.5000	123.6250	124.5000	125.1875

Average bottom elevation = 124.0568 feet

Water surface elevations (inches)

73.3125	73.8125	74.0000	74.0625	74.1250	74.1875	74.1875	74.2500	74.4375	74.3750	74.5000	74.1875	0.3125
73.3125	73.7813	73.9375	73.9688	74.0000	74.0313	74.0000	74.0313	74.1875	74.0938	74.1875		

Water depth (feet)

4.2287	4.1896	4.1766	4.1740	4.1714	4.1688	4.1714	4.1688	4.1558	4.1636	4.1558

Average depth =	4.17	feet	corrected depth u.s.=	4.17661	feet
Average area =	33.34	sf	corrected depth d.s.=	4.163589	feet
Average perim.=	16.33	feet	diff=	0.013021	feet
Average H.Radius=	2.04	feet			
Average E.slope=	0.0004				
Average n=	0.038437				

n guess = 0.046

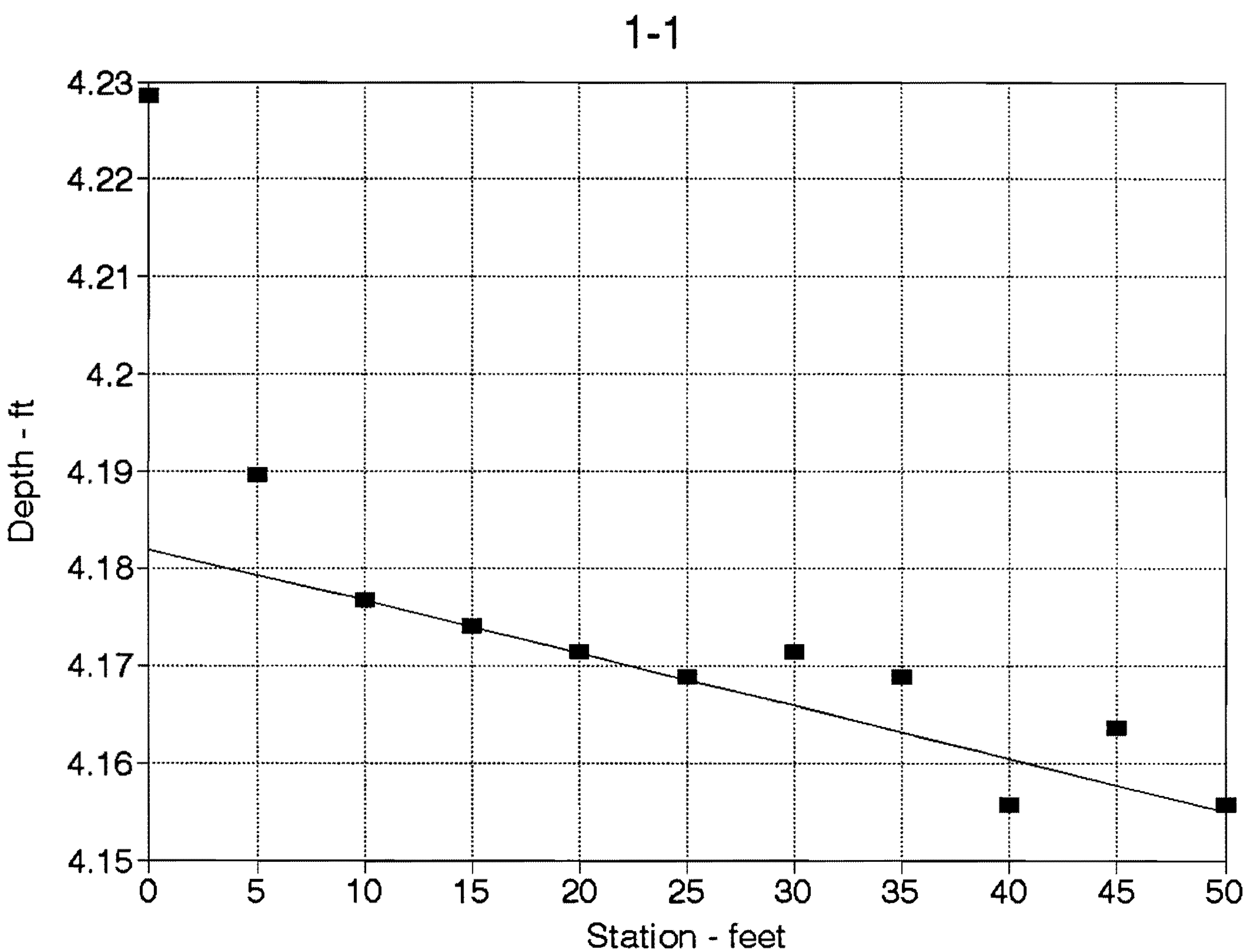
station	0	5	10	15	20	25	30	35	40	45	50
depth	4.228693	4.189631	4.17661	4.174006	4.171402	4.168797	4.171402	4.168797	4.155777	4.163589	4.155777
area	33.82955	33.51705	33.41288	33.39205	33.37121	33.35038	33.37121	33.35038	33.24621	33.30871	33.24621
perimeter	16.45739	16.37926	16.35322	16.34801	16.3428	16.33759	16.3428	16.33759	16.31155	16.32718	16.31155
Sf	0.000513	0.000525	0.00053	0.000531	0.000531	0.000532	0.000531	0.000532	0.000537	0.000534	0.000537
Froude	0.101329	0.102749	0.10323	0.103327	0.103423	0.10352	0.103423	0.10352	0.104007	0.103715	0.104007
dY		-0.00265	-0.00268	-0.00268	-0.00269	-0.00269	-0.00269	-0.00269	-0.00271	-0.0027	-0.00271
Y calc	4.228693	4.226038	4.223361	4.22068	4.217994	4.215304	4.212618	4.209927	4.207214	4.204514	4.201801
Y adj	4.181942	4.179287	4.17661	4.173928	4.171242	4.168552	4.165866	4.163175	4.160462	4.157763	4.15505

Average depth =	4.17
Average velocity =	1.20
Average n =	0.046

Velocity Profile station 25 feet vel. at plant center = 0.7 fps

Yo=	4.168797	ft		
V=	1.199387	fps		
Sf=	0.000532		Prandtl C	55.75722
Rh=	2.041327	ft	Prandtl n=	0.030017
V*=	0.187057	fps	Test n=	0.046
X=	1			
Ks=	1	ft	Ks/psi =	1143.66

elev	Y	V meas	Prandtl V
6	3.67	1.6	1.78
12	3.17	1.6	1.71
18	2.67	1.4	1.63
24	2.17	0.9	1.53
30	1.67	0.6	1.41
36	1.17	0.7	1.24
42	0.67	0.4	0.98
48	0.17	0.2	0.34
49	0.09	0.1	0.02
	0	0	0



1-1
4.23
4.22
4.21
4.2
4.19
4.18
4.17
4.16
4.15
Depth - ft
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 1-2
Date: 4-22-94
Plants: Dogwoods at 16" spacing

FLOW =	66	cfs		
dP =		inches between taps		
Drag =	12	micro inches	calibr=	40 micro-in / lbs
Drag =	0.3	lbs		

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
124.1875	124.6250	125.0000	124.8750	123.2500	122.6250	123.2500	123.5000	123.6250	124.5000	125.1875		
Average bottom elevation =		124.0568	feet									
Water surface elevations (inches)												
74.3125	74.3750	74.5000	74.6250	74.8125	74.8750	75.0000	75.1250	75.2500	75.3750	75.4375	74.9375	0.5000
74.3125	74.3250	74.4000	74.4750	74.6125	74.6250	74.7000	74.7750	74.8500	74.9250	74.9375		
Water depth (feet)												
4.1454	4.1443	4.1381	4.1318	4.1204	4.1193	4.1131	4.1068	4.1006	4.0943	4.0933		

Average depth =	4.12	feet	corrected depth u.s.=	4.138068	feet
Average area =	32.95	sf	corrected depth d.s.=	4.094318	feet
Average perim.=	16.24	feet	diff=	0.04375	feet
Average H.Radius=	2.03	feet			
Average E.slope=	0.0012				
Average n=	0.042043				
			intercept	4.118845	

n guess = 0.042

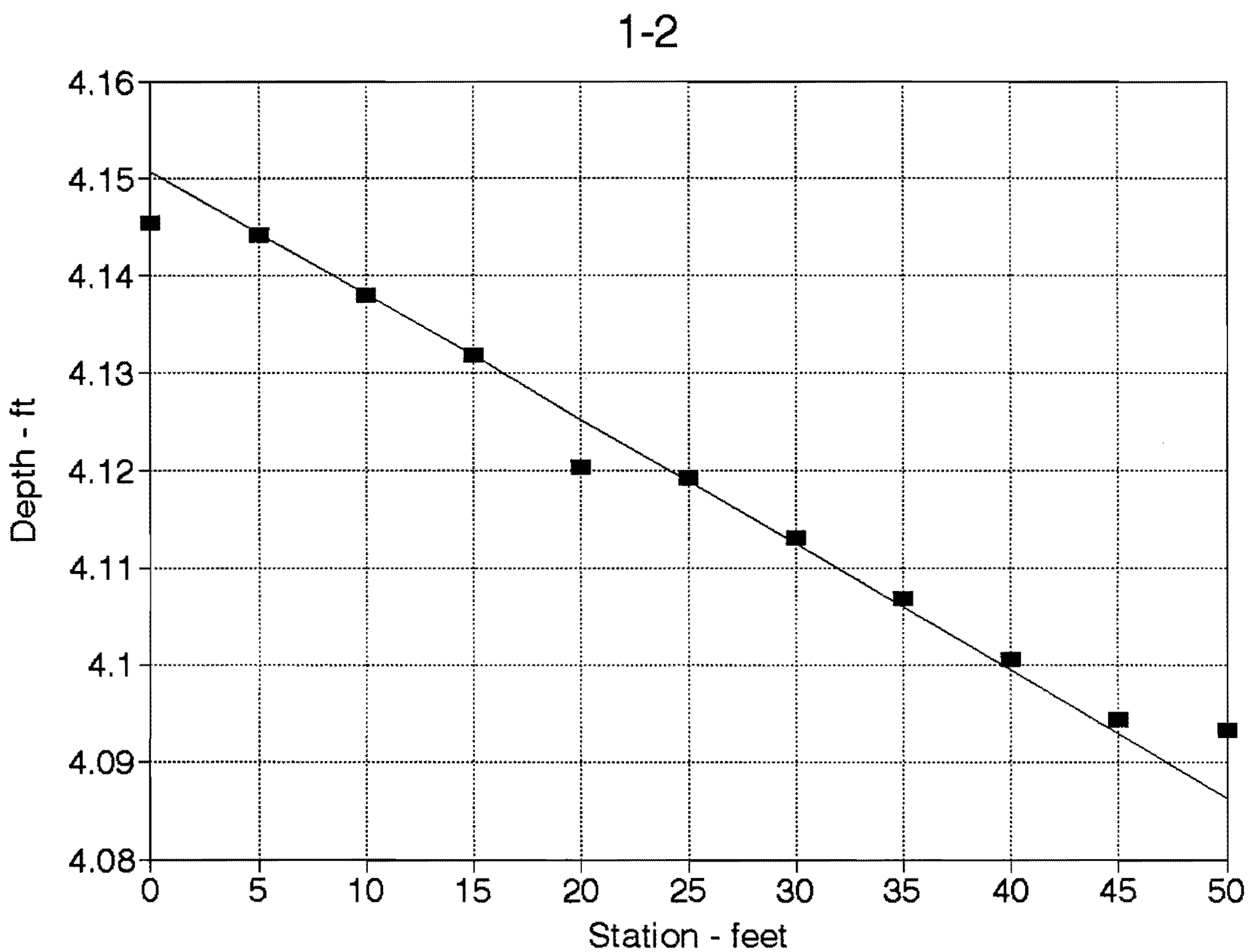
station	0	5	10	15	20	25	30	35	40	45	50
depth	4.14536	4.144318	4.138068	4.131818	4.12036	4.119318	4.113068	4.106818	4.100568	4.094318	4.093277
area	33.16288	33.15455	33.10455	33.05455	32.96288	32.95455	32.90455	32.85455	32.80455	32.75455	32.74621
perimeter	16.29072	16.28864	16.27614	16.26364	16.24072	16.23864	16.22614	16.21364	16.20114	16.18864	16.18655
Sf	0.001226	0.001227	0.001232	0.001237	0.001246	0.001247	0.001252	0.001257	0.001262	0.001267	0.001268
Froude	0.172259	0.172324	0.172715	0.173107	0.173829	0.173895	0.174292	0.17469	0.175089	0.175491	0.175557
dY		-0.00632	-0.00635	-0.00638	-0.00643	-0.00643	-0.00646	-0.00648	-0.00651	-0.00654	-0.00654
Y calc	4.14536	4.139036	4.132686	4.126309	4.119884	4.113454	4.106997	4.100513	4.094002	4.087464	4.080921
Y adj	4.15075	4.144427	4.138077	4.1317	4.125275	4.118845	4.112388	4.105904	4.099393	4.092854	4.086311

Average depth =	4.12
Average velocity =	2.00
Average n =	0.042

Velocity Profile station 25 feet vel. at plant center = 1.3 fps

Yo=	4.119318	ft		
V=	2.002759	fps		
Sf=	0.001247		Prandtl C	55.58802
Rh=	2.029391	ft	Prandtl n=	0.030079
V*=	0.285469	fps	Test n=	0.042
X=	1			
Ks=	1	ft	Ks/psi =	1745.349

elev	Y	V meas	Prandtl V
6	3.62	2.8	2.70
12	3.12	2.6	2.60
18	2.62	2.5	2.47
24	2.12	2.3	2.32
30	1.62	1.9	2.13
36	1.12	1.3	1.87
42	0.62	0.8	1.45
48	0.12	0.7	0.27
49	0.04	0.5	-0.58
	0	0	0


1-2
Depth - ft
4.16
4.15
4.14
4.13
4.12
4.11
4.1
4.09
4.08
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 1-3
Date: 4-22-94
Plants: Dogwoods at 16" spacing

FLOW = 72.3 cfs
dP = inches between taps
Drag = 15 micro inches calibr= 40 micro-in / lbs
Drag = 0.375 lbs

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
124.1875	124.6250	125.0000	124.8750	123.2500	122.6250	123.2500	123.5000	123.6250	124.5000	125.1875		
Average bottom elevation =		124.0568	feet									
Water surface elevations (inches)												
79.3125	79.1250	79.5000	79.3750	79.5000	79.5625	79.6250	79.6250	79.6250	79.8125	79.8750	80.5000	-0.6250
79.3125	79.1875	79.6250	79.5625	79.7500	79.8750	80.0000	80.0625	80.1250	80.3750	80.5000		
Water depth (feet)												
3.7287	3.7391	3.7027	3.7079	3.6922	3.6818	3.6714	3.6662	3.6610	3.6402	3.6297		

Average depth = 3.68 feet corrected depth u.s.= 3.702652 feet
Average area = 29.47 sf corrected depth d.s.= 3.640152 feet
Average perim.= 15.37 feet diff= 0.0625 feet
Average H.Radius= 1.92 feet
Average E.slope= 0.0018
Average n= 0.039507

intercept 3.683712

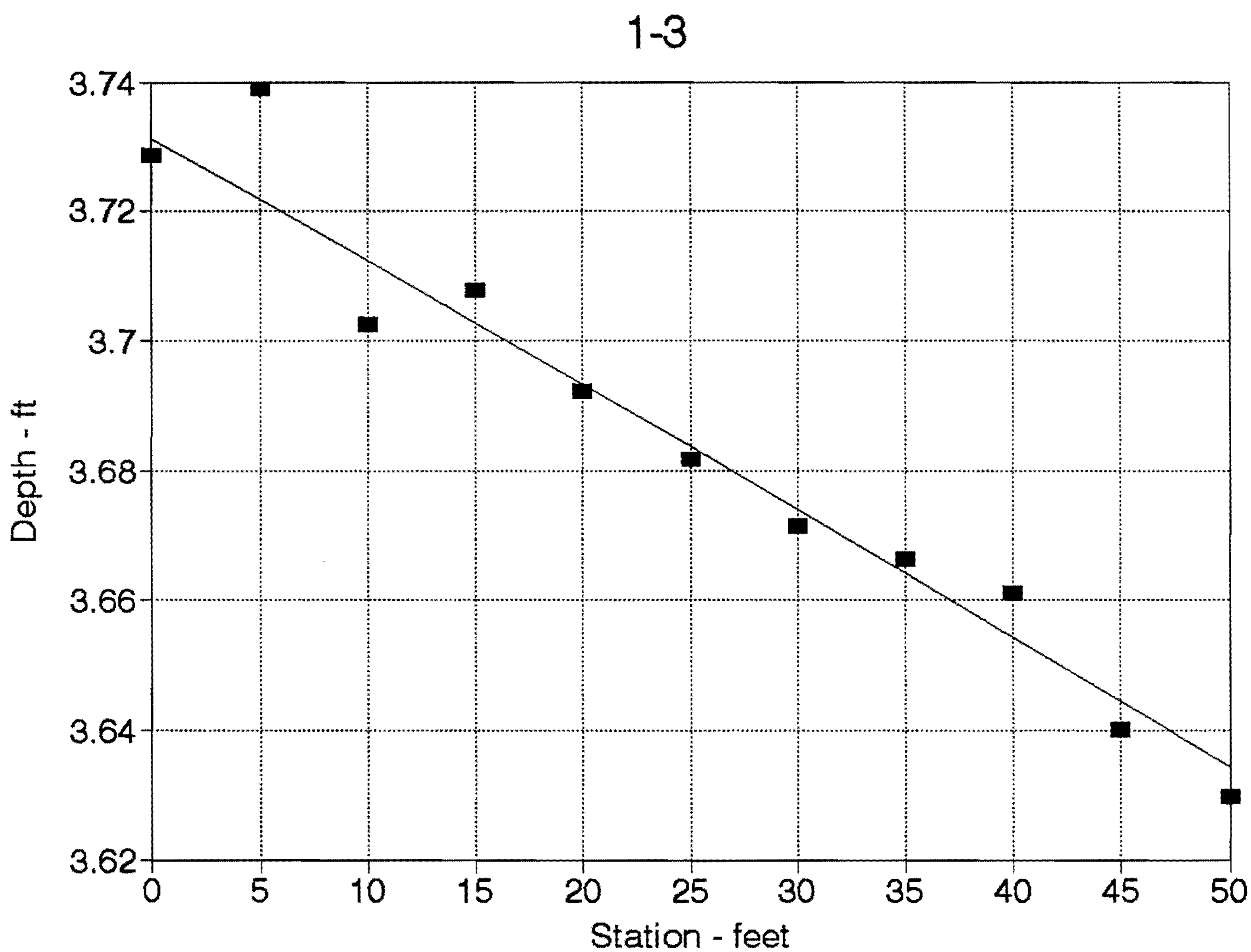
n guess = 0.04

station	0	5	10	15	20	25	30	35	40	45	50
depth	3.728693	3.73911	3.702652	3.70786	3.692235	3.681818	3.671402	3.666193	3.660985	3.640152	3.629735
area	29.82955	29.91288	29.62121	29.66288	29.53788	29.45455	29.37121	29.32955	29.28788	29.12121	29.03788
perimeter	15.45739	15.47822	15.4053	15.41572	15.38447	15.36364	15.3428	15.33239	15.32197	15.2803	15.25947
Sf	0.001772	0.001758	0.001805	0.001799	0.001819	0.001833	0.001847	0.001854	0.001861	0.00189	0.001905
Froude	0.2212	0.220276	0.223538	0.223067	0.224485	0.225438	0.226398	0.226881	0.227365	0.22932	0.230307
dY		-0.00924	-0.0095	-0.00946	-0.00958	-0.00966	-0.00973	-0.00977	-0.00981	-0.00998	-0.01006
Y calc	3.728693	3.719453	3.709951	3.700487	3.690908	3.681252	3.671518	3.661744	3.65193	3.641954	3.631897
Y adj	3.731153	3.721912	3.712411	3.702947	3.693368	3.683712	3.673978	3.664204	3.65439	3.644414	3.634356

Average depth = 3.68
Average velocity = 2.45
Average n = 0.040

Velocity Profile station 25 feet vel. at plant center = 1.8 fps
Yo= 3.681818 ft
V= 2.45463 fps
Sf= 0.001833 Prandtl C 53.99696
Rh= 1.91716 ft Prandtl n= 0.030673
V*= 0.336392 fps Test n= 0.04
X= 1
Ks= 1 ft Ks/psi = 2056.687

elev	Y	V meas	Prandtl V
6	3.18	3.4	3.08
12	2.68	3.2	2.93
18	2.18	3.2	2.76
24	1.68	2.8	2.54
30	1.18	1.8	2.25
36	0.68	1.4	1.78
42	0.18	0.3	0.67
48	-0.32	0	ERR
49	-0.40	0	ERR
	0	0	0


1-3
3.74
3.72
3.7
3.68
3.66
3.64
3.62
Depth - ft
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 1-4
Date: 4-22-94
Plants: Dogwoods at 16" spacing

FLOW =	39	cfs		
dP =		inches between taps		
Drag =	15	micro inches	calibr=	40 micro-in / lbs
Drag =	0.375	lbs		

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
124.1875	124.6250	125.0000	124.8750	123.2500	122.6250	123.2500	123.5000	123.6250	124.5000	125.1875		
Average bottom elevation =		124.0568	feet									
Water surface elevations (inches)												
86.5625	86.6250	86.8125	86.9375	87.0625	87.2500	87.2500	87.4375	87.5625	87.6250	87.6875	87.2500	0.4375
86.5625	86.5813	86.7250	86.8063	86.8875	87.0313	88.9875	87.1313	87.2125	87.2313	87.2500		
Water depth (feet)												
3.1245	3.1230	3.1110	3.1042	3.0974	3.0855	3.0891	3.0771	3.0704	3.0688	3.0672		

Average depth =	3.09	feet	corrected depth u.s.=	3.110985	feet
Average area =	24.74	sf	corrected depth d.s.=	3.068797	feet
Average perim.=	14.19	feet	diff=	0.042188	feet
Average H.Radius=	1.74	feet			
Average E.slope=	0.0012				
Average n=	0.047421				
			intercept	3.092566	

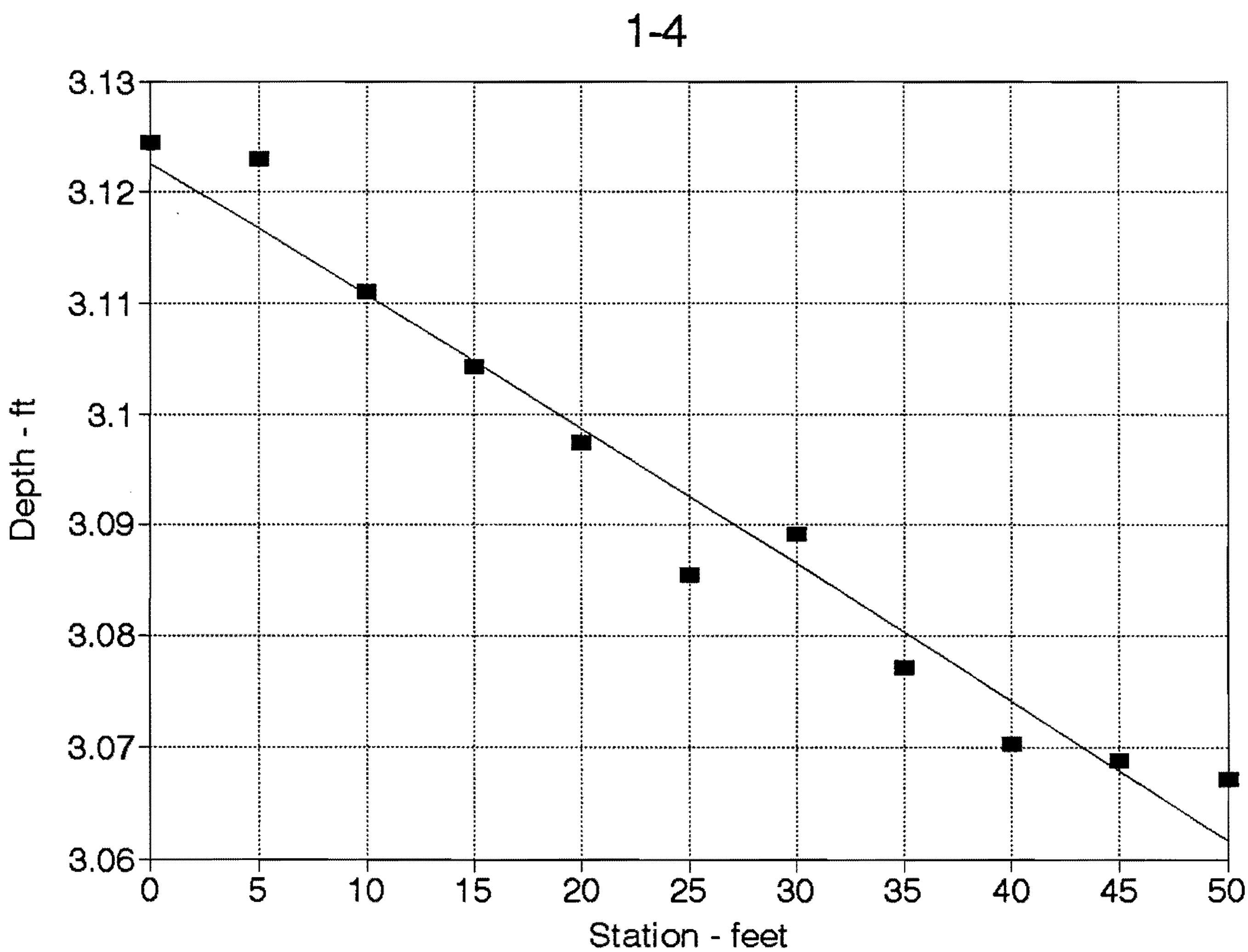
n guess = 0.047

station	0	5	10	15	20	25	30	35	40	45	50
depth	3.124527	3.122964	3.110985	3.104214	3.097443	3.085464	3.08911	3.077131	3.07036	3.068797	3.067235
area	24.99621	24.98371	24.88788	24.83371	24.77955	24.68371	24.71288	24.61705	24.56288	24.55038	24.53788
perimeter	14.24905	14.24593	14.22197	14.20843	14.19489	14.17093	14.17822	14.15426	14.14072	14.13759	14.13447
Sf	0.001151	0.001153	0.001165	0.001172	0.001179	0.001192	0.001188	0.0012	0.001208	0.001209	0.001211
Froude	0.15555	0.155667	0.156567	0.157079	0.157595	0.158513	0.158233	0.159158	0.159685	0.159806	0.159929
dY		-0.00591	-0.00597	-0.00601	-0.00604	-0.00611	-0.00609	-0.00616	-0.0062	-0.00621	-0.00621
Y calc	3.124527	3.11862	3.11265	3.106642	3.100597	3.094486	3.088395	3.082237	3.07604	3.069834	3.063619
Y adj	3.122607	3.116701	3.11073	3.104722	3.098678	3.092566	3.086475	3.080317	3.07412	3.067914	3.061699

Average depth = 3.09
Average velocity = 1.58
Average n = 0.047

Velocity Profile station 25 feet			vel. at plant center =	1.2 fps
Yo=	3.085464	ft		
V=	1.579989	fps		
Sf=	0.001192		Prandtl C	51.493
Rh=	1.741856	ft	Prandtl n=	0.031655
V*=	0.258519	fps	Test n=	0.047
X=	1			
Ks=	1	ft	Ks/psi =	1580.576

elev	Y	V meas	Prandtl V
6	2.59	2.1	2.23
12	2.09	2	2.09
18	1.59	1.7	1.92
24	1.09	1.2	1.67
30	0.59	0.8	1.27
36	0.09	0.1	0.03
42	-0.41	0	ERR
48	-0.91	0	ERR
49	-1.00	0	ERR
	0	0	0



1-4
3.13
3.12
3.11
3.1
3.09
3.08
3.07
3.06
Depth - ft
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 1-5
Date: 4-22-94
Plants: Dogwoods at 16" spacing

FLOW = 51.6 cfs
dP = inches between taps
Drag = 15 micro inches calibr= 40 micro-in / lbs
Drag = 0.375 lbs

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50

Bottom elevations by transit reading (inches)

124.1875	124.3125	124.1875	124.5000	123.9375	123.8750	123.7500	123.6250	123.6250	124.5000	124.1250

Average bottom elevation = 124.0568 feet

Water surface elevations (inches)

83.4375	83.5563	83.4875	83.6688	83.7875	83.9063	83.9000	84.0188	84.0750	84.1938	84.1875

Water depth (feet)

3.3849	3.3750	3.3808	3.3657	3.3558	3.3459	3.3464	3.3365	3.3318	3.3219	3.3224

Average depth =	3.35	feet	corrected depth u.s.=	3.384943	feet
Average area =	26.76	sf	corrected depth d.s.=	3.321922	feet
Average perim.=	14.69	feet	diff=	0.063021	feet
Average H.Radius=	1.82	feet			
Average E.slope=	0.0014				
Estimated n =	0.043021				
			intercept	3.35	

Calc n = 0.043

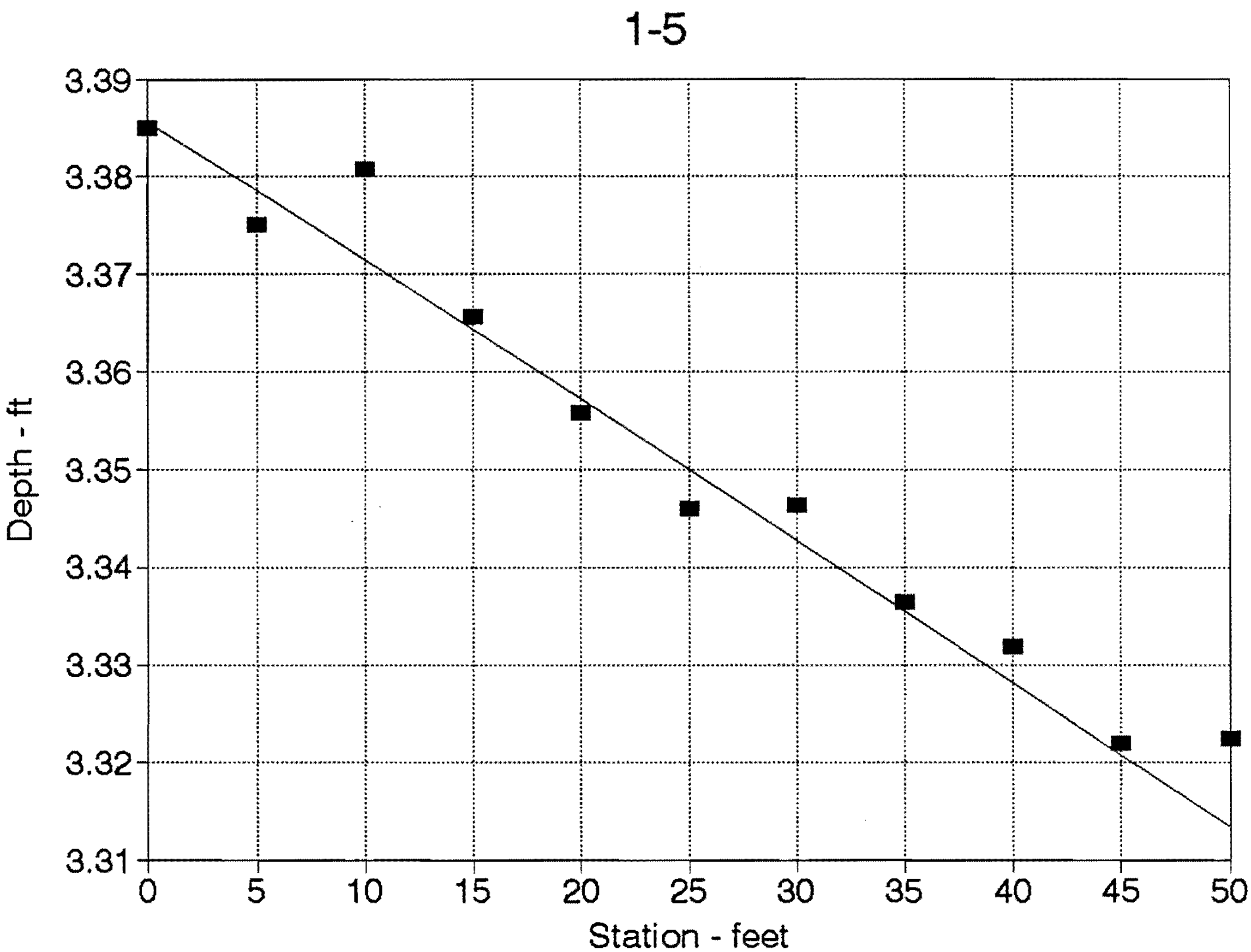
station	0	5	10	15	20	25	30	35	40	45	50
depth	3.384943	3.375047	3.380777	3.365672	3.355777	3.345881	3.346402	3.336506	3.331818	3.321922	3.322443
area	27.07955	27.00038	27.04621	26.92538	26.84621	26.76705	26.77121	26.69205	26.65455	26.57538	26.57955
perimeter	14.76989	14.75009	14.76155	14.73134	14.71155	14.69176	14.6928	14.67301	14.66364	14.64384	14.64489
Sf	0.001355	0.001366	0.001359	0.001376	0.001387	0.001398	0.001398	0.001409	0.001415	0.001426	0.001425
Froude	0.182518	0.183321	0.182855	0.184087	0.184902	0.185723	0.18568	0.186507	0.1869	0.187736	0.187692
dY		-0.00707	-0.00703	-0.00712	-0.00718	-0.00724	-0.00724	-0.0073	-0.00733	-0.00739	-0.00739
Y calc	3.384943	3.377877	3.370845	3.363723	3.356542	3.3493	3.342061	3.334762	3.327433	3.320042	3.312655
Y adj	3.385643	3.378577	3.371545	3.364423	3.357242	3.35	3.342761	3.335462	3.328133	3.320742	3.313355

Average depth = 3.35
Average velocity = 1.93
Average n = 0.043

Velocity Profile station 25 feet 1.2

Yo=	3.345881 ft			
V=	1.927744 fps			
Sf=	0.001398		Prandtl C	52.64119
Rh=	1.821909 ft		Prandtl n=	0.031197
V*=	0.286422 fps		Test n=	0.043
X=	1			
Ks=	1 ft		Ks/psi =	1751.171

elev	Y	V meas	Prandtl V
6	2.85	2.6	2.54
12	2.35	2.4	2.40
18	1.85	2.2	2.23
24	1.35	1.3	2.01
30	0.85	1	1.67
36	0.35	0.9	1.03
39	0.10	0.6	0.12
	0.00	0	0.00



1-5
3.39
3.38
3.37
3.36
3.35
3.34
3.33
3.32
3.31
Depth - ft
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 1-6
Date: 4-22-94
Plants: Dogwoods at 16" spacing

FLOW =	62.4	cfs			
dP =		inches between taps			
Drag =	20	micro inches	calibr=	40	micro-in / lbs
Drag =	0.5	lbs			

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
124.1875	124.6250	125.0000	124.8750	123.2500	122.6250	123.2500	123.5000	123.6250	124.5000	125.1875		
Average bottom elevation =		124.0568	feet									
Water surface elevations (inches)												
82.2500	82.3750	82.5000	82.5625	82.7500	82.8750	83.0625	83.1250	83.2500	83.3750	83.5625	83.2500	0.3125
82.2500	82.3438	82.4375	82.4688	82.6250	82.7188	82.8750	82.9063	83.0000	83.0938	83.2500		
Water depth (feet)												
3.4839	3.4761	3.4683	3.4657	3.4527	3.4448	3.4318	3.4292	3.4214	3.4136	3.4006		

Average depth =	3.44	feet	corrected depth u.s.=	3.483902	feet
Average area =	27.55	sf	corrected depth d.s.=	3.421402	feet
Average perim.=	14.89	feet	diff=	0.0625	feet
Average H.Radius=	1.85	feet			
Average E.slope=	0.0016				
Average n=	0.039099				
			intercept	3.444366	

n guess = 0.04

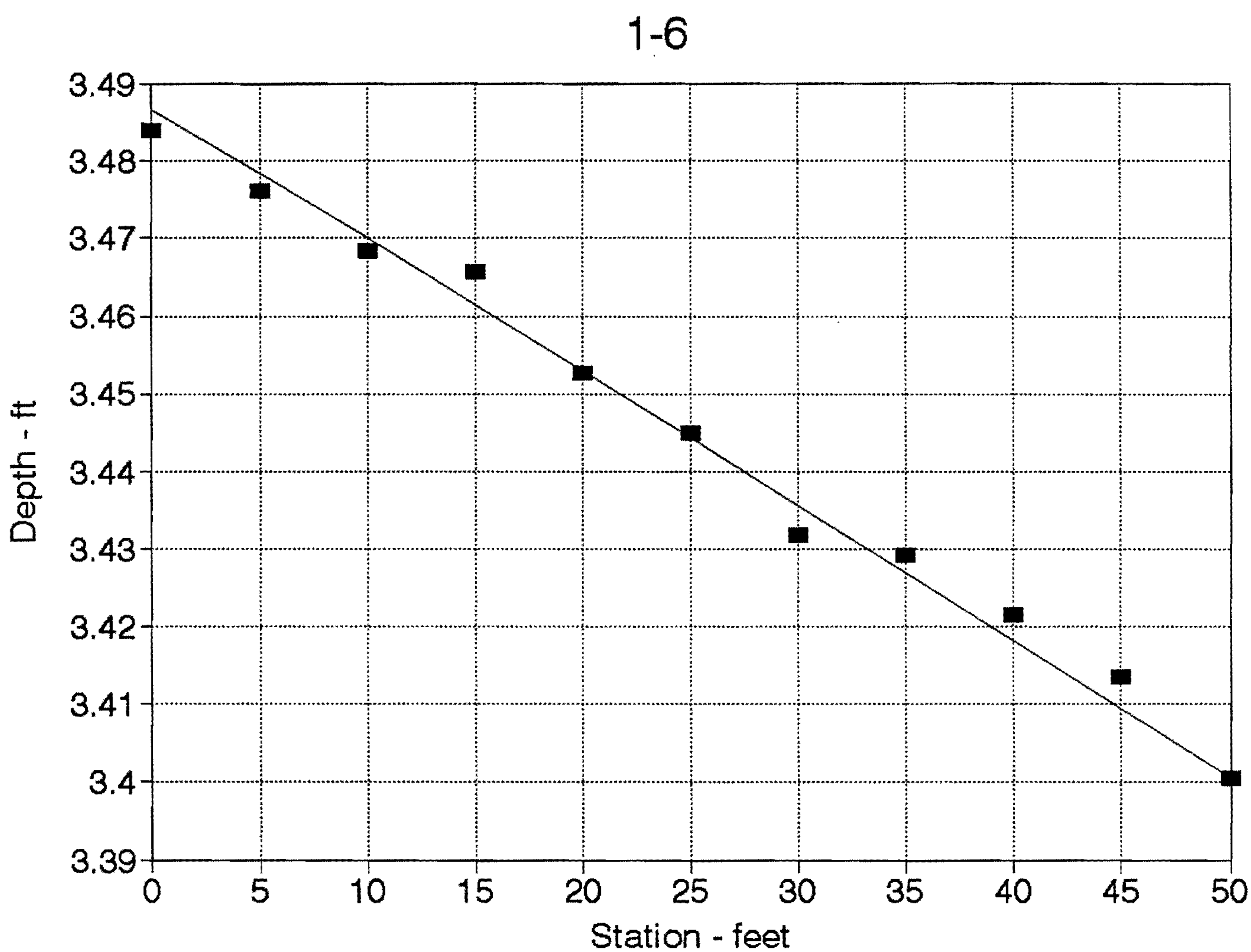
station	0	5	10	15	20	25	30	35	40	45	50
depth	3.483902	3.476089	3.468277	3.465672	3.452652	3.444839	3.431818	3.429214	3.421402	3.413589	3.400568
area	27.87121	27.80871	27.74621	27.72538	27.62121	27.55871	27.45455	27.43371	27.37121	27.30871	27.20455
perimeter	14.9678	14.95218	14.93655	14.93134	14.9053	14.88968	14.86364	14.85843	14.8428	14.82718	14.80114
Sf	0.001585	0.001595	0.001605	0.001608	0.001625	0.001635	0.001652	0.001655	0.001665	0.001676	0.001693
Froude	0.211382	0.212095	0.212812	0.213052	0.214258	0.214988	0.216212	0.216459	0.2172	0.217946	0.219199
dY		-0.00835	-0.00841	-0.00842	-0.00851	-0.00857	-0.00866	-0.00868	-0.00874	-0.0088	-0.00889
Y calc	3.483902	3.47555	3.467145	3.458722	3.450208	3.441639	3.432976	3.424294	3.415555	3.406759	3.397866
Y adj	3.486628	3.478277	3.469872	3.461449	3.452935	3.444366	3.435703	3.427021	3.418282	3.409486	3.400592

Average depth =	3.44
Average velocity =	2.26
Average n =	0.040

Velocity Profile station 25 feet vel. at plant center = 1.8 fps

Yo=	3.444839 ft			
V=	2.264257 fps			
Sf=	0.001635		Prandtl C	53.05422
Rh=	1.85086 ft		Prandtl n=	0.031036
V*=	0.312128 fps		Test n=	0.04
X=	1			
Ks=	1 ft		Ks/psi =	1908.339

elev	Y	V meas	Prandtl V
6	2.94	3.1	2.80
12	2.44	3.2	2.65
18	1.94	2.9	2.47
24	1.44	2	2.24
30	0.94	1.7	1.91
36	0.44	1.2	1.32
42	-0.06	0.5	ERR
48	-0.56	0	ERR
49	-0.64	0	ERR
	0	0	0



1-6
Depth - ft
3.49
3.48
3.47
3.46
3.45
3.44
3.43
3.42
3.41
3.4
3.39
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 1-7
Date: 4-22-94
Plants: Dogwoods at 16" spacing

FLOW = 40.6 cfs
dP = inches between taps
Drag = 31 micro inches calibr= 40 micro-in / lbs
Drag = 0.775 lbs

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		

Bottom elevations by transit reading (inches)

124.1875	124.6250	125.0000	124.8750	123.2500	122.6250	123.2500	123.5000	123.6250	124.5000	125.1875

Average bottom elevation = 124.0568 feet

Water surface elevations (inches)

100.8750	101.1875	101.4375	101.8750	102.1875	102.9375	103.2500	103.8750	103.8750	104.8750	105.1250	105.2500	-0.1250
100.8750	101.2000	101.4625	101.9125	102.2375	103.0000	103.3250	103.9625	103.9750	104.9875	105.2500		

Water depth (feet)

1.9318	1.9047	1.8829	1.8454	1.8183	1.7547	1.7277	1.6745	1.6735	1.5891	1.5672

Average depth = 1.76 feet corrected depth u.s.= 1.931818 feet
Average area = 14.09 sf corrected depth d.s.= 1.673485 feet
Average perim.= 11.52 feet diff= 0.258333 feet
Average H.Radius= 1.22 feet
Average E.slope= 0.0065
Average n= 0.047378
intercept 1.77

n guess = 0.048

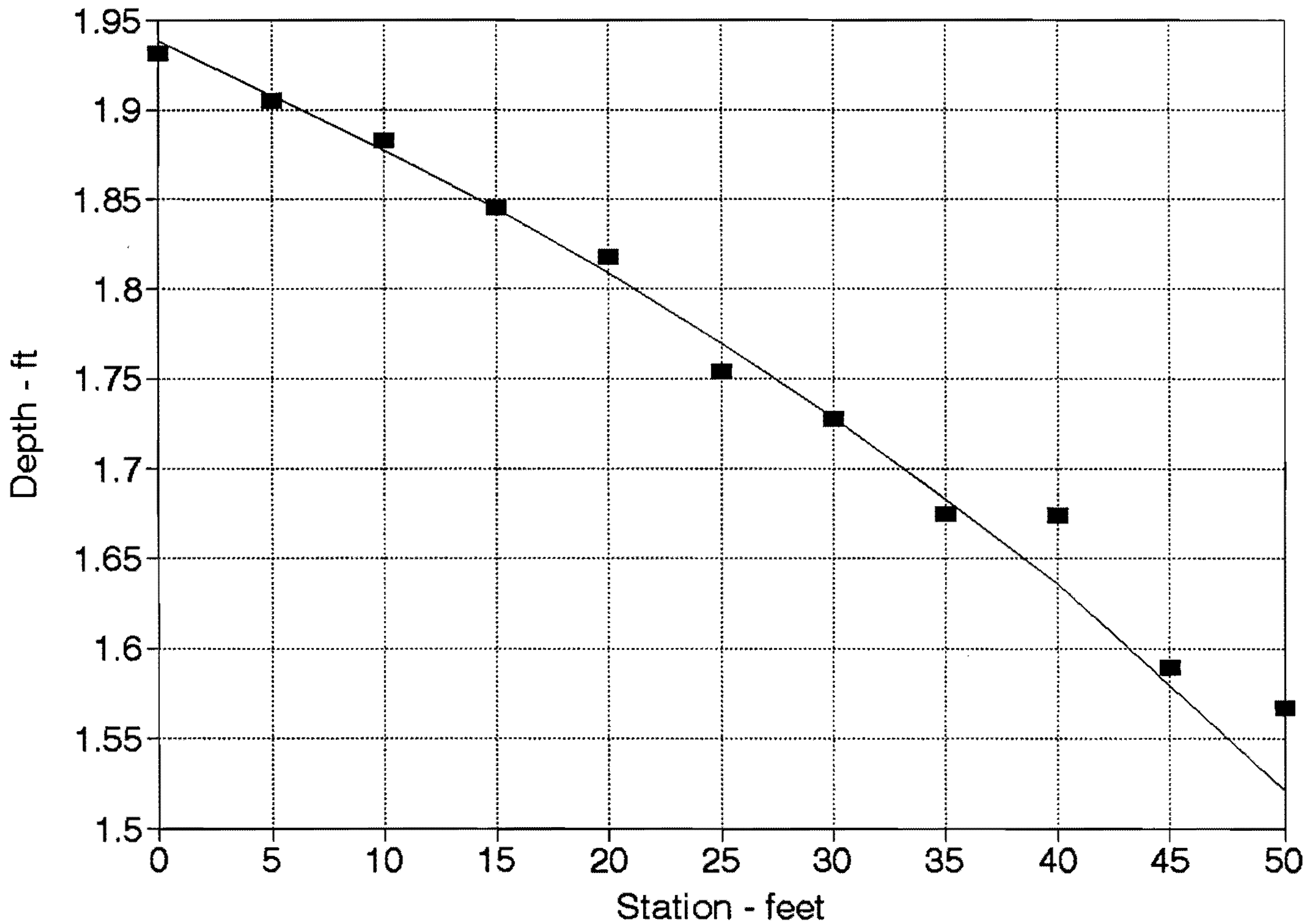
station	0	5	10	15	20	25	30	35	40	45	50
depth	1.931818	1.904735	1.88286	1.84536	1.818277	1.754735	1.727652	1.674527	1.673485	1.58911	1.567235
area	15.45455	15.23788	15.06288	14.76288	14.54621	14.03788	13.82121	13.39621	13.38788	12.71288	12.53788
perimeter	11.86364	11.80947	11.76572	11.69072	11.63655	11.50947	11.4553	11.34905	11.34697	11.17822	11.13447
Sf	0.005061	0.005273	0.005453	0.005782	0.006036	0.006697	0.007009	0.007683	0.007697	0.008964	0.009339
Froude	0.333088	0.340217	0.346163	0.356769	0.364769	0.384761	0.393844	0.412734	0.413119	0.446455	0.455834
dY		-0.02982	-0.03098	-0.03312	-0.03481	-0.03931	-0.04148	-0.0463	-0.0464	-0.05598	-0.05894
Y calc	1.931818	1.902002	1.871026	1.837902	1.803088	1.763783	1.722302	1.676002	1.6296	1.573621	1.514677
Y adj	1.938035	1.908219	1.877242	1.844118	1.809305	1.77	1.728518	1.682219	1.635816	1.579837	1.520894

Average depth = 1.76
Average velocity = 2.88
Average n = 0.048

Velocity Profile station 25 feet vel. at plant center = 3 fps
Yo= 1.754735 ft
V= 2.892175 fps
Sf= 0.006697 Prandtl C 43.49549
Rh= 1.219681 ft Prandtl n= 0.035314
V*= 0.512862 fps Test n= 0.048
X= 1
Ks= 1 ft Ks/psi = 3135.62

elev	Y	V meas	Prandtl V
6	1.25	3.7	3.50
12	0.75	2.5	2.85
18	0.25	2.4	1.46
24	-0.25	1.1	ERR
30	-0.75	0	ERR
36	-1.25	0	ERR
42	-1.75	0	ERR
48	-2.25	0	ERR
49	-2.33	0	ERR
	0	0	0

1-7



1.95
1.9
1.85
1.8
1.75
1.7
1.65
1.6
1.55
1.5
Depth - ft
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 1-8
Date: 4-22-94
Plants: Dogwoods at 16" spacing

FLOW =	61.1	cfs			
dP =	1.5	inches between taps			
Drag =	35	micro inches	calibr=	40	micro-in / lbs
Drag =	0.875	lbs			

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
124.1875	124.6250	125.0000	124.8750	123.2500	122.6250	123.2500	123.5000	123.6250	124.5000	125.1875		
Average bottom elevation =		124.0568	feet									
Water surface elevations (inches)												
94.0000	94.4375	94.7500	95.4375	96.1250	96.4375	96.9375	97.5000	97.7500	98.3750	98.6875	97.0000	1.6875
94.0000	94.2688	94.4125	94.9313	95.4500	95.5938	95.9250	96.3188	96.4000	96.8563	97.0000		
Water depth (feet)												
2.5047	2.4823	2.4704	2.4271	2.3839	2.3719	2.3443	2.3115	2.3047	2.2667	2.2547		

Average depth =	2.35	feet	corrected depth u.s.=	2.47036	feet
Average area =	18.79	sf	corrected depth d.s.=	2.266714	feet
Average perim.=	12.70	feet	diff=	0.203646	feet
Average H.Radius=	1.48	feet			
Average E.slope=	0.0058				
Average n=	0.045256				

n guess = 0.041

station	0	5	10	15	20	25	30	35	40	45	50
depth	2.504735	2.482339	2.47036	2.427131	2.383902	2.371922	2.344318	2.311506	2.304735	2.266714	2.254735
area	20.03788	19.85871	19.76288	19.41705	19.07121	18.97538	18.75455	18.49205	18.43788	18.13371	18.03788
perimeter	13.00947	12.96468	12.94072	12.85426	12.7678	12.74384	12.68864	12.62301	12.60947	12.53343	12.50947
Sf	0.003979	0.004081	0.004137	0.004349	0.004576	0.004642	0.004799	0.004995	0.005037	0.005281	0.005362
Froude	0.339532	0.344137	0.346643	0.355946	0.365671	0.368445	0.374972	0.382984	0.384673	0.394392	0.397539
dY		-0.02315	-0.02351	-0.0249	-0.02641	-0.02686	-0.02792	-0.02927	-0.02956	-0.03127	-0.03184
Y calc	2.504735	2.481587	2.458075	2.433175	2.406762	2.379906	2.351986	2.322717	2.293158	2.261887	2.230046
Y adj	2.517019	2.493872	2.47036	2.44546	2.419047	2.392191	2.36427	2.335002	2.305443	2.274172	2.24233

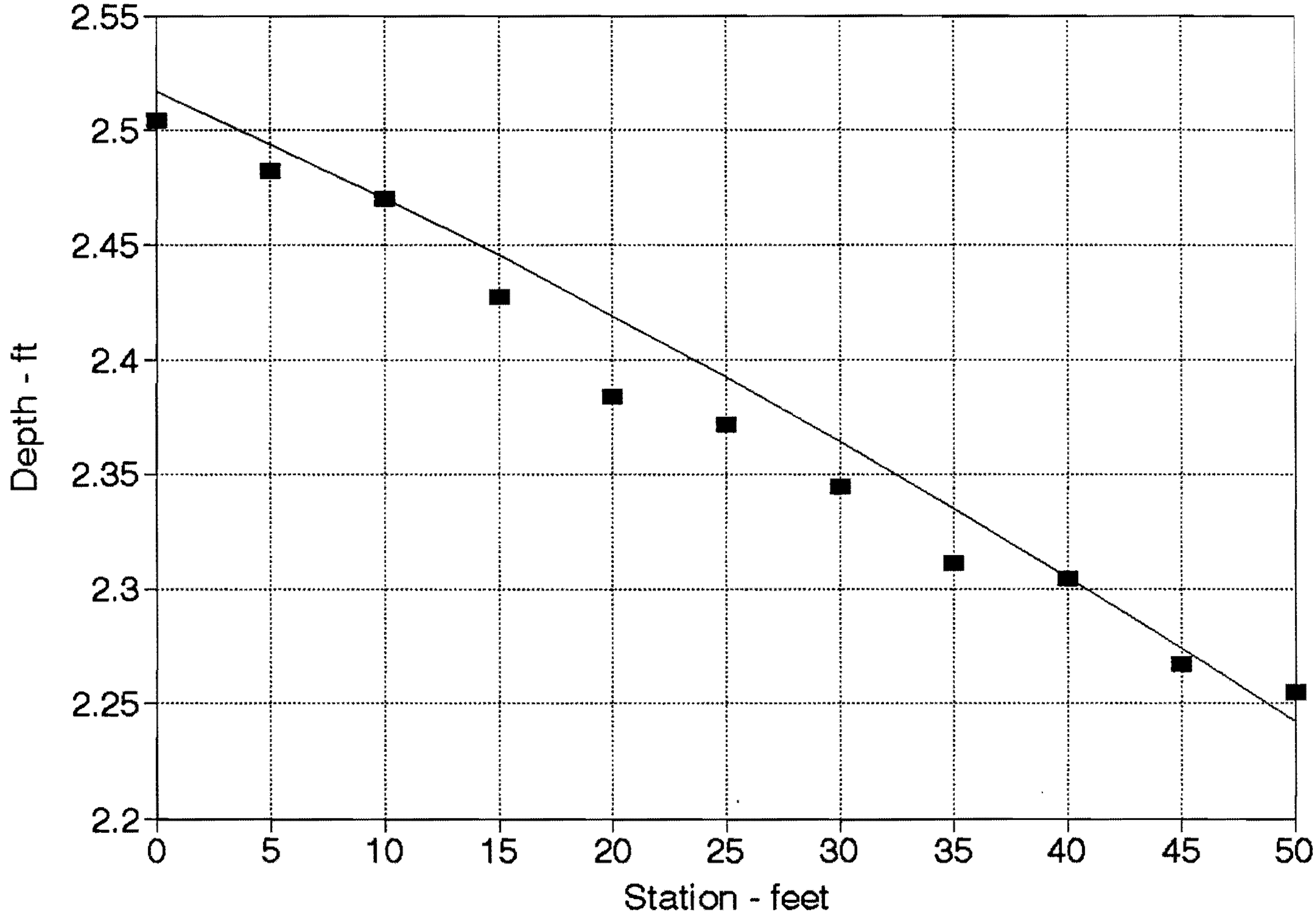
Average depth =	2.35
Average velocity =	3.25
Average n =	0.041

Velocity Profile station 25 feet vel. at plant center = 3.2 fps

Yo=	2.371922 ft			
V=	3.219962 fps			
Sf=	0.004642		Prandtl C	47.76618
Rh=	1.488984 ft		Prandtl n=	0.033244
V* =	0.471768 fps		Test n=	0.041
X=	1			
Ks=	1 ft		Ks/psi =	2884.374

elev	Y	V meas	Prandtl V
6	1.87	4.6	3.69
12	1.37	3.5	3.33
18	0.87	3	2.79
24	0.37	2.2	1.79
30	-0.13	1.5	ERR
36	-0.63	0	ERR
42	-1.13	0	ERR
48	-1.63	0	ERR
49	-1.71	0	ERR
	0	0	0

1-8


2.55
2.5
2.45
2.4
2.35
2.3
2.25
2.2
Depth - ft
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 1-9
Date: 4-22-94
Plants: Dogwoods at 16" spacing

FLOW = 83.5 cfs
dP = inches between taps
Drag = 30 micro inches calibr= 40 micro-in / lbs
Drag = 0.75 lbs

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
124.1875	124.6250	125.0000	124.8750	123.2500	122.6250	123.2500	123.5000	123.6250	124.5000	125.1875		
Average bottom elevation =		124.0568 feet										
Water surface elevations (inches)												
87.8750	88.6250	89.2500	89.6250	90.5000	90.9375	91.2500	91.9375	93.3750	93.6250	94.0000	90.1875	3.8125
87.8750	88.2438	88.4875	88.4813	88.9750	89.0313	88.9625	89.2688	90.3250	90.1938	90.1875		
Water depth (feet)												
3.0152	2.9844	2.9641	2.9646	2.9235	2.9188	2.9245	2.8990	2.8110	2.8219	2.8224		

Average depth = 2.91 feet corrected depth u.s.= 3.015152 feet
Average area = 23.31 sf corrected depth d.s.= 2.810985 feet
Average perim.= 13.83 feet diff= 0.204167 feet
Average H.Radius= 1.69 feet
Average E.slope= 0.0051
Average n= 0.041976
intercept 2.913589

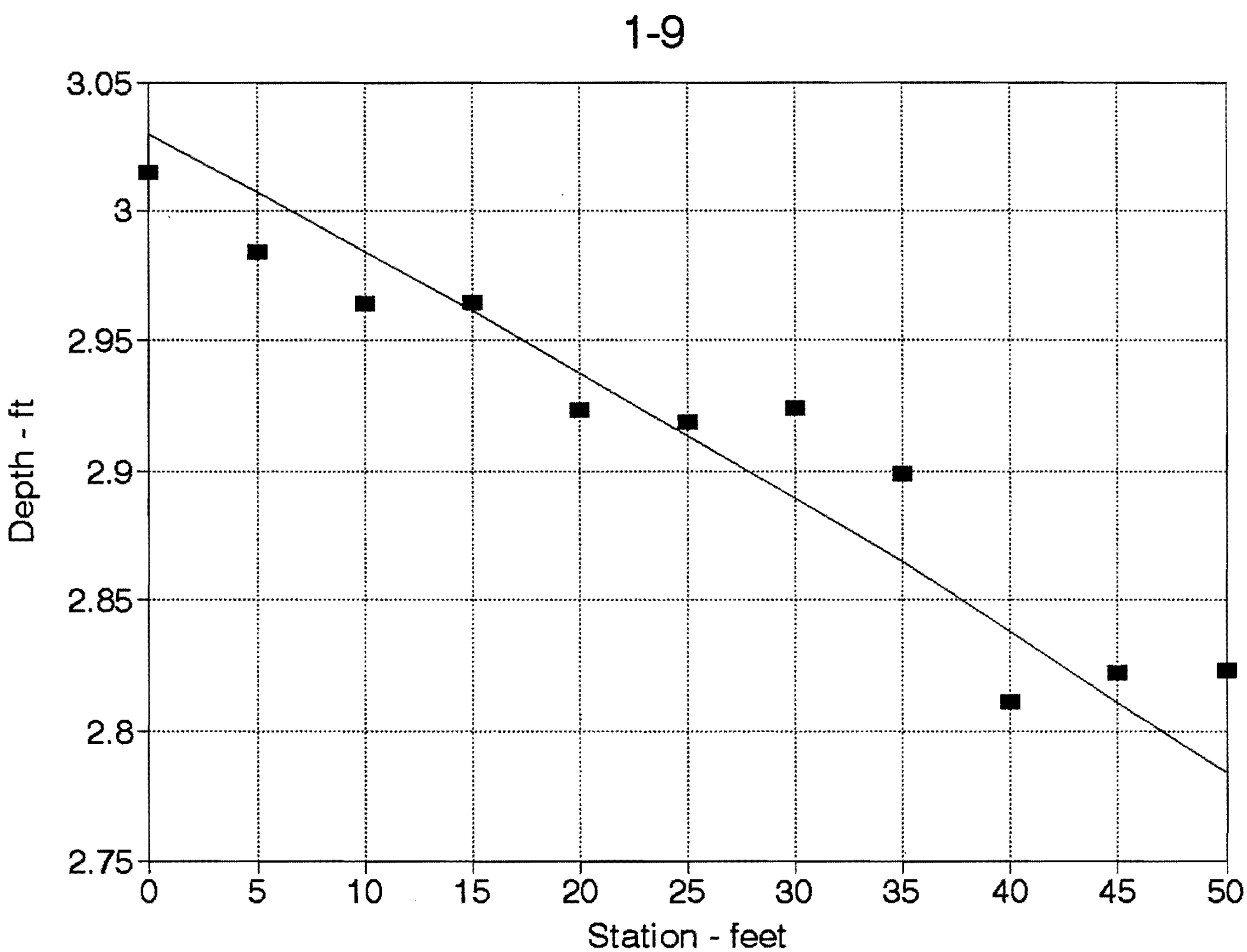
n guess = 0.038

station	0	5	10	15	20	25	30	35	40	45	50
depth	3.015152	2.984422	2.96411	2.964631	2.923485	2.918797	2.924527	2.899006	2.810985	2.821922	2.822443
area	24.12121	23.87538	23.71288	23.71705	23.38788	23.35038	23.39621	23.19205	22.48788	22.57538	22.57955
perimeter	14.0303	13.96884	13.92822	13.92926	13.84697	13.83759	13.84905	13.79801	13.62197	13.64384	13.64489
Sf	0.003805	0.003914	0.003989	0.003987	0.004144	0.004162	0.00414	0.004242	0.004621	0.004571	0.004569
Froude	0.351322	0.356762	0.360435	0.36034	0.367974	0.368861	0.367778	0.372645	0.390284	0.388017	0.38791
dY		-0.02242	-0.02292	-0.02291	-0.02396	-0.02409	-0.02394	-0.02463	-0.02726	-0.02691	-0.02689
Y calc	3.015152	2.992728	2.969807	2.9469	2.922935	2.898846	2.87491	2.850282	2.823026	2.796118	2.769227
Y adj	3.029894	3.00747	2.98455	2.961642	2.937678	2.913589	2.889652	2.865025	2.837768	2.810861	2.78397

Average depth = 2.91
Average velocity = 3.58
Average n = 0.038

Velocity Profile station 25 feet vel. at plant center = 3.7 fps
Yo= 2.918797 ft
V= 3.575959 fps
Sf= 0.004162 Prandtl C 50.70612
Rh= 1.887459 ft Prandtl n= 0.031976
V*= 0.475568 fps Test n= 0.038
X= 1
Ks= 1 ft Ks/psi = 2907.609

elev	Y	V meas	Prandtl V
6	2.42	5	4.03
12	1.92	4.9	3.75
18	1.42	3.9	3.39
24	0.92	3.2	2.88
30	0.42	2.2	1.94
36	-0.08	0.9	ERR
42	-0.58	0	ERR
48	-1.08	0	ERR
49	-1.16	0	ERR
	0	0	0


1-9
3.05
3
2.95
2.9
2.85
2.8
2.75
Depth - ft
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 2-1
Date: 4-23-94
Plants: Dogwoods at 16" spacing with 50% of plants removed

FLOW =	89.5	cfs			
dP =		inches between taps			
Drag =	11	micro inches	calibr=	40	micro-in / lbs
Drag =	0.275	lbs			

Stations from upstream end of test section (feet)

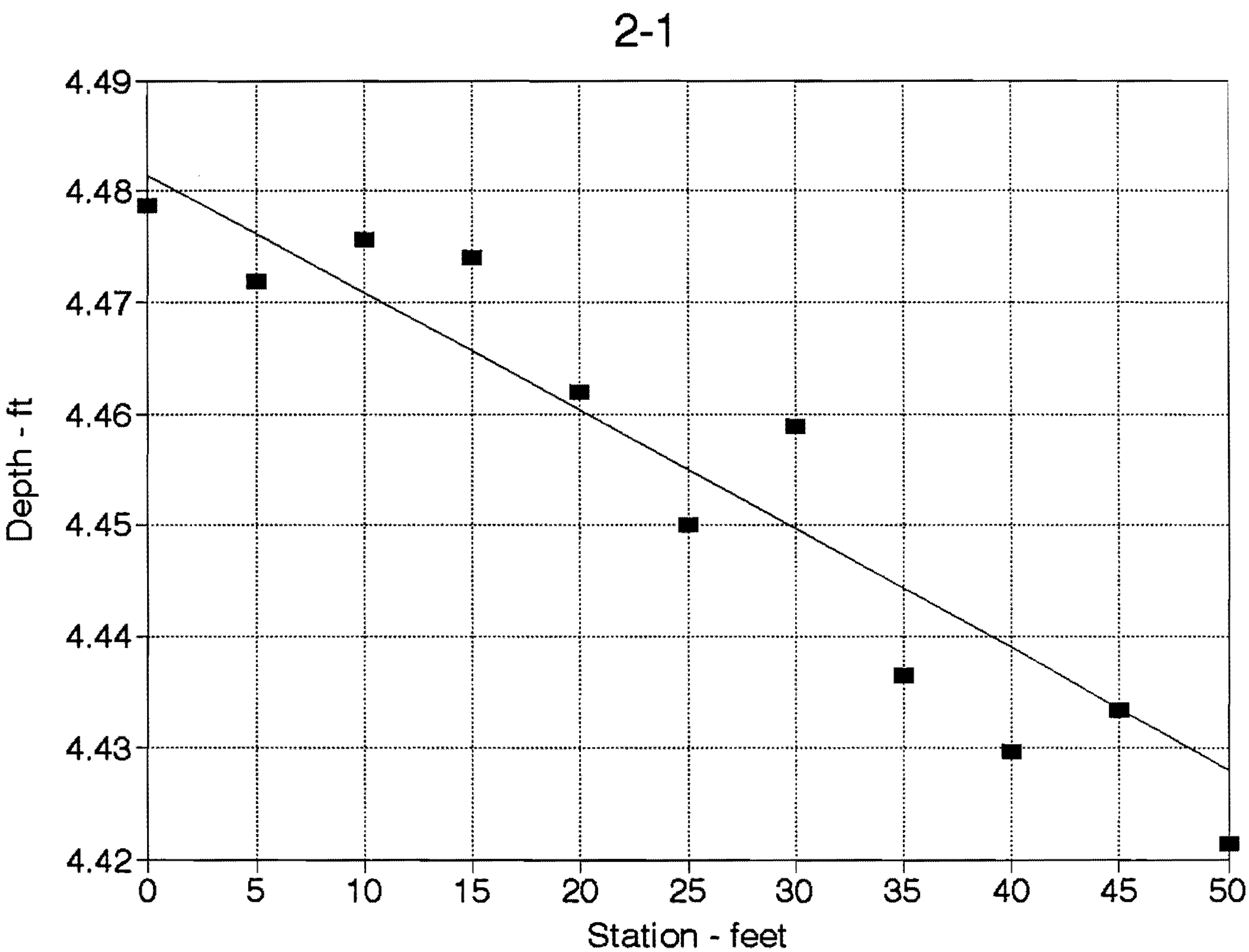
0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
124.1875	124.6250	125.0000	124.8750	123.2500	122.6250	123.2500	123.5000	123.6250	124.5000	125.1875		
Average bottom elevation =			124.0568	feet								
Water surface elevations (inches)												
70.3125	70.8125	71.1875	71.6250	72.1875	72.7500	73.0625	73.7500	74.2500	74.6250	75.1875	71.0000	4.1875
70.3125	70.3938	70.3500	70.3688	70.5125	70.6563	70.5500	70.8188	70.9000	70.8563	71.0000		
Water depth (feet)												
4.4787	4.4719	4.4756	4.4740	4.4620	4.4500	4.4589	4.4365	4.4297	4.4334	4.4214		

Average depth =	4.45	feet	corrected depth u.s.=	4.475568	feet
Average area =	35.59	sf	corrected depth d.s.=	4.433381	feet
Average perim.=	16.90	feet	diff=	0.042188	feet
Average H.Radius=	2.11	feet			
Average E.slope=	0.0012				
Average n=	0.033713				
			intercept	4.455	

n guess = 0.031

station	0	5	10	15	20	25	30	35	40	45	50
depth	4.478693	4.471922	4.475568	4.474006	4.462027	4.450047	4.458902	4.436506	4.429735	4.433381	4.421402
area	35.82955	35.77538	35.80455	35.79205	35.69621	35.60038	35.67121	35.49205	35.43788	35.46705	35.37121
perimeter	16.95739	16.94384	16.95114	16.94801	16.92405	16.90009	16.9178	16.87301	16.85947	16.86676	16.8428
Sf	0.001002	0.001006	0.001003	0.001004	0.001011	0.001019	0.001013	0.001027	0.001031	0.001029	0.001036
Froude	0.208007	0.20848	0.208225	0.208334	0.209174	0.210019	0.209394	0.210981	0.211465	0.211204	0.212063
dY		-0.00526	-0.00524	-0.00525	-0.00529	-0.00533	-0.0053	-0.00537	-0.0054	-0.00538	-0.00542
Y calc	4.478693	4.473437	4.468193	4.462943	4.457655	4.452327	4.447028	4.441655	4.436259	4.430875	4.425451
Y adj	4.481366	4.47611	4.470866	4.465616	4.460328	4.455	4.449701	4.444328	4.438932	4.433548	4.428124

Average depth =	4.45
Average velocity =	2.51
Average n =	0.031


2-1
4.49
4.48
4.47
4.46
4.45
4.44
4.43
4.42
Depth - ft
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 2-2

Date: 4-23-94

Plants: Dogwoods at 16" spacing with 50% of plants removed

FLOW = 91.5 cfs

dP = inches between taps

Drag = 43 micro inches calibr= 40 micro-in / lbs

Drag = 1.075 lbs

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
124.1875	124.6250	125.0000	124.8750	123.2500	122.6250	123.2500	123.5000	123.6250	124.5000	125.1875		
Average bottom elevation =		124.0568	feet									
Water surface elevations (inches)												
77.8750	78.0000	78.2500	78.5000	78.5000	78.7500	78.8750	79.0000	79.0000	79.1250	79.0625	79.0625	0.0000
77.8750	78.0000	78.2500	78.5000	78.5000	78.7500	78.8750	79.0000	79.0000	79.1250	79.0625		
Water depth (feet)												
3.8485	3.8381	3.8172	3.7964	3.7964	3.7756	3.7652	3.7547	3.7547	3.7443	3.7495		

Average depth = 3.77 feet   corrected depth u.s.= 3.817235 feet

Average area = 30.18 sf   corrected depth d.s.= 3.744318 feet

Average perim.= 15.55 feet   diff= 0.072917 feet

Average H.Radius= 1.94 feet

Average E.slope= 0.0021

Average n= 0.034818

intercept 3.79

n guess = 0.031

station	0	5	10	15	20	25	30	35	40	45	50
depth	3.848485	3.838068	3.817235	3.796402	3.796402	3.775568	3.765152	3.754735	3.754735	3.744318	3.749527
area	30.78788	30.70455	30.53788	30.37121	30.37121	30.20455	30.12121	30.03788	30.03788	29.95455	29.99621
perimeter	15.69697	15.67614	15.63447	15.5928	15.5928	15.55114	15.5303	15.50947	15.50947	15.48864	15.49905
Sf	0.001566	0.001577	0.0016	0.001624	0.001624	0.001648	0.00166	0.001673	0.001673	0.001685	0.001679
Froude	0.266974	0.268061	0.270259	0.272486	0.272486	0.274745	0.275886	0.277035	0.277035	0.278192	0.277612
dY		-0.0085	-0.00863	-0.00877	-0.00877	-0.00891	-0.00899	-0.00906	-0.00906	-0.00913	-0.0091
Y calc	3.848485	3.839989	3.831358	3.822587	3.813817	3.804904	3.795918	3.786859	3.7778	3.768667	3.759571
Y adj	3.833581	3.825086	3.816454	3.807684	3.798913	3.79	3.781014	3.771956	3.762897	3.753763	3.744668

Average depth = 3.77

Average velocity = 3.03

Average n = 0.031

Velocity Profile station 25 feet   vel. at plant center = 2.9 fps

Yo= 3.775568 ft

V= 3.029345 fps

Sf= 0.001648   Prandtl C 54.35327

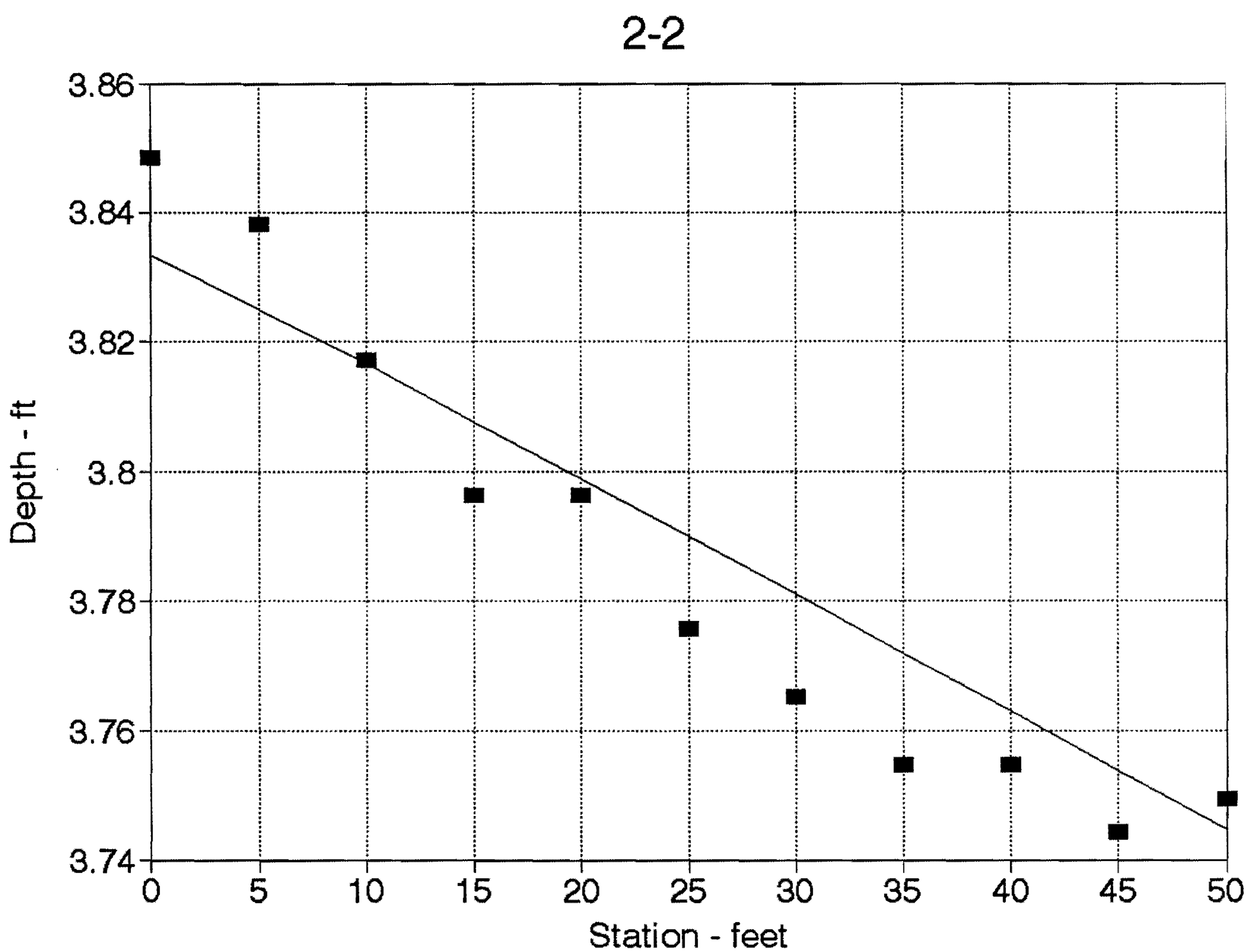
Rh= 1.942273 ft   Prandtl n= 0.030538

V*= 0.321046 fps   Test n= 0.031

X= 1

Ks= 1 ft   Ks/psi = 1962.867

elev	Y	V meas	Prandtl V
6	3.28	4	2.96
12	2.78	3.7	2.83
18	2.28	3.6	2.67
24	1.78	3.4	2.47
30	1.28	3.1	2.21
36	0.78	1.8	1.81
42	0.28	0.9	0.98
48	-0.22	0.4	ERR
49	-0.31	0	ERR
	0	0	0


2-2
3.86
3.84
3.82
3.8
3.78
3.76
3.74
Depth - ft
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 2-3
Date: 4-23-94
Plants: Dogwoods at 16" spacing with 50% of plants removed

FLOW = 46.8 cfs
dP = inches between taps
Drag = 35 micro inches calibr= 40 micro-in / lbs
Drag = 0.875 lbs

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
124.1875	124.6250	125.0000	124.8750	123.2500	122.6250	123.2500	123.5000	123.6250	124.5000	125.1875		
Average bottom elevation =		124.0568	feet									
Water surface elevations (inches)												
101.3125	101.7500	102.0625	102.3750	102.8750	103.2500	103.8125	104.5625	105.0625	105.1250	105.5625	105.5000	0.0625
101.3125	101.7438	102.0500	102.3563	102.8500	103.2188	103.7750	104.5188	105.0125	105.0688	105.5000		
Water depth (feet)												
1.8954	1.8594	1.8339	1.8084	1.7672	1.7365	1.6902	1.6282	1.5870	1.5823	1.5464		

Average depth =	1.69	feet	corrected depth u.s.=	1.833902	feet
Average area =	13.49	sf	corrected depth d.s.=	1.582339	feet
Average perim. =	11.37	feet	diff=	0.251562	feet
Average H.Radius=	1.19	feet			
Average E.slope=	0.0072				
Average n=	0.040707				
			intercept	1.74	

n guess = 0.04

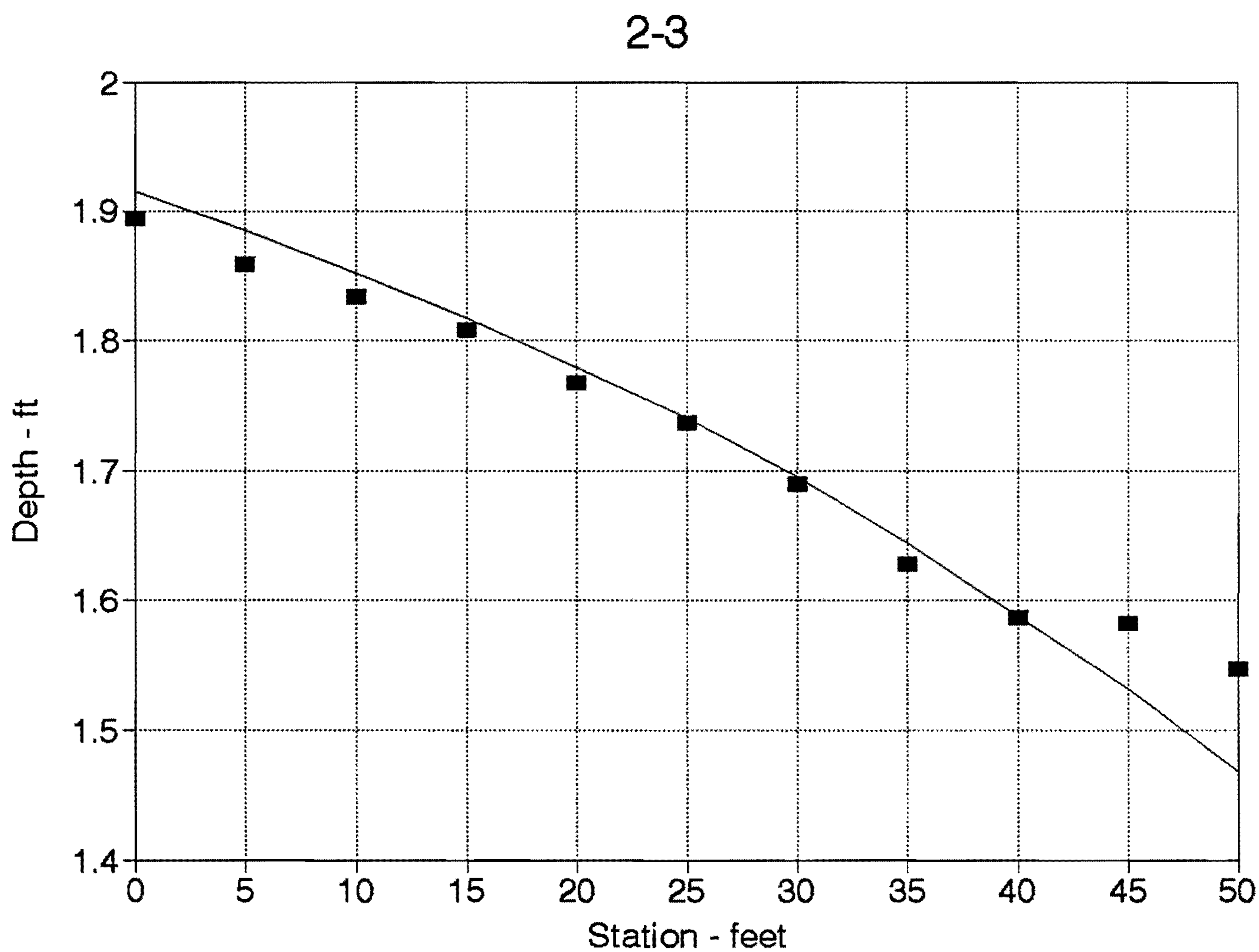
station	0	5	10	15	20	25	30	35	40	45	50
depth	1.89536	1.859422	1.833902	1.808381	1.767235	1.736506	1.690152	1.628172	1.587027	1.582339	1.546402
area	15.16288	14.87538	14.67121	14.46705	14.13788	13.89205	13.52121	13.02538	12.69621	12.65871	12.37121
perimeter	11.79072	11.71884	11.6678	11.61676	11.53447	11.47301	11.3803	11.25634	11.17405	11.16468	11.0928
Sf	0.004936	0.005218	0.005433	0.005659	0.006053	0.006372	0.006898	0.0077	0.008304	0.008377	0.008966
Froude	0.395085	0.406594	0.415111	0.423929	0.43882	0.45052	0.46918	0.496224	0.515646	0.517939	0.536098
dY		-0.03126	-0.03282	-0.0345	-0.03748	-0.03997	-0.04423	-0.05107	-0.05656	-0.05724	-0.06291
Y calc	1.89536	1.864101	1.831283	1.796787	1.759306	1.719334	1.675109	1.624034	1.567477	1.510239	1.44733
Y adj	1.916026	1.884766	1.851948	1.817453	1.779972	1.74	1.695774	1.6447	1.588143	1.530905	1.467996

Average depth = 1.69
Average velocity = 3.47
Average n = 0.040

Velocity Profile station 25 feet vel. at plant center = 4.4 fps

Yo=	1.736506 ft			
V=	3.368834 fps			
Sf=	0.006372		Prandtl C	43.34751
Rh=	1.210846 ft		Prandtl n=	0.035392
V*=	0.498426 fps		Test n=	0.04
X=	1			
Ks=	1 ft		Ks/psi =	3047.358

elev	Y	V meas	Prandtl V
6	1.24	4.8	3.38
12	0.74	4.3	2.74
18	0.24	2.8	1.33
24	-0.26	1.3	ERR
30	-0.76	1.9	ERR
36	-1.26	1.3	ERR
42	-1.76	0.8	ERR
48	-2.26	0.7	ERR
49	-2.35	0.5	ERR
	0	0	0


2-3
Depth - ft
2
1.9
1.8
1.7
1.6
1.5
1.4
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 2-4

Date: 4-23-94

Plants: Dogwoods at 16" spacing with 50% of plants removed

FLOW =	25.6	cfs			
dP =		inches between taps			
Drag =	43	micro inches	calibr=	40	micro-in / lbs
Drag =	1.075	lbs			

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
124.1875	124.6250	125.0000	124.8750	123.2500	122.6250	123.2500	123.5000	123.6250	124.5000	125.1875		
Average bottom elevation =		124.0568	feet									
Water surface elevations (inches)												
106.7500	107.0625	107.1875	107.3125	107.8750	107.8750	108.1250	108.6250	109.0000	109.1875	109.5000	109.7500	-0.2500
106.7500	107.0875	107.2375	107.3875	107.9750	108.0000	108.2750	108.8000	109.2000	109.4125	109.7500		
Water depth (feet)												
1.4422	1.4141	1.4016	1.3891	1.3402	1.3381	1.3152	1.2714	1.2381	1.2204	1.1922		

Average depth =	1.30	feet	corrected depth u.s.=	1.40161	feet
Average area =	10.41	sf	corrected depth d.s.=	1.22036	feet
Average perim.=	10.60	feet	diff=	0.18125	feet
Average H.Radius=	0.98	feet			
Average E.slope=	0.0052				
Average n=	0.042928				
			intercept	1.34	

n guess = 0.042

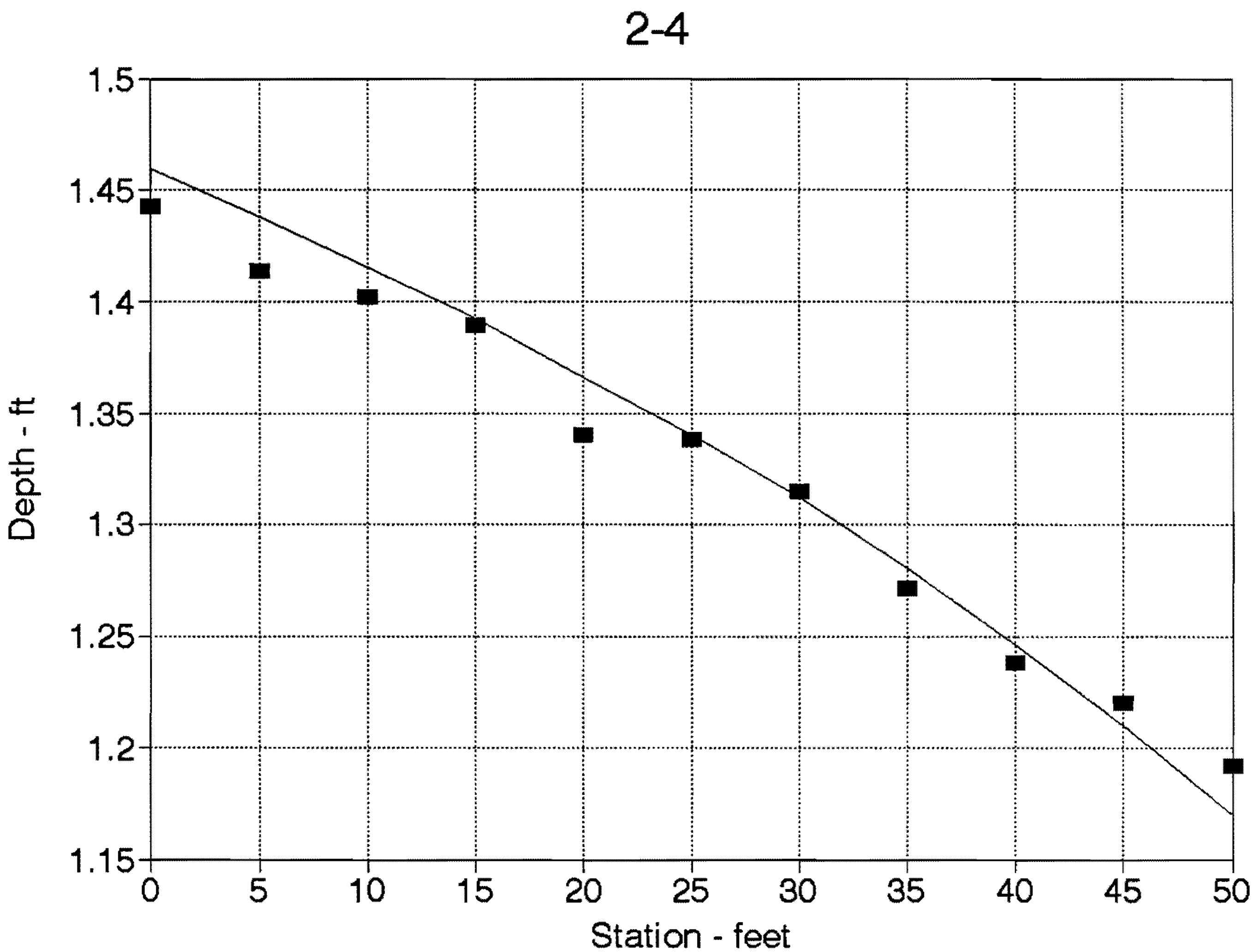
station	0	5	10	15	20	25	30	35	40	45	50
depth	1.442235	1.41411	1.40161	1.38911	1.340152	1.338068	1.315152	1.271402	1.238068	1.22036	1.192235
area	11.53788	11.31288	11.21288	11.11288	10.72121	10.70455	10.52121	10.17121	9.904545	9.762879	9.537879
perimeter	10.88447	10.82822	10.80322	10.77822	10.6803	10.67614	10.6303	10.5428	10.47614	10.44072	10.38447
Sf	0.003639	0.003859	0.003962	0.00407	0.004531	0.004553	0.004795	0.005309	0.005751	0.006007	0.006446
Froude	0.325588	0.335349	0.339845	0.344443	0.363489	0.364338	0.373902	0.393367	0.40936	0.418302	0.433191
dY		-0.02174	-0.0224	-0.02309	-0.02611	-0.02625	-0.02787	-0.0314	-0.03455	-0.0364	-0.03967
Y calc	1.442235	1.420497	1.398098	1.375009	1.348903	1.322655	1.294784	1.263382	1.228837	1.192433	1.152758
Y adj	1.45958	1.437842	1.415443	1.392354	1.366247	1.34	1.312129	1.280727	1.246182	1.209777	1.170103

Average depth =	1.30
Average velocity =	2.46
Average n =	0.042

Velocity Profile station 25 feet vel. at plant center = 3.2 fps

Yo=	1.338068	ft		
V=	2.391507	fps		
Sf=	0.004553		Prandtl C	39.65404
Rh=	1.002661	ft	Prandtl n=	0.037491
V*=	0.383387	fps	Test n=	0.042
X=	1			
Ks=	1	ft	Ks/psi =	2344.017

elev	Y	V meas	Prandtl V
6	0.84	2.9	2.23
12	0.34	2.2	1.36
18	-0.16	1.3	ERR
24	-0.66	2.3	ERR
30	-1.16	1.9	ERR
36	-1.66	1.3	ERR
42	-2.16	0.8	ERR
48	-2.66	0.7	ERR
49	-2.75	0.5	ERR
	0	0	0



2-4
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
Depth - ft
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 3-1
Date: 5-6-94
Plants: Elderberry at 18" spacing & 24" rows

FLOW =	30.5	cfs		
dP =		inches between taps		
Drag =	9	micro inches	calibr=	200 micro-in / lbs
Drag =	0.045	lbs		

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
123.5000	123.2500	123.6875	122.7500	122.8125	122.3750	122.8125	122.1250	122.5625	122.6250	122.7500		
Average bottom elevation =		122.8409	feet									
Water surface elevations (inches)												
75.2500	75.2500	75.2500	75.2813	75.2813	75.3125	75.3125	75.3125	75.3438	75.3438	75.3750	75.4375	-0.0625
75.2500	75.2563	75.2625	75.3000	75.3063	75.3438	75.3500	75.3563	75.3938	75.4000	75.4375		
Water depth (feet)												
3.9659	3.9654	3.9649	3.9617	3.9612	3.9581	3.9576	3.9571	3.9539	3.9534	3.9503		

Average depth =	3.96	feet	corrected depth u.s. =	3.965909	feet
Average area =	31.67	sf	corrected depth d.s. =	3.95393	feet
Average perim. =	15.92	feet	diff=	0.011979	feet
Average H.Radius=	1.99	feet			
Average E.slope=	0.0003				
Average n=	0.042245				
			intercept	3.959044	

n guess = 0.042

station	0	5	10	15	20	25	30	35	40	45	50
depth	3.965909	3.965388	3.964867	3.961742	3.961222	3.958097	3.957576	3.957055	3.95393	3.953409	3.950284
area	31.72727	31.72311	31.71894	31.69394	31.68977	31.66477	31.66061	31.65644	31.63144	31.62727	31.60227
perimeter	15.93182	15.93078	15.92973	15.92348	15.92244	15.91619	15.91515	15.91411	15.90786	15.90682	15.90057
Sf	0.000295	0.000295	0.000295	0.000295	0.000296	0.000296	0.000296	0.000296	0.000297	0.000297	0.000298
Froude	0.085068	0.085085	0.085102	0.085203	0.085219	0.08532	0.085337	0.085354	0.085455	0.085472	0.085574
dY		-0.00148	-0.00149	-0.00149	-0.00149	-0.00149	-0.00149	-0.00149	-0.0015	-0.0015	-0.0015
Y calc	3.965909	3.964425	3.96294	3.961451	3.959963	3.958471	3.956978	3.955485	3.953989	3.952493	3.950993
Y adj	3.966482	3.964997	3.963512	3.962024	3.960535	3.959044	3.957551	3.956058	3.954562	3.953065	3.951566

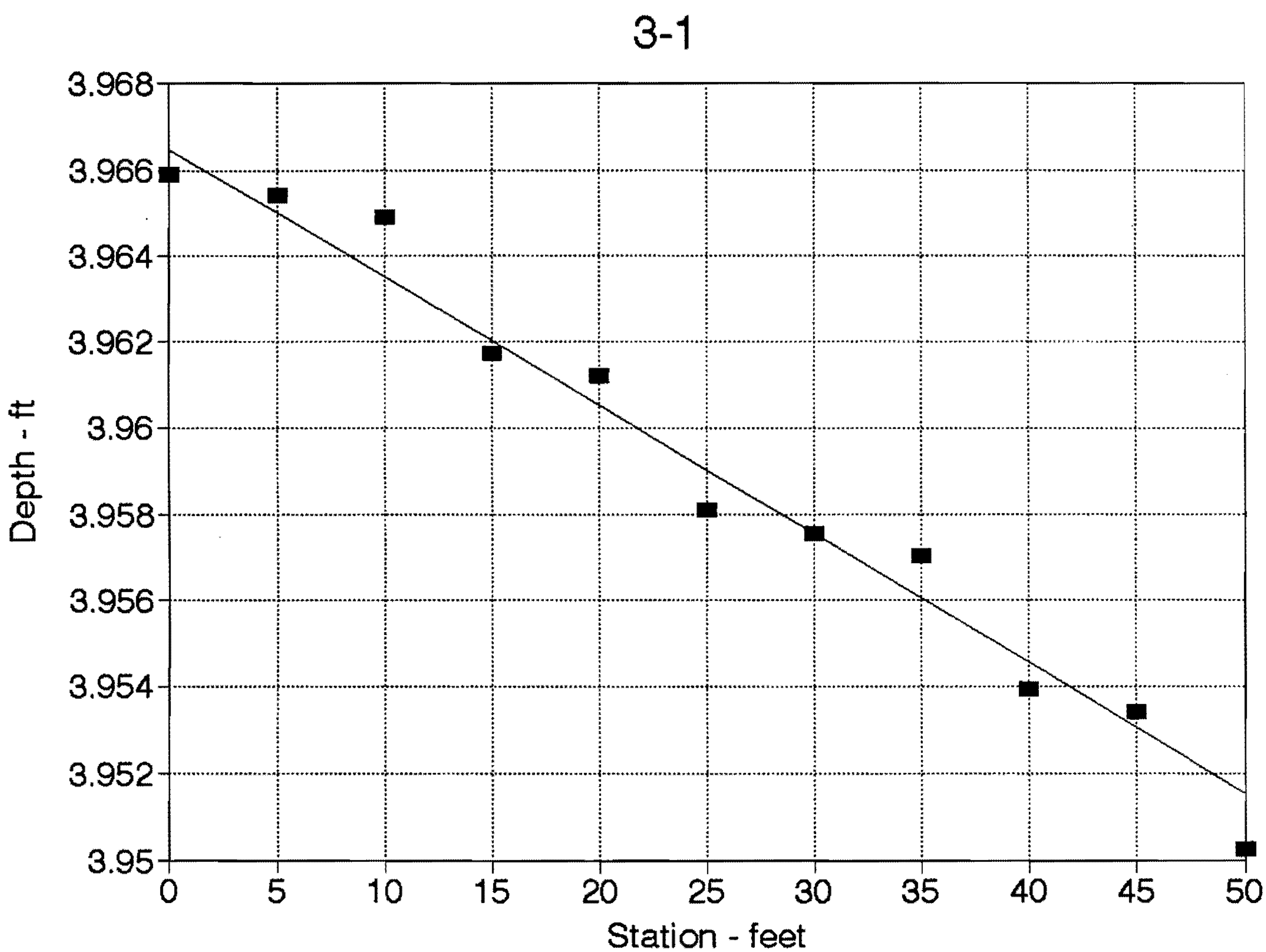
Average depth =	3.959	Average n =	0.042
Average velocity =	0.963	n bed =	0.064
		R bed =	3.720

n
0.042

Velocity Profile station 25 feet vel. at plant center = 0.6 fps

Yo=	3.958097	ft		
V=	0.963216	fps		
Sf=	0.000296		Prandtl C	55.02228
Rh=	1.989469	ft	Prandtl n=	0.030288
V*=	0.13775	fps	Test n=	0.042
X=	1			
Ks=	1	ft	Ks/psi =	842.2

elev	Y	V meas	Prandtl V
3	3.71	1.15	1.31
6	3.46	1.1	1.29
9	3.21	1.1	1.26
12	2.96	1.15	1.24
15	2.71	1.2	1.21
18	2.46	1.2	1.17
21	2.21	1.1	1.13
24	1.96	0.9	1.09
27	1.71	0.9	1.05
30	1.46	0.6	0.99
33	1.21	0.6	0.93
36	0.96	0.6	0.85
39	0.71	0.6	0.74


3-1
Depth - ft
3.968
3.966
3.964
3.962
3.96
3.958
3.956
3.954
3.952
3.95
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 3-2
Date: 5-6-94
Plants: Elderberry at 18" spacing & 24" rows

FLOW =	40.5	cfs			
dP =		inches between taps			
Drag =	10	micro inches	calibr=	200	micro-in / lbs
Drag =	0.05	lbs			

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
123.5000	123.2500	123.6875	122.7500	122.8125	122.3750	122.8125	122.1250	122.5625	122.6250	122.7500		
Average bottom elevation =		122.8409	feet									
Water surface elevations (inches)												
84.0000	84.2500	84.3750	84.5000	84.6875	84.8125	84.9375	85.1250	85.2500	85.5000	85.6250	84.2500	1.3750
84.0000	84.1125	84.1000	84.0875	84.1375	84.1250	84.1125	84.1625	84.1500	84.2625	84.2500		
Water depth (feet)												
3.2367	3.2274	3.2284	3.2295	3.2253	3.2263	3.2274	3.2232	3.2242	3.2149	3.2159		

Average depth =	3.23	feet	corrected depth u.s.=	3.236742	feet
Average area =	25.80	sf	corrected depth d.s.=	3.224242	feet
Average perim.=	14.45	feet	diff=	0.0125	feet
Average H.Radius=	1.79	feet			
Average E.slope=	0.0003				
Average n=	0.024633				
			intercept	3.225379	

n guess = 0.035

station	0	5	10	15	20	25	30	35	40	45	50
depth	3.236742	3.227367	3.228409	3.229451	3.225284	3.226326	3.227367	3.223201	3.224242	3.214867	3.215909
area	25.89394	25.81894	25.82727	25.83561	25.80227	25.81061	25.81894	25.78561	25.79394	25.71894	25.72727
perimeter	14.47348	14.45473	14.45682	14.4589	14.45057	14.45265	14.45473	14.4464	14.44848	14.42973	14.43182
Sf	0.000625	0.00063	0.000629	0.000629	0.000631	0.00063	0.00063	0.000632	0.000632	0.000637	0.000636
Froude	0.153206	0.153874	0.153799	0.153725	0.154023	0.153948	0.153874	0.154172	0.154097	0.154772	0.154697
dY		-0.00323	-0.00322	-0.00322	-0.00323	-0.00323	-0.00323	-0.00324	-0.00323	-0.00326	-0.00326
Y calc	3.236742	3.233517	3.230294	3.227075	3.223843	3.220615	3.217389	3.214152	3.210917	3.207657	3.204399
Y adj	3.241507	3.238281	3.235058	3.231839	3.228607	3.225379	3.222153	3.218916	3.215682	3.212421	3.209163

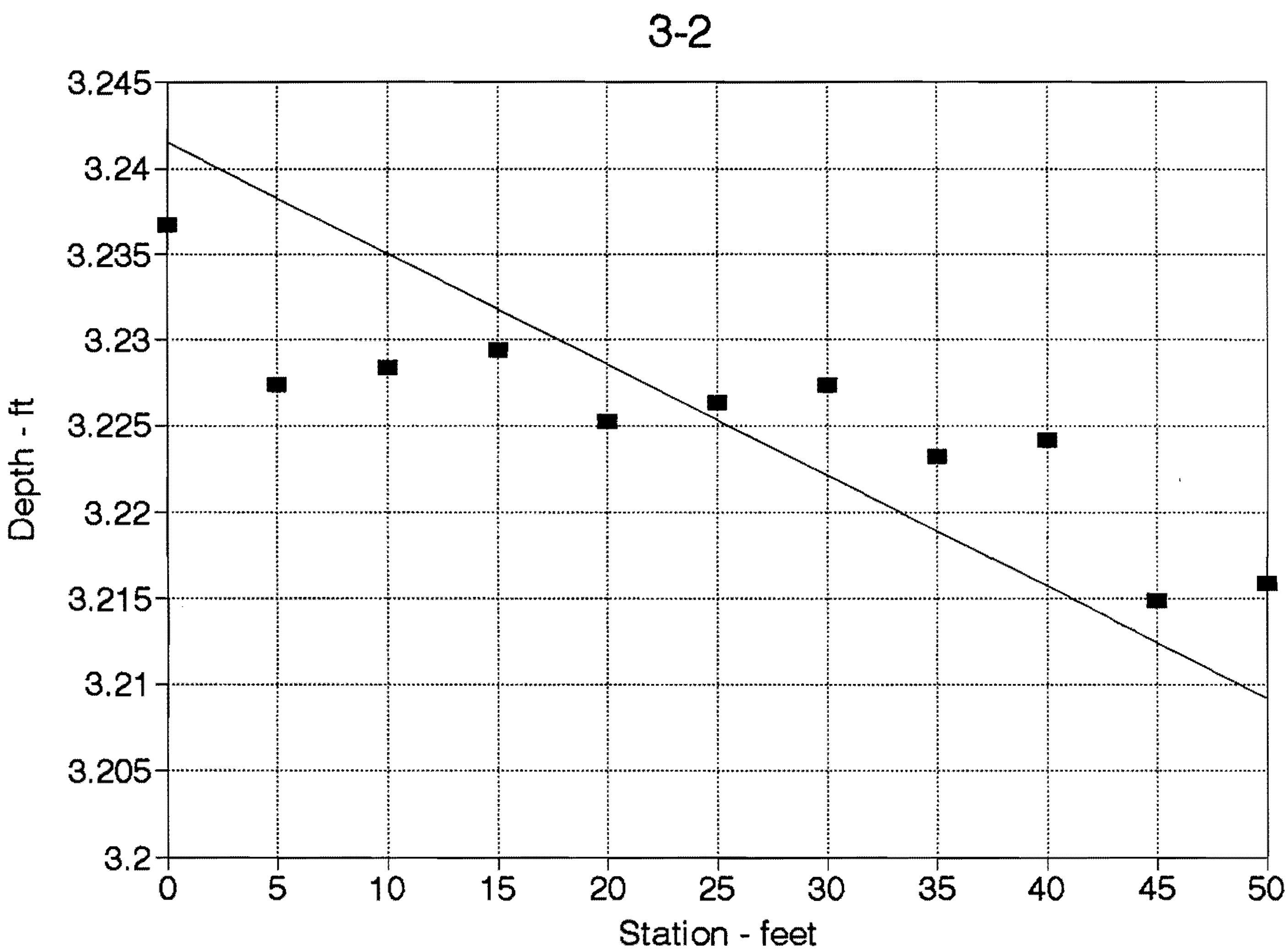
Average depth =	3.225	Average n =	0.035
Average velocity =	1.570	n bed =	0.050
		R bed =	3.011

n
0.035

Velocity Profile station 25 feet vel. at plant center = 1.2 fps

Yo=	3.226326 ft			
V=	1.569122 fps			
Sf=	0.00063		Prandtl C	52.12559
Rh=	1.785873 ft		Prandtl n=	0.031401
V*=	0.190396 fps		Test n=	0.035
X=	1			
Ks=	1 ft		Ks/psi =	1164.077

elev	Y	V meas	Prandtl V
3	2.98	1.9	1.71
6	2.73	1.85	1.67
9	2.48	1.8	1.62
12	2.23	1.8	1.57
15	1.98	1.6	1.52
18	1.73	1.5	1.45
21	1.48	1.2	1.38
24	1.23	1.2	1.29
27	0.98	1.2	1.18
30	0.73	1.2	1.04
33	0.48	1.2	0.84
35	0.31	1.1	0.63
0	3.23	0.6	1.75


3-2
Depth - ft
3.245
3.24
3.235
3.23
3.225
3.22
3.215
3.21
3.205
3.2
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 3-3
Date: 5-6-94
Plants: Elderberry at 18" spacing & 24" rows

FLOW = 54 cfs
dP = inches between taps
Drag = 9 micro inches calibr= 200 micro-in / lbs
Drag = 0.045 lbs

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		

Bottom elevations by transit reading (inches)

123.5000	123.2500	123.6875	122.7500	122.8125	122.3750	122.8125	122.1250	122.5625	122.6250	122.7500

Average bottom elevation = 122.8409 feet

Water surface elevations (inches)

80.7500	80.8125	80.9375	81.0625	81.2500	81.4375	81.5000	81.6875	81.7500	81.9375	81.9375	81.1250	0.8125
80.7500	80.7313	80.7750	80.8188	80.9250	81.0313	81.0125	81.1188	81.1000	81.2063	81.1250		

Water depth (feet)

3.5076	3.5091	3.5055	3.5018	3.4930	3.4841	3.4857	3.4768	3.4784	3.4696	3.4763

Average depth = 3.49 feet corrected depth u.s.= 3.507576 feet
Average area = 27.92 sf corrected depth d.s.= 3.478409 feet
Average perim.= 14.98 feet diff= 0.029167 feet
Average H.Radius= 1.86 feet
Average E.slope= 0.0007
Average n= 0.031419

intercept 3.49

n guess = 0.034

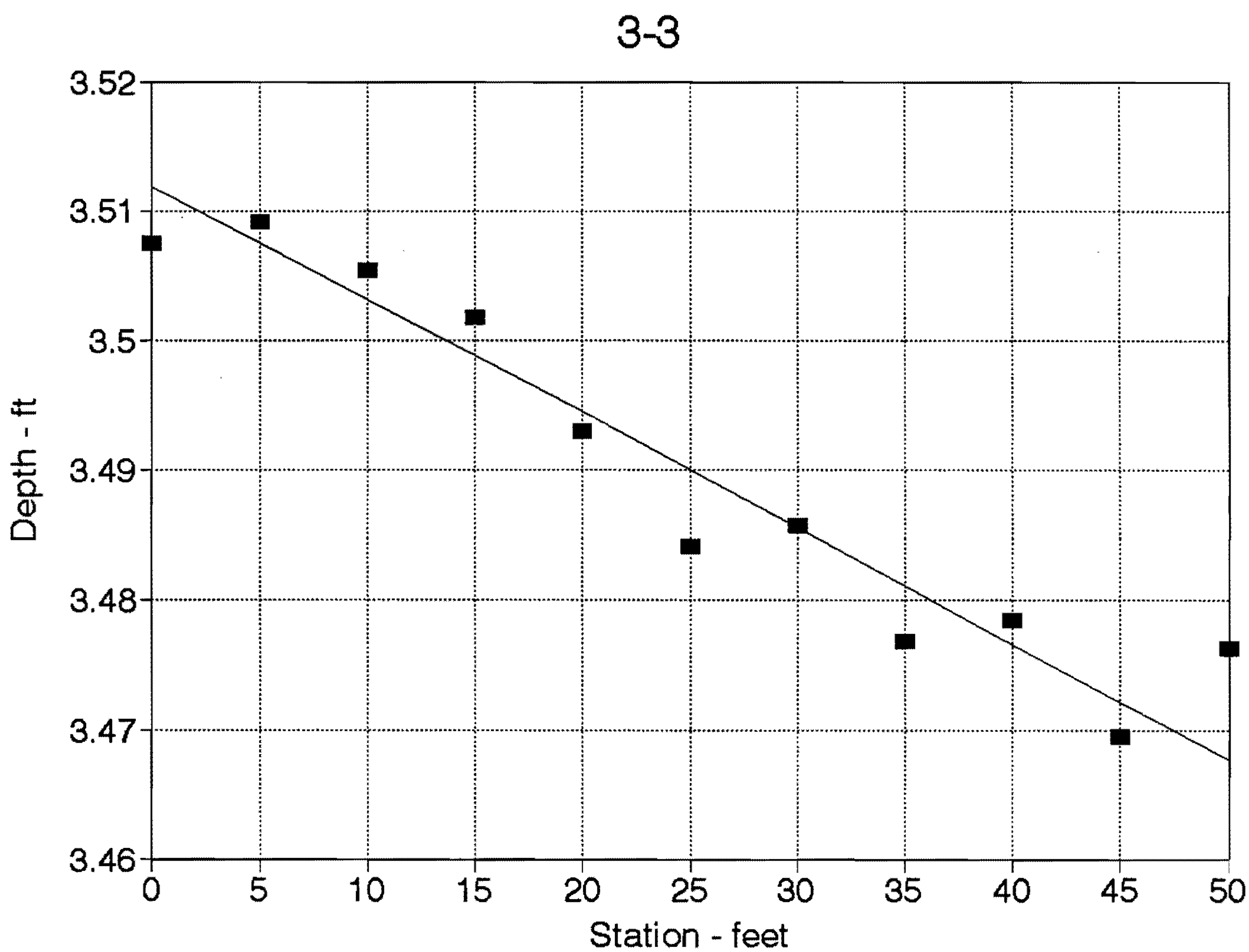
station	0	5	10	15	20	25	30	35	40	45	50
depth	3.507576	3.509138	3.505492	3.501847	3.492992	3.484138	3.485701	3.476847	3.478409	3.469555	3.476326
area	28.06061	28.07311	28.04394	28.01477	27.94394	27.87311	27.88561	27.81477	27.82727	27.75644	27.81061
perimeter	15.01515	15.01828	15.01098	15.00369	14.98598	14.96828	14.9714	14.95369	14.95682	14.93911	14.95265
Sf	0.000842	0.000841	0.000844	0.000846	0.000852	0.000858	0.000857	0.000863	0.000862	0.000867	0.000863
Froude	0.181078	0.180957	0.181239	0.181522	0.182213	0.182908	0.182785	0.183484	0.18336	0.184062	0.183525
dY		-0.00435	-0.00436	-0.00437	-0.00441	-0.00444	-0.00443	-0.00446	-0.00446	-0.00449	-0.00446
Y calc	3.507576	3.503227	3.498866	3.494492	3.490087	3.48565	3.481219	3.476756	3.472299	3.467809	3.463344
Y adj	3.511925	3.507577	3.503216	3.498842	3.494437	3.49	3.485569	3.481106	3.476648	3.472159	3.467694

Average depth = 3.490 Average n = 0.034
Average velocity = 1.934 n bed = 0.049
R bed = 3.244

n
0.034

Velocity Profile station 25 feet vel. at plant center = fps
Yo= 3.484138 ft
V= 1.937351 fps
Sf= 0.000858 Prandtl C 53.21496
Rh= 1.862145 ft Prandtl n= 0.030973
V*= 0.226774 fps Test n= 0.034
X= 1
Ks= 1 ft Ks/psi = 1386.491

elev	Y	V meas	Prandtl V
3	3.23		2.08
6	2.98		2.04
9	2.73		1.99
12	2.48		1.94
15	2.23		1.88
18	1.98		1.81
21	1.73		1.73
24	1.48		1.64
27	1.23		1.54
30	0.98		1.41
33	0.73		1.24
36	0.48		1.01
39	0.23		0.60


3-3
Depth - ft
3.52
3.51
3.5
3.49
3.48
3.47
3.46
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 3-4

Date: 5-6-94

Plants: Elderberry at 18" spacing & 24" rows

FLOW = 24.9 cfs

dP = inches between taps

Drag = 90 micro inches calibr= 200 micro-in / lbs

Drag = 0.45 lbs

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
123.5000	123.2500	123.6875	122.7500	122.8125	122.3750	122.8125	122.1250	122.5625	122.6250	122.7500		
Average bottom elevation =		122.8409 feet										
Water surface elevations (inches)												
85.3125	85.3750	85.3750	85.5625	85.6875	85.7500	85.7500	85.7500	85.8750	86.0625	86.0000	85.3125	0.6875
85.3125	85.3063	85.2375	85.3563	85.4125	85.4063	85.3375	85.2688	85.3250	85.4438	85.3125		
Water depth (feet)												
3.1274	3.1279	3.1336	3.1237	3.1190	3.1196	3.1253	3.1310	3.1263	3.1164	3.1274		

Average depth =	3.13	feet	corrected depth u.s.=	3.127367	feet
Average area =	25.00	sf	corrected depth d.s.=	3.126326	feet
Average perim.=	14.25	feet	diff=	0.001042	feet
Average H.Radius=	1.75	feet			
Average E.slope=	0.0000				
Average n=	0.011076				
			intercept	3.125237	

n guess = 0.045

station	0	5	10	15	20	25	30	35	40	45	50
depth	3.127367	3.127888	3.133617	3.123722	3.119034	3.119555	3.125284	3.131013	3.126326	3.11643	3.127367
area	25.01894	25.02311	25.06894	24.98977	24.95227	24.95644	25.00227	25.04811	25.01061	24.93144	25.01894
perimeter	14.25473	14.25578	14.26723	14.24744	14.23807	14.23911	14.25057	14.26203	14.25265	14.23286	14.25473
Sf	0.000429	0.000429	0.000427	0.00043	0.000432	0.000432	0.00043	0.000428	0.000429	0.000433	0.000429
Froude	0.099177	0.099153	0.098881	0.099351	0.099575	0.09955	0.099277	0.099004	0.099227	0.0997	0.099177
dY		-0.00217	-0.00215	-0.00217	-0.00218	-0.00218	-0.00217	-0.00216	-0.00217	-0.00219	-0.00217
Y calc	3.127367	3.125202	3.123047	3.120874	3.118691	3.116509	3.114339	3.112179	3.110011	3.107823	3.105657
Y adj	3.136095	3.133929	3.131775	3.129601	3.127418	3.125237	3.123066	3.120907	3.118738	3.11655	3.114384

Average depth =	3.125	Average n =	0.045
Average velocity =	0.996	n bed =	0.064
		R bed =	2.979

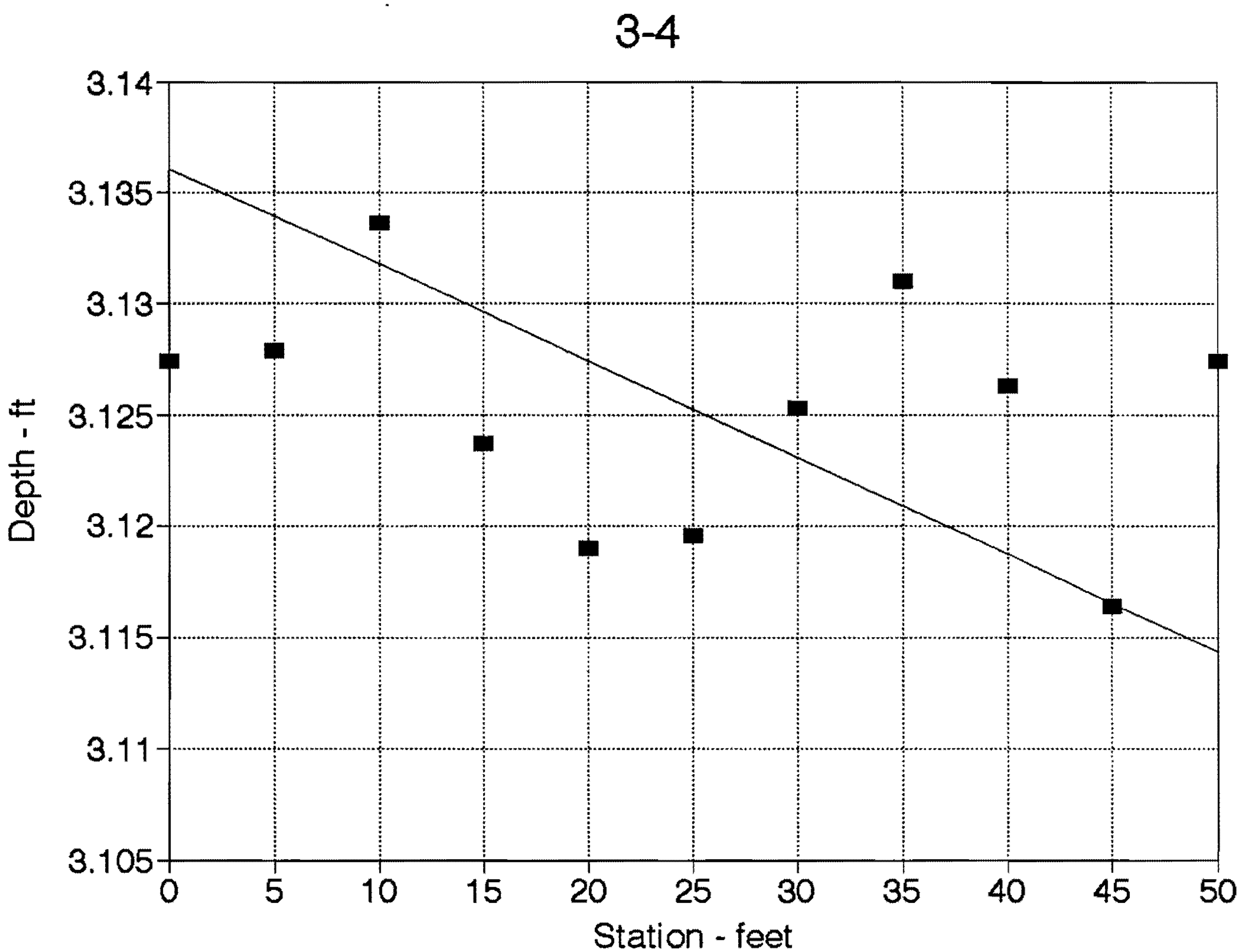
n

0.045

Velocity Profile station 25 feet vel. at plant center = 0.6 fps

Yo=	3.119555	ft		
V=	0.997738	fps		
Sf=	0.000432		Prandtl C	51.64871
Rh=	1.752669	ft	Prandtl n=	0.031592
V*=	0.156143	fps	Test n=	0.045
X=	1			
Ks=	1	ft	Ks/psi =	954.651

elev	Y	V meas	Prandtl V
3	2.87	1.1	1.39
6	2.62	1	1.35
9	2.37	1.1	1.31
12	2.12	1	1.27
15	1.87	1	1.22
18	1.62	0.7	1.17
21	1.37	0.6	1.10
24	1.12	0.6	1.02
27	0.87	0.6	0.92
30	0.62	0.6	0.79
0	3.12	0	1.42
0	3.12	0	1.42
0	3.12	0	1.42


3-4
3.14
3.135
3.13
3.125
3.12
3.115
3.11
3.105
Depth - ft
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 3-5
Date: 5-6-94
Plants: Elderberry at 18" spacing & 24" rows

FLOW =	31.5	cfs			
dP =		inches between taps			
Drag =	20	micro inches	calibr=	200	micro-in / lbs
Drag =	0.1	lbs			

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
123.5000	123.2500	123.6875	122.7500	122.8125	122.3750	122.8125	122.1250	122.5625	122.6250	122.7500		
Average bottom elevation =		122.8409	feet									
Water surface elevations (inches)												
94.3750	94.2500	94.1875	94.0000	93.9375	93.8125	93.6250	93.5000	93.2500	92.9375	92.6875	95.3750	-2.6875
94.3750	94.5188	94.7250	94.8063	95.0125	95.1563	95.2375	95.3813	95.4000	95.3563	95.3750		
Water depth (feet)												
2.3722	2.3602	2.3430	2.3362	2.3190	2.3071	2.3003	2.2883	2.2867	2.2904	2.2888		

Average depth =	2.32	feet	corrected depth u.s.=	2.372159	feet
Average area =	18.54	sf	corrected depth d.s.=	2.286742	feet
Average perim.=	12.63	feet	diff=	0.085417	feet
Average H.Radius=	1.47	feet			
Average E.slope=	0.0021				
Average n=	0.052188				
			intercept	2.317472	

n guess = 0.04

station	0	5	10	15	20	25	30	35	40	45	50
depth	2.372159	2.36018	2.342992	2.336222	2.319034	2.307055	2.300284	2.288305	2.286742	2.290388	2.288826
area	18.97727	18.88144	18.74394	18.68977	18.55227	18.45644	18.40227	18.30644	18.29394	18.32311	18.31061
perimeter	12.74432	12.72036	12.68598	12.67244	12.63807	12.61411	12.60057	12.57661	12.57348	12.58078	12.57765
Sf	0.001174	0.001191	0.001216	0.001226	0.001252	0.001271	0.001281	0.0013	0.001303	0.001297	0.0013
Froude	0.189923	0.19137	0.19348	0.194322	0.196486	0.198018	0.198893	0.200457	0.200663	0.200184	0.200389
dY		-0.00618	-0.00632	-0.00637	-0.00651	-0.00661	-0.00667	-0.00677	-0.00679	-0.00676	-0.00677
Y calc	2.372159	2.365978	2.359661	2.35329	2.346779	2.340166	2.333496	2.326721	2.319933	2.313176	2.306406
Y adj	2.349464	2.343283	2.336966	2.330596	2.324084	2.317472	2.310801	2.304026	2.297238	2.290482	2.283712

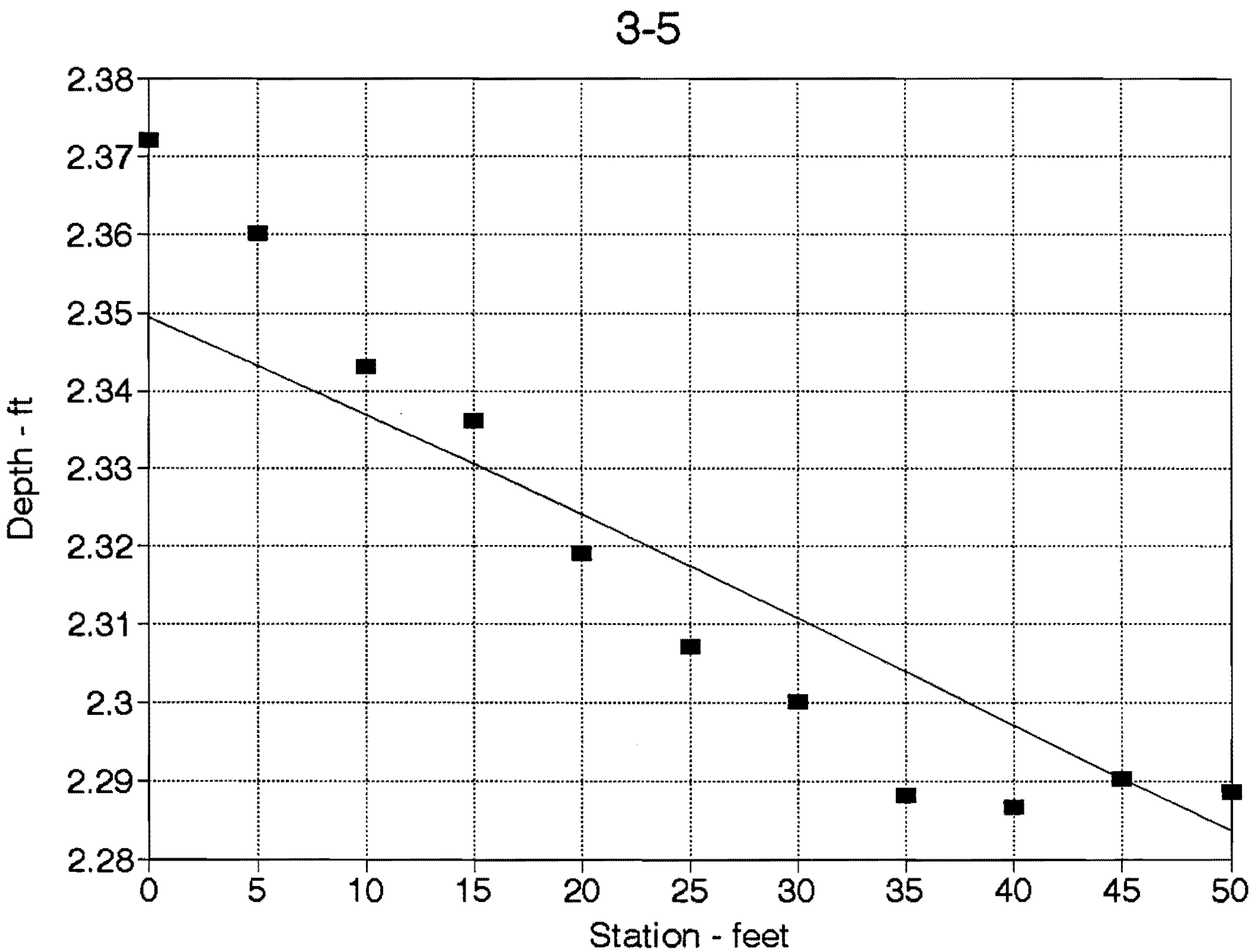
Average depth =	2.317	Average n =	0.040
Average velocity =	1.699	n bed =	0.053
		R bed =	2.219

n
0.04

Velocity Profile station 25 feet vel. at plant center = 1.8 fps

Yo=	2.307055 ft			
V=	1.706721 fps			
Sf=	0.001271		Prandtl C	47.37326
Rh=	1.463158 ft		Prandtl n=	0.033422
V*=	0.244671 fps		Test n=	0.04
X=	1			
Ks=	1 ft		Ks/psi =	1495.912

elev	Y	V meas	Prandtl V
3	2.06	2.2	1.97
6	1.81	2.1	1.89
9	1.56	2	1.80
12	1.31	1.8	1.70
15	1.06	1.7	1.57
18	0.81	1.8	1.40
21	0.56	1.3	1.17
24	0.31	1.2	0.81
0	2.31	0	2.04
0	2.31	0	2.04
0	2.31	0	2.04
0	2.31	0	2.04
0	2.31	0	2.04


3-5
2.38
2.37
2.36
2.35
2.34
2.33
2.32
2.31
2.3
2.29
2.28
Depth - ft
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 3-6
Date: 5-6-94
Plants: Elderberry at 18" spacing & 24" rows

FLOW =	41.3	cfs		
dP =		inches between taps		
Drag =	3	micro inches	calibr=	200 micro-in / lbs
Drag =	0.015	lbs		

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
123.5000	123.2500	123.6875	122.7500	122.8125	122.3750	122.8125	122.1250	122.5625	122.6250	122.7500		
Average bottom elevation =		122.8409	feet									
Water surface elevations (inches)												
91.7500	91.8750	91.9375	92.0000	92.1250	92.1875	92.2500	92.3750	92.4375	92.5625	92.5625	92.3125	0.2500
91.7500	91.8500	91.8875	91.9250	92.0250	92.0625	92.1000	92.2000	92.2375	92.3375	92.3125		
Water depth (feet)												
2.5909	2.5826	2.5795	2.5763	2.5680	2.5649	2.5617	2.5534	2.5503	2.5420	2.5440		

Average depth =	2.56	feet	corrected depth u.s.=	2.590909	feet
Average area =	20.52	sf	corrected depth d.s.=	2.550284	feet
Average perim.=	13.13	feet	diff=	0.040625	feet
Average H.Radius=	1.56	feet			
Average E.slope=	0.0010				
Average n=	0.031685				
			intercept	2.564867	

n guess = 0.033

station	0	5	10	15	20	25	30	35	40	45	50
depth	2.590909	2.582576	2.579451	2.576326	2.567992	2.564867	2.561742	2.553409	2.550284	2.541951	2.544034
area	20.72727	20.66061	20.63561	20.61061	20.54394	20.51894	20.49394	20.42727	20.40227	20.33561	20.35227
perimeter	13.18182	13.16515	13.1589	13.15265	13.13598	13.12973	13.12348	13.10682	13.10057	13.0839	13.08807
Sf	0.001071	0.001081	0.001084	0.001088	0.001098	0.001102	0.001105	0.001116	0.001119	0.00113	0.001127
Froude	0.218149	0.219206	0.219605	0.220004	0.221076	0.22148	0.221886	0.222973	0.223383	0.224482	0.224206
dY		-0.00568	-0.0057	-0.00572	-0.00577	-0.00579	-0.00581	-0.00587	-0.00589	-0.00595	-0.00593
Y calc	2.590909	2.585234	2.579538	2.573821	2.56805	2.562257	2.556444	2.550574	2.544682	2.538734	2.532799
Y adj	2.593519	2.587844	2.582148	2.576431	2.57066	2.564867	2.559054	2.553184	2.547293	2.541344	2.535409

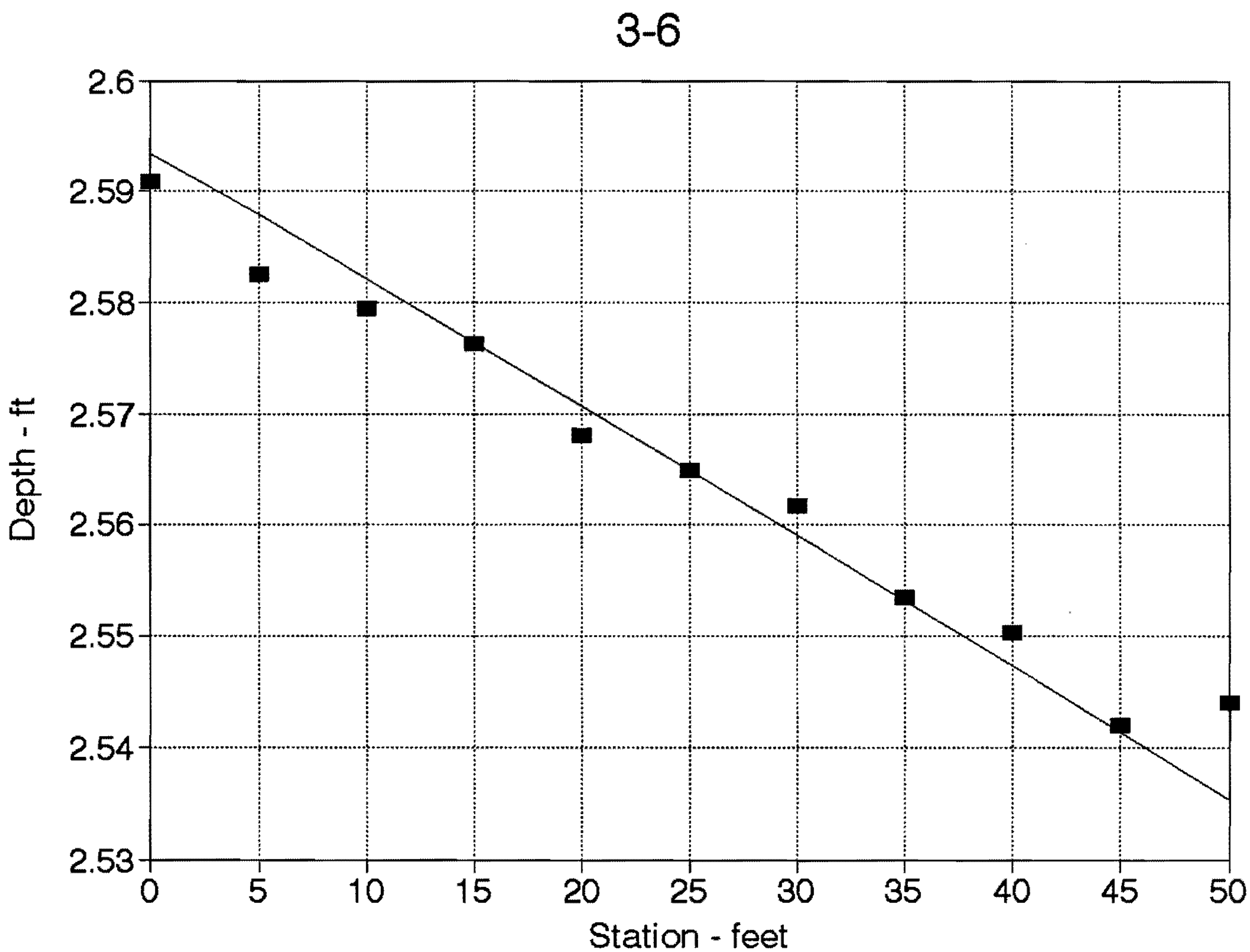
Average depth =	2.565	Average n =	0.033
Average velocity =	2.013	n bed =	0.044
		R bed =	2.410

n
0.033

Velocity Profile station 25 feet vel. at plant center = 1.5 fps

Yo=	2.564867	ft		
V=	2.012775	fps		
Sf=	0.001102		Prandtl C	48.87439
Rh=	1.562784	ft	Prandtl n=	0.032753
V*=	0.235452	fps	Test n=	0.033
X=	1			
Ks=	1	ft	Ks/psi =	1439.543

elev	Y	V meas	Prandtl V
3	2.31	2.2	1.97
6	2.06	2.2	1.90
9	1.81	2.1	1.82
12	1.56	1.8	1.74
15	1.31	1.8	1.64
18	1.06	1.6	1.51
21	0.81	1.7	1.35
24	0.56	1.5	1.14
27	0.31	1.3	0.79
30	0.06	0.7	-0.13
0	2.56	0	2.03
0	2.56	0	2.03
0	2.56	0	2.03


3-6
Depth - ft
2.6
2.59
2.58
2.57
2.56
2.55
2.54
2.53
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 3-7
Date: 5-6-94
Plants: Elderberry at 18" spacing & 24" rows

FLOW = 50.6 cfs
dP = inches between taps
Drag = 25 micro inches calibr= 200 micro-in / lbs
Drag = 0.125 lbs

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
123.5000	123.2500	123.6875	122.7500	122.8125	122.3750	122.8125	122.1250	122.5625	122.6250	122.7500		
Average bottom elevation =		122.8409	feet									
Water surface elevations (inches)												
89.1250	89.2500	89.3125	89.4375	89.7500	89.7500	89.8125	90.0000	90.1875	90.2500	90.3125	89.6250	0.6875
89.1250	89.1813	89.1750	89.2313	89.4750	89.4063	89.4000	89.5188	89.6375	89.6313	89.6250		
Water depth (feet)												
2.8097	2.8050	2.8055	2.8008	2.7805	2.7862	2.7867	2.7768	2.7670	2.7675	2.7680		

Average depth = 2.79 feet corrected depth u.s.= 2.809659 feet
Average area = 22.29 sf corrected depth d.s.= 2.766951 feet
Average perim.= 13.57 feet diff= 0.042708 feet
Average H.Radius= 1.64 feet
Average E.slope= 0.0011
Average n= 0.029781

intercept 2.786695

n guess = 0.032

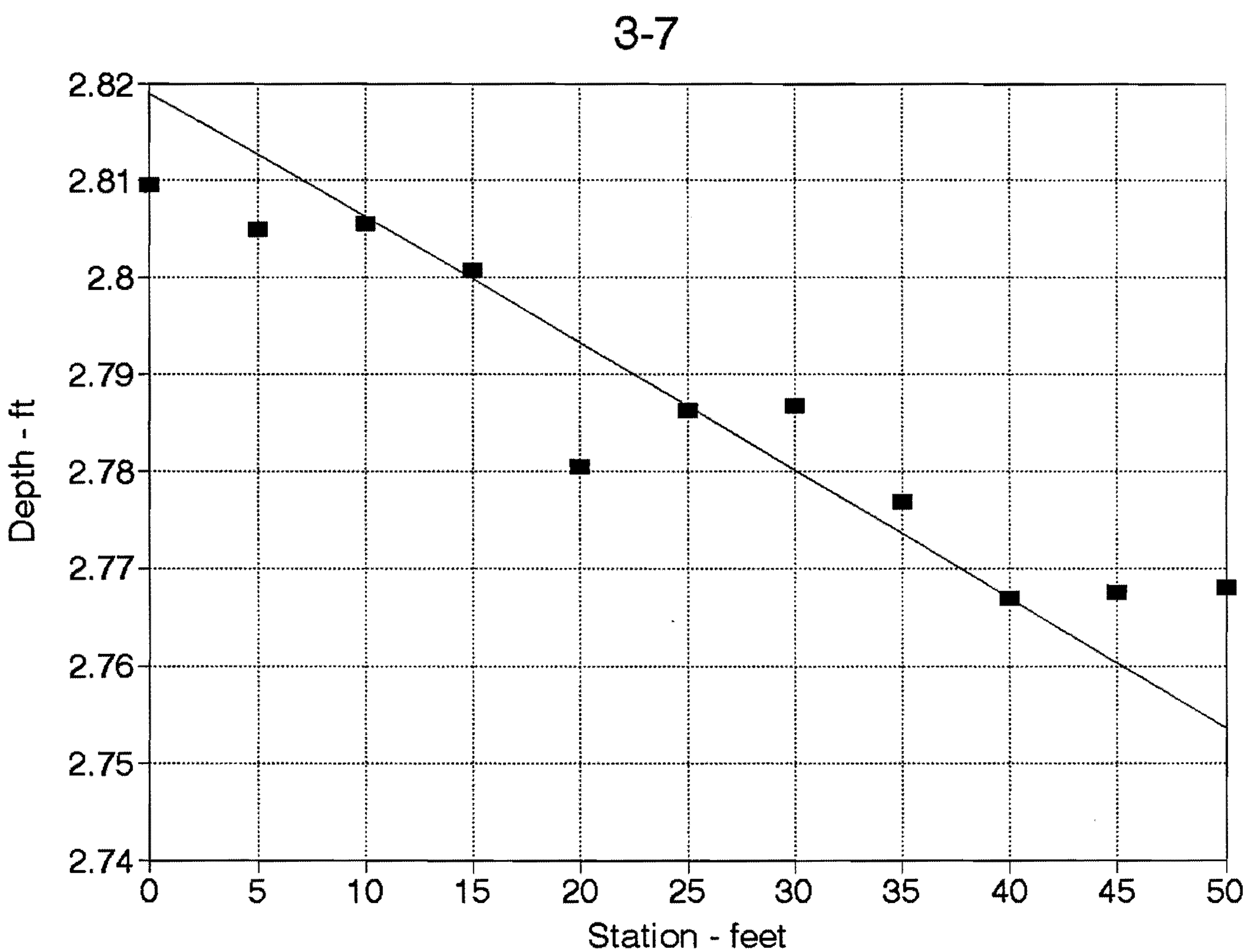
station	0	5	10	15	20	25	30	35	40	45	50
depth	2.809659	2.804972	2.805492	2.800805	2.780492	2.786222	2.786742	2.776847	2.766951	2.767472	2.767992
area	22.47727	22.43977	22.44394	22.40644	22.24394	22.28977	22.29394	22.21477	22.13561	22.13977	22.14394
perimeter	13.61932	13.60994	13.61098	13.60161	13.56098	13.57244	13.57348	13.55369	13.5339	13.53494	13.53598
Sf	0.001205	0.001211	0.00121	0.001216	0.00124	0.001233	0.001233	0.001245	0.001257	0.001257	0.001256
Froude	0.236675	0.237268	0.237202	0.237798	0.240409	0.239667	0.2396	0.240882	0.242176	0.242107	0.242039
dY		-0.00641	-0.00641	-0.00644	-0.00658	-0.00654	-0.00654	-0.00661	-0.00668	-0.00668	-0.00667
Y calc	2.809659	2.803245	2.796835	2.790393	2.78381	2.777268	2.770729	2.76412	2.757441	2.750766	2.744095
Y adj	2.819086	2.812673	2.806262	2.79982	2.793238	2.786695	2.780156	2.773548	2.766869	2.760194	2.753522

Average depth = 2.787 Average n = 0.032
Average velocity = 2.270 n bed = 0.043
R bed = 2.603

n
0.032

Velocity Profile station 25 feet vel. at plant center = 2 fps
Yo= 2.786222 ft
V= 2.270099 fps
Sf= 0.001233 Prandtl C 50.0474
Rh= 1.642282 ft Prandtl n= 0.032251
V*= 0.255385 fps Test n= 0.032
X= 1
Ks= 1 ft Ks/psi = 1561.417

elev	Y	V meas	Prandtl V
3	2.54	2.7	2.19
6	2.29	2.7	2.13
9	2.04	2.7	2.05
12	1.79	2.7	1.97
15	1.54	2.3	1.87
18	1.29	2.3	1.76
21	1.04	2.1	1.62
24	0.79	2	1.45
27	0.54	1.9	1.20
30	0.29	1.7	0.80
33	0.04	0.8	-0.52
0	2.79	0	2.25
0	2.79	0	2.25


3-7
Depth - ft
2.82
2.81
2.8
2.79
2.78
2.77
2.76
2.75
2.74
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project   RUN #:   3-8

Date: 5-6-94

Plants: Elderberry at 18" spacing & 24" rows

NOTE: soil and sand moving

FLOW =	54	cfs			
dP =		inches between taps			
Drag =	240	micro inches	calibr=	200	micro-in / lbs
Drag =	1.2	lbs			

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
123.5000	123.2500	123.6875	122.7500	122.8125	122.3750	122.8125	122.1250	122.5625	122.6250	122.7500		
Water surface elevations (inches)												
89.6875	89.7500	89.9375	91.0000	91.3125	91.4375	91.6250	91.7500	91.8750	91.9375	92.1250	91.3125	0.8125
89.6875	89.6688	89.7750	90.7563	90.9875	91.0313	91.1375	91.1813	91.2250	91.2063	91.3125		
Water depth (feet)												
2.7628	2.7643	2.7555	2.6737	2.6545	2.6508	2.6420	2.6383	2.6347	2.6362	2.6274		

Average bottom elevation = 122.8409 feet

Average depth =	2.68	feet	corrected depth u.s.=	2.762784	feet
Average area =	21.41	sf	corrected depth d.s.=	2.634659	feet
Average perim.=	13.35	feet	diff=	0.128125	feet
Average H.Radius=	1.60	feet			
Average E.slope=	0.0032				
Average n=	0.045683				
			intercept	2.676373	

n guess = 0.033

station	0	5	10	15	20	25	30	35	40	45	50
depth	2.762784	2.764347	2.755492	2.673722	2.654451	2.650805	2.641951	2.638305	2.634659	2.636222	2.627367
area	22.10227	22.11477	22.04394	21.38977	21.23561	21.20644	21.13561	21.10644	21.07727	21.08977	21.01894
perimeter	13.52557	13.52869	13.51098	13.34744	13.3089	13.30161	13.2839	13.27661	13.26932	13.27244	13.25473
Sf	0.001529	0.001527	0.001541	0.001676	0.00171	0.001717	0.001733	0.00174	0.001747	0.001744	0.00176
Froude	0.259033	0.258814	0.260062	0.272083	0.275051	0.275619	0.277006	0.27758	0.278156	0.277909	0.279315
dY		-0.00818	-0.00826	-0.00905	-0.00925	-0.00929	-0.00939	-0.00943	-0.00947	-0.00945	-0.00955
Y calc	2.762784	2.754601	2.746338	2.737288	2.728036	2.718746	2.70936	2.699935	2.690469	2.681021	2.671475
Y adj	2.720411	2.712228	2.703966	2.694915	2.685664	2.676373	2.666987	2.657562	2.648096	2.638648	2.629102

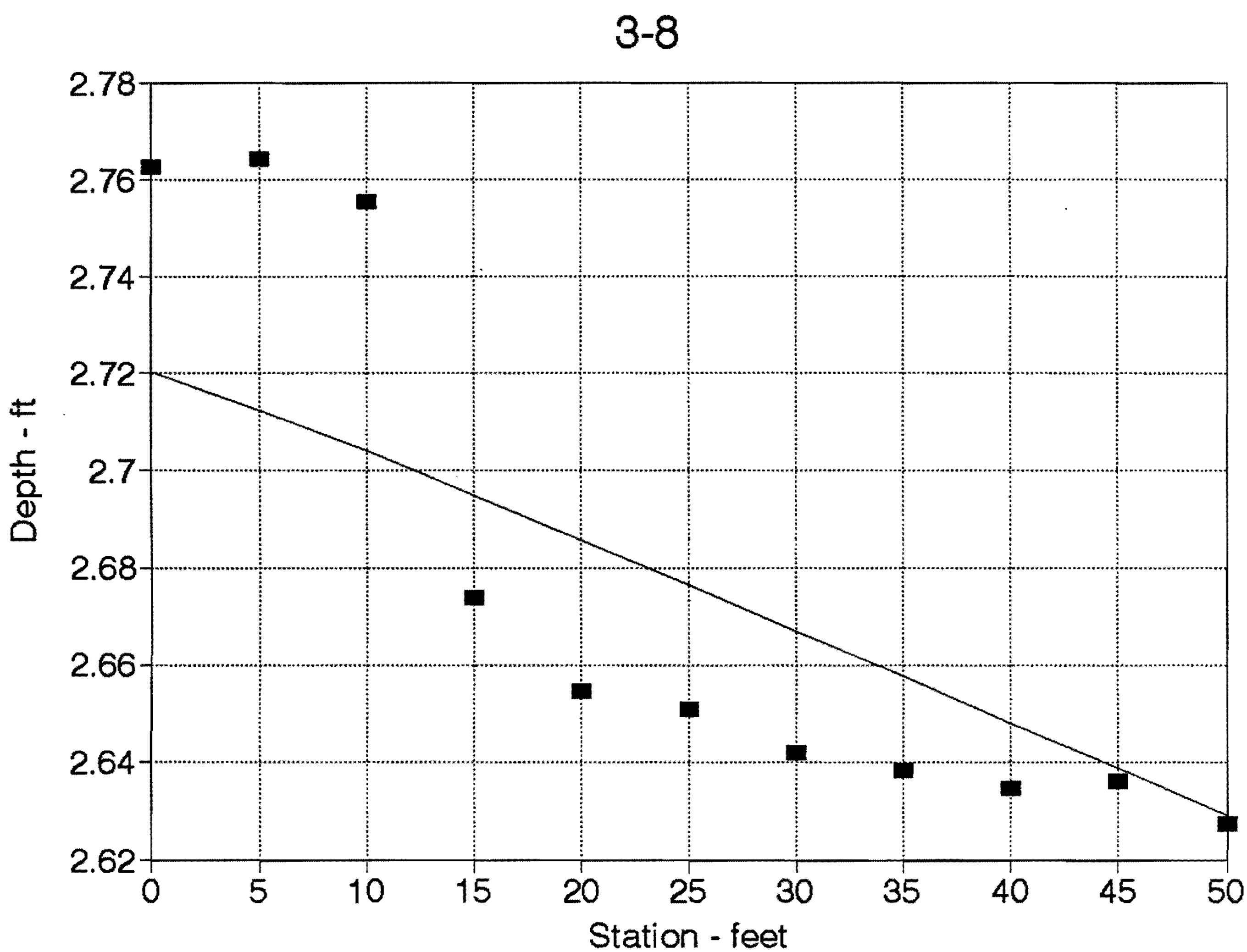
Average depth =	2.676	Average n =	0.033
Average velocity =	2.522	n bed =	0.045
		R bed =	2.516

n
0.033

Velocity Profile station 25 feet   vel. at plant center = 2.4 fps

Yo=	2.650805	ft		
V=	2.546396	fps		
Sf=	0.001717		Prandtl C	49.3414
Rh=	1.594276	ft	Prandtl n=	0.032551
V*=	0.296885	fps	Test n=	0.033
X=	1			
Ks=	1	ft	Ks/psi =	1815.145

elev	Y	V meas	Prandtl V
3	2.40	3.2	2.51
6	2.15	3.1	2.43
9	1.90	3.1	2.33
12	1.65	2.9	2.23
15	1.40	2.7	2.11
18	1.15	2.7	1.96
21	0.90	2.4	1.78
24	0.65	2.4	1.54
27	0.40	2	1.18
30	0.15	2	0.46
33	-0.10	1.7	ERR
35	-0.27	0.6	ERR
0	2.65	0	2.58


3-8
Depth - ft
2.78
2.76
2.74
2.72
2.7
2.68
2.66
2.64
2.62
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project   RUN #: 3-9
Date: 5-6-94
Plants: Elderberry at 18" spacing & 24" rows

NOTE: few leaves and stems breaking

FLOW =	55.5	cfs			
dP =		inches between taps			
Drag =	40	micro inches	calibr=	200	micro-in / lbs
Drag =	0.2	lbs			

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		

Bottom elevations by transit reading (inches)

123.5000	123.2500	123.6875	122.7500	122.8125	122.3750	122.8125	122.1250	122.5625	122.6250	122.7500		

Average bottom elevation = 122.8409 feet

Water surface elevations (inches)

92.7500	92.7500	92.9375	93.0000	93.1875	93.3750	93.3750	93.4375	93.5625	93.6250	93.6250	93.9375	-0.3125
92.7500	92.7813	93.0000	93.0938	93.3125	93.5313	93.5625	93.6563	93.8125	93.9063	93.9375		

Water depth (feet)

2.5076	2.5050	2.4887	2.4789	2.4607	2.4425	2.4399	2.4321	2.4190	2.4112	2.4086

Average depth =	2.45	feet	corrected depth u.s.=	2.507576	feet
Average area =	19.63	sf	corrected depth d.s.=	2.419034	feet
Average perim.=	12.91	feet	diff=	0.088542	feet
Average H.Radius=	1.52	feet			
Average E.slope=	0.0022				
Average n=	0.032704				
			intercept	2.453835	

n guess = 0.031

station	0	5	10	15	20	25	30	35	40	45	50
depth	2.507576	2.504972	2.486742	2.47893	2.460701	2.442472	2.439867	2.432055	2.419034	2.411222	2.408617
area	20.06061	20.03977	19.89394	19.83144	19.68561	19.53977	19.51894	19.45644	19.35227	19.28977	19.26894
perimeter	13.01515	13.00994	12.97348	12.95786	12.9214	12.88494	12.87973	12.86411	12.83807	12.82244	12.81723
Sf	0.001871	0.001876	0.001915	0.001933	0.001973	0.002015	0.002021	0.00204	0.002071	0.00209	0.002096
Froude	0.307889	0.308369	0.311766	0.313241	0.316728	0.320281	0.320794	0.322341	0.324947	0.326527	0.327057
dY		-0.01037	-0.01061	-0.01071	-0.01097	-0.01123	-0.01127	-0.01138	-0.01158	-0.0117	-0.01174
Y calc	2.507576	2.497208	2.486599	2.475885	2.464919	2.453691	2.442425	2.431044	2.419467	2.40777	2.396033
Y adj	2.50772	2.497352	2.486744	2.476029	2.465063	2.453835	2.442569	2.431188	2.419611	2.407914	2.396177

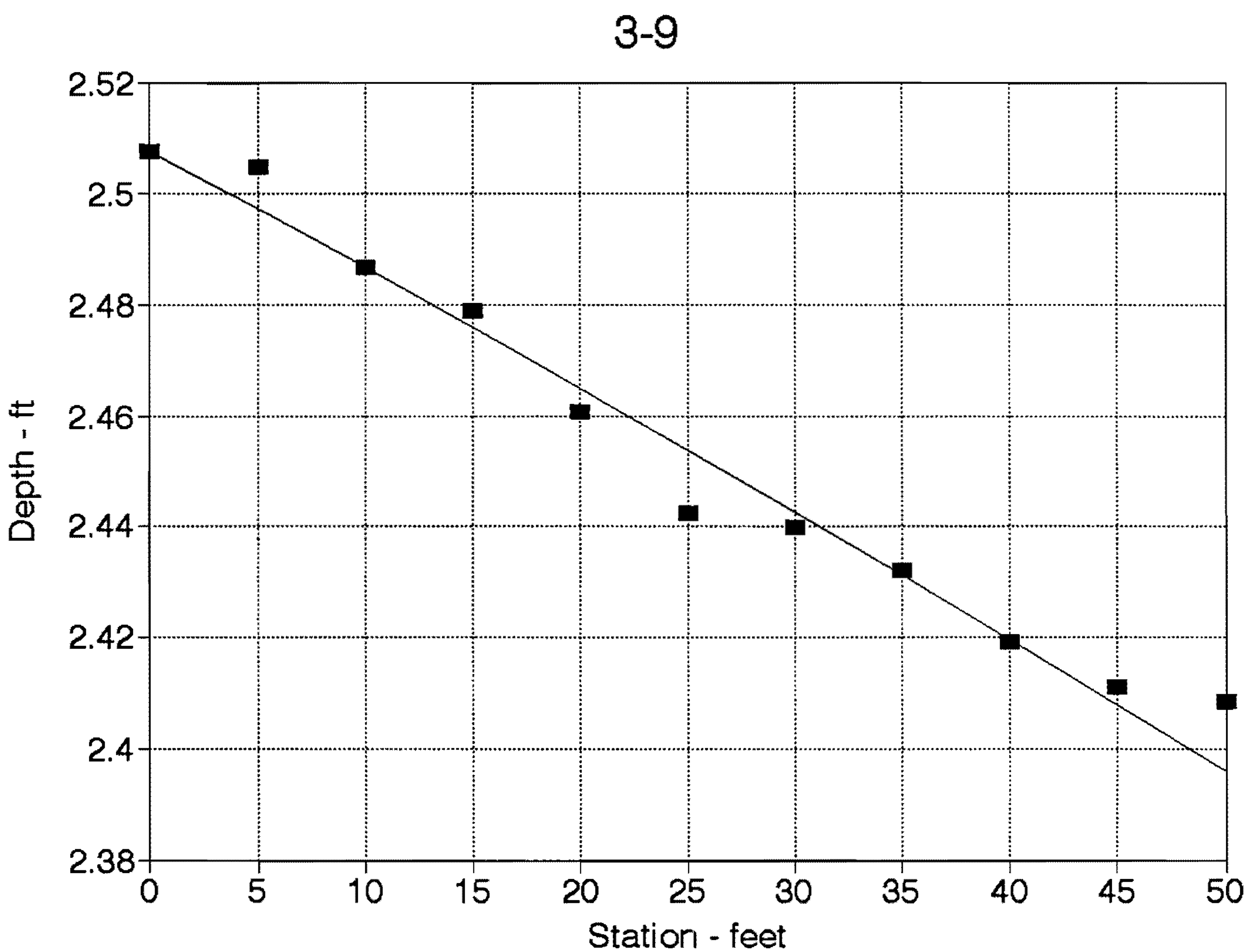
Average depth =	2.454	Average n =	0.031
Average velocity =	2.827	n bed =	0.041
		R bed =	2.303

n
0.031

Velocity Profile station 25 feet   vel. at plant center = 2.6 fps

Yo=	2.442472 ft			
V=	2.840361 fps			
Sf=	0.002015		Prandtl C	48.18151
Rh=	1.516481 ft		Prandtl n=	0.033058
V*=	0.313693 fps		Test n=	0.031
X=	1			
Ks=	1 ft		Ks/psi =	1917.908

elev	Y	V meas	Prandtl V
3	2.19	3.5	2.58
6	1.94	3.5	2.48
9	1.69	3.5	2.38
12	1.44	3.2	2.25
15	1.19	3	2.10
18	0.94	2.6	1.92
21	0.69	2.6	1.68
24	0.44	2.4	1.33
27	0.19	2	0.67
0	2.44	0	2.66
0	2.44	0	2.66
0	2.44	0	2.66
0	2.44	0	2.66


3-9
Depth - ft
2.52
2.5
2.48
2.46
2.44
2.42
2.4
2.38
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 3-10
Date: 5-6-94
Plants: Elderberry at 18" spacing & 24" rows

NOTE: leaves and stems failing

FLOW = 74.5 cfs
dP = inches between taps
Drag = 49 micro inches calibr= 100 micro-in / lbs
Drag = 0.49 lbs

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
123.5000	123.2500	123.6875	122.7500	122.8125	122.3750	122.8125	122.1250	122.5625	122.6250	122.7500		
Average bottom elevation =		122.8409	feet									
Water surface elevations (inches)												
86.3750	86.5625	87.0000	87.5625	87.6875	88.0625	88.3125	88.6250	88.8750	89.1875	89.4375	87.1250	2.3125
86.3750	86.3313	86.5375	86.8688	86.7625	86.9063	86.9250	87.0063	87.0250	87.1063	87.1250		
Water depth (feet)												
3.0388	3.0425	3.0253	2.9977	3.0065	2.9946	2.9930	2.9862	2.9847	2.9779	2.9763		

Average depth = 3.00 feet corrected depth u.s.= 3.038826 feet
Average area = 24.02 sf corrected depth d.s.= 2.984659 feet
Average perim.= 14.00 feet diff= 0.054167 feet
Average H.Radius= 1.71 feet
Average E.slope= 0.0014
Average n= 0.025258

intercept 3.002131

n guess = 0.03

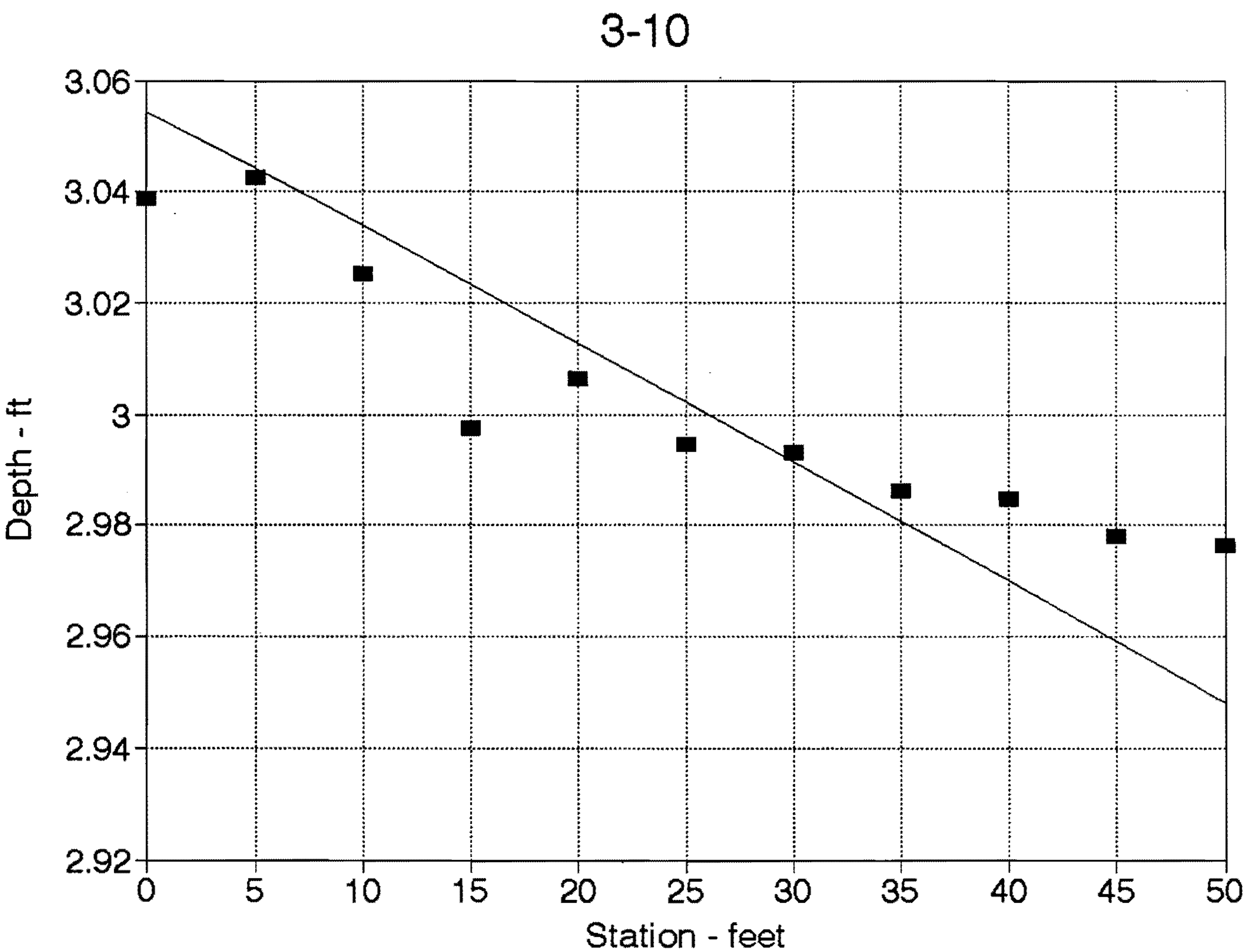
station	0	5	10	15	20	25	30	35	40	45	50
depth	3.038826	3.042472	3.025284	2.99768	3.006534	2.994555	2.992992	2.986222	2.984659	2.977888	2.976326
area	24.31061	24.33977	24.20227	23.98144	24.05227	23.95644	23.94394	23.88977	23.87727	23.82311	23.81061
perimeter	14.07765	14.08494	14.05057	13.99536	14.01307	13.98911	13.98598	13.97244	13.96932	13.95578	13.95265
Sf	0.001847	0.001841	0.00187	0.001918	0.001903	0.001924	0.001927	0.001939	0.001941	0.001954	0.001957
Froude	0.309799	0.309242	0.311881	0.316199	0.314803	0.316694	0.316942	0.318021	0.31827	0.319356	0.319608
dY		-0.01018	-0.01036	-0.01066	-0.01056	-0.01069	-0.01071	-0.01078	-0.0108	-0.01088	-0.0109
Y calc	3.038826	3.028645	3.018286	3.007629	2.997069	2.986378	2.975669	2.964885	2.954083	2.943205	2.93231
Y adj	3.054579	3.044398	3.034039	3.023382	3.012822	3.002131	2.991422	2.980638	2.969836	2.958958	2.948063

Average depth = 3.002 Average n = 0.030
Average velocity = 3.102 n bed = 0.041
R bed = 2.784

n
0.03

Velocity Profile station 25 feet vel. at plant center = 2.5 fps
Yo= 2.994555 ft
V= 3.109811 fps
Sf= 0.001924 Prandtl C 51.06922
Rh= 1.712506 ft Prandtl n= 0.031827
V*= 0.325706 fps Test n= 0.03
X= 1
Ks= 1 ft Ks/psi = 1991.355

elev	Y	V meas	Prandtl V
3	2.74	3.7	2.86
6	2.49	3.7	2.78
9	2.24	3.6	2.70
12	1.99	3.5	2.60
15	1.74	3.5	2.49
18	1.49	3.5	2.37
21	1.24	3.2	2.22
24	0.99	3	2.03
27	0.74	2.6	1.80
30	0.49	2.3	1.47
33	0.24	2.2	0.89
34	0.16	1.7	0.55
35	0.08	1.3	-0.04


3-10
3.06
3.04
3.02
3
2.98
2.96
2.94
2.92
Depth - ft
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 4-1
Date: 5-20-94
Plants: Euonymus on 10" centers and 11" rows

NOTE: few leaves and stems breaking

FLOW =	32.5	cfs		
dP =		inches between taps		
Drag =	10	micro inches	calibr=	200 micro-in / lbs
Drag =	0.05	lbs		

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		

Bottom elevations by transit reading (inches)

123.4375	122.1875	121.5625	121.2500	121.2500	121.3125	120.7500	120.6250	120.2500	121.5625	122.5000

Average bottom elevation = 121.5170 feet

Water surface elevations (inches)

75.0625	75.1250	75.2500	75.5000	75.6250	75.8750	75.9375	76.0625	76.2500	76.4375	76.6250	75.0000	1.6250
75.0625	74.9625	74.9250	75.0125	74.9750	75.0625	74.9625	74.9250	74.9500	74.9750	75.0000		

Water depth (feet)

3.8712	3.8795	3.8827	3.8754	3.8785	3.8712	3.8795	3.8827	3.8806	3.8785	3.8764

Average depth =	3.88	feet	corrected depth u.s.=	3.871212	feet
Average area =	31.02	sf	corrected depth d.s.=	3.880587	feet
Average perim.=	15.76	feet	diff=	-0.00937	feet
Average H.Radius=	1.97	feet			
Average E.slope=	-0.0002				
Average n=	ERR				
			intercept	3.877841	

n guess = 0.045

station	0	5	10	15	20	25	30	35	40	45	50
depth	3.871212	3.879545	3.88267	3.875379	3.878504	3.871212	3.879545	3.88267	3.880587	3.878504	3.87642
area	30.9697	31.03636	31.06136	31.00303	31.02803	30.9697	31.03636	31.06136	31.0447	31.02803	31.01136
perimeter	15.74242	15.75909	15.76534	15.75076	15.75701	15.74242	15.75909	15.76534	15.76117	15.75701	15.75284
Sf	0.00041	0.000407	0.000406	0.000409	0.000408	0.00041	0.000407	0.000406	0.000407	0.000408	0.000408
Froude	0.093993	0.09369	0.093577	0.093841	0.093728	0.093993	0.09369	0.093577	0.093652	0.093728	0.093804
dY		-0.00205	-0.00205	-0.00206	-0.00206	-0.00207	-0.00205	-0.00205	-0.00205	-0.00206	-0.00206
Y calc	3.871212	3.869157	3.867107	3.865046	3.86299	3.860923	3.858869	3.856818	3.854765	3.852709	3.85065
Y adj	3.88813	3.886075	3.884025	3.881964	3.879908	3.877841	3.875786	3.873736	3.871683	3.869626	3.867567

Average depth =	3.878	Average n =	0.045
Average velocity =	1.048	n bed =	0.068
		R bed =	3.674

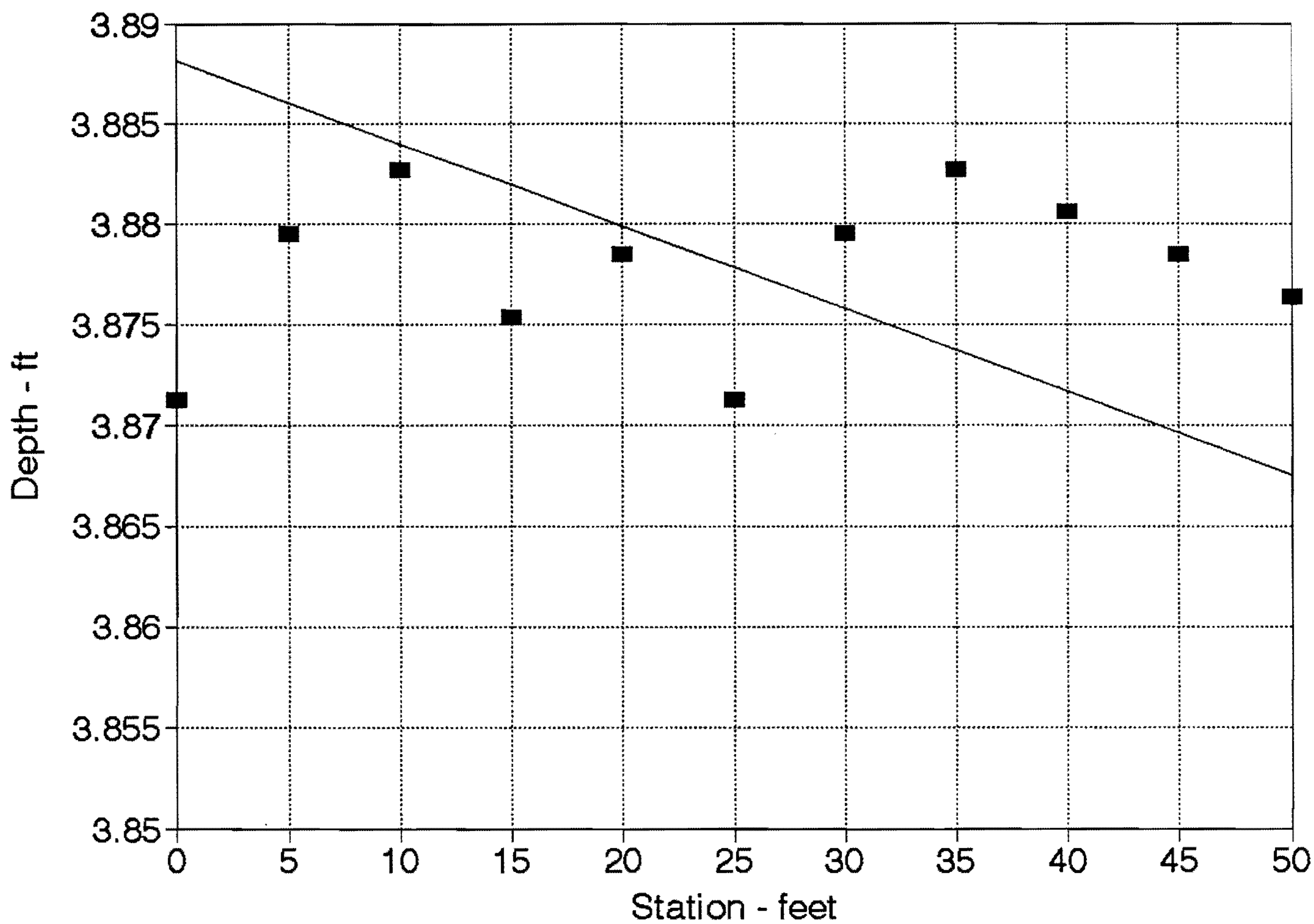
n
0.045

Velocity Profile station 25 feet vel. at plant center = 0.4 fps

Yo=	3.871212	ft		
V=	1.049413	fps		
Sf=	0.00041		Prandtl C	54.70776
Rh=	1.967276	ft	Prandtl n=	0.030405
V*=	0.161098	fps	Test n=	0.045
X=	1			
Ks=	1	ft	Ks/psi =	984.9482

elev	Y	V meas	Prandtl V
3	3.62	1.3	1.53
6	3.37	1.3	1.50
9	3.12	1.3	1.47
12	2.87	1.3	1.43
15	2.62	1.3	1.40
18	2.37	1.3	1.36
21	2.12	1.3	1.31
24	1.87	1.2	1.26
27	1.62	1	1.20
30	1.37	0.9	1.14
33	1.12	0.9	1.05
36	0.87	0.8	0.95
39	0.62	0.2	0.82

4-1



3.89
3.885
3.88
3.875
3.87
3.865
3.86
3.855
3.85
Depth - ft
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 4-2

Date: 5-20-94

Plants: Euonymus on 10" centers and 11" rows

NOTE: few leaves and stems breaking

FLOW = 43.2 cfs

dP = inches between taps

Drag = 12 micro inches calibr= 200 micro-in / lbs

Drag = 0.06 lbs

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
123.4375	122.1875	121.5625	121.2500	121.2500	121.3125	120.7500	120.6250	120.2500	121.5625	122.5000		
Average bottom elevation =		121.5170	feet									
Water surface elevations (inches)												
74.2500	74.4375	74.5000	74.6875	74.7500	74.8750	74.9375	75.0000	75.1250	75.1250	75.1875	74.5000	0.6875
74.2500	74.3688	74.3625	74.4813	74.4750	74.5313	74.5250	74.5188	74.5750	74.5063	74.5000		
Water depth (feet)												
3.9389	3.9290	3.9295	3.9196	3.9202	3.9155	3.9160	3.9165	3.9118	3.9176	3.9181		

Average depth =	3.92	feet	corrected depth u.s.=	3.93892	feet
Average area =	31.37	sf	corrected depth d.s.=	3.911837	feet
Average perim.=	15.84	feet	diff=	0.027083	feet
Average H.Radius=	1.98	feet			
Average E.slope=	0.0007				
Average n=	0.044274				
			intercept	3.921165	

n guess = 0.04

station	0	5	10	15	20	25	30	35	40	45	50
depth	3.93892	3.929025	3.929545	3.91965	3.92017	3.915483	3.916004	3.916525	3.911837	3.917566	3.918087
area	31.51136	31.4322	31.43636	31.3572	31.36136	31.32386	31.32803	31.3322	31.2947	31.34053	31.3447
perimeter	15.87784	15.85805	15.85909	15.8393	15.84034	15.83097	15.83201	15.83305	15.82367	15.83513	15.83617
Sf	0.000546	0.00055	0.00055	0.000553	0.000553	0.000555	0.000555	0.000554	0.000556	0.000554	0.000554
Froude	0.121731	0.122191	0.122167	0.122629	0.122605	0.122825	0.122801	0.122776	0.122997	0.122727	0.122703
dY		-0.00279	-0.00279	-0.00281	-0.00281	-0.00282	-0.00282	-0.00281	-0.00282	-0.00281	-0.00281
Y calc	3.93892	3.93613	3.933341	3.930533	3.927725	3.924909	3.922093	3.919279	3.916455	3.913643	3.910831
Y adj	3.935176	3.932386	3.929597	3.926789	3.923981	3.921165	3.918349	3.915535	3.912711	3.909899	3.907087

Average depth =	3.921	Average n =	0.040
Average velocity =	1.377	n bed =	0.060
		R bed =	3.681

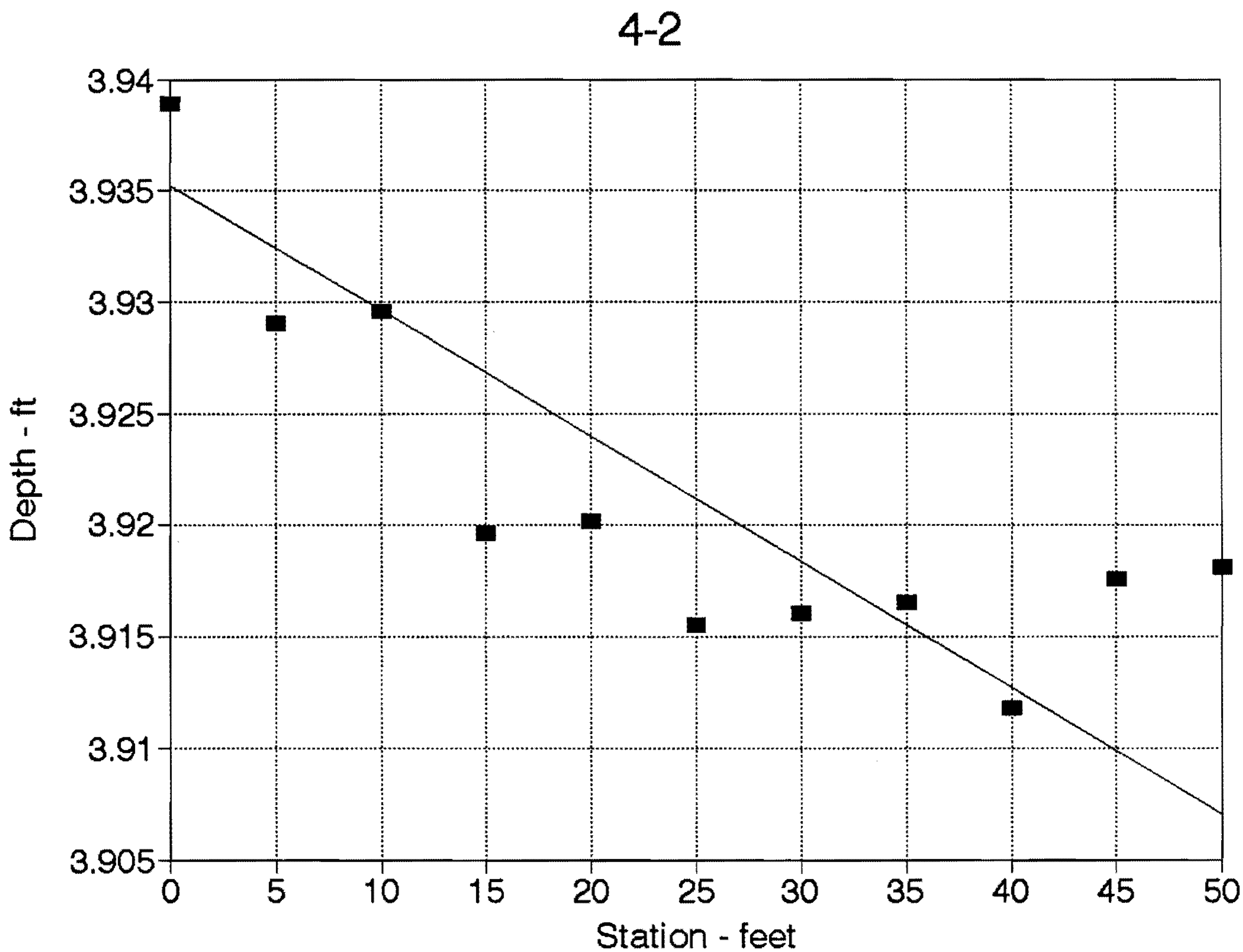
n

0.04

Velocity Profile station 25 feet vel. at plant center = 0.4 fps

Yo=	3.915483	ft		
V=	1.37914	fps		
Sf=	0.000555		Prandtl C	54.86889
Rh=	1.978645	ft	Prandtl n=	0.030345
V*=	0.188011	fps	Test n=	0.04
X=	1			
Ks=	1	ft	Ks/psi =	1149.492

elev	Y	V meas	Prandtl V
3	3.67	1.7	1.79
6	3.42	1.7	1.75
9	3.17	1.6	1.72
12	2.92	1.6	1.68
15	2.67	1.6	1.64
18	2.42	1.6	1.59
21	2.17	1.6	1.54
24	1.92	1.6	1.48
27	1.67	1.6	1.42
30	1.42	1.3	1.34
33	1.17	1	1.25
36	0.92	1	1.14
39	0.67	0.8	0.99


4-2
3.94
3.935
3.93
3.925
3.92
3.915
3.91
3.905
Depth - ft
0
5
10
15
20
25
30
35
40
45
50
Station - feet

q RUN #: 4-3

Date: 5-20-94

Plants: Euonymus on 10" centers and 11" rows

NOTE: few leaves and stems breaking

FLOW = 64.5 cfs

dP = inches between taps

Drag = 23 micro inches calibr= 200 micro-in / lbs

Drag = 0.115 lbs

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
123.4375	122.1875	121.5625	121.2500	121.2500	121.3125	120.7500	120.6250	120.2500	121.5625	122.5000		
Average bottom elevation =		121.5170	feet									
Water surface elevations (inches)												
77.0000	77.0625	77.1250	77.2500	77.3750	77.5625	77.6250	77.7500	77.8125	77.8125	77.8750	77.8125	0.0625
77.0000	77.0563	77.1125	77.2313	77.3500	77.5313	77.5875	77.7063	77.7625	77.7563	77.8125		
Water depth (feet)												
3.7098	3.7051	3.7004	3.6905	3.6806	3.6655	3.6608	3.6509	3.6462	3.6467	3.6420		

Average depth =	3.67	feet	corrected depth u.s.=	3.709754	feet
Average area =	29.38	sf	corrected depth d.s.=	3.646212	feet
Average perim.=	15.35	feet	diff=	0.063542	feet
Average H.Radius=	1.91	feet			
Average E.slope=	0.0016				
Average n=	0.041599				
			intercept	3.672585	

n guess = 0.042

station	0	5	10	15	20	25	30	35	40	45	50
depth	3.709754	3.705066	3.700379	3.690483	3.680587	3.665483	3.660795	3.6509	3.646212	3.646733	3.642045
area	29.67803	29.64053	29.60303	29.52386	29.4447	29.32386	29.28636	29.2072	29.1697	29.17386	29.13636
perimeter	15.41951	15.41013	15.40076	15.38097	15.36117	15.33097	15.32159	15.3018	15.29242	15.29347	15.28409
Sf	0.001576	0.001581	0.001587	0.001598	0.00161	0.001628	0.001633	0.001645	0.001651	0.00165	0.001656
Froude	0.198849	0.199227	0.199606	0.200409	0.201218	0.202463	0.202852	0.203677	0.20407	0.204026	0.20442
dY		-0.00823	-0.00826	-0.00833	-0.00839	-0.00849	-0.00852	-0.00858	-0.00861	-0.00861	-0.00864
Y calc	3.709754	3.70152	3.693257	3.684931	3.676542	3.668055	3.659538	3.650955	3.64234	3.63373	3.625087
Y adj	3.714284	3.70605	3.697787	3.689461	3.681072	3.672585	3.664068	3.655485	3.64687	3.638259	3.629617

Average depth =	3.673	Average n =	0.042
Average velocity =	2.195	n bed =	0.063
		R bed =	3.489

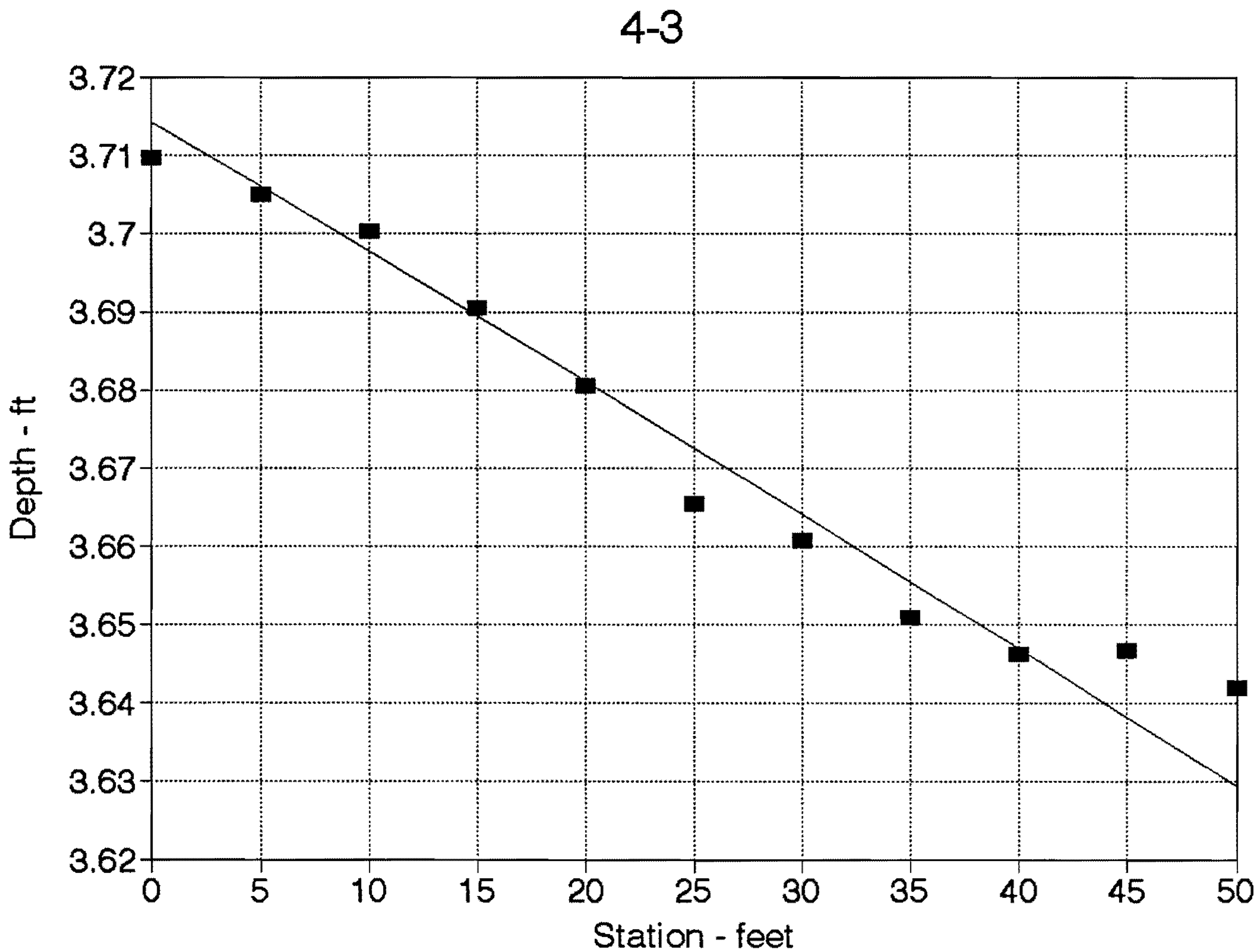
n

0.042

Velocity Profile station 25 feet vel. at plant center = 0.7 fps

Yo=	3.665483 ft			
V=	2.199574 fps			
Sf=	0.001628		Prandtl C	53.93395
Rh=	1.912721 ft		Prandtl n=	0.030697
V*=	0.316632 fps		Test n=	0.042
X=	1			
Ks=	1 ft		Ks/psi =	1935.878

elev	Y	V meas	Prandtl V
3	3.42	3	2.95
6	3.17	3	2.89
9	2.92	3	2.83
12	2.67	3	2.76
15	2.42	3	2.68
18	2.17	3	2.59
21	1.92	2.7	2.50
24	1.67	2.7	2.39
27	1.42	2.4	2.26
30	1.17	2.2	2.10
33	0.92	1.5	1.91
36	0.67	1.1	1.66
39	0.42	0.4	1.29


4-3
Depth - ft
3.72
3.71
3.7
3.69
3.68
3.67
3.66
3.65
3.64
3.63
3.62
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 4-4

Date: 5-20-94

Plants: Euonymus on 10" centers and 11" rows

NOTE: few leaves and stems breaking

FLOW =	48	cfs			
dP =		inches between taps			
Drag =	30	micro inches	calibr=	200	micro-in / lbs
Drag =	0.15	lbs			

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
123.4375	122.1875	121.5625	121.2500	121.2500	121.3125	120.7500	120.6250	120.2500	121.5625	122.5000		
Average bottom elevation =		121.5170	feet									
Water surface elevations (inches)												
87.3125	87.5625	87.7500	87.7500	87.8125	87.8125	87.8125	87.8125	87.6875	87.6875	87.5000	88.8750	-1.3750
87.3125	87.7000	88.0250	88.1625	88.3625	88.5000	88.6375	88.7750	88.7875	88.9250	88.8750		
Water depth (feet)												
2.8504	2.8181	2.7910	2.7795	2.7629	2.7514	2.7400	2.7285	2.7275	2.7160	2.7202		

Average depth =	2.76	feet	corrected depth u.s.=	2.850379	feet
Average area =	22.10	sf	corrected depth d.s.=	2.727462	feet
Average perim.=	13.52	feet	diff=	0.122917	feet
Average H.Radius=	1.63	feet			
Average E.slope=	0.0031				
Average n=	0.052611				
			intercept	2.762311	

n guess = 0.045

station	0	5	10	15	20	25	30	35	40	45	50
depth	2.850379	2.818087	2.791004	2.779545	2.762879	2.75142	2.739962	2.728504	2.727462	2.716004	2.72017
area	22.80303	22.5447	22.32803	22.23636	22.10303	22.01136	21.9197	21.82803	21.8197	21.72803	21.76136
perimeter	13.70076	13.63617	13.58201	13.55909	13.52576	13.50284	13.47992	13.45701	13.45492	13.43201	13.44034
Sf	0.00206	0.002126	0.002184	0.00221	0.002247	0.002273	0.0023	0.002327	0.002329	0.002357	0.002347
Froude	0.21972	0.223507	0.226768	0.228172	0.23024	0.23168	0.233134	0.234605	0.234739	0.236226	0.235683
dY		-0.01119	-0.01151	-0.01165	-0.01186	-0.01201	-0.01216	-0.01231	-0.01233	-0.01248	-0.01242
Y calc	2.850379	2.839188	2.827674	2.81602	2.804156	2.792146	2.779987	2.767675	2.75535	2.74287	2.730446
Y adj	2.820543	2.809352	2.797838	2.786184	2.774321	2.762311	2.750151	2.73784	2.725514	2.713034	2.70061

Average depth =	2.762	Average n =	0.045
Average velocity =	2.172	n bed =	0.062
		R bed =	2.658

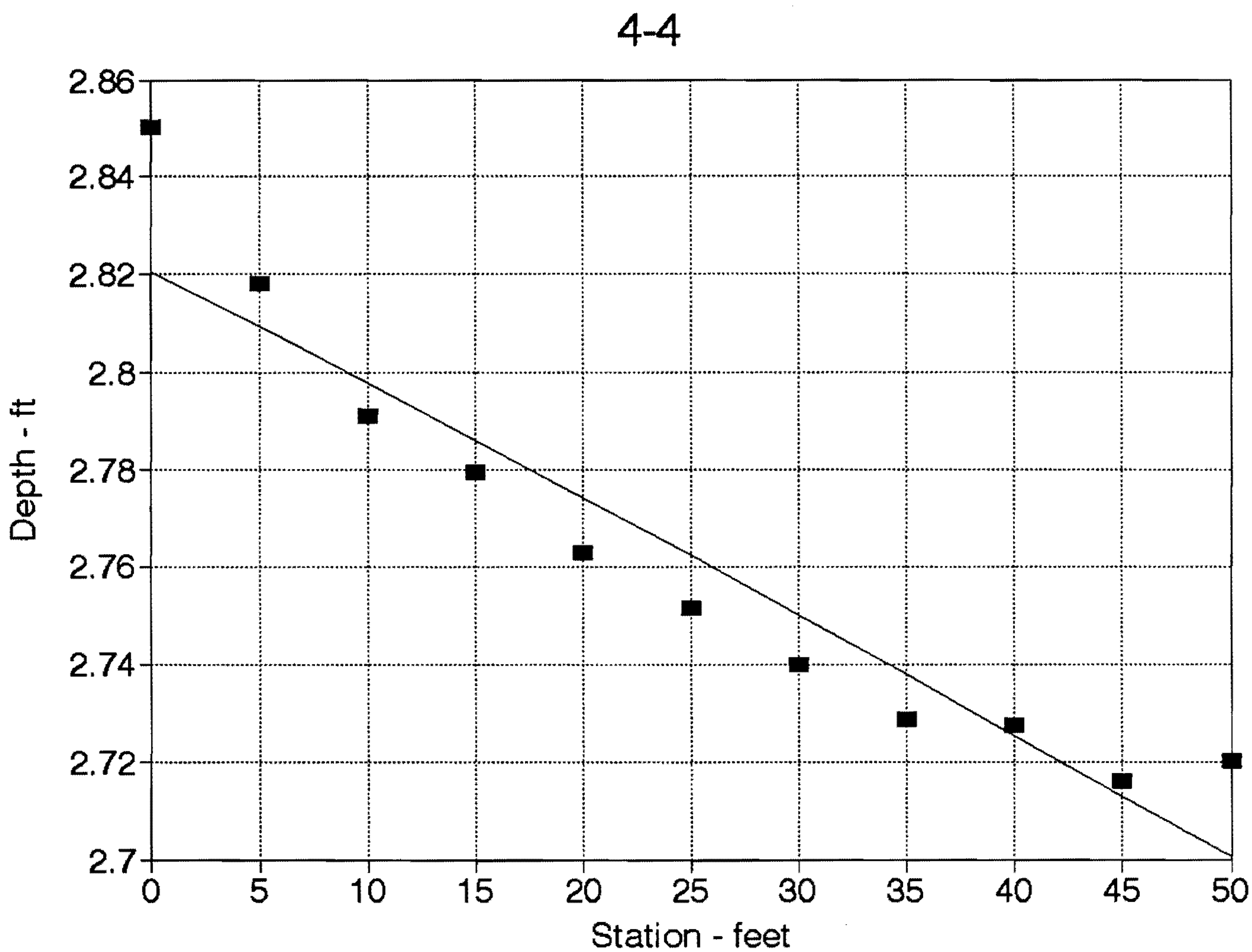
n

0.045

Velocity Profile station 25 feet vel. at plant center = 0.9 fps

Yo=	2.75142	ft		
V=	2.180692	fps		
Sf=	0.002273		Prandtl C	49.8693
Rh=	1.630128	ft	Prandtl n=	0.032326
V*=	0.345419	fps	Test n=	0.045
X=	1			
Ks=	1	ft	Ks/psi =	2111.877

elev	Y	V meas	Prandtl V
3	2.50	3.3	2.95
6	2.25	3.3	2.86
9	2.00	3.3	2.76
12	1.75	3	2.65
15	1.50	2.9	2.51
18	1.25	2.6	2.36
21	1.00	2	2.16
24	0.75	1.3	1.92
27	0.50	0.5	1.57
30	0.25	0.4	0.97
33	0.00	0	-3.49
36	-0.25	0	ERR
39	-0.50	0	ERR


4-4
2.86
2.84
2.82
2.8
2.78
2.76
2.74
2.72
2.7
Depth - ft
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project   RUN #: 4-5

Date: 5-20-94

Plants: Euonymus on 10" centers and 11" rows

NOTE: few leaves and stems breaking

FLOW =	58.5	cfs			
dP =	0	inches between taps			
Drag =	32	micro inches	calibr=	200	micro-in / lbs
Drag =	0.16	lbs			

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
123.4375	122.1875	121.5625	121.2500	121.2500	121.3125	120.7500	120.6250	120.2500	121.5825	122.5000		
Average bottom elevation =		121.5170	feet									
Water surface elevations (inches)												
85.7500	86.1250	86.3750	86.5000	66.7500	86.8750	87.0625	87.2500	87.3750	87.5000	87.6250	87.1250	0.5000
85.7500	86.0750	86.2750	66.3500	86.5500	86.6250	86.7625	86.9000	86.9750	87.0500	87.1250		
Water depth (feet)												
2.9806	2.9535	2.9368	2.9306	2.9139	2.9077	2.8962	2.8848	2.8785	2.8723	2.8660		

Average depth =	2.91	feet	corrected depth u.s.=	2.980587	feet
Average area =	23.29	sf	corrected depth d.s.=	2.878504	feet
Average perim.=	13.82	feet	diff=	0.102083	feet
Average H.Radius=	1.68	feet			
Average E.slope=	0.0026				
Average n=	0.042314				
			intercept	2.910985	

n guess = 0.042

station	0	5	10	15	20	25	30	35	40	45	50
depth	2.980587	2.953504	2.936837	2.930587	2.91392	2.90767	2.896212	2.884754	2.878504	2.872254	2.866004
area	23.8447	23.62803	23.4947	23.4447	23.31136	23.26136	23.1697	23.07803	23.02803	22.97803	22.92803
perimeter	13.96117	13.90701	13.87367	13.86117	13.82784	13.81534	13.79242	13.76951	13.75701	13.74451	13.73201
Sf	0.002355	0.002415	0.002454	0.002468	0.002507	0.002522	0.00255	0.002578	0.002594	0.00261	0.002625
Froude	0.250429	0.253882	0.256046	0.256866	0.259073	0.259908	0.261452	0.263012	0.263869	0.26473	0.265597
dY		-0.01291	-0.01313	-0.01321	-0.01344	-0.01353	-0.01369	-0.01385	-0.01394	-0.01403	-0.01412
Y calc	2.980587	2.967678	2.954549	2.941337	2.927899	2.914373	2.900687	2.886837	2.872898	2.858866	2.844743
Y adj	2.977199	2.96429	2.951161	2.937949	2.92451	2.910985	2.897299	2.883449	2.869509	2.855478	2.841355

Average depth =	2.911	Average n =	0.042
Average velocity =	2.512	n bed =	0.059
		R bed =	2.787

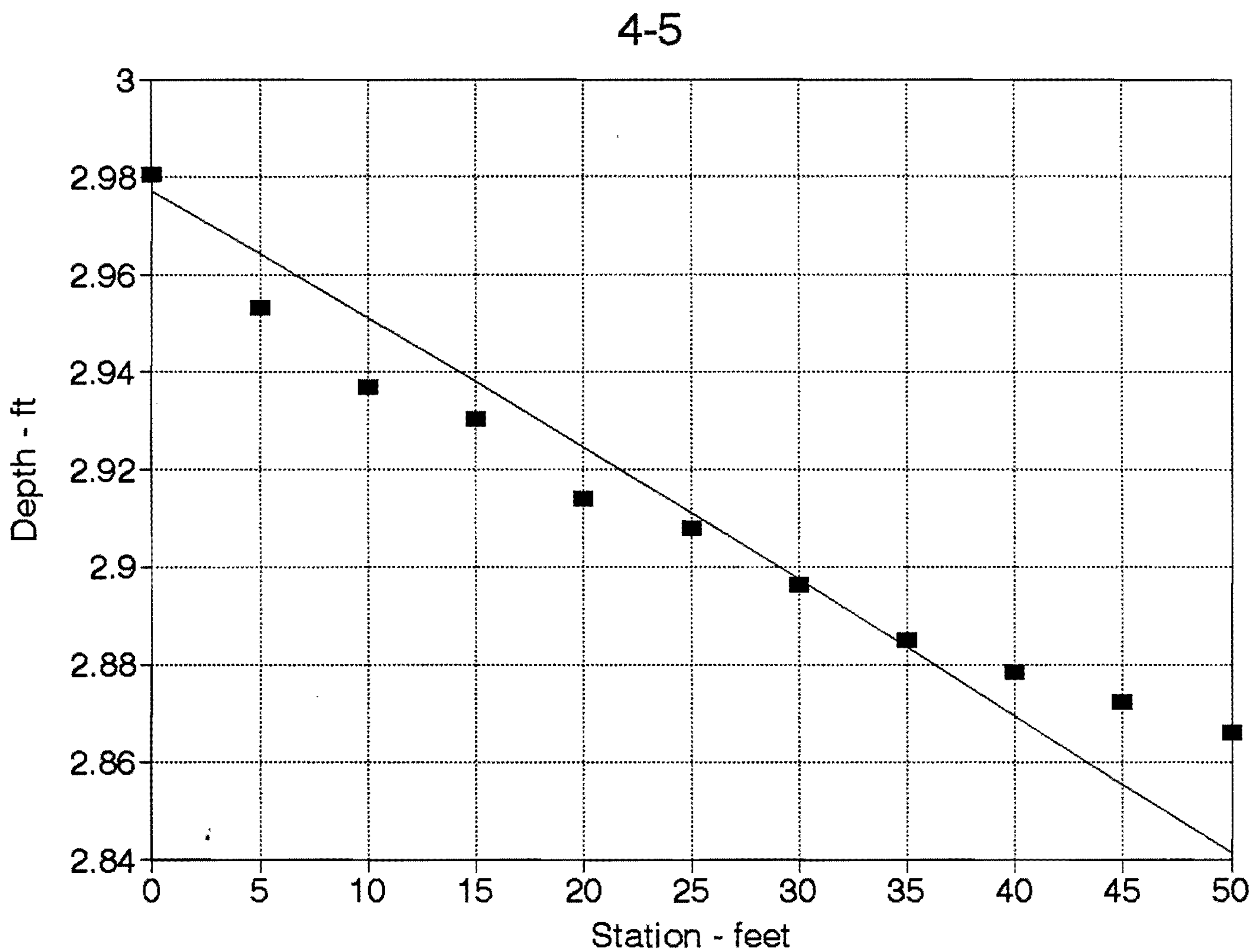
n

0.042

Velocity Profile station 25 feet   vel. at plant center = 1.6 fps

Yo=	2.90767	ft		
V=	2.5149	fps		
Sf=	0.002522		Prandtl C	50.65199
Rh=	1.683734	ft	Prandtl n=	0.031999
V*=	0.3698	fps	Test n=	0.042
X=	1			
Ks=	1	ft	Ks/psi =	2260.944

elev	Y	V meas	Prandtl V
3	2.66	3.5	3.22
6	2.41	3.5	3.13
9	2.16	3.5	3.03
12	1.91	3.5	2.91
15	1.66	3.3	2.78
18	1.41	3.1	2.63
21	1.16	3	2.45
24	0.91	2.6	2.23
27	0.66	2	1.93
30	0.41	1.2	1.49
33	0.16	0.8	0.61
36	-0.09	0	ERR
39	-0.34	0	ERR


4-5
3
2.98
2.96
2.94
2.92
2.9
2.88
2.86
2.84
Depth - ft
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project   RUN #: 4-6
Date: 5-20-94
Plants: Euonymus on 10" centers and 11" rows

NOTE: few leaves and stems breaking

FLOW = 65.5 cfs
dP = 0 inches between taps
Drag = 50 micro inches   calibr= 200 micro-in / lbs
Drag = 0.25 lbs

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
123.4375	122.1875	121.5625	121.2500	121.2500	121.3125	120.7500	120.6250	120.2500	121.5625	122.5000		
Average bottom elevation =		121.5170 feet										
Water surface elevations (inches)												
89.0000	89.5000	89.8750	90.1250	90.2500	90.7500	90.8750	91.2500	91.2500	91.3750	91.3750	91.8750	-0.5000
89.0000	89.5500	89.9750	90.2750	90.4500	91.0000	91.1750	91.6000	91.6500	91.8250	91.8750		
Water depth (feet)												
2.7098	2.6639	2.6285	2.6035	2.5889	2.5431	2.5285	2.4931	2.4889	2.4743	2.4702		

Average depth = 2.56 feet   corrected depth u.s.= 2.709754 feet
Average area = 20.50 sf   corrected depth d.s.= 2.48892 feet
Average perim.= 13.13 feet   diff= 0.220833 feet
Average H.Radius= 1.56 feet
Average E.slope= 0.0055
Average n= 0.046532

intercept 2.562973

n guess = 0.041

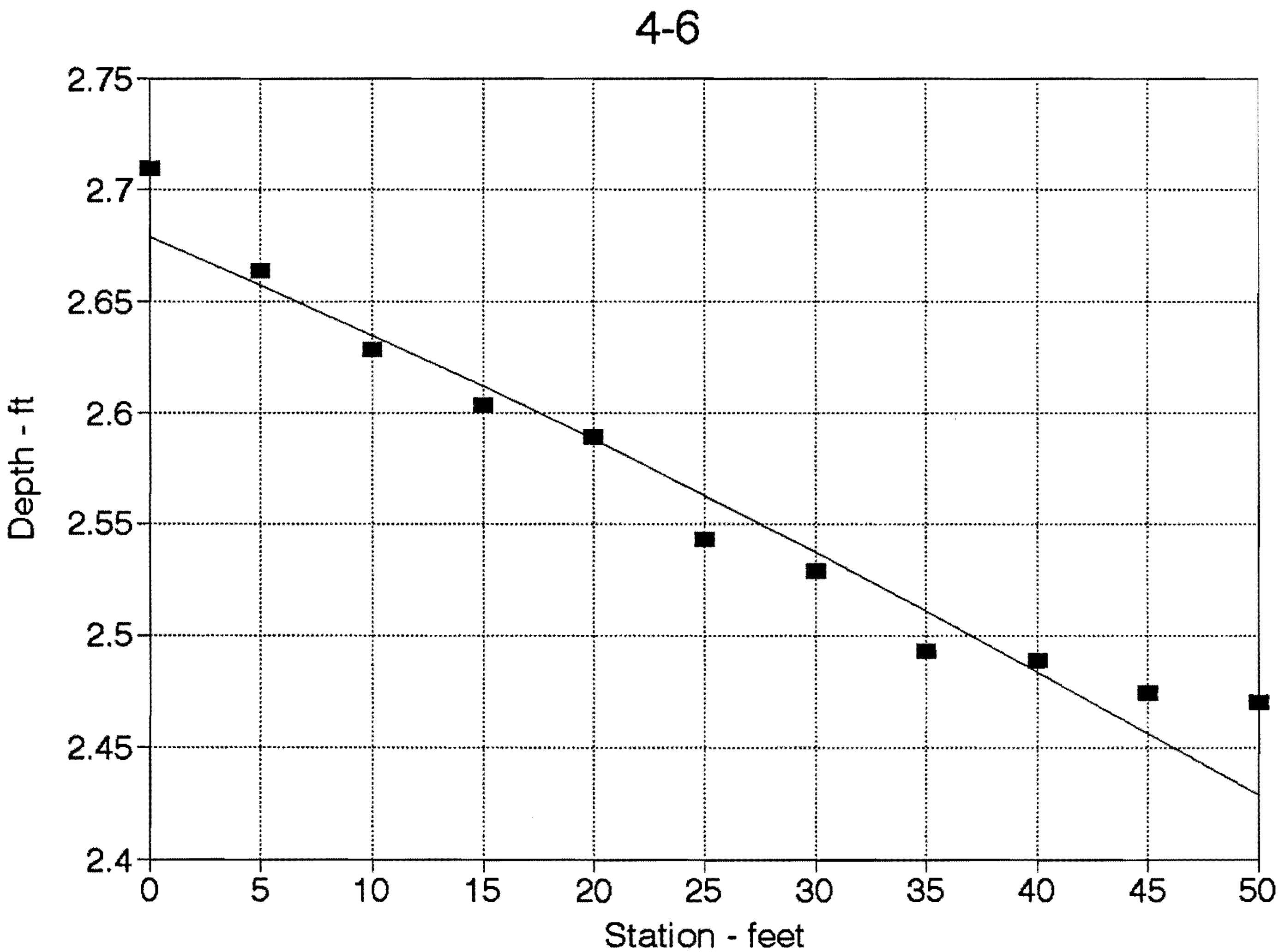
station	0	5	10	15	20	25	30	35	40	45	50
depth	2.709754	2.66392	2.628504	2.603504	2.58892	2.543087	2.528504	2.493087	2.48892	2.474337	2.47017
area	21.67803	21.31136	21.02803	20.82803	20.71136	20.3447	20.22803	19.9447	19.91136	19.7947	19.76136
perimeter	13.41951	13.32784	13.25701	13.20701	13.17784	13.08617	13.05701	12.98617	12.97784	12.94867	12.94034
Sf	0.003667	0.003846	0.003993	0.004101	0.004167	0.004381	0.004453	0.004633	0.004655	0.004733	0.004756
Froude	0.323466	0.33185	0.338579	0.343468	0.346374	0.35578	0.358862	0.366536	0.367457	0.370711	0.371649
dY		-0.02161	-0.02255	-0.02325	-0.02367	-0.02508	-0.02555	-0.02676	-0.02691	-0.02744	-0.02759
Y calc	2.709754	2.688145	2.665596	2.642347	2.618674	2.593593	2.568039	2.541276	2.514366	2.48693	2.459341
Y adj	2.679134	2.657525	2.634976	2.611727	2.588054	2.562973	2.537419	2.510657	2.483747	2.45631	2.428721

Average depth = 2.563   Average n = 0.041
Average velocity = 3.195   n bed = 0.056
R bed = 2.463

n
0.041

Velocity Profile station 25 feet   vel. at plant center = 1.2 fps
Yo= 2.543087 ft
V= 3.219512 fps
Sf= 0.004381   Prandtl C 48.75354
Rh= 1.554671 ft   Prandtl n= 0.032806
V*= 0.468321 fps   Test n= 0.041
X= 1
Ks= 1 ft   Ks/psi = 2863.296

elev	Y	V meas	Prandtl V
3	2.29	5	3.90
6	2.04	5	3.77
9	1.79	5	3.61
12	1.54	4.5	3.44
15	1.29	4.2	3.23
18	1.04	3.5	2.98
21	0.79	3.1	2.66
24	0.54	2.8	2.22
27	0.29	1.6	1.50
30	0.04	0.6	-0.75
33	-0.21	0	ERR
36	-0.46	0	ERR
39	-0.71	0	ERR


4-6
Depth - ft
2.75
2.7
2.65
2.6
2.55
2.5
2.45
2.4
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 4-7

Date: 5-20-94

Plants: Euonymus on 10" centers and 11" rows

NOTE: few leaves and stems breaking
some plants have been torn out after last run

FLOW =	34.5	cfs			
dP =	0	inches between taps			
Drag =	50	micro inches	calibr=	200	micro-in / lbs
Drag =	0.25	lbs			

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
123.4375	122.1875	121.5625	121.2500	121.2500	121.3125	120.7500	120.6250	120.2500	121.5625	122.5000		
Average bottom elevation =		121.5170	feet									
Water surface elevations (inches)												
100.1875	100.6250	101.0000	101.2500	101.6250	102.1250	102.3750	102.6875	102.7500	103.0000	103.1250	103.7500	-0.6250
100.1875	100.6875	101.1250	101.4375	101.8750	102.4375	102.7500	103.1250	103.2500	103.5625	103.7500		
Water depth (feet)												
1.7775	1.7358	1.6993	1.6733	1.6368	1.5900	1.5639	1.5327	1.5223	1.4962	1.4806		

Average depth =	1.61	feet	corrected depth u.s.=	1.777462	feet
Average area =	12.88	sf	corrected depth d.s.=	1.522254	feet
Average perim.=	11.22	feet	diff=	0.255208	feet
Average H.Radius=	1.15	feet			
Average E.slope=	0.0064				
Average n=	0.048576				
			intercept	1.609848	

n guess = 0.042

station	0	5	10	15	20	25	30	35	40	45	50
depth	1.777462	1.735795	1.699337	1.673295	1.636837	1.589962	1.56392	1.53267	1.522254	1.496212	1.480587
area	14.2197	13.88636	13.5947	13.38636	13.0947	12.7197	12.51136	12.26136	12.17803	11.9697	11.8447
perimeter	11.55492	11.47159	11.39867	11.34659	11.27367	11.17992	11.12784	11.06534	11.04451	10.99242	10.96117
Sf	0.003566	0.003822	0.004068	0.004256	0.004542	0.004948	0.005196	0.005516	0.005628	0.005924	0.006112
Froude	0.320701	0.332318	0.343069	0.351109	0.362905	0.379071	0.388579	0.400523	0.404642	0.415252	0.421842
dY		-0.02148	-0.02305	-0.02427	-0.02615	-0.02889	-0.0306	-0.03285	-0.03365	-0.03579	-0.03717
Y calc	1.777462	1.755979	1.732928	1.708653	1.682502	1.65361	1.623012	1.590165	1.556514	1.520723	1.483549
Y adj	1.7337	1.712218	1.689166	1.664892	1.63874	1.609848	1.579251	1.546404	1.512753	1.476961	1.439788

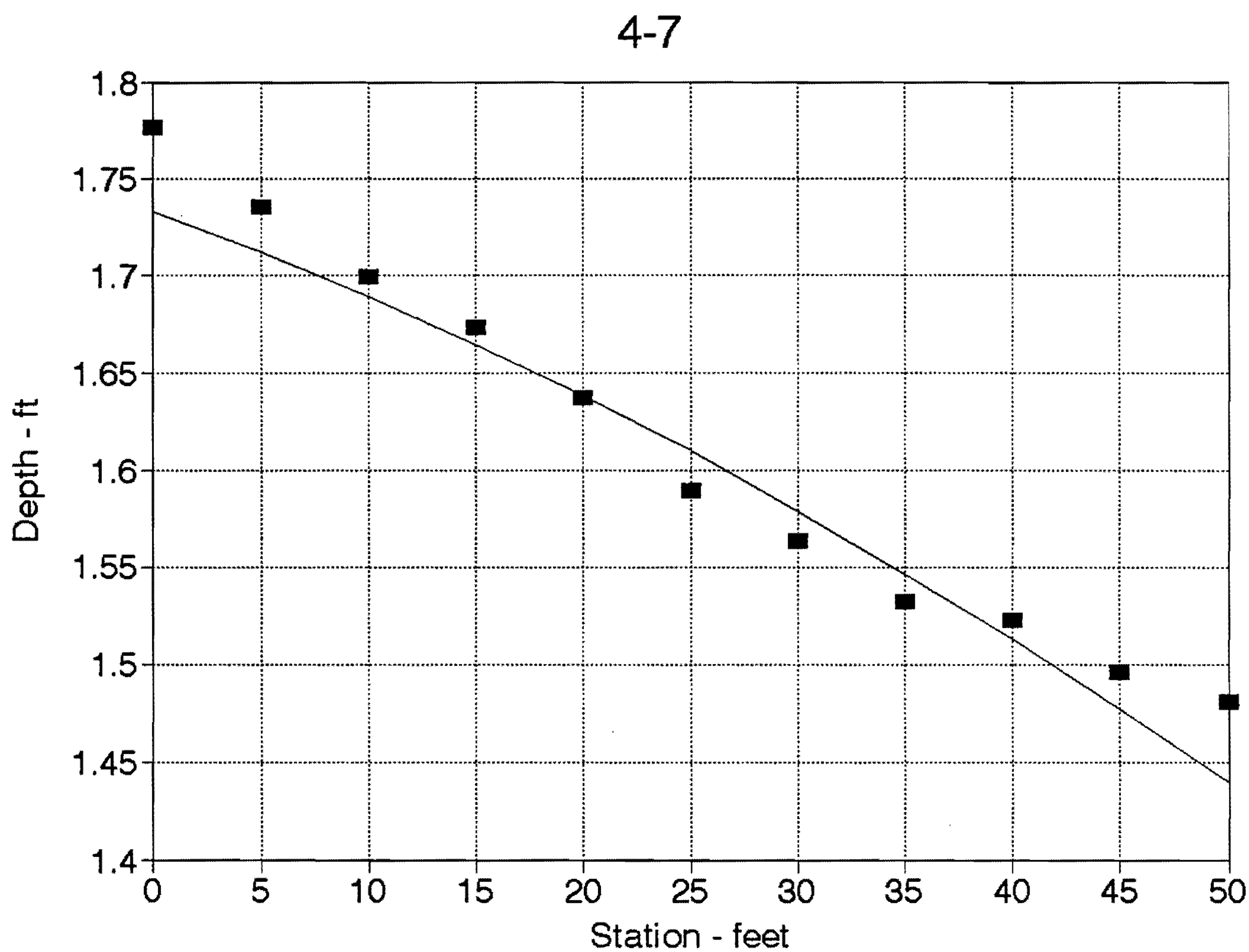
Average depth =	1.610	Average n =	0.042
Average velocity =	2.679	n bed =	0.052
		R bed =	1.565

n
0.042

Velocity Profile station 25 feet vel. at plant center = 1.2 fps

Yo=	1.589962 ft			
V=	2.712329 fps			
Sf=	0.004948		Prandtl C	42.09818
Rh=	1.137727 ft		Prandtl n=	0.036066
V*=	0.425756 fps		Test n=	0.042
X=	1			
Ks=	1 ft		Ks/psi =	2603.059

elev	Y	V meas	Prandtl V
3	1.34	4	2.98
6	1.09	4	2.76
9	0.84	3.4	2.48
12	0.59	2.2	2.10
15	0.34	1.9	1.52
18	0.09	0.8	0.11
21	-0.16	0	ERR
24	-0.41	0	ERR
27	-0.66	0	ERR
30	-0.91	0	ERR
33	-1.16	0	ERR
36	-1.41	0	ERR
39	-1.66	0	ERR


4-7
Depth - ft
Station - feet
1.8
1.75
1.7
1.65
1.6
1.55
1.5
1.45
1.4
0
5
10
15
20
25
30
35
40
45
50

C.O.E. Large Flume Project   RUN #: 5-1

Date: 5-21-94   ***** 200 plants (apprx. 45%) removed *******

Plants: Euonymus on 10" centers and 11" rows

FLOW =	36.5	cfs		
dP =	0	inches between taps		
Drag =	18	micro inches	calibr=	200 micro-in / lbs
Drag =	0.09	lbs		

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
123.4375	122.1875	121.5625	121.2500	121.2500	121.3125	120.7500	120.6250	120.2500	121.5625	122.5000		
Average bottom elevation =			121.5170	feet								
Water surface elevations (inches)												
80.7500	80.7500	80.8125	80.8125	80.8750	80.8750	80.8750	80.9375	80.9375	80.9375	80.9375	81.0000	-0.0625
80.7500	80.7563	80.8250	80.8313	80.9000	80.9063	80.9125	80.9813	80.9875	80.9938	81.0000		
Water depth (feet)												
3.3973	3.3967	3.3910	3.3905	3.3848	3.3842	3.3837	3.3780	3.3775	3.3769	3.3764		

Average depth =	3.39	feet	corrected depth u.s.=	3.397254	feet
Average area =	27.08	sf	corrected depth d.s.=	3.377462	feet
Average perim.=	14.77	feet	diff=	0.019792	feet
Average H.Radius=	1.83	feet			
Average E.slope=	0.0005				
Average n=	0.036739				
			intercept	3.38518	

n guess = 0.038

station	0	5	10	15	20	25	30	35	40	45	50
depth	3.397254	3.396733	3.391004	3.390483	3.384754	3.384233	3.383712	3.377983	3.377462	3.376941	3.37642
area	27.17803	27.17386	27.12803	27.12386	27.07803	27.07386	27.0697	27.02386	27.0197	27.01553	27.01136
perimeter	14.79451	14.79347	14.78201	14.78097	14.76951	14.76847	14.76742	14.75597	14.75492	14.75388	14.75284
Sf	0.000524	0.000524	0.000527	0.000527	0.00053	0.00053	0.00053	0.000532	0.000533	0.000533	0.000533
Froude	0.128405	0.128435	0.12876	0.12879	0.129117	0.129147	0.129177	0.129506	0.129536	0.129566	0.129596
dY		-0.00267	-0.00268	-0.00268	-0.00269	-0.00269	-0.00269	-0.00271	-0.00271	-0.00271	-0.00271
Y calc	3.397254	3.394588	3.391909	3.389229	3.386536	3.383843	3.381148	3.378441	3.375732	3.373022	3.370311
Y adj	3.398591	3.395925	3.393246	3.390566	3.387874	3.38518	3.382485	3.379778	3.377069	3.374359	3.371648

Average depth =	3.385	Average n =	0.038
Average velocity =	1.348	n bed =	0.055
		R bed =	3.177

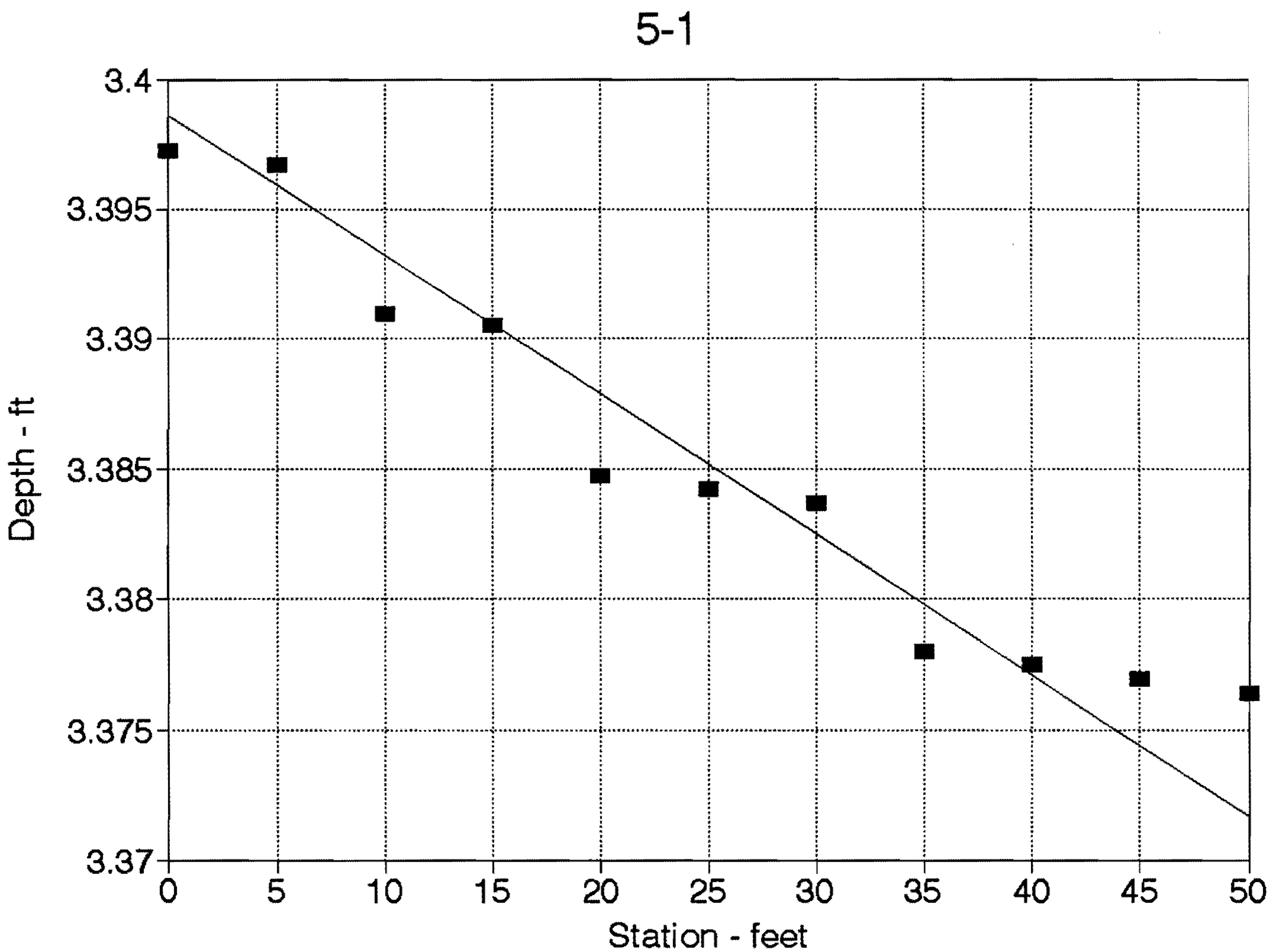
n

0.038

Velocity Profile station 25 feet   vel. at plant center = 0.6 fps

Yo=	3.384233	ft		
V=	1.348164	fps		
Sf=	0.00053		Prandtl C	52.8027
Rh=	1.833221	ft	Prandtl n=	0.031134
V*=	0.176834	fps	Test n=	0.038
X=	1			
Ks=	1	ft	Ks/psi =	1081.158

elev	Y	V meas	Prandtl V
3	3.13	1.9	1.61
6	2.88	1.9	1.57
9	2.63	1.9	1.53
12	2.38	1.8	1.49
15	2.13	1.8	1.44
18	1.88	1.8	1.39
21	1.63	1.6	1.32
24	1.38	1.6	1.25
27	1.13	1.1	1.16
30	0.88	1	1.05
33	0.63	0.9	0.91
36	0.38	0.6	0.68
39	0.13	0.3	0.22


5-1
3.4
3.395
3.39
3.385
3.38
3.375
3.37
Depth - ft
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 5-2

Date: 5-21-94 ***** 200 plants (apprx. 45%) removed *******

Plants: Euonymus on 10" centers and 11" rows

FLOW =	56.3	cfs			
dP =	0	inches between taps			
Drag =	30	micro inches	calibr=	200	micro-in / lbs
Drag =	0.15	lbs			

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
123.4375	122.1875	121.5625	121.2500	121.2500	121.3125	120.7500	120.6250	120.2500	121.5625	122.5000		
Average bottom elevation =		121.5170	feet									
Water surface elevations (inches)												
80.3125	80.8250	80.7500	80.8750	81.0000	81.2500	81.3750	81.5625	81.6250	81.6875	81.7500	81.0000	0.7500
80.3125	80.5500	80.6000	80.6500	80.7000	80.8750	80.9250	81.0375	81.0250	81.0125	81.0000		
Water depth (feet)												
3.4337	3.4139	3.4098	3.4056	3.4014	3.3868	3.3827	3.3733	3.3743	3.3754	3.3764		

Average depth =	3.39	feet	corrected depth u.s.=	3.433712	feet
Average area =	27.15	sf	corrected depth d.s.=	3.374337	feet
Average perim.=	14.79	feet	diff=	0.059375	feet
Average H.Radius=	1.84	feet			
Average E.slope=	0.0015				
Average n=	0.0414				
			intercept	3.393939	

n guess = 0.035

station	0	5	10	15	20	25	30	35	40	45	50
depth	3.433712	3.41392	3.409754	3.405587	3.40142	3.386837	3.38267	3.373295	3.374337	3.375379	3.37642
area	27.4697	27.31136	27.27803	27.2447	27.21136	27.0947	27.06136	26.98636	26.9947	27.00303	27.01136
perimeter	14.86742	14.82784	14.81951	14.81117	14.80284	14.77367	14.76534	14.74659	14.74867	14.75076	14.75284
Sf	0.001028	0.001044	0.001048	0.001051	0.001055	0.001067	0.001071	0.001079	0.001078	0.001077	0.001076
Froude	0.194915	0.196612	0.196973	0.197334	0.197697	0.198975	0.199343	0.200175	0.200082	0.199989	0.199897
dY		-0.00543	-0.00545	-0.00547	-0.00549	-0.00555	-0.00557	-0.00562	-0.00561	-0.00561	-0.0056
Y calc	3.433712	3.428282	3.422832	3.417364	3.411877	3.406322	3.400748	3.395129	3.389516	3.383907	3.378303
Y adj	3.421329	3.415899	3.41045	3.404981	3.399494	3.393939	3.388365	3.382747	3.377133	3.371524	3.365921

Average depth =	3.394	Average n =	0.035
Average velocity =	2.074	n bed =	0.050
		R bed =	3.172

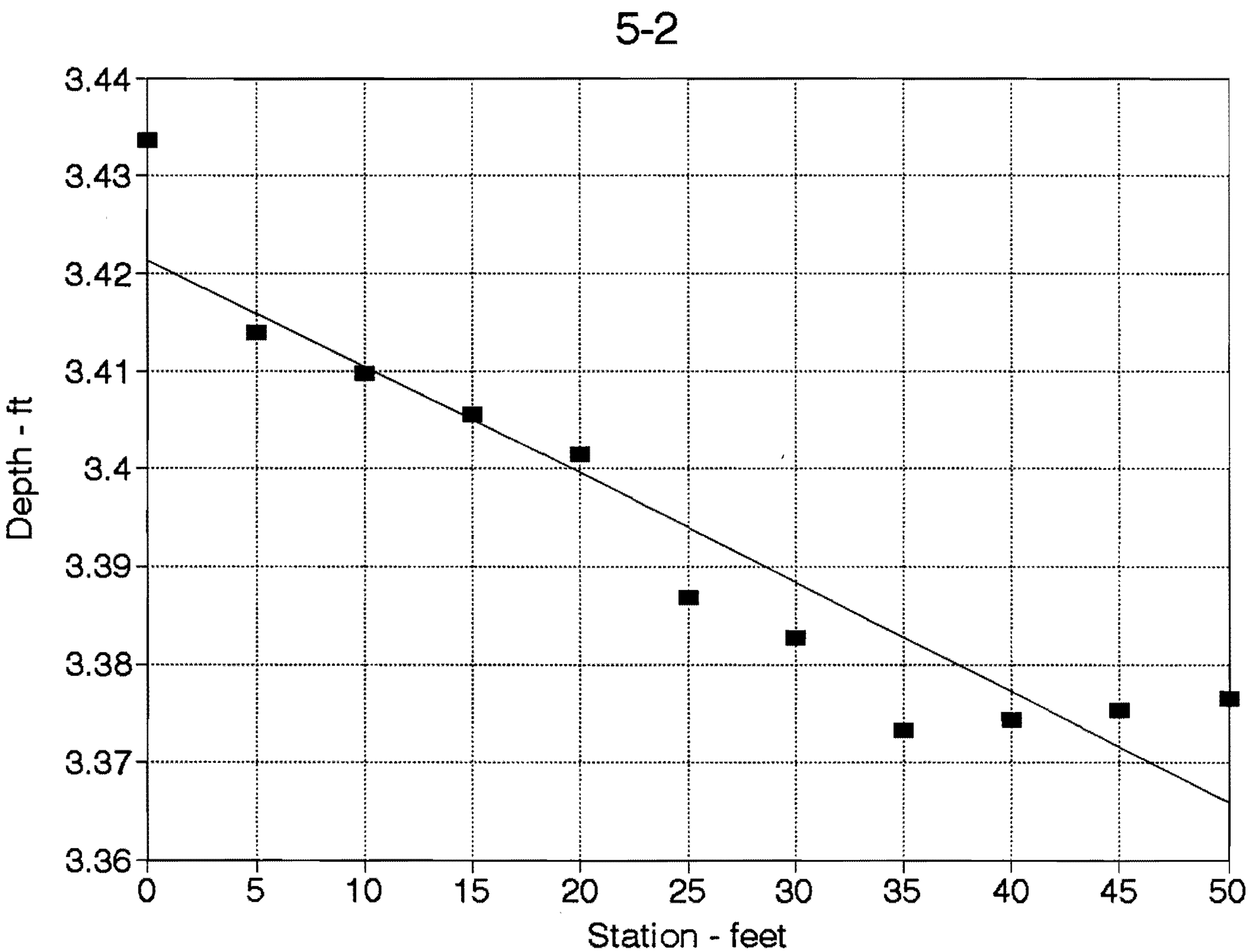
n

0.035

Velocity Profile station 25 feet vel. at plant center = 1 fps

Yo=	3.386837 ft			
V=	2.077897 fps			
Sf=	0.001067		Prandtl C	52.8136
Rh=	1.833985 ft		Prandtl n=	0.03113
V*=	0.251016 fps		Test n=	0.035
X=	1			
Ks=	1 ft		Ks/psi =	1534.705

elev	Y	V meas	Prandtl V
3	3.14	2.8	2.29
6	2.89	2.8	2.24
9	2.64	2.8	2.18
12	2.39	2.8	2.12
15	2.14	2.6	2.05
18	1.89	2.6	1.97
21	1.64	2.4	1.88
24	1.39	2.4	1.78
27	1.14	2.1	1.65
30	0.89	1.9	1.50
33	0.64	1.3	1.29
36	0.39	1.1	0.98
39	0.14	1	0.32



5-2
Depth - ft
3.44
3.43
3.42
3.41
3.4
3.39
3.38
3.37
3.36
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 5-3
Date: 5-21-94 ***** 200 plants (apprx. 45%) removed *******
Plants: Euonymus on 10" centers and 11" rows

FLOW =	58.6	cfs			
dP =	0	inches between taps			
Drag =	30	micro inches	calibr=	200	micro-in / lbs
Drag =	0.15	lbs			

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
123.4375	122.1875	121.5625	121.2500	121.2500	121.3125	120.7500	120.6250	120.2500	121.5625	122.5000		
Average bottom elevation =		121.5170 feet										
Water surface elevations (inches)												
92.2500	92.7500	93.1250	93.2500	93.3750	93.6250	93.7500	94.2500	94.2500	94.2500	94.2500	94.5000	-0.2500
92.2500	92.7750	93.1750	93.3250	93.4750	93.7500	93.9000	94.4250	94.4500	94.4750	94.5000		
Water depth (feet)												
2.4389	2.3952	2.3618	2.3493	2.3368	2.3139	2.3014	2.2577	2.2556	2.2535	2.2514		

Average depth =	2.32	feet	corrected depth u.s.=	2.43892	feet
Average area =	18.56	sf	corrected depth d.s.=	2.255587	feet
Average perim.=	12.64	feet	diff=	0.183333	feet
Average H.Radius=	1.47	feet			
Average E.slope=	0.0046				
Average n=	0.041153				
			intercept	2.319602	

n guess = 0.04

station	0	5	10	15	20	25	30	35	40	45	50
depth	2.43892	2.39517	2.361837	2.349337	2.336837	2.31392	2.30142	2.25767	2.255587	2.253504	2.25142
area	19.51136	19.16136	18.8947	18.7947	18.6947	18.51136	18.41136	18.06136	18.0447	18.02803	18.01136
perimeter	12.87784	12.79034	12.72367	12.69867	12.67367	12.62784	12.60284	12.51534	12.51117	12.50701	12.50284
Sf	0.003756	0.003953	0.004114	0.004176	0.00424	0.00436	0.004428	0.004677	0.004689	0.004702	0.004714
Froude	0.338909	0.348237	0.355635	0.358477	0.361357	0.366739	0.369731	0.38053	0.381057	0.381586	0.382116
dY		-0.02249	-0.02355	-0.02396	-0.02438	-0.02519	-0.02565	-0.02734	-0.02743	-0.02751	-0.0276
Y calc	2.43892	2.416426	2.392879	2.36892	2.344537	2.319347	2.293701	2.266356	2.238927	2.211412	2.183811
Y adj	2.439176	2.416681	2.393135	2.369175	2.344792	2.319602	2.293956	2.266611	2.239182	2.211667	2.184067

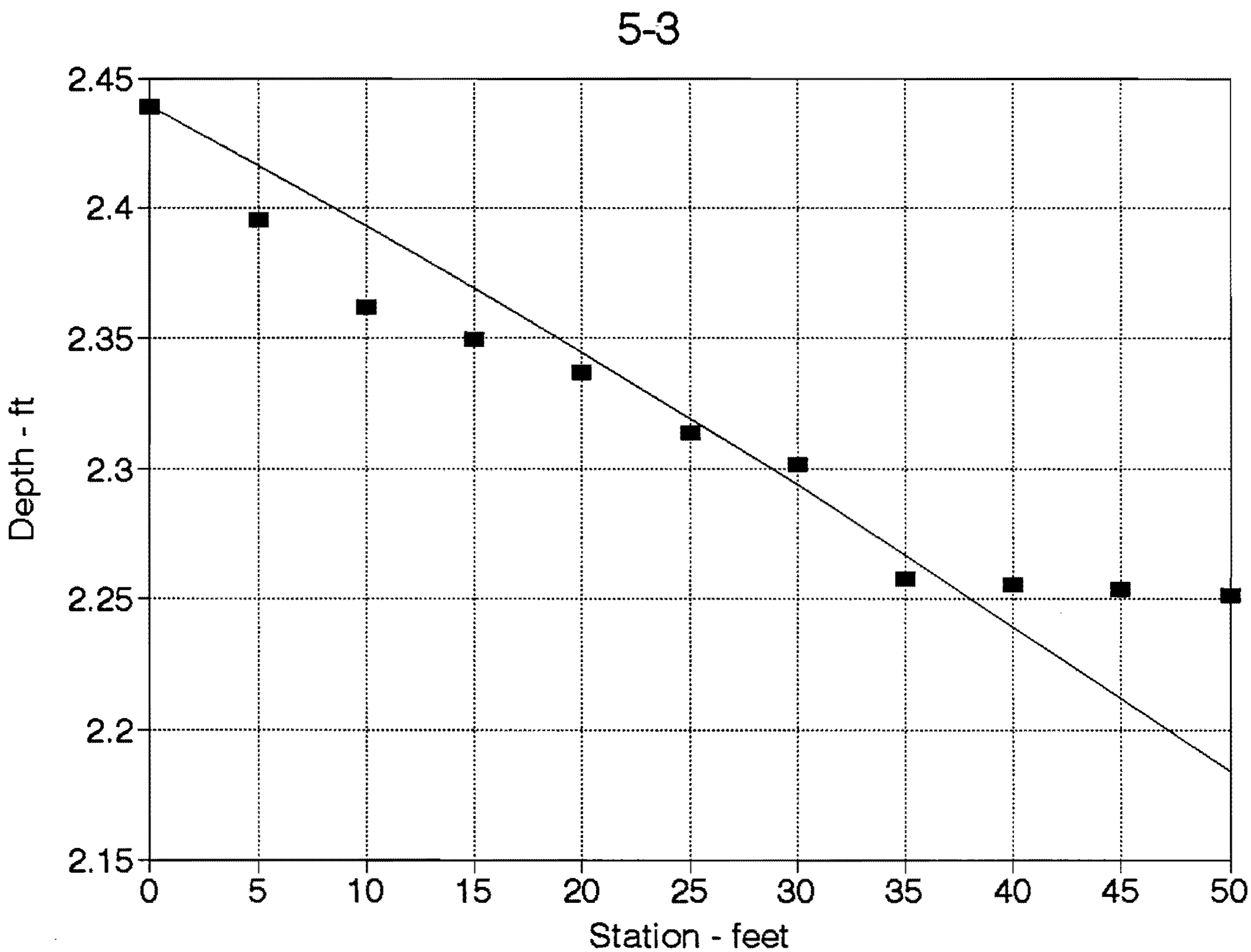
Average depth =	2.320	Average n =	0.040
Average velocity =	3.158	n bed =	0.053
		R bed =	2.231

n
0.04

Velocity Profile station 25 feet vel. at plant center = 1.9 fps

Yo=	2.31392	ft		
V=	3.165623	fps		
Sf=	0.00436		Prandtl C	47.41536
Rh=	1.465917	ft	Prandtl n=	0.033403
V*=	0.453674	fps	Test n=	0.04
X=	1			
Ks=	1	ft	Ks/psi =	2773.744

elev	Y	V meas	Prandtl V
3	2.06	4.5	3.66
6	1.81	4.5	3.52
9	1.56	4.5	3.35
12	1.31	4.1	3.15
15	1.06	3.8	2.91
18	0.81	3.1	2.61
21	0.56	2.3	2.19
24	0.31	1.9	1.53
27	0.06	1.8	-0.28
30	-0.19	0	ERR
33	-0.44	0	ERR
36	-0.69	0	ERR
39	-0.94	0	ERR


5-3
2.45
2.4
2.35
2.3
2.25
2.2
2.15
Depth - ft
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 6-1

Date: 6-9-94

Plants: 36-40" Dogwoods at 3' spacing and 3' rows (45 plants)

FLOW =	35.1 cfs			
dP =	0 inches between taps			
Drag =	255 micro inches	calibr=	100	micro-in / lbs
Drag =	2.55 lbs			

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
122.5000	122.2000	121.8000	121.5000	121.6000	121.4000	121.0000	121.3000	121.0000	121.5000	121.5000		
Average bottom elevation =			121.5727	feet								
Water surface elevations (inches)												
71.5000	71.5000	71.3750	71.4375	71.3750	71.3750	71.3750	71.3125	71.3750	71.3125	71.3125	72.2500	-0.9375
71.5000	71.5938	71.5625	71.7188	71.7500	71.8438	71.9375	71.9688	72.1250	72.1563	72.2500		
Water depth (feet)												
4.1727	4.1649	4.1675	4.1545	4.1519	4.1441	4.1363	4.1337	4.1206	4.1180	4.1102		

Average depth =	4.14 feet	corrected depth u.s.=	4.172727	feet
Average area =	33.15 sf	corrected depth d.s.=	4.120644	feet
Average perim.=	16.29 feet	diff=	0.052083	feet
Average H.Radius=	2.035 feet			
Average E.slope=	0.0013			
Average n=	0.081317			
		intercept	4.143134	

n guess = 0.075

station	0	5	10	15	20	25	30	35	40	45	50
depth	4.172727	4.164915	4.167519	4.154498	4.151894	4.144081	4.136269	4.133665	4.120644	4.11804	4.110227
area	33.38182	33.31932	33.34015	33.23598	33.21515	33.15265	33.09015	33.06932	32.96515	32.94432	32.88182
perimeter	16.34545	16.32983	16.33504	16.309	16.30379	16.28816	16.27254	16.26733	16.24129	16.23608	16.22045
Sf	0.001087	0.001092	0.001091	0.0011	0.001101	0.001107	0.001113	0.001114	0.001124	0.001126	0.001131
Froude	0.090711	0.090966	0.090881	0.091309	0.091394	0.091653	0.091913	0.092	0.092436	0.092524	0.092788
dY		-0.00551	-0.0055	-0.00554	-0.00555	-0.00558	-0.00561	-0.00562	-0.00567	-0.00568	-0.00571
Y calc	4.172727	4.16722	4.161722	4.156178	4.150624	4.145042	4.139432	4.133813	4.128146	4.122469	4.116763
Y adj	4.170819	4.165312	4.159814	4.15427	4.148716	4.143134	4.137524	4.131905	4.126238	4.120561	4.114855

Average depth =	4.143	Average n =	0.075
Average velocity =	1.059	n bed =	0.119
		R bed =	4.046

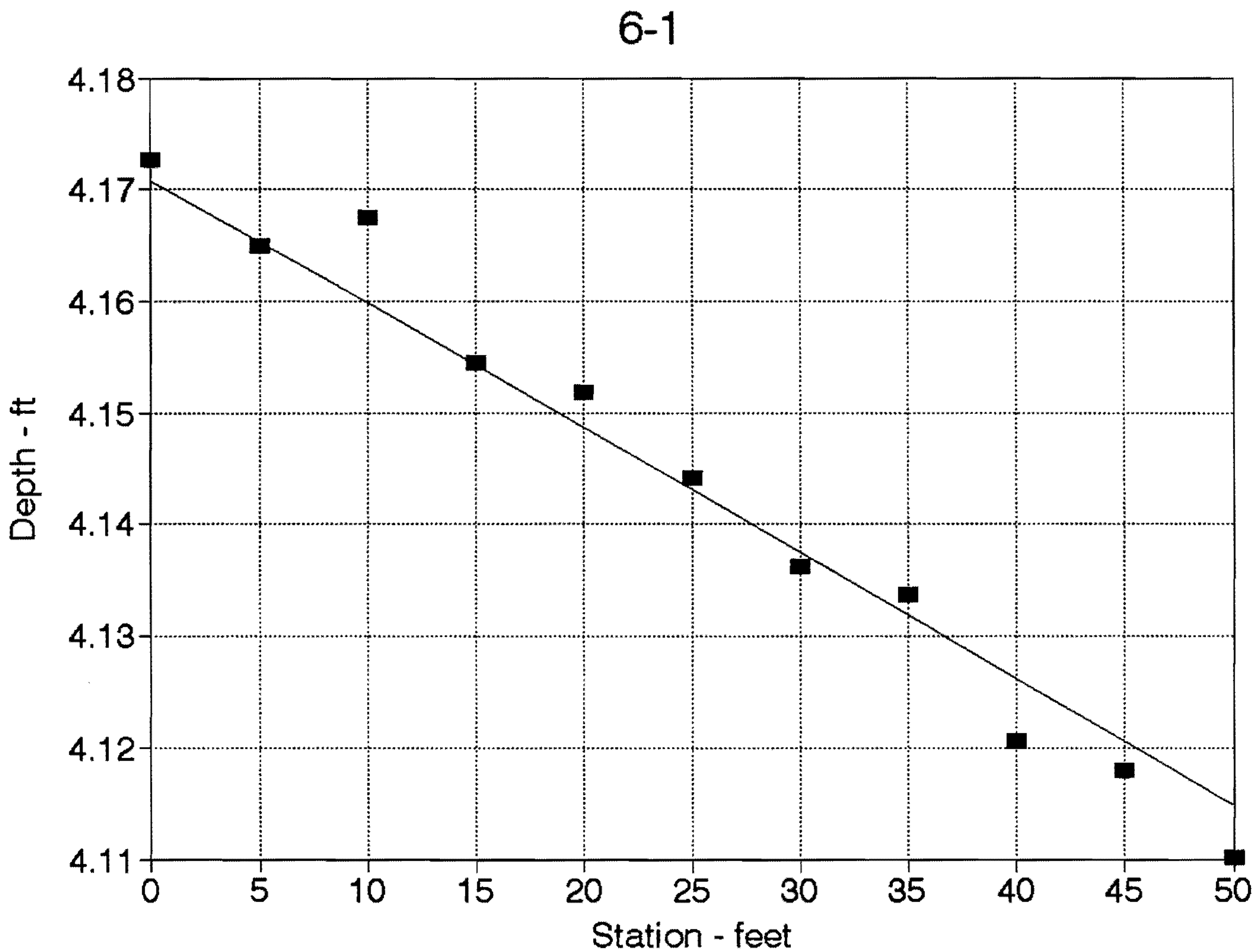
n

0.075

Velocity Profile station 25 feet vel. at plant center = 0.4 fps

Yo=	4.144081 ft		
V=	1.058739 fps		
Sf=	0.001107	Prandtl C	55.67295
Rh=	2.035383 ft	Prandtl n=	0.030048
V*=	0.269351 fps	Test n=	0.075
X=	1		
Ks=	1 ft	Ks/psi =	1646.801

elev	Y	V meas	Prandtl V
3	3.89	1.5	2.60
6	3.64	1.2	2.56
9	3.39	1.1	2.51
12	3.14	0.8	2.46
15	2.89	0.9	2.40
18	2.64	0.6	2.34
21	2.39	0.5	2.27
24	2.14	0.3	2.20
27	1.89	0.4	2.12
30	1.64	0.3	2.02
33	1.39	0.3	1.91
36	1.14	0.6	1.78
39	0.89	0.85	1.61


6-1
Depth - ft
4.18
4.17
4.16
4.15
4.14
4.13
4.12
4.11
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 6-2
Date: 6-9-94
Plants: 36-40" Dogwoods at 3' spacing and 3' rows (45 plants)

FLOW =	52.2	cfs			
dP =	0	inches between taps			
Drag =	340	micro inches	calibr=	100	micro-in / lbs
Drag =	3.4	lbs			

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
122.5000	122.2000	121.8000	121.5000	121.6000	121.4000	121.0000	121.3000	121.0000	121.5000	121.5000		
Average bottom elevation =			121.5727	feet								
Water surface elevations (inches)												
71.3750	71.5000	71.7500	72.0000	72.1875	72.5000	72.6250	73.1250	73.4375	73.4375	73.4375	72.0625	1.3750
71.3750	71.3625	71.4750	71.5875	71.6375	71.8125	71.8000	72.1625	72.3375	72.2000	72.0625		
Water depth (feet)												
4.1831	4.1842	4.1748	4.1654	4.1613	4.1467	4.1477	4.1175	4.1029	4.1144	4.1259		

Average depth =	4.15	feet	corrected depth u.s.=	4.183144	feet
Average area =	33.18	sf	corrected depth d.s.=	4.102936	feet
Average perim.=	16.30	feet	diff=	0.080208	feet
Average H.Radius=	2.04	feet			
Average E.slope=	0.0020				
Average n=	0.067952				
			intercept	4.147633	

n guess = 0.07

station	0	5	10	15	20	25	30	35	40	45	50
depth	4.183144	4.184186	4.174811	4.165436	4.161269	4.146686	4.147727	4.117519	4.102936	4.114394	4.125852
area	33.46515	33.47348	33.39848	33.32348	33.29015	33.17348	33.18182	32.94015	32.82348	32.91515	33.00682
perimeter	16.36629	16.36837	16.34962	16.33087	16.32254	16.29337	16.29545	16.23504	16.20587	16.22879	16.2517
Sf	0.00208	0.002079	0.002091	0.002104	0.002109	0.002129	0.002128	0.002169	0.00219	0.002174	0.002158
Froude	0.1344	0.13435	0.134802	0.135258	0.135461	0.136176	0.136125	0.137626	0.13836	0.137762	0.137209
dY		-0.01059	-0.01065	-0.01072	-0.01074	-0.01085	-0.01084	-0.01106	-0.01116	-0.01108	-0.011
Y calc	4.183144	4.172558	4.161908	4.151193	4.140449	4.129602	4.118762	4.107705	4.096542	4.085462	4.074466
Y adj	4.201175	4.190589	4.179939	4.169224	4.15848	4.147633	4.136793	4.125736	4.114572	4.103493	4.092497

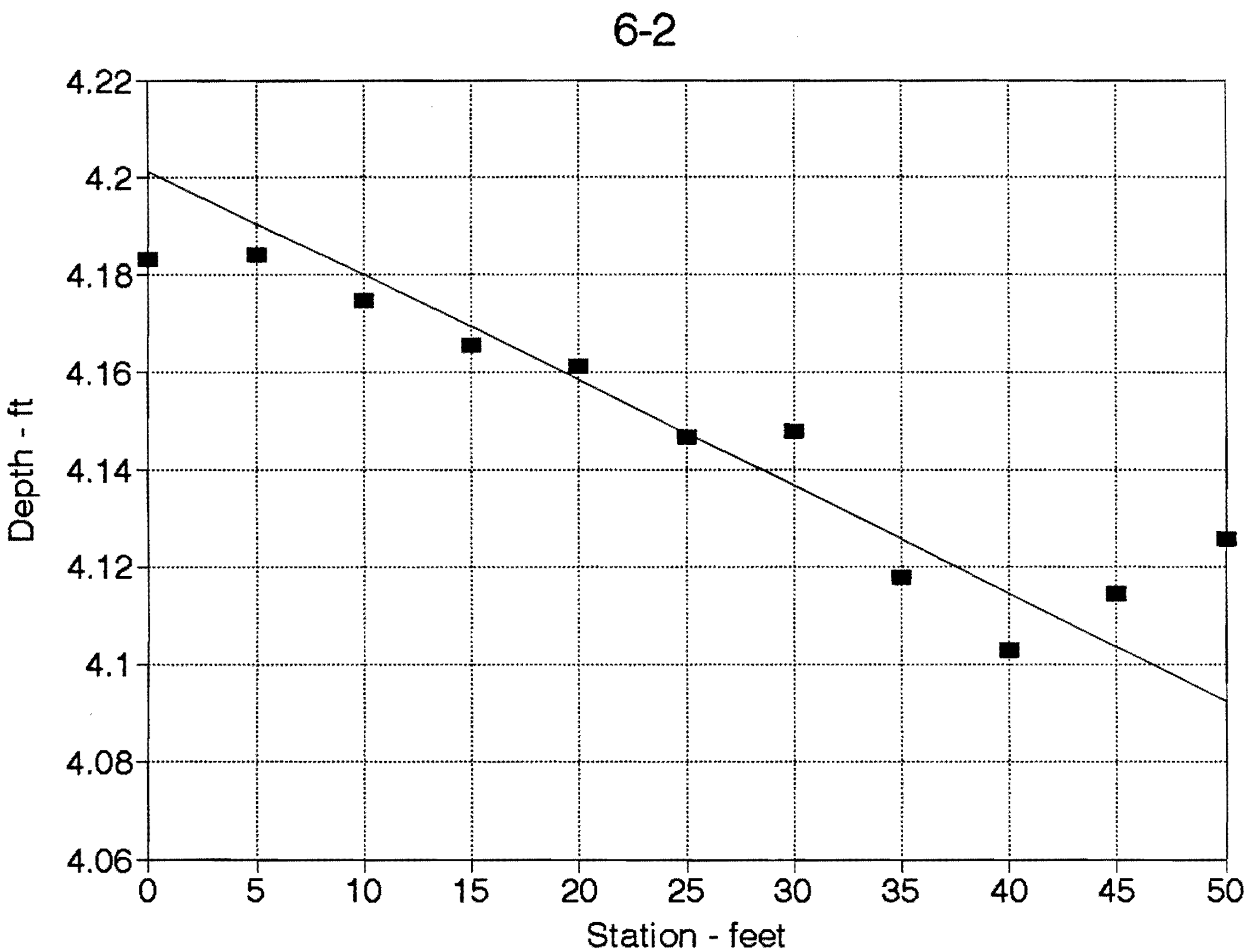
Average depth =	4.148	Average n =	0.070
Average velocity =	1.573	n bed =	0.111
		R bed =	4.046

n
0.07

Velocity Profile station 25 feet vel. at plant center = 0.6 fps

Yo=	4.146686	ft		
V=	1.573546	fps		
Sf=	0.002129		Prandtl C	55.68186
Rh=	2.036011	ft	Prandtl n=	0.030045
V*=	0.373614	fps	Test n=	0.07
X=	1			
Ks=	1	ft	Ks/psi =	2284.263

elev	Y	V meas	Prandtl V
3	3.90	2.3	3.61
6	3.65	2.2	3.55
9	3.40	2.1	3.48
12	3.15	1.9	3.41
15	2.90	1.7	3.33
18	2.65	1.4	3.25
21	2.40	1.3	3.15
24	2.15	1.15	3.05
27	1.90	0.9	2.94
30	1.65	0.7	2.80
33	1.40	0.6	2.65
36	1.15	0.75	2.47
39	0.90	0.7	2.24


6-2
4.22
4.2
4.18
4.16
4.14
4.12
4.1
4.08
4.06
Depth - ft
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project   RUN #: 6-3

Date: 6-9-94

Plants: 36-40" Dogwoods at 3' spacing and 3' rows (45 plants)

FLOW =	66.2	cfs		
dP =	0	inches between taps		
Drag =	580	micro inches	calibr=	100 micro-in / lbs
Drag =	5.8	lbs		

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
122.5000	122.2000	121.8000	121.5000	121.6000	121.4000	121.0000	121.3000	121.0000	121.5000	121.5000		
Average bottom elevation =			121.5727	feet								
Water surface elevations (inches)												
69.8750	69.9375	70.0000	70.3125	70.3125	70.5000	70.6250	70.8750	71.0000	71.1250	71.1250	71.1875	-0.0625
69.8750	69.9438	70.0125	70.3313	70.3375	70.5313	70.6625	70.9188	71.0500	71.1813	71.1875		
Water depth (feet)												
4.3081	4.3024	4.2967	4.2701	4.2696	4.2535	4.2425	4.2212	4.2102	4.1993	4.1988		

Average depth =	4.25	feet	corrected depth u.s.=	4.308144	feet
Average area =	34.02	sf	corrected depth d.s.=	4.210227	feet
Average perim.=	16.50	feet	diff=	0.097917	feet
Average H.Radius=	2.06	feet			
Average E.slope=	0.0024				
Average n=	0.05939				
			intercept	4.252036	

n guess = 0.062

station	0	5	10	15	20	25	30	35	40	45	50
depth	4.308144	4.302415	4.296686	4.270123	4.269602	4.253456	4.242519	4.221165	4.210227	4.19929	4.198769
area	34.46515	34.41932	34.37348	34.16098	34.15682	34.02765	33.94015	33.76932	33.68182	33.59432	33.59015
perimeter	16.61629	16.60483	16.59337	16.54025	16.5392	16.50691	16.48504	16.44233	16.42045	16.39858	16.39754
Sf	0.002577	0.002586	0.002595	0.002638	0.002639	0.002665	0.002684	0.00272	0.002738	0.002757	0.002758
Froude	0.168008	0.168344	0.168681	0.170257	0.170289	0.171259	0.171922	0.173228	0.173903	0.174583	0.174616
dY		-0.01331	-0.01336	-0.01358	-0.01359	-0.01373	-0.01383	-0.01402	-0.01412	-0.01422	-0.01423
Y calc	4.308144	4.294837	4.281482	4.267898	4.25431	4.24058	4.226754	4.212734	4.198615	4.184394	4.170169
Y adj	4.3196	4.306293	4.292937	4.279354	4.265766	4.252036	4.238209	4.22419	4.21007	4.19585	4.181625

Average depth =	4.252	Average n =	0.062
Average velocity =	2.005	n bed =	0.099
		R bed =	4.129

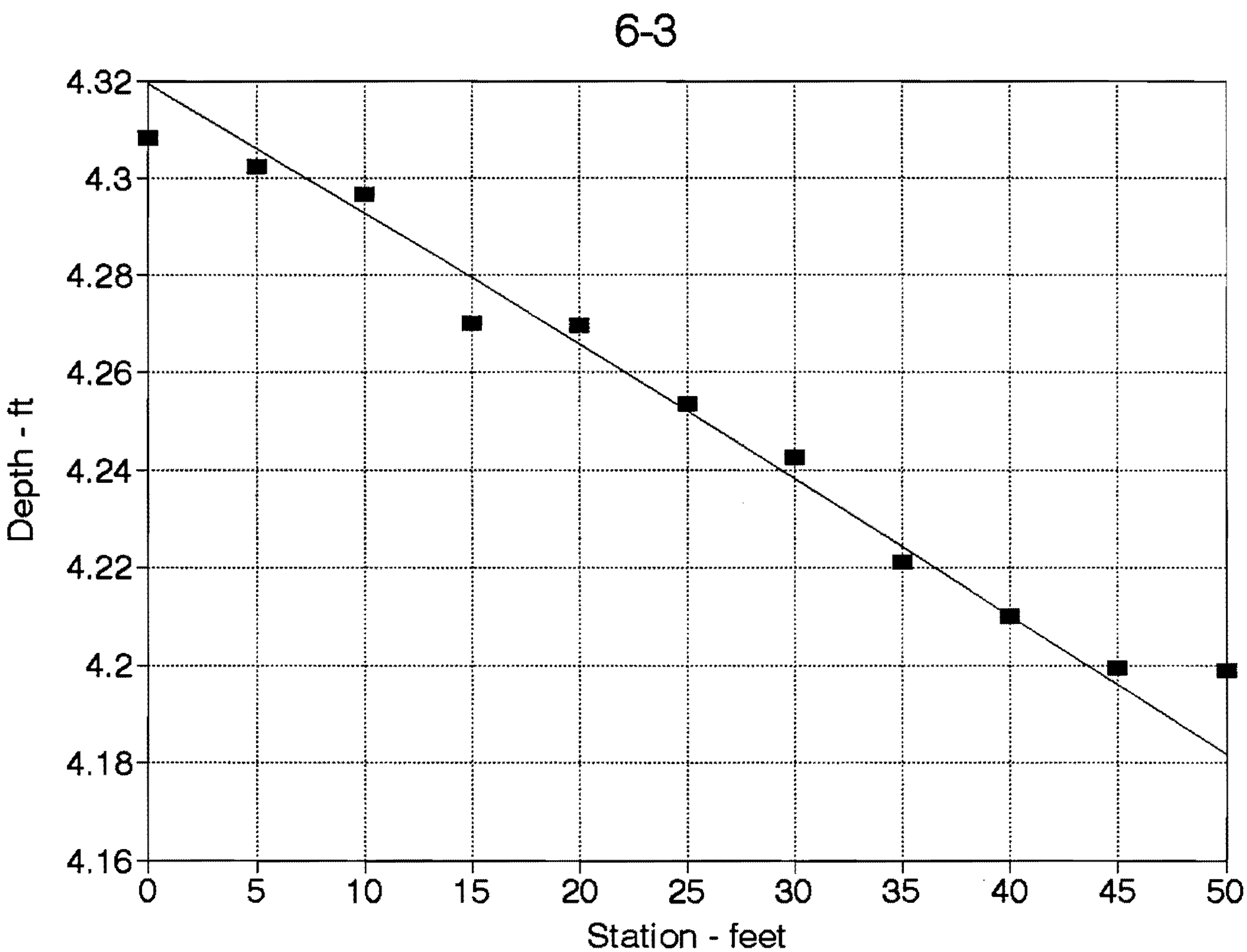
n

0.062

Velocity Profile station 25 feet   vel. at plant center = 0.8 fps

Yo=	4.253456	ft		
V=	2.004252	fps		
Sf=	0.002665		Prandtl C	56.0421
Rh=	2.061418	ft	Prandtl n=	0.029913
V*=	0.420622	fps	Test n=	0.062
X=	1			
Ks=	1	ft	Ks/psi =	2571.669

elev	Y	V meas	Prandtl V		
3	4.00	3	4.09	4.003456	3
6	3.75	2.6	4.02	3.753456	2.6
9	3.50	2.7	3.95	3.503456	2.7
12	3.25	2.6	3.87	3.253456	2.6
15	3.00	2.5	3.79	3.003456	2.5
18	2.75	2.2	3.70	2.753456	2.2
21	2.50	1.6	3.60	2.503456	1.6
24	2.25	1.3	3.49	2.253456	1.3
27	2.00	1	3.36	2.003456	1
30	1.75	0.9	3.22	1.753456	0.9
33	1.50	0.8	3.06	1.503456	0.8
36	1.25	0.9	2.87	1.253456	0.9
39	1.00	1.1	2.64	1.003456	1.1



6-3
4.32
4.3
4.28
4.26
4.24
4.22
4.2
4.18
4.16
Depth - ft
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 6-4

Date: 6-9-94

Plants: 36-40" Dogwoods at 3' spacing and 3' rows (45 plants)

FLOW =	28.1	cfs			
dP =	0	inches between taps			
Drag =	230	micro inches	calibr=	100	micro-in / lbs
Drag =	2.3	lbs			

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
122.5000	122.2000	121.8000	121.5000	121.6000	121.4000	121.0000	121.3000	121.0000	121.5000	121.5000		
Average bottom elevation =		121.5727	feet									
Water surface elevations (inches)												
83.7500	83.7500	83.8125	83.8125	83.8750	83.8125	83.7500	83.6875	83.6250	83.3750	83.2500	85.0000	-1.7500
83.7500	83.9250	84.1625	84.3375	84.5750	84.6875	84.8000	84.9125	85.0250	84.9500	85.0000		
Water depth (feet)												
3.1519	3.1373	3.1175	3.1029	3.0831	3.0738	3.0644	3.0550	3.0456	3.0519	3.0477		

Average depth =	3.08	feet	corrected depth u.s.=	3.151894	feet
Average area =	24.68	sf	corrected depth d.s.=	3.045644	feet
Average perim.=	14.17	feet	diff=	0.10625	feet
Average H.Radius=	1.74	feet			
Average E.slope=	0.0027				
Average n=	0.097359				
			intercept	3.084659	

n guess = 0.085

station	0	5	10	15	20	25	30	35	40	45	50
depth	3.151894	3.137311	3.117519	3.102936	3.083144	3.073769	3.064394	3.055019	3.045644	3.051894	3.047727
area	25.21515	25.09848	24.94015	24.82348	24.66515	24.59015	24.51515	24.44015	24.36515	24.41515	24.38182
perimeter	14.30379	14.27462	14.23504	14.20587	14.16629	14.14754	14.12879	14.11004	14.09129	14.10379	14.09545
Sf	0.001908	0.001933	0.001967	0.001992	0.002027	0.002044	0.002062	0.002079	0.002097	0.002085	0.002093
Froude	0.110619	0.111392	0.112454	0.113248	0.11434	0.114863	0.115391	0.115922	0.116458	0.116101	0.116339
dY		-0.00978	-0.00996	-0.01009	-0.01027	-0.01036	-0.01045	-0.01054	-0.01063	-0.01057	-0.01061
Y calc	3.151894	3.14211	3.132151	3.122062	3.11179	3.101431	3.090983	3.080446	3.069817	3.059249	3.04864
Y adj	3.135122	3.125337	3.115379	3.10529	3.095018	3.084659	3.074211	3.063673	3.053045	3.042477	3.031868

Average depth =	3.085	Average n =	0.085
Average velocity =	1.139	n bed =	0.123
		R bed =	3.036

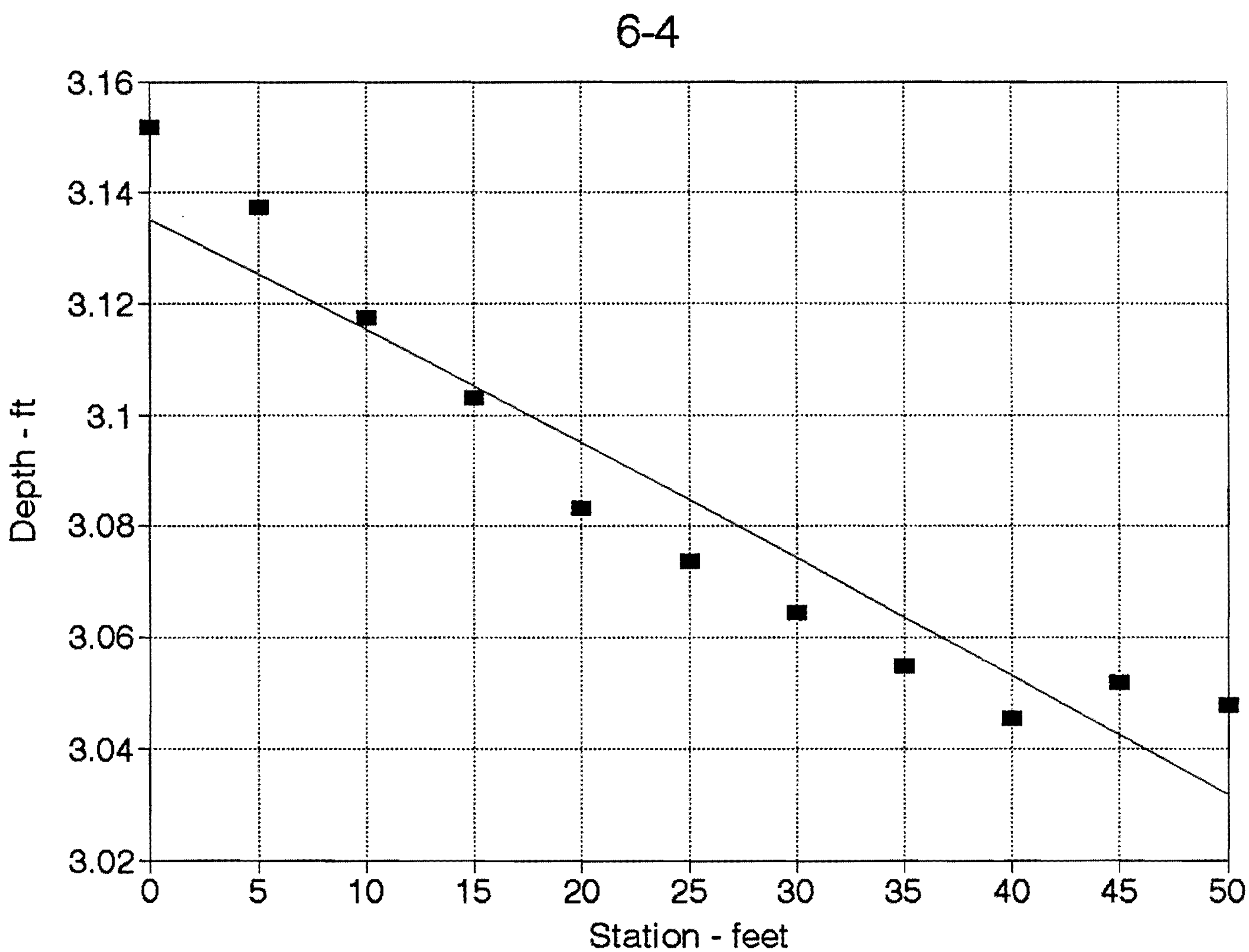
n

0.085

Velocity Profile station 25 feet vel. at plant center = 0.5 fps

Yo=	3.073769	ft		
V=	1.142734	fps		
Sf=	0.002044		Prandtl C	51.43919
Rh=	1.738122	ft	Prandtl n=	0.031677
V*=	0.338267	fps	Test n=	0.085
X=	1			
Ks=	1	ft	Ks/psi =	2068.153

elev	Y	V meas	Prandtl V
3	2.82	1.3	2.99
6	2.57	1.1	2.92
9	2.32	0.85	2.83
12	2.07	0.5	2.73
15	1.82	0.5	2.63
18	1.57	0.75	2.50
21	1.32	0.8	2.35
24	1.07	0.95	2.18
27	0.82	1.25	1.95
30	0.57	1.2	1.65
33	0.32	1.1	1.17
36	0.07	0.6	-0.08
39	-0.18	0	ERR


6-4
3.16
3.14
3.12
3.1
3.08
3.06
3.04
3.02
Depth - ft
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project   RUN #:   6-5
Date: 6-9-94
Plants: 36-40" Dogwoods at 3' spacing and 3' rows (45 plants)

FLOW =   39.7 cfs
dP =   0 inches between taps
Drag =   615 micro inches   calibr=   100 micro-in / lbs
Drag =   6.15 lbs

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
122.5000	122.2000	121.8000	121.5000	121.6000	121.4000	121.0000	121.3000	121.0000	121.5000	121.5000		
Average bottom elevation =		121.5727	feet									
Water surface elevations (inches)												
90.5000	90.5000	91.0000	91.2500	91.4375	91.5000	91.8750	92.3125	92.5000	92.8750	92.8750	93.0000	-0.1250
90.5000	90.5125	91.0250	91.2875	91.4875	91.5625	91.9500	92.4000	92.6000	92.9875	93.0000		
Water depth (feet)												
2.5894	2.5884	2.5456	2.5238	2.5071	2.5009	2.4686	2.4311	2.4144	2.3821	2.3811		

Average depth =   2.48 feet   corrected depth u.s.= 2.589394 feet
Average area =   19.88 sf   corrected depth d.s.= 2.414394 feet
Average perim. =   12.97 feet   diff=   0.175 feet
Average H.Radius=   1.53 feet
Average E.slope=   0.0044
Average n=   0.065422
intercept   2.484754

n guess =   0.07

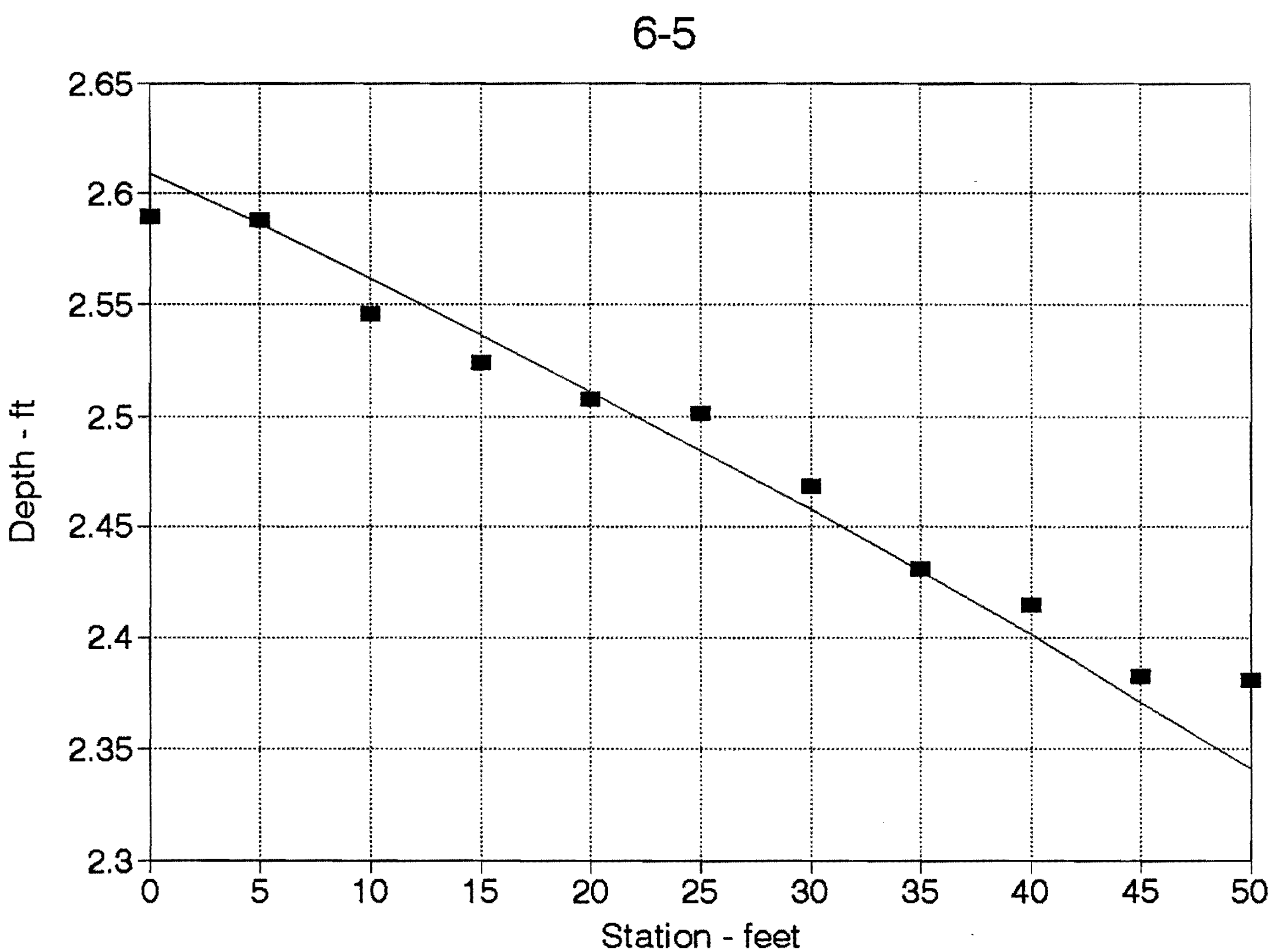
station	0	5	10	15	20	25	30	35	40	45	50
depth	2.589394	2.588352	2.545644	2.523769	2.507102	2.500852	2.468561	2.431061	2.414394	2.382102	2.381061
area	20.71515	20.70682	20.36515	20.19015	20.05682	20.00682	19.74848	19.44848	19.31515	19.05682	19.04848
perimeter	13.17879	13.1767	13.09129	13.04754	13.0142	13.0017	12.93712	12.86212	12.82879	12.7642	12.76212
Sf	0.004459	0.004464	0.004678	0.004793	0.004884	0.004918	0.005102	0.005328	0.005432	0.005644	0.005651
Froude	0.209882	0.210009	0.215316	0.218121	0.2203	0.221126	0.225479	0.230717	0.23311	0.237866	0.238022
dY		-0.02335	-0.02453	-0.02516	-0.02586	-0.02566	-0.02688	-0.02814	-0.02872	-0.02991	-0.02995
Y calc	2.589394	2.566042	2.541513	2.516348	2.490684	2.464828	2.437952	2.409816	2.381093	2.351182	2.321232
Y adj	2.609319	2.585967	2.561438	2.536274	2.510609	2.484754	2.457877	2.429741	2.401018	2.371107	2.341157

Average depth =   2.485   Average n =   0.070
Average velocity =   1.997   n bed =   0.095
R bed =   2.442

n
0.07

Velocity Profile station 25 feet   vel. at plant center =   1.4 fps
Yo=   2.500852 ft
V=   1.984324 fps
Sf=   0.004918   Prandtl C   48.51623
Rh=   1.538784 ft   Prandtl n=   0.03291
V*=   0.493655 fps   Test n=   0.07
X=   1
Ks=   1 ft   Ks/psi =   3018.188

elev	Y	V meas	Prandtl V
3	2.25	1.1	4.09
6	2.00	0.7	3.95
9	1.75	1.3	3.78
12	1.50	1.45	3.59
15	1.25	1.6	3.37
18	1.00	1.7	3.09
21	0.75	1.9	2.74
24	0.50	2	2.24
27	0.25	1.9	1.39
30	0.00	0.9	-5.62
33	-0.25	0	ERR
36	-0.50	0	ERR
39	-0.75	0	ERR


6-5
Depth - ft
2.65
2.6
2.55
2.5
2.45
2.4
2.35
2.3
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 6-7
Date: 6-9-94
Plants: 36-40" Dogwoods at 3' spacing and 3' rows (45 plants)

FLOW =	31.6	cfs			
dP =	0	inches between taps			
Drag =	830	micro inches	calibr=	100	micro-in / lbs
Drag =	8.3	lbs			

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
122.5000	122.2000	121.8000	121.5000	121.6000	121.4000	121.0000	121.3000	121.0000	121.5000	121.5000		
Average bottom elevation =		121.5727	feet									
Water surface elevations (inches)												
98.2500	98.5000	99.3125	99.1875	99.5000	100.1250	100.4375	100.9375	101.8750	102.3750	101.7500	102.1875	-0.4375
98.2500	98.5438	99.4000	99.3188	99.6750	100.3438	100.7000	101.2438	102.2250	102.7688	102.1875		
Water depth (feet)												
1.9436	1.9191	1.8477	1.8545	1.8248	1.7691	1.7394	1.6941	1.6123	1.5670	1.6154		

Average depth =	1.76	feet	corrected depth u.s. =	1.943561	feet
Average area =	14.10	sf	corrected depth d.s. =	1.612311	feet
Average perim. =	11.52	feet	diff=	0.33125	feet
Average H.Radius=	1.22	feet			
Average E.slope=	0.0083				
Average n=	0.069019				
			intercept	1.762453	

n guess = 0.07

station	0	5	10	15	20	25	30	35	40	45	50
depth	1.943561	1.919081	1.847727	1.854498	1.824811	1.769081	1.739394	1.694081	1.612311	1.566998	1.615436
area	15.54848	15.35265	14.78182	14.83598	14.59848	14.15265	13.91515	13.55265	12.89848	12.53598	12.92348
perimeter	11.88712	11.83816	11.69545	11.709	11.64962	11.53816	11.47879	11.38816	11.22462	11.134	11.23087
Sf	0.006407	0.006647	0.007421	0.007342	0.007696	0.008425	0.008853	0.009566	0.011065	0.012038	0.011002
Froude	0.256905	0.261836	0.277148	0.275632	0.282386	0.295834	0.30344	0.315695	0.340013	0.354868	0.339027
dY		-0.03568	-0.04019	-0.03973	-0.04181	-0.04617	-0.04876	-0.05312	-0.06256	-0.06886	-0.06216
Y calc	1.943561	1.907879	1.867686	1.827956	1.786143	1.739975	1.69122	1.638096	1.575537	1.506678	1.444522
Y adj	1.966038	1.930356	1.890164	1.850433	1.80862	1.762453	1.713697	1.660574	1.598014	1.529155	1.466999

Average depth =	1.762	Average n =	0.070
Average velocity =	2.241	n bed =	0.089
		R bed =	1.739

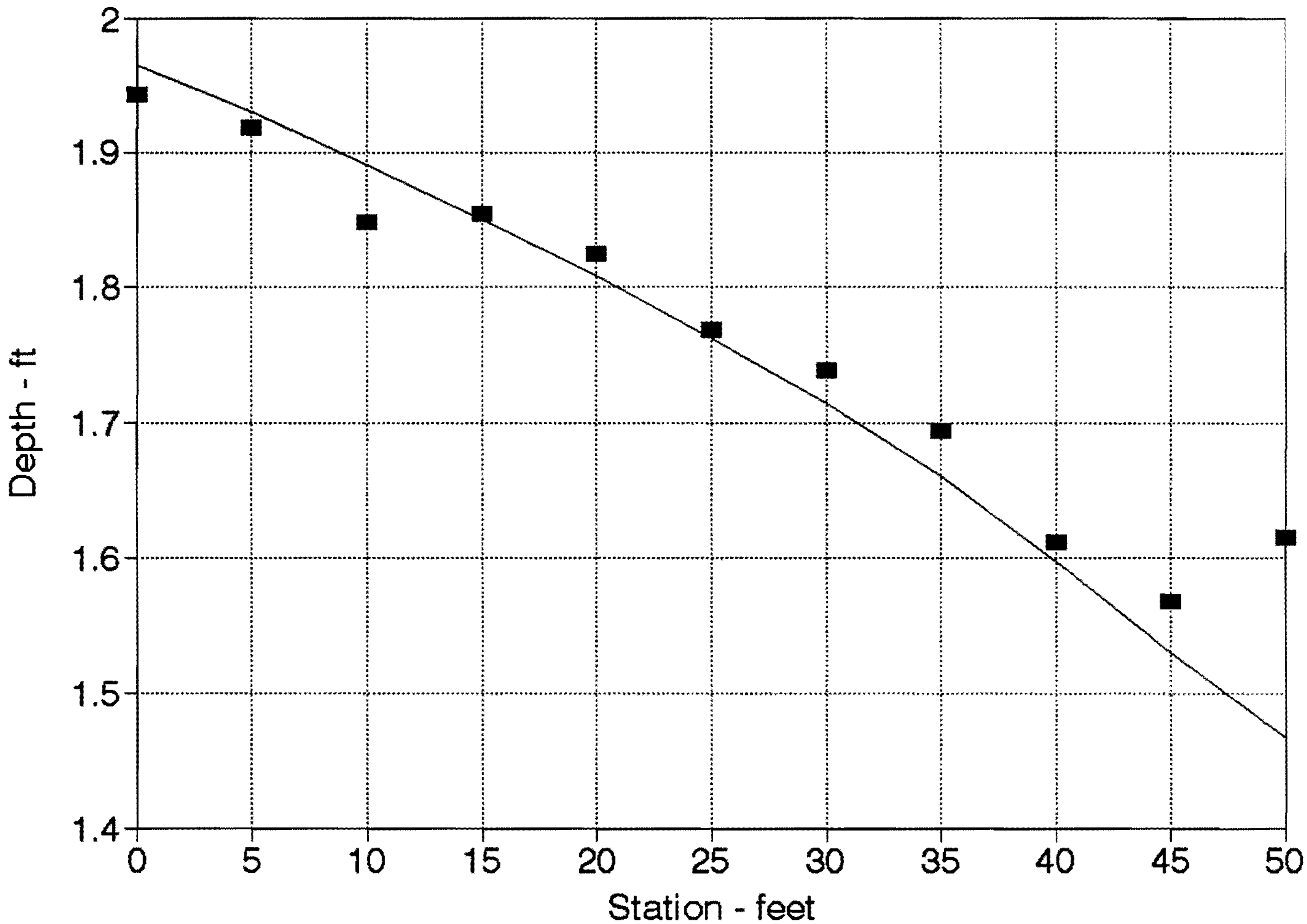
n
0.07

Velocity Profile station 25 feet vel. at plant center = 0.7 fps

Yo=	1.769081 ft			
V=	2.232797 fps			
Sf=	0.008425		Prandtl C	43.61087
Rh=	1.226595 ft		Prandtl n=	0.035254
V* =	0.576863 fps		Test n=	0.07
X=	1			
Ks=	1 ft		Ks/psi =	3526.922

elev	Y	V meas	Prandtl V
3	1.52	1	4.21
6	1.27	1.5	3.95
9	1.02	2.2	3.64
12	0.77	2.4	3.23
15	0.52	2.3	2.67
18	0.27	1.3	1.72
21	0.02	1	-2.09
24	-0.23	0	ERR
27	-0.48	0	ERR
30	-0.73	0	ERR
33	-0.98	0	ERR
36	-1.23	0	ERR
39	-1.48	0	ERR

6-7


2
1.9
1.8
1.7
1.6
1.5
1.4
Depth - ft
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 6-8
Date: 6-9-94
Plants: 36-40" Dogwoods at 3' spacing and 3' rows (45 plants)

FLOW =	77.4	cfs			
dP =	0	inches between taps			
Drag =	710	micro inches	calibr=	100	micro-in / lbs
Drag =	7.1	lbs			

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
122.5000	122.2000	121.8000	121.5000	121.6000	121.4000	121.0000	121.3000	121.0000	121.5000	121.5000		
Average bottom elevation =		121.5727	feet									
Water surface elevations (inches)												
83.0000	82.8750	83.0000	83.0000	83.1875	83.1250	83.2500	83.1250	83.3125	83.0000	83.0000	86.4375	-3.4375
83.0000	83.2188	83.6875	84.0313	84.5625	84.8438	85.3125	85.5313	86.0625	86.0938	86.4375		
Water depth (feet)												
3.2144	3.1962	3.1571	3.1285	3.0842	3.0607	3.0217	3.0035	2.9592	2.9566	2.9279		

Average depth =	3.06	feet	corrected depth u.s.=	3.214394	feet
Average area =	24.52	sf	corrected depth d.s.=	2.959186	feet
Average perim.=	14.13	feet	diff=	0.255208	feet
Average H.Radius=	1.74	feet			
Average E.slope=	0.0064				
Average n=	0.054289				
			intercept	3.064536	

n guess = 0.05

station	0	5	10	15	20	25	30	35	40	45	50
depth	3.214394	3.196165	3.157102	3.128456	3.084186	3.060748	3.021686	3.003456	2.959186	2.956581	2.927936
area	25.71515	25.56932	25.25682	25.02765	24.67348	24.48598	24.17348	24.02765	23.67348	23.65265	23.42348
perimeter	14.42879	14.39233	14.3142	14.25691	14.16837	14.1215	14.04337	14.00691	13.91837	13.91316	13.85587
Sf	0.004747	0.004821	0.004987	0.005113	0.005318	0.00543	0.005626	0.005721	0.005961	0.005975	0.006136
Froude	0.295852	0.298387	0.303942	0.308126	0.314784	0.318406	0.3246	0.32756	0.334938	0.335381	0.340315
dY		-0.02646	-0.02747	-0.02825	-0.02951	-0.03022	-0.03144	-0.03204	-0.03357	-0.03366	-0.03471
Y calc	3.214394	3.187931	3.16046	3.132213	3.102701	3.072486	3.041041	3.008999	2.975429	2.941767	2.907055
Y adj	3.206444	3.179982	3.152511	3.124263	3.094751	3.064536	3.033092	3.001049	2.96748	2.933817	2.899105

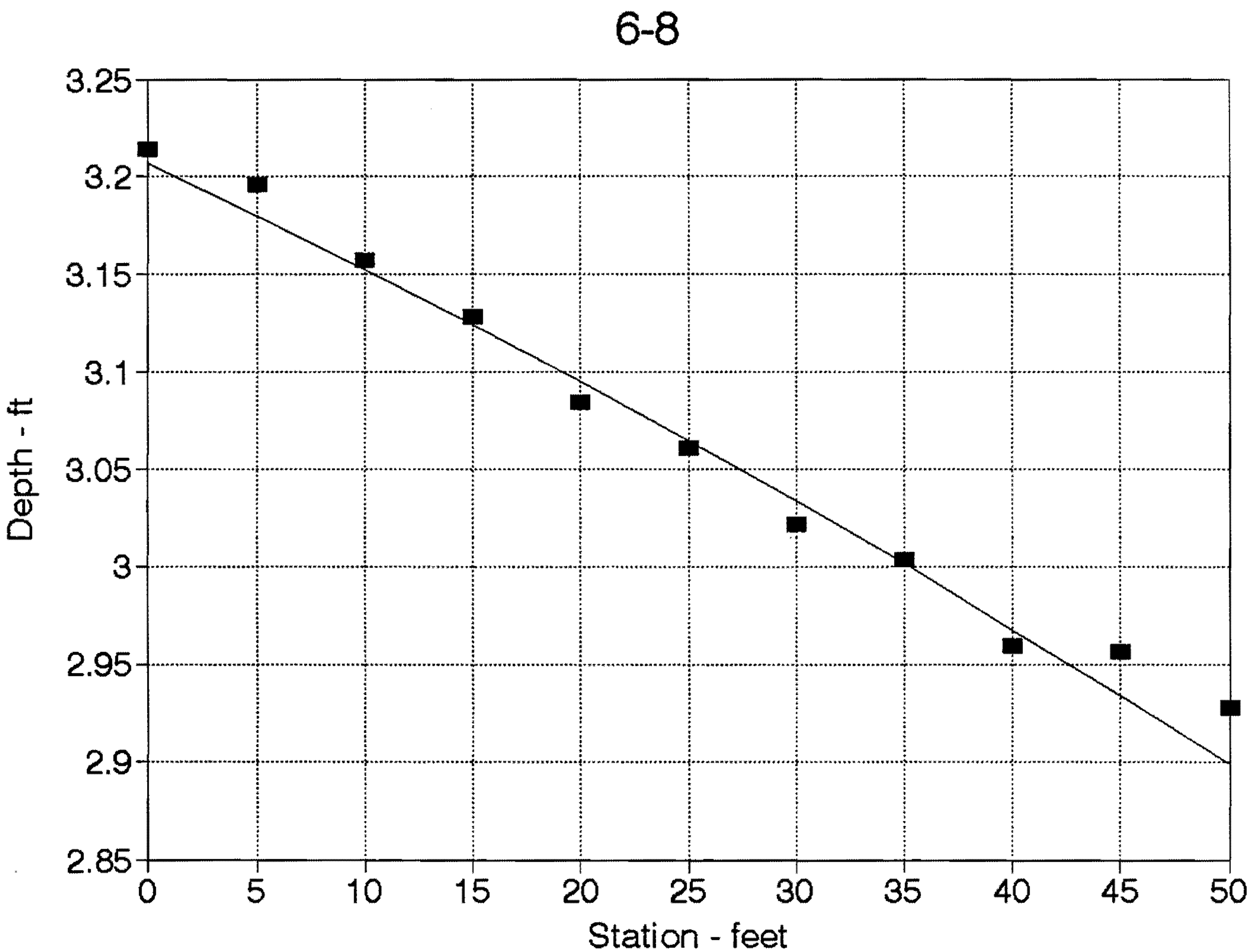
Average depth =	3.065	Average n =	0.050
Average velocity =	3.157	n bed =	0.072
		R bed =	2.968

n
0.05

Velocity Profile station 25 feet vel. at plant center = 2 fps

Yo=	3.060748 ft			
V=	3.160992 fps			
Sf=	0.00543		Prandtl C	51.37903
Rh=	1.733951 ft		Prandtl n=	0.031701
V*=	0.550634 fps		Test n=	0.05
X=	1			
Ks=	1 ft		Ks/psi =	3366.557

elev	Y	V meas	Prandtl V
3	2.81	4.8	4.87
6	2.56	4.5	4.74
9	2.31	3.3	4.60
12	2.06	3.2	4.44
15	1.81	2	4.26
18	1.56	2.2	4.06
21	1.31	2.4	3.82
24	1.06	2.4	3.53
27	0.81	2.5	3.16
30	0.56	2.6	2.65
33	0.31	2.1	1.84
36	0.06	1	-0.40
39	-0.19	0	ERR


6-8
3.25
3.2
3.15
3.1
3.05
3
2.95
2.9
2.85
Depth - ft
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 7-1
Date: 6-9-94
Plants: 36-40" Dogwoods at 3' spacing and 3' rows thinned by 50%(23 plants)

FLOW =	35.5	cfs		
dP =	0	inches between taps		
Drag =	318	micro inches	calibr=	100 micro-in / lbs
Drag =	3.18	lbs		

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
122.5000	122.2000	121.8000	121.5000	121.6000	121.4000	121.0000	121.3000	121.0000	121.5000	121.5000		
Average bottom elevation =		121.5727	feet									
Water surface elevations (inches)												
74.6250	74.6250	74.6250	74.6250	74.6875	74.5000	74.6875	74.6875	74.8125	74.6250	74.5000	75.1250	-0.6250
74.6250	74.6875	74.7500	74.8125	74.9375	74.8125	75.0625	75.1250	75.3125	75.1875	75.1250		
Water depth (feet)												
3.9123	3.9071	3.9019	3.8967	3.8863	3.8967	3.8759	3.8706	3.8550	3.8654	3.8706		

Average depth =	3.89	feet	corrected depth u.s.=	3.912311	feet
Average area =	31.08	sf	corrected depth d.s.=	3.855019	feet
Average perim.=	15.77	feet	diff=	0.057292	feet
Average H.Radius=	1.97	feet			
Average E.slope=	0.0014				
Average n=	0.077405				
			intercept	3.885322	

n guess = 0.07

station	0	5	10	15	20	25	30	35	40	45	50
depth	3.912311	3.907102	3.901894	3.896686	3.886269	3.896686	3.875852	3.870644	3.855019	3.865436	3.870644
area	31.29848	31.25682	31.21515	31.17348	31.09015	31.17348	31.00682	30.96515	30.84015	30.92348	30.96515
perimeter	15.82462	15.8142	15.80379	15.79337	15.77254	15.79337	15.7517	15.74129	15.71004	15.73087	15.74129
Sf	0.00115	0.001154	0.001158	0.001162	0.001171	0.001162	0.001179	0.001183	0.001196	0.001188	0.001183
Froude	0.101056	0.101258	0.101461	0.101664	0.102073	0.101664	0.102485	0.102692	0.103317	0.102899	0.102692
dY		-0.00583	-0.00585	-0.00587	-0.00591	-0.00587	-0.00596	-0.00598	-0.00605	-0.006	-0.00598
Y calc	3.912311	3.906481	3.90063	3.894758	3.888844	3.882972	3.877014	3.871035	3.864989	3.858988	3.853008
Y adj	3.914661	3.908831	3.90298	3.897108	3.891194	3.885322	3.879364	3.873385	3.867339	3.861338	3.855358

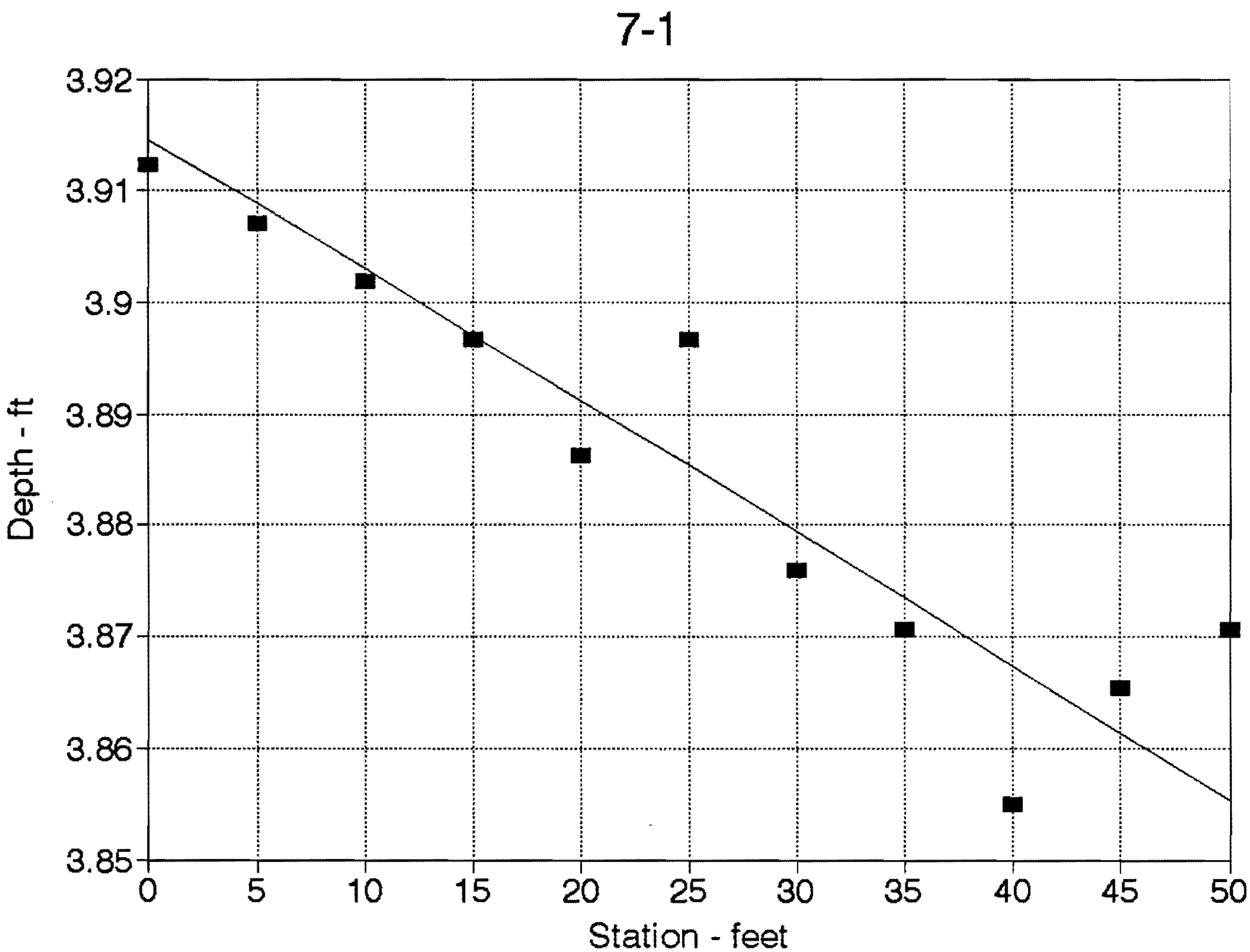
Average depth =	3.885	Average n =	0.070
Average velocity =	1.142	n bed =	0.108
		R bed =	3.788

n
0.07

Velocity Profile station 25 feet vel. at plant center = 0.7 fps

Yo=	3.896686	ft		
V=	1.138788	fps		
Sf=	0.001162		Prandtl C	54.8007
Rh=	1.973833	ft	Prandtl n=	0.03037
V*=	0.271789	fps	Test n=	0.07
X=	1			
Ks=	1	ft	Ks/psi =	1661.708

elev	Y	V meas	Prandtl V
3	3.65	1.6	2.58
6	3.40	1.6	2.53
9	3.15	1.4	2.48
12	2.90	1.4	2.42
15	2.65	1	2.36
18	2.40	1	2.29
21	2.15	1	2.22
24	1.90	0.7	2.14
27	1.65	0.6	2.04
30	1.40	0.5	1.93
33	1.15	0.9	1.79
36	0.90	0.8	1.63
39	0.65	0.9	1.41


7-1
Depth - ft
3.92
3.91
3.9
3.89
3.88
3.87
3.86
3.85
0
5
10
15
20
25
30
35
40
45
50
Station - feet

C.O.E. Large Flume Project RUN #: 7-2
Date: 6-9-94
Plants: 36-40" Dogwoods at 3' spacing and 3' rows thinned by 50%(23 plants)
flow at top of plants

FLOW = 35.5 cfs
dP = 0 inches between taps
Drag = 860 micro inches calibr= 100 micro-in / lbs
Drag = 8.6 lbs

Stations from upstream end of test section (feet)

0	5	10	15	20	25	30	35	40	45	50		
Bottom elevations by transit reading (inches)												
122.5000	122.2000	121.8000	121.5000	121.6000	121.4000	121.0000	121.3000	121.0000	121.5000	121.5000		
Average bottom elevation =		121.5727	feet									
Water surface elevations (inches)												
88.4375	88.5000	88.5625	88.5625	88.7500	88.8125	88.8750	88.8125	89.0000	89.0000	88.3125	89.6250	-1.3125
88.4375	68.6313	88.8250	88.9563	89.2750	89.4688	89.6625	89.7313	90.0500	90.1813	89.6250		
Water depth (feet)												
2.7613	2.7451	2.7290	2.7180	2.6915	2.6753	2.6592	2.6535	2.6269	2.6160	2.6623		

Average depth = 2.69 feet corrected depth u.s.= 2.761269 feet
Average area = 21.48 sf corrected depth d.s.= 2.626894 feet
Average perim. = 13.37 feet diff= 0.134375 feet
Average H.Radius= 1.61 feet
Average E.slope= 0.0034
Average n= 0.071496
intercept 2.685275

n guess = 0.07

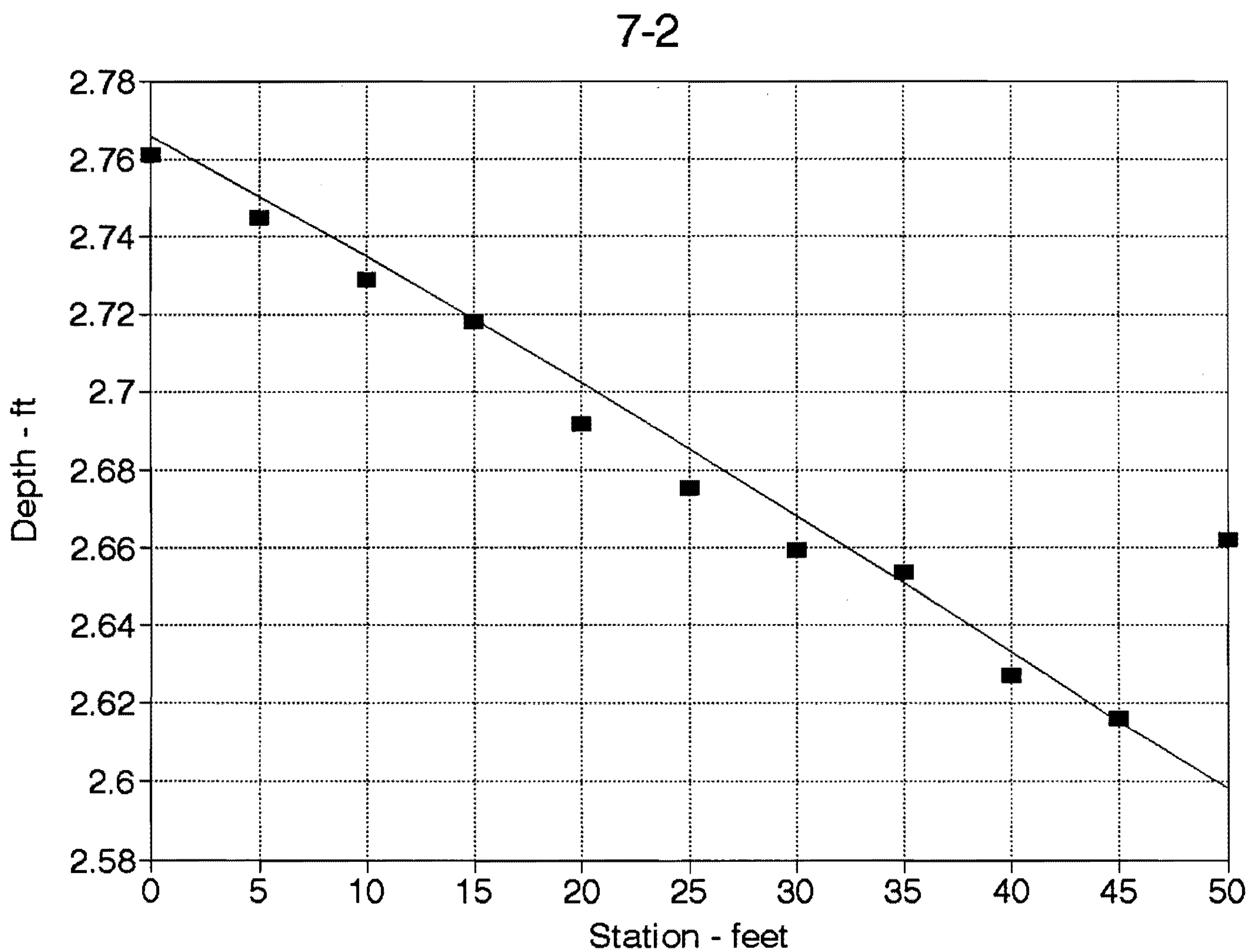
station	0	5	10	15	20	25	30	35	40	45	50
depth	2.761269	2.745123	2.728977	2.71804	2.691477	2.675331	2.659186	2.653456	2.626894	2.615956	2.662311
area	22.09015	21.96098	21.83182	21.74432	21.53182	21.40265	21.27348	21.22765	21.01515	20.92765	21.29848
perimeter	13.52254	13.49025	13.45795	13.43608	13.38295	13.35066	13.31837	13.30691	13.25379	13.23191	13.32462
Sf	0.002979	0.003028	0.003078	0.003113	0.0032	0.003254	0.003309	0.003329	0.003425	0.003465	0.003299
Froude	0.170431	0.171936	0.173464	0.174513	0.177102	0.178708	0.180338	0.180922	0.183674	0.184827	0.180021
dY		-0.0156	-0.01587	-0.01605	-0.01652	-0.01681	-0.0171	-0.01721	-0.01772	-0.01794	-0.01705
Y calc	2.761269	2.745668	2.7298	2.713747	2.697232	2.680426	2.663322	2.646112	2.62839	2.610452	2.593407
Y adj	2.766118	2.750517	2.734649	2.718596	2.70208	2.685275	2.668171	2.65096	2.633239	2.615301	2.598256

Average depth = 2.685 Average n = 0.070
Average velocity = 1.653 n bed = 0.097
R bed = 2.635

n
0.07

Velocity Profile station 25 feet vel. at plant center = 1.8 fps
Yo= 2.675331 ft
V= 1.658673 fps
Sf= 0.003254 Prandtl C 49.4719
Rh= 1.603115 ft Prandtl n= 0.032495
V*= 0.409833 fps Test n= 0.07
X= 1
Ks= 1 ft Ks/psi = 2505.706

elev	Y	V meas	Prandtl V
3	2.43	1.4	3.47
6	2.18	1.1	3.36
9	1.93	0.9	3.24
12	1.68	0.9	3.09
15	1.43	1.1	2.93
18	1.18	1.3	2.73
21	0.93	1.3	2.49
24	0.68	1.2	2.16
27	0.43	1.5	1.69
30	0.18	0	0.78
33	-0.07	0	ERR
36	-0.32	0	ERR
39	-0.57	0	ERR


7-2
Depth - ft
2.78
2.76
2.74
2.72
2.7
2.68
2.66
2.64
2.62
2.6
2.58
0
5
10
15
20
25
30
35
40
45
50
Station - feet

APPENDIX B
DRAG FORCE TEST DATA

Plant Parameters Date - 9-9-94
Prop # - 84574 Run -

NOTE: Plant data collected with the strain gauge set in tension and held horizontal
Flume data obtained with strain gauge set in compression.
Strain Gauge Settings - HORIZONTAL IN TENSION
Gauge factor - 1.10
5 lbs = 1160 micro-inches / inch

Plant Type -	Staghorn Sumac (Rhus typhina)	Number of leaves -	140
		Leaf Thickness (in) -	0.016
Plant Height (in) -	30	Leaf Width (in) -	0.5
Stem to First Branch (in) -	18	Leaf Length (in) -	2
Stem Diameter (in) -	0.456	Avg. Branch Diameter (in) -	0.104
Number of Stems -	1	Height of effective leave area (in) -	12
Number of branches -	12	Width of effective leave area (in) -	10

	micro-inches/inch Around Stem	Force	With String	Force
Average force required to pull the topmost part of stem horizontal -	115	0.496	NA	NA
Average force required to pull the center of stem 45 degrees -	121	0.522	NA	NA
****** Deflection From Vertical (in) -				
Average force required to pull the center of stem horizontal -	168	0.724	NA	NA

DRAG AND VELOCITY DATA

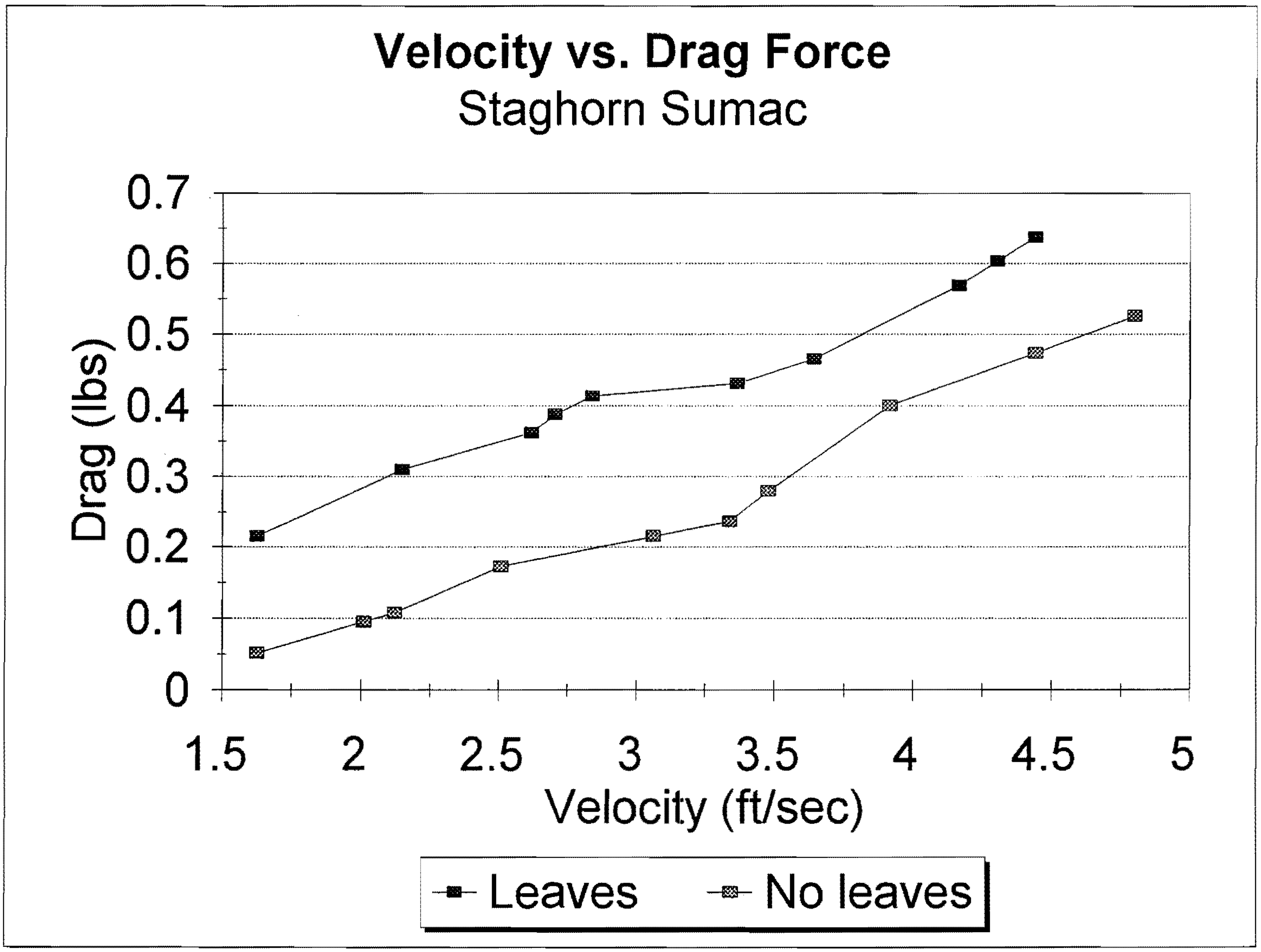
Run #	Deflection (deg - horiz)	With Leaves Counter	With Leaves Time (sec)	With Leaves Strain	Without Leaves Counter	Without Leaves Time (sec)	Without Leaves Strain
1		58	30	50	58	30	12
2		77	30	72	72	30	22
3		94	30	84	76	30	25
4	60	97	30	90	90	30	40
5		102	30	96	110	30	50
6		121	30	100	120	30	55
7		131	30	108	125	30	65
8		150	30	132	141	30	93
9		155	30	140	160	30	110
10		160	30	148	173	30	122

Additional Notes -

Analysis Staghorn Sumac (Rhus typhina)

Run #	With Leaves Velocity (ft/sec)	With Leaves Drag Force (lbs)	Without Leaves Velocity (ft/sec)	Without Leaves Drag Forc (lbs)
1	1.63	0.216	1.63	0.052
2	2.15	0.310	2.01	0.095
3	2.62	0.362	2.12	0.108
4	2.70	0.388	2.51	0.172
5	2.84	0.414	3.06	0.216
6	3.37	0.431	3.34	0.237
7	3.64	0.466	3.48	0.280
8	4.17	0.569	3.92	0.401
9	4.31	0.603	4.44	0.474
10	4.44	0.638	4.80	0.526

Drag force (lbs) at 2 ft/sec 0.283



Velocity vs. Drag Force
Staghorn Sumac
Drag (lbs)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.5
2
2.5
3
3.5
4
4.5
5
Velocity (ft/sec)
Leaves
No leaves

Plant Parameters Date - 9-12-94
Prop # - 84574 Run -

NOTE: Plant data collected with the strain gauge set in tension and held horizontal
Flume data obtained with strain gauge set in compression.

Strain Gauge Settings - HORIZONTAL IN TENSION

Gauge factor 1.10
5 lbs = 1160 micro-inches / inch

Plant Type - Arctic Blue Willow (Salix purpurea nana)		Number of leaves -	700
		Leaf Thickness (in) -	0.014
Plant Height (in) -	22	Leaf Width (in) -	0.125
Stem to First Branch (in) -	2	Leaf Length (in) -	1
Stem Diameter (in) -	0.509	Avg. Branch Diameter (in) -	0.114
Number of Stems -	1	Height of effective leave area (in) -	20
Number of branches -	50	Width of effective leave area (in) -	10

	micro-inches/inch Around Stem	Force	With String	Force
***** NOTE - MULTI STEMMED PLANT ******				
Average force required to pull the topmost part of stem horizontal -	NA	NA	115	0.496
Average force required to pull the center of stem 45 degrees -	82	0.353	162	0.698
****** Deflection From Vertical (in) -				
Average force required to pull the center of stem horizontal -	154	0.664	320	1.379

DRAG AND VELOCITY DATA

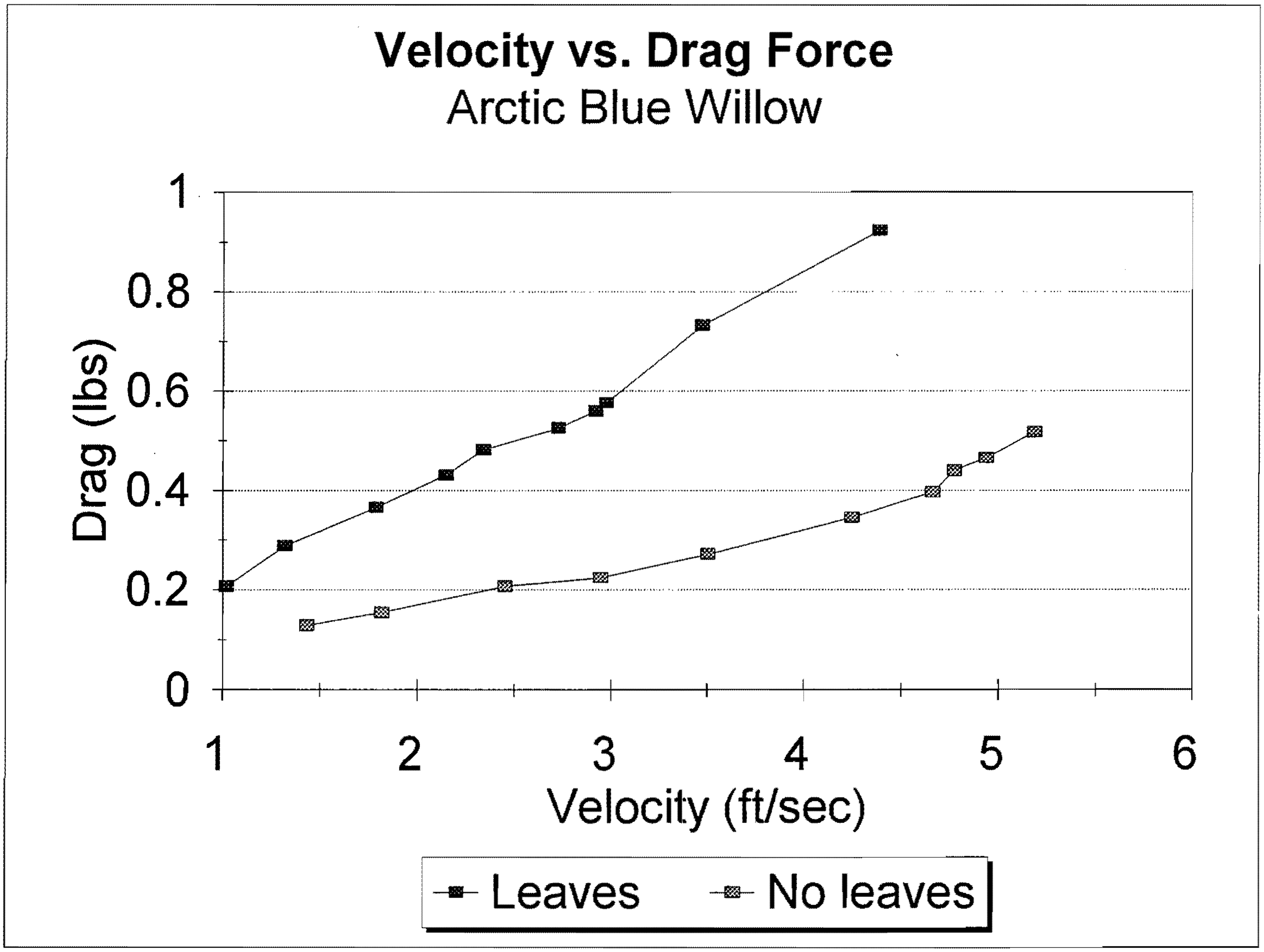
Run #	Deflection (deg - horiz)	With Leaves Counter	With Leaves Time (sec)	With Leaves Strain	Without Leaves Counter	Without Leaves Time (sec)	Without Leaves Strain
1		36	30	48	51	30	30
2		47	30	67	65	30	36
3	50	64	30	85	88	30	48
4	40	77	30	100	106	30	52
5		84	30	112	126	30	63
6	20	98	30	122	153	30	80
7	0	105	30	130	168	30	92
8		107	30	134	172	30	102
9		125	30	170	178	30	108
10		158	30	214	187	30	120

Additional Notes -

Analysis Arctic Blue Willow (Salix purpurea nana)

Run #	With Leaves Velocity (ft/sec)	With Leaves Drag Force (lbs)	Without Leaves Velocity (ft/sec)	Without Leaves Drag Force (lbs)
1	1.02	0.207	1.43	0.129
2	1.32	0.289	1.82	0.155
3	1.79	0.366	2.46	0.207
4	2.15	0.431	2.95	0.224
5	2.34	0.483	3.50	0.272
6	2.73	0.526	4.25	0.345
7	2.92	0.560	4.66	0.397
8	2.98	0.578	4.77	0.440
9	3.48	0.733	4.94	0.466
10	4.39	0.922	5.19	0.517

Drag force (lbs) at 2 ft/sec = 0.404


Velocity vs. Drag Force
Arctic Blue Willow
Drag (lbs)
1
0.8
0.6
0.4
0.2
0
1
2
3
4
5
6
Velocity (ft/sec)
Leaves
No leaves

Plant Parameters Date - 9-26-94
Prop # - 84574 Run -

NOTE: Plant data collected with the strain gauge set in tension and held horizontal
Flume data obtained with strain gauge set in compression.

Strain Gauge Settings - HORIZONTAL IN TENSION

Gauge facto	1.10
5 lbs =	1120 micro-inches / inch

Plant Type - Norway Maple (Acer platenoides)

		Number of leaves -	40
		Leaf Thickness (in) -	0.009
Plant Height (in) -	28	Leaf Width (in) -	
Stem to First Branch (in)	8	Leaf Length (in) -	
Stem Diameter (in) -	0.347	Avg. Branch Diameter (in) -	0.146
Number of Stems -	1	Height of effective leave area (in) -	12
Number of branches -	3	Width of effective leave area (in) -	18

	micro-inches/inch Around Stem	Force	With String	Force
Average force required to pull the topmost part of stem horizontal -	45	0.201	NA	NA
Average force required to pull the center of stem 45 degrees -	120	0.536	NA	NA
****** Deflection From Vertical (in) -	12			
Average force required to pull the center of stem horizontal -	290	1.295	NA	NA

DRAG AND VELOCITY DATA

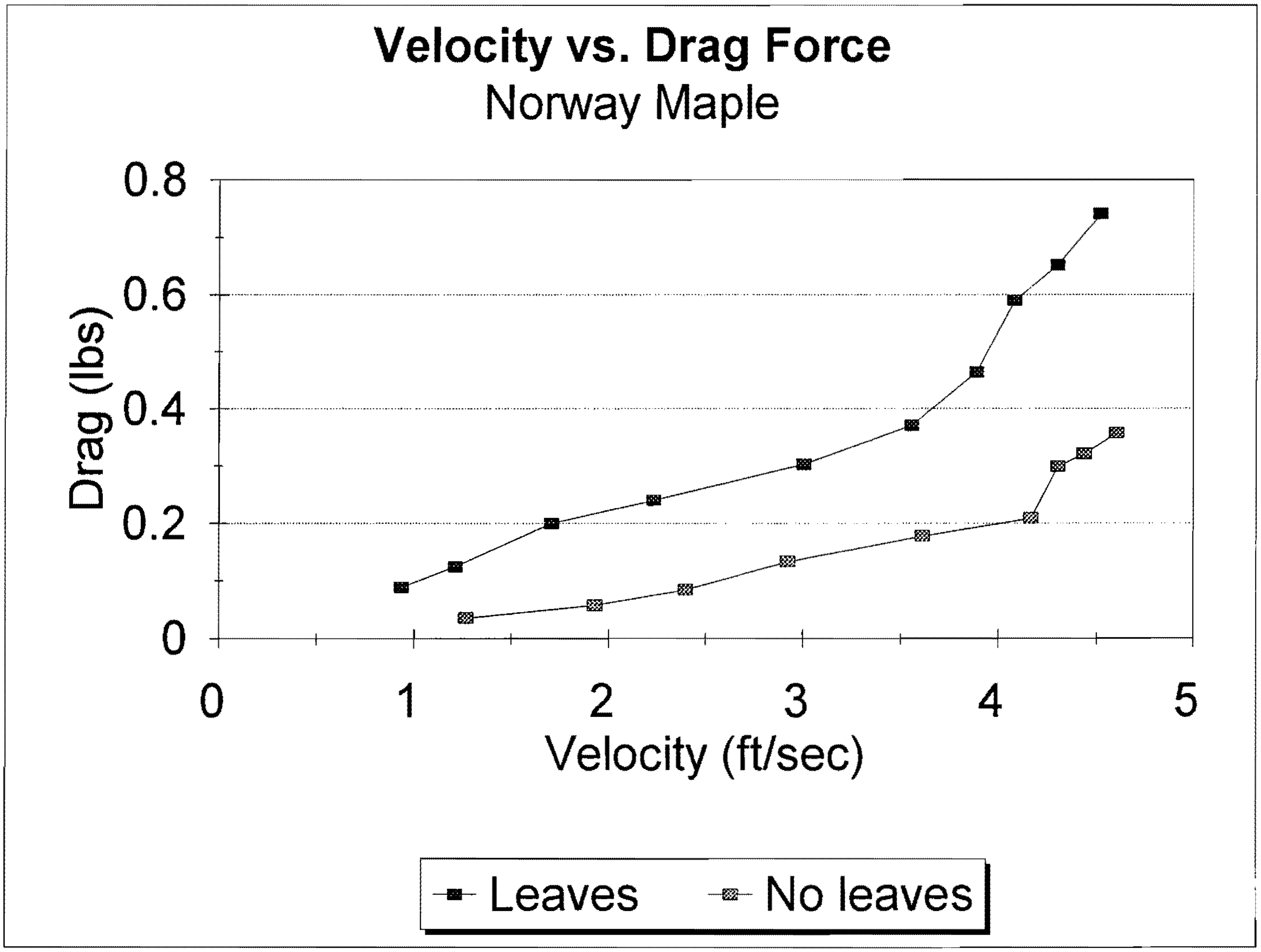
Run #	Deflection (deg - horiz	With Leaves Counter	With Leaves Time (sec)	With Leaves Strain	Without Leaves Counter	Without Leaves Time (sec)	Without Leaves Strain
1	60	33	30	20	45	30	8
2	50	43	30	28	69	30	13
3	40	61	30	45	86	30	19
4		80	30	54	105	30	30
5		108	30	68	130	30	40
6		128	30	83	150	30	47
7		140	30	104	155	30	67
8		147	30	132	160	30	72
9		155	30	146	166	30	80
10		163	30	166	NA	30	NA

Additional Notes -

Analysis Norway Maple (Acer platenoides)

Run #	With Leaves Velocity (ft/sec)	With Leaves Drag Force (lbs)	Without Leaves Velocity (ft/sec)	Without Leaves Drag Force (lbs)
1	0.94	0.089	1.27	0.036
2	1.21	0.125	1.93	0.058
3	1.71	0.201	2.40	0.085
4	2.23	0.241	2.92	0.134
5	3.01	0.304	3.61	0.179
6	3.56	0.371	4.17	0.210
7	3.89	0.464	4.31	0.299
8	4.08	0.589	4.44	0.321
9	4.31	0.652	4.61	0.357
10	4.53	0.741	NA	NA

Drag force (lbs) at 2 ft/sec = 0.223



Velocity vs. Drag Force
Norway Maple
Drag (lbs)
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
Velocity (ft/sec)
Leaves
No leaves

Plant Parameters Date - 9-26-94
Prop # - 84574 Run -

NOTE: Plant data collected with the strain gauge set in tension and held horizontal
Flume data obtained with strain gauge set in compression.

Strain Gauge Settings - HORIZONTAL IN TENSION
Gauge facto 1.10
5 lbs = 1120 micro-inches / inch

Plant Type -	Western Sand Cherry (Prunis besseyi)	Number of leaves -	100
		Leaf Thickness (in) -	0.057
Plant Height (in) -	29	Leaf Width (in) -	1
Stem to First Branch (in) -	8	Leaf Length (in) -	2
Stem Diameter (in) -	0.303	Avg. Branch Diameter (in) -	0.104
Number of Stems -	1	Height of effective leave area (in) -	20
Number of branches -	7	Width of effective leave area (in) -	6

	micro-inches/inch Around Stem	Force	With String	Force
Average force required to pull the topmost part of stem horizontal -	40	0.179	NA	NA
Average force required to pull the center of stem 45 degrees -	138	0.616	NA	NA
****** Deflection From Vertical (in) -				
Average force required to pull the center of stem horizontal -	216	0.964	NA	NA

DRAG AND VELOCITY DATA

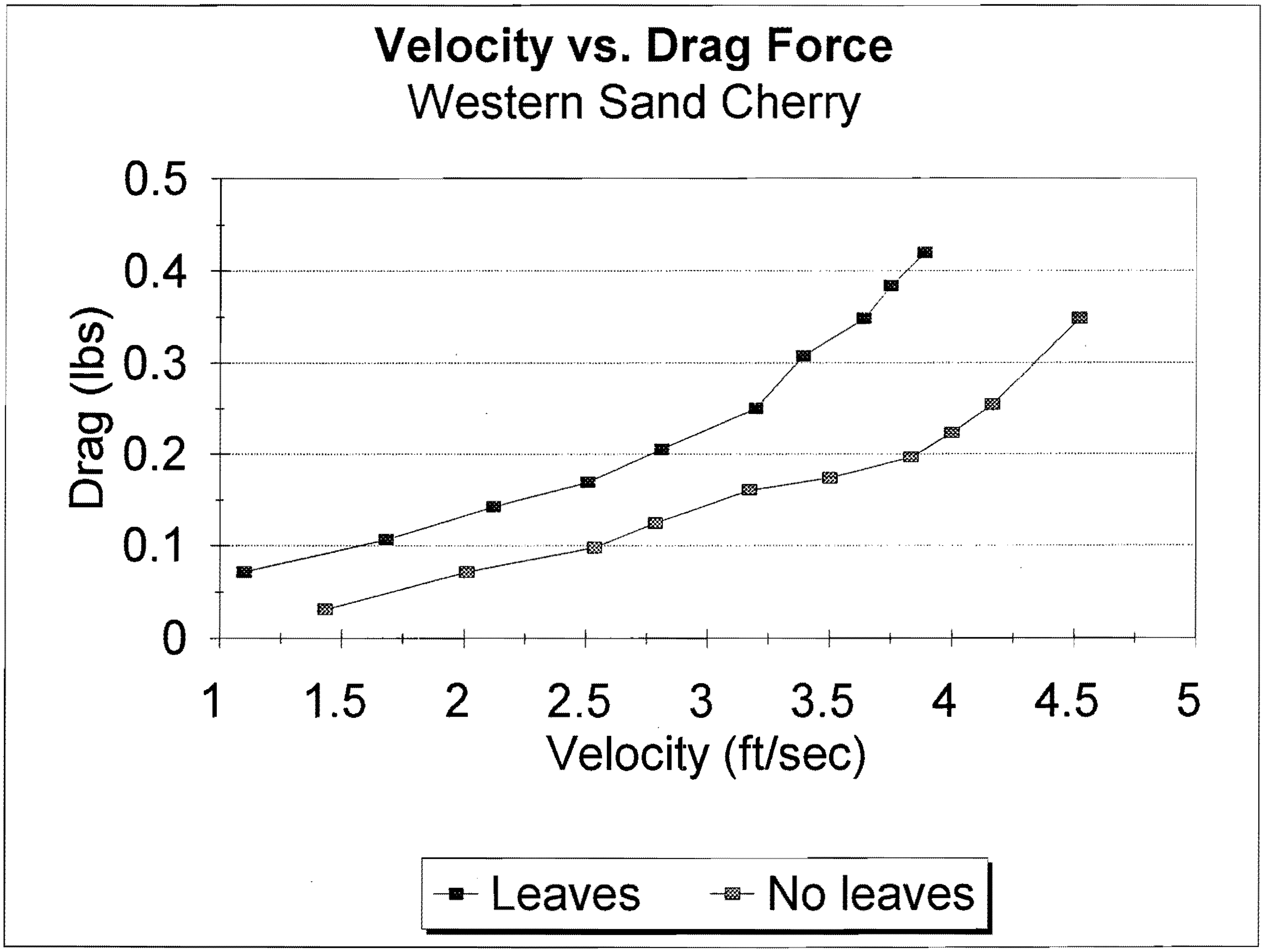
Run #	Deflection (deg - horiz)	With Leaves Counter	With Leaves Time (sec)	With Leaves Strain	Without Leaves Counter	Without Leaves Time (sec)	Without Leaves Strain
1		39	30	16	51	30	7
2		60	30	24	72	30	16
3	40	76	30	32	91	30	22
4	30	90	30	38	100	30	28
5		101	30	46	114	30	36
6	20	115	30	56	126	30	39
7		122	30	69	138	30	44
8		131	30	78	144	30	50
9		135	30	86	150	30	57
10		140	30	94	163	30	78

Additional Notes -

Analysis Western Sand Cherry (Prunis besseyi)

Run #	With Leaves		Without Leaves	
	Velocity (ft/sec)	Drag Force (lbs)	Velocity (ft/sec)	Drag Force (lbs)
1	1.10	0.071	1.43	0.031
2	1.68	0.107	2.01	0.071
3	2.12	0.143	2.54	0.098
4	2.51	0.170	2.79	0.125
5	2.81	0.205	3.17	0.161
6	3.20	0.250	3.50	0.174
7	3.39	0.308	3.84	0.196
8	3.64	0.348	4.00	0.223
9	3.75	0.384	4.17	0.254
10	3.89	0.420	4.53	0.348

Drag force (lbs) at 2 ft/sec = 0.133



Velocity vs. Drag Force
Western Sand Cherry
0.5
0.4
0.3
0.2
0.1
0
Drag (lbs)
1
1.5
2
2.5
3
3.5
4
4.5
5
Velocity (ft/sec)
Leaves
No leaves

Plant Parameters Date - 10-6-94
Prop # - 84574 Run -

NOTE: Plant data collected with the strain gauge set in tension and held horizontal
Flume data obtained with strain gauge set in compression.

Strain Gauge Settings - HORIZONTAL IN TENSION
Gauge facto 1.10
5 lbs = 1060 micro-inches / inch

Plant Type - Common Privet (Ligustrum vulgare)		Number of leaves -	275
		Leaf Thickness (in) -	0.011
Plant Height (in) -	32	Leaf Width (in) -	1.3
Stem to First Branch (in)	0.5	Leaf Length (in) -	0.375
Stem Diameter (in) -	0.5	Avg. Branch Diameter (in) -	0.203
Number of Stems -	1	Height of effective leave area (in) -	27
Number of branches -	6	Width of effective leave area (in) -	10

	micro-inches/inch Around Stem	Force	With String	Force
Average force required to pull the topmost part of stem horizontal -	180	0.849	NA	NA
Average force required to pull the center of stem 45 degrees -	242	1.142	NA	NA
****** Deflection From Vertical (in) -				
Average force required to pull the center of stem horizontal -	295	1.392	NA	NA

DRAG AND VELOCITY DATA

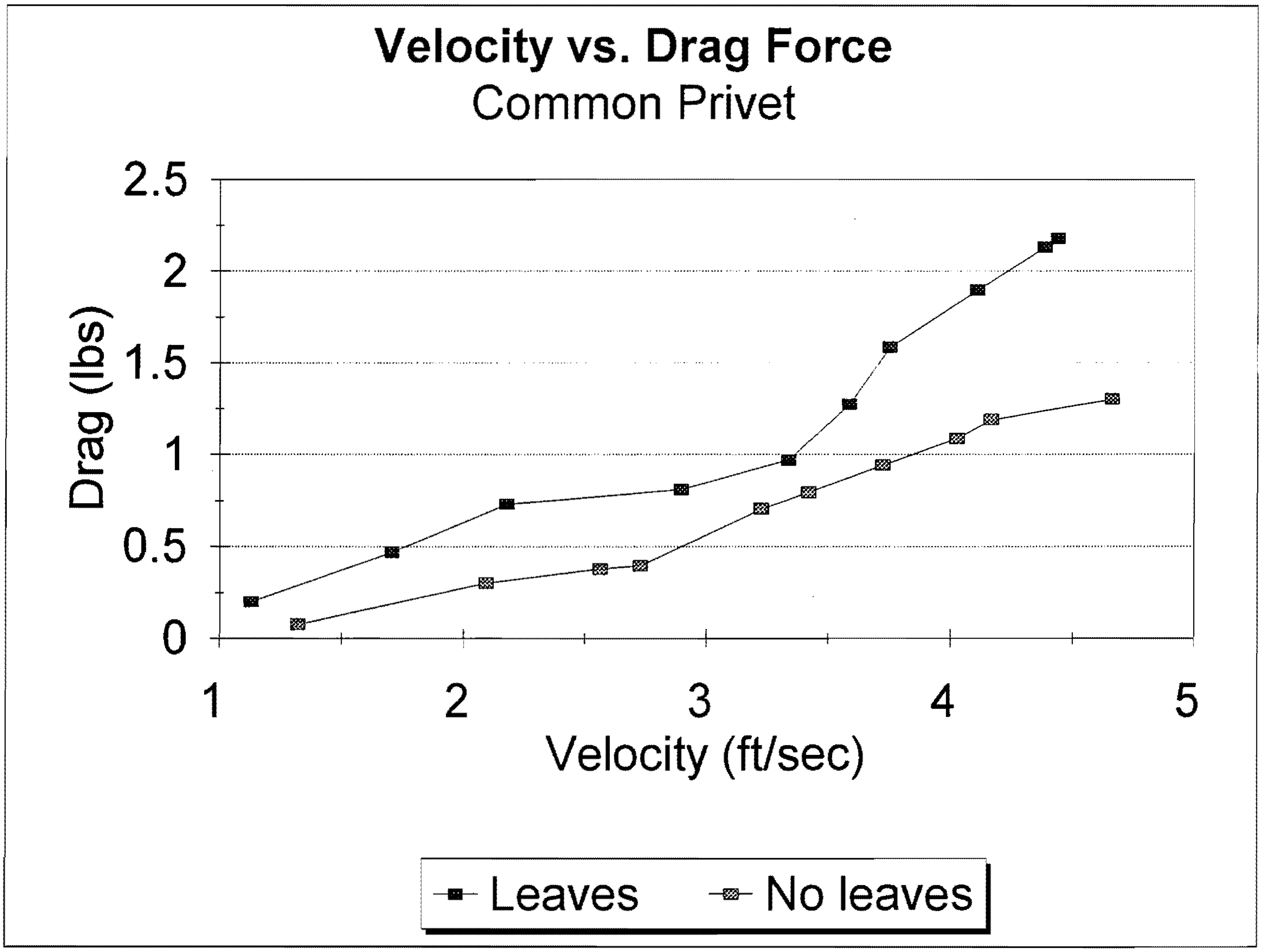
Run #	Deflection (deg - horiz)	With Leaves Counter	With Leaves Time (sec)	With Leaves Strain	Without Leaves Counter	Without Leaves Time (sec)	Without Leaves Strain
1		40	30	42	47	30	16
2		61	30	100	75	30	64
3		78	30	155	92	30	80
4		104	30	172	98	30	84
5	60	120	30	206	116	30	150
6	40	129	30	270	123	30	169
7	30	135	30	336	134	30	200
8		148	30	402	145	30	230
9		158	30	452	150	30	252
10	20	160	30	462	168	30	276

Additional Notes -

Analysis Common Privet (Ligustrum vulgare)

Run #	With Leaves Velocity (ft/sec)	With Leaves Drag Force (lbs)	Without Leaves Velocity (ft/sec)	Without Leaves Drag Force (lbs)
1	1.13	0.198	1.32	0.075
2	1.71	0.472	2.10	0.302
3	2.18	0.731	2.57	0.377
4	2.90	0.811	2.73	0.396
5	3.34	0.972	3.23	0.708
6	3.59	1.274	3.42	0.797
7	3.75	1.585	3.73	0.943
8	4.11	1.896	4.03	1.085
9	4.39	2.132	4.17	1.189
10	4.44	2.179	4.66	1.302

Drag force (lbs) at 2 ft/sec = 0.632


Velocity vs. Drag Force
Common Privet
Drag (lbs)
2.5
2
1.5
1
0.5
0
1
2
3
4
5
Velocity (ft/sec)
Leaves
No leaves

Plant Parameters Date - 10-6-94
Prop # - 84574 Run -

NOTE: Plant data collected with the strain gauge set in tension and held horizontal
Flume data obtained with strain gauge set in compression.
Strain Gauge Settings - HORIZONTAL IN TENSION
Gauge facto 1.10
5 lbs = 1060 micro-inches / inch

Plant Type - Blue Elderberry (Sambucus canadensis)		Number of leaves -	175
		Leaf Thickness (in) -	0.018
Plant Height (in) -	21	Leaf Width (in) -	2.5
Stem to First Branch (in)	2	Leaf Length (in) -	0.75
Stem Diameter (in) -	1	Avg. Branch Diameter (in) -	0.213
Number of Stems -	1	Height of effective leave area (in) -	16
Number of branches -	3	Width of effective leave area (in) -	18

	micro-inches/inch Around Stem	Force	With String	Force
Average force required to pull the topmost part of stem horizontal -	90	0.425	NA	NA
Average force required to pull the center of stem 45 degrees -	300	1.415	NA	NA
****** Deflection From Vertical (in) -				
Average force required to pull the center of stem horizontal -		0.000	NA	NA

DRAG AND VELOCITY DATA

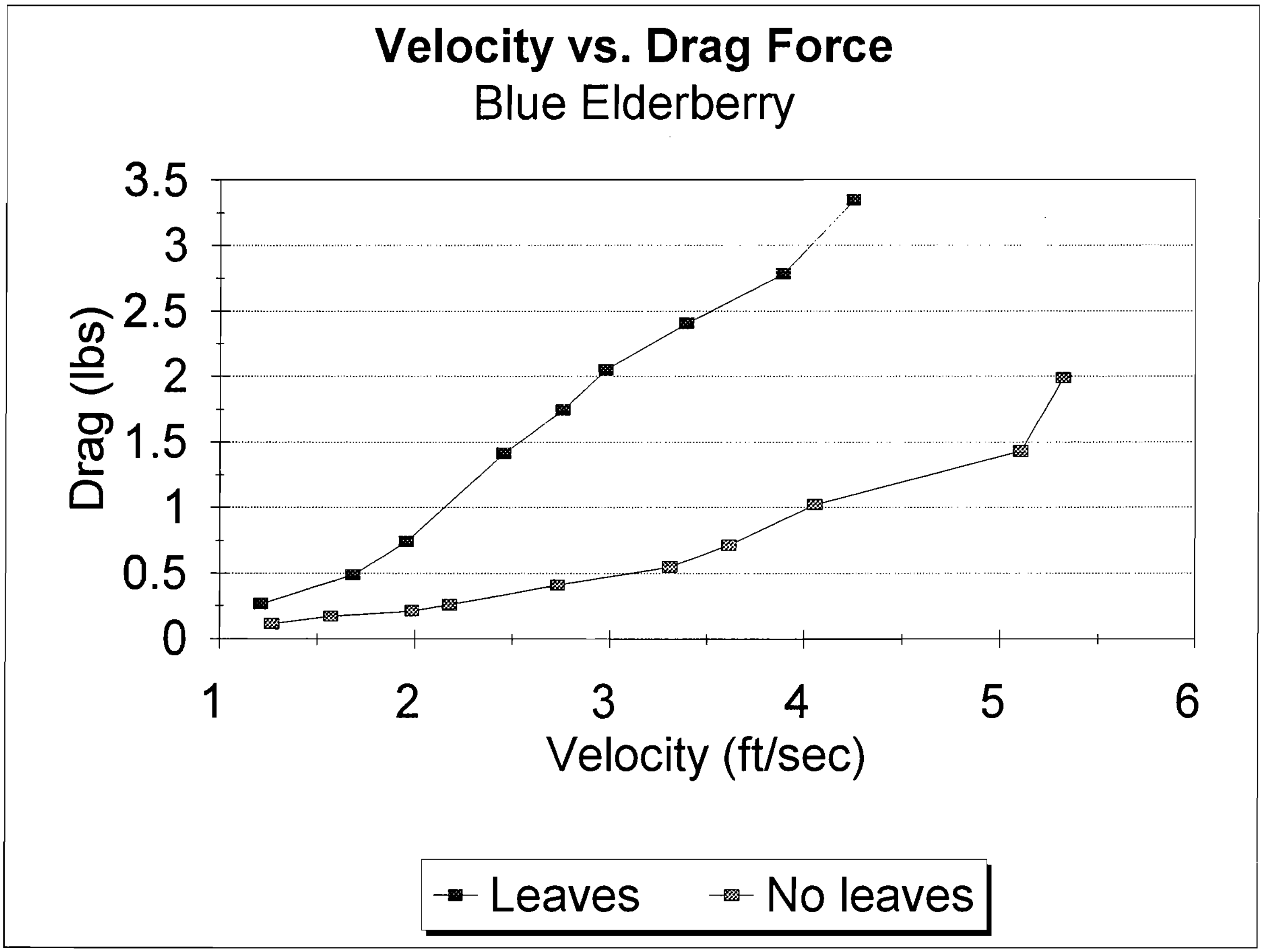
Run #	Deflection (deg - horiz	With Leaves Counter	With Leaves Time (sec)	With Leaves Strain		Without Leaves Counter	Without Leaves Time (sec)	Without Leaves Strain
1		43	30	57		45	30	24
2	40	60	30	104		56	30	36
3		70	30	158		71	30	45
4	20	88	30	300		78	30	55
5		99	30	370		98	30	87
6		107	30	435		119	30	117
7	20	122	30	510		130	30	152
8	0	140	30	590	40	146	30	217
9		153	30	710		184	30	304
10		NA	NA	NA		192	30	422

Additional Notes - The trunk would not bend . Only the branches bent, but the whole plant did not go into a teardrop shape. The overall structure stayed the same.

Analysis Blue Elderberry (Sambucus canadensis)

Run #	With Leaves Velocity (ft/sec)	With Leaves Drag Force (lbs)	Without Leaves Velocity (ft/sec)	Without Leaves Drag Force (lbs)
1	1.21	0.269	1.27	0.113
2	1.68	0.491	1.57	0.170
3	1.96	0.745	1.99	0.212
4	2.46	1.415	2.18	0.259
5	2.76	1.745	2.73	0.410
6	2.98	2.052	3.31	0.552
7	3.39	2.406	3.61	0.717
8	3.89	2.783	4.06	1.024
9	4.25	3.349	5.11	1.434
10	NA	NA	5.33	1.991

Drag force (lbs) at 2 ft/sec = 0.801


Velocity vs. Drag Force
Blue Elderberry
Drag (lbs)
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
Velocity (ft/sec)
Leaves
No leaves

Plant Parameters		Date -	10-20-94
Prop # -	84574	Run -	

NOTE: Plant data collected with the strain gauge set in tension and held horizontal
Flume data obtained with strain gauge set in compression.

Strain Gauge Settings - HORIZONTAL IN TENSION

Gauge fact 1.10

5 lbs = 1040 micro-inches / inch

Plant Type	French Pink Pussywillow (Salix caprea pendula	Number of leaves -	90
		Leaf Thickness (in) -	
Plant Height (in) -	36	Leaf Width (in) -	1.5
Stem to First Branch (i	3	Leaf Length (in) -	0.5
Stem Diameter (in) -	0.75	Avg. Branch Diameter (in) -	0.235
Number of Stems -	1	Height of effective leave area (in) -	10
Number of branches -	4	Width of effective leave area (in) -	10

stem to leaves = 25"

	micro-inches/inch			
	Around Stem	Force	With String	Force
Average force required to pull the topmost part of stem horizontal -	70	0.337	NA	NA
Average force required to pull the center of stem 45 degrees -	120	0.577	NA	NA
****** Deflection From Vertical (in) -				
Average force required to pull the center of stem horizontal -	260	1.250	NA	NA

DRAG AND VELOCITY DATA

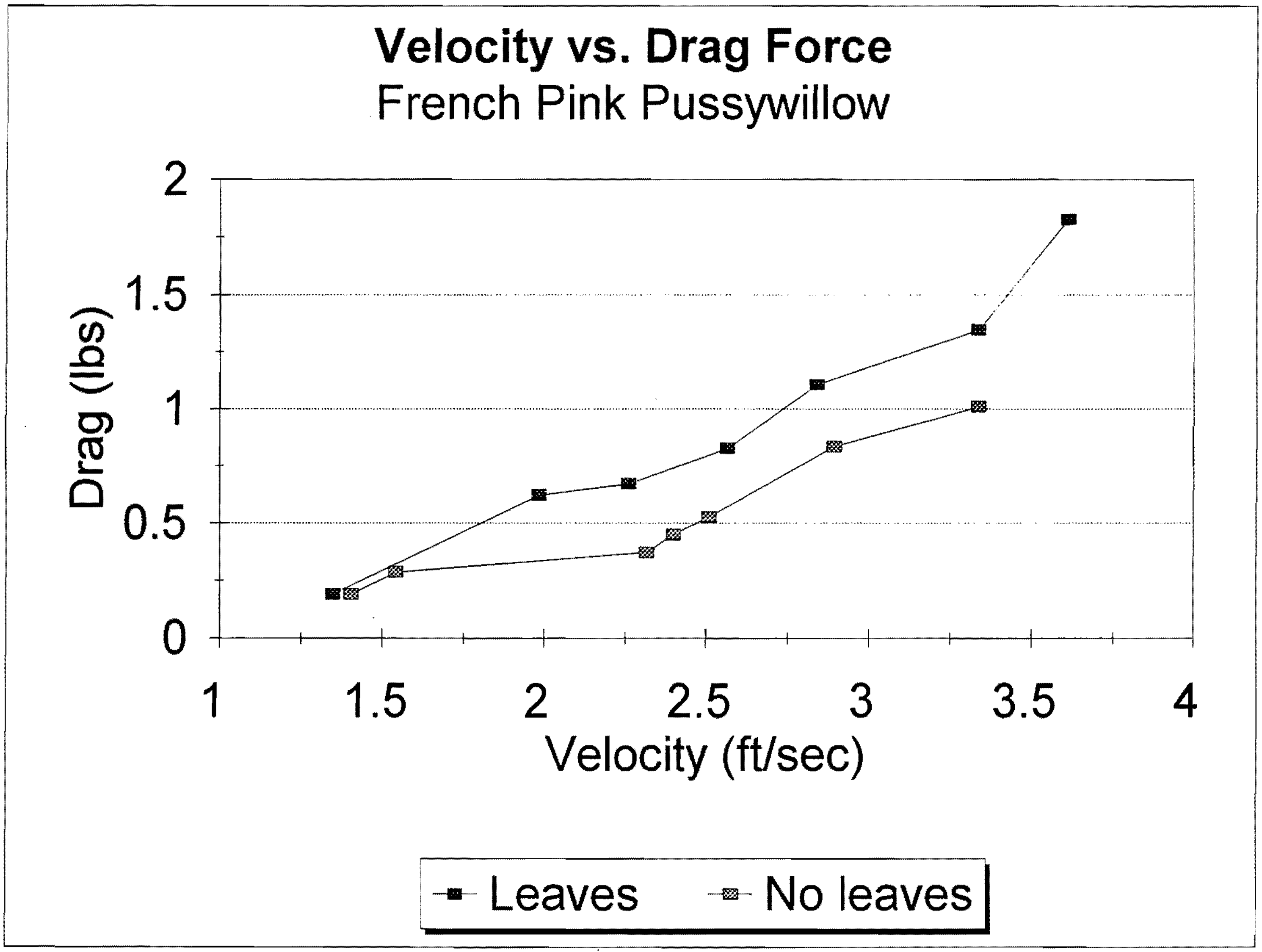
	Deflection		With Leaves			Without Leaves	
Run #	(deg - horiz	Counter	Time (sec)	Strain	Counter	Time (sec)	Strain
1		48	30	40	50	30	40
2	40	71	30	130	55	30	60
3		81	30	140	83	30	78
4		92	30	172	86	30	94
5		102	30	230	90	30	110
6		120	30	280	104	30	174
7		130	30	380	120	30	210
8		NA	30	NA	NA	30	NA
9		NA	30	NA	NA	30	NA
10		NA	30	NA	NA	30	NA

Additional Notes - Branched tree. Branches left trunk immediately. Trunk did NOT bend only individual braches bent....entire plant did not go into teardrop shape

Analysis French Pink Pussywillow (Salix caprea pendula)

Run #	With Leaves		Without Leaves	
	Velocity (ft/sec)	Drag Force (lbs)	Velocity (ft/sec)	Drag Force (lbs)
1	1.35	0.192	1.41	0.192
2	1.99	0.625	1.54	0.288
3	2.26	0.673	2.32	0.375
4	2.57	0.827	2.40	0.452
5	2.84	1.106	2.51	0.529
6	3.34	1.346	2.90	0.837
7	3.61	1.827	3.34	1.010
8	NA	NA	NA	NA
9	NA	NA	NA	NA
10	NA	NA	NA	NA

Drag force (lbs) at 2 ft/sec = 0.627



Velocity vs. Drag Force
French Pink Pussywillow
Drag (lbs)
2
1.5
1
0.5
0
1
1.5
2
2.5
3
3.5
4
Velocity (ft/sec)
Leaves
No leaves

Plant Parameters		Date -	10-20-94
Prop # -	84574	Run -	

NOTE: Plant data collected with the strain gauge set in tension and held horizontal
Flume data obtained with strain gauge set in compression.

Strain Gauge Settings - HORIZONTAL IN TENSION

Gauge fact	1.10	
5 lbs =	1040	micro-inches / inch

Plant Type	Sycamore (Platenus acer ifolia)	Number of leaves -	23
		Leaf Thickness (in) -	
Plant Height (in) -	36	Leaf Width (in) -	6
Stem to First Branch (i	2	Leaf Length (in) -	6
Stem Diameter (in) -	0.413	Avg. Branch Diameter (in) -	0.025
Number of Stems -	1	Height of effective leave area (in) -	33
Number of branches -	3	Width of effective leave area (in) -	8

	micro-inches/inch			
	Around Stem	Force	With String	Force
Average force required to pull the topmost part of stem horizontal -	148	0.712	NA	NA
Average force required to pull the center of stem 45 degrees -	274	1.317	NA	NA
****** Deflection From Vertical (in) -				
Average force required to pull the center of stem horizontal -	320	1.538	NA	NA

DRAG AND VELOCITY DATA

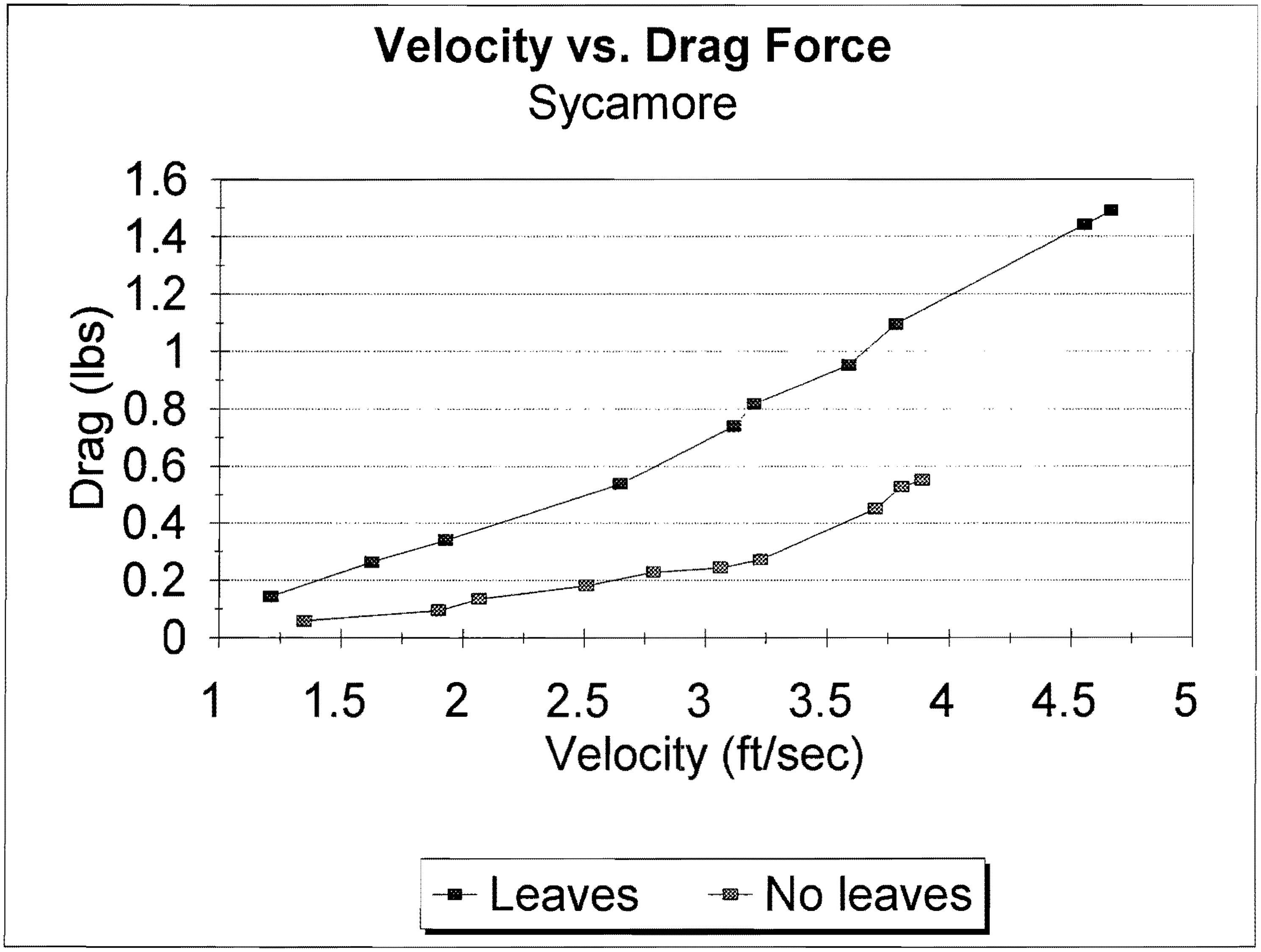
	Deflection		With Leaves			Without Leaves	
Run #	(deg - horiz	Counter	Time (sec)	Strain	Counter	Time (sec)	Strain
1	40	43	30	30	48	30	12
2	30	58	30	55	68	30	20
3	20	69	30	71	74	30	28
4	0	95	30	112	90	30	38
5		112	30	154	100	30	48
6		115	30	170	110	30	51
7		129	30	198	116	30	57
8		136	30	228	133	30	94
9		164	30	300	137	30	110
10		168	30	310	140	30	115

Additional Notes - Cut from shoot, one long branch & 2 small branches.

Analysis Sycamore (Platenus acer ifolia)

Run #	With Leaves Velocity (ft/sec)	With Leaves Drag Force (lbs)	Without Leaves Velocity (ft/sec)	Without Leaves Drag Force (lbs)
1	1.21	0.144	1.35	0.058
2	1.63	0.264	1.90	0.096
3	1.93	0.341	2.07	0.135
4	2.65	0.538	2.51	0.183
5	3.12	0.740	2.79	0.231
6	3.20	0.817	3.06	0.245
7	3.59	0.952	3.23	0.274
8	3.78	1.096	3.70	0.452
9	4.55	1.442	3.81	0.529
10	4.66	1.490	3.89	0.553

Drag force (lbs) at 2 ft/sec = 0.360



Velocity vs. Drag Force
Sycamore
Drag (lbs)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
1.5
2
2.5
3
3.5
4
4.5
5
Velocity (ft/sec)
Leaves
No leaves

Plant Parameters		Date - 7-7-94
Prop # - 84574		Run - 1-1

NOTE: Plant data collected with the strain gauge set in tension and held horizontal
Flume data obtained with strain gauge set in compression.

Strain Gauge Settings - HORIZONTAL IN TENSION

Gauge factor 1.10
5 lbs = 1020 micro-inches / inch

Plant Type - Dogwood 1-1		Number of leaves -	50
		Leaf Thickness (in) -	
Plant Height (in) -	17	Leaf Width (in) -	0.5
Stem to First Branch (in) -		Leaf Length (in) -	3
Stem Diameter (in) -	0.375	Avg. Branch Diameter (in) -	
Number of Stems -	1	Height of effective leave area (in) -	13
Number of branches -	11	Width of effective leave area (in) -	9

	micro-inches/inch Around Stem	Force	With String	Force
Average force required to pull the topmost part of stem horizontal -	25	0.123	NA	NA
Average force required to pull the center of stem 45 degrees -	64	0.314	NA	NA
****** Deflection From Vertical (in) -				
Average force required to pull the center of stem horizontal -	NA	NA	NA	NA

DRAG AND VELOCITY DATA

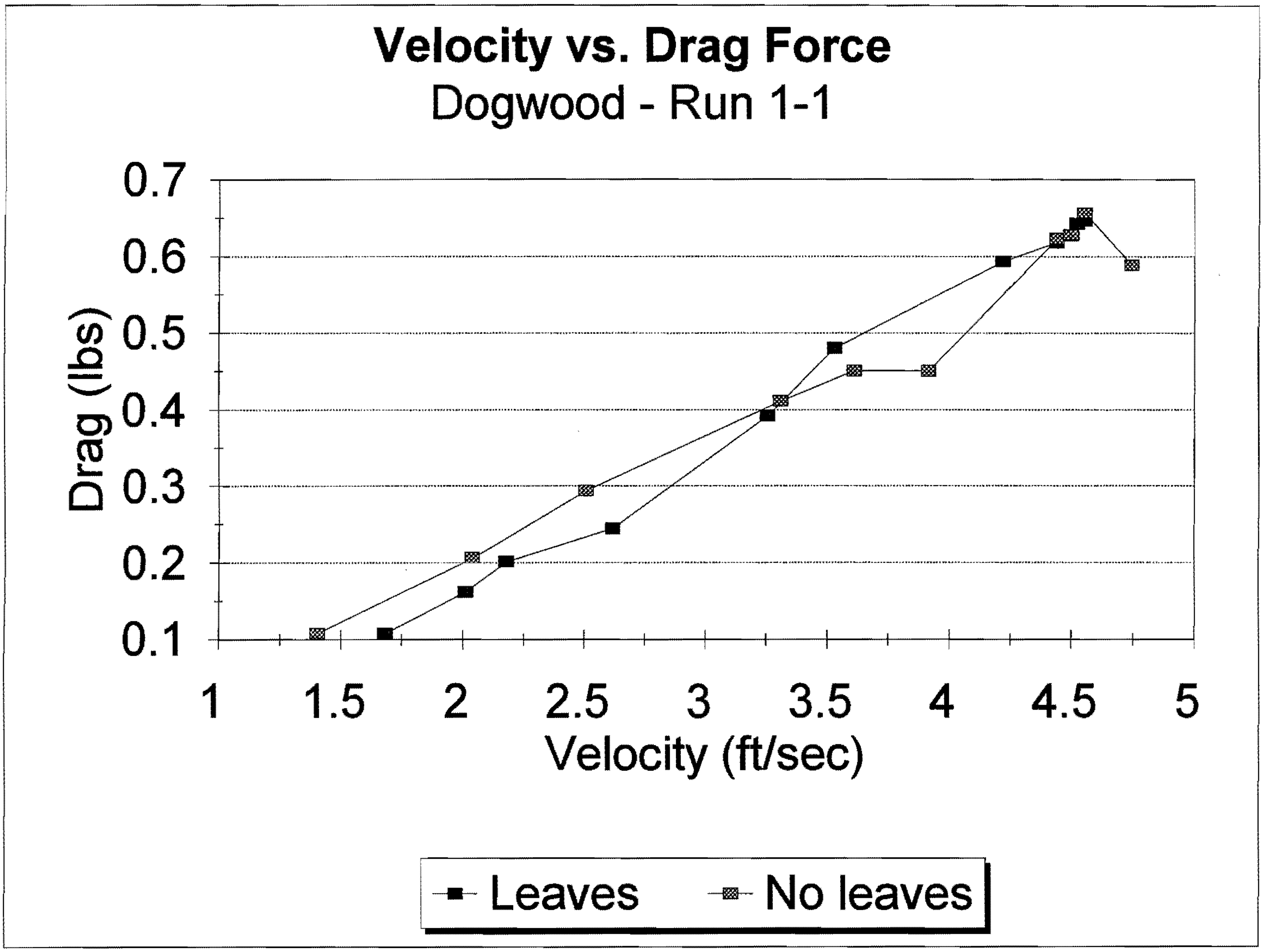
Run #	Deflection (deg - horiz)	With Leaves Counter	With Leaves Time (sec)	With Leaves Strain	Without Leaves Counter	Without Leaves Time (sec)	Without Leaves Strain
1		60	30	22	50	30	22
2		72	30	33	73	30	42
3		78	30	41	90	30	60
4		94	30	50	119	30	84
5		117	30	80	130	30	92
6		127	30	98	141	30	92
7		152	30	121	160	30	127
8		160	30	126	162	30	128
9		164	30	132	164	30	134
10		163	30	131	171	30	120

Additional Notes -

Analysis Dogwood 1-1

Run #	With Leaves Velocity (ft/sec)	With Leaves Drag Force (lbs)	Without Leaves Velocity (ft/sec)	Without Leaves Drag Force (lbs)
1	1.68	0.108	1.41	0.108
2	2.01	0.162	2.04	0.206
3	2.18	0.201	2.51	0.294
4	2.62	0.245	3.31	0.412
5	3.26	0.392	3.61	0.451
6	3.53	0.480	3.92	0.451
7	4.22	0.593	4.44	0.623
8	4.44	0.618	4.50	0.627
9	4.55	0.647	4.55	0.657
10	4.53	0.642	4.75	0.588

Drag force (lbs) at 2 ft/sec 0.160


Velocity vs. Drag Force
Dogwood - Run 1-1
Drag (lbs)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1
1.5
2
2.5
3
3.5
4
4.5
5
Velocity (ft/sec)
Leaves
No leaves

Plant Parameters   Date - 7-9-94
Prop # - 84574   Run - 2-1

NOTE: Plant data collected with the strain gauge set in tension and held horizontal
Flume data obtained with strain gauge set in compression.

Strain Gauge Settings - HORIZONTAL IN TENSION

Gauge factor 1.10
5 lbs = 1020 micro-inches / inch

Plant Type - Dogwood 2-1		Number of leaves -	30
		Leaf Thickness (in) -	
Plant Height (in) -	15	Leaf Width (in) -	1
Stem to First Branch (in) -		Leaf Length (in) -	2
Stem Diameter (in) -	0.4375	Avg. Branch Diameter (in) -	
Number of Stems -	1	Height of effective leave area (in) -	10
Number of branches -	20	Width of effective leave area (in) -	8

	micro-inches/inch Around Stem	Force	With String	Force
Average force required to pull the topmost part of stem horizontal -	20	0.098	NA	NA
Average force required to pull the center of stem 45 degrees -	84	0.412	NA	NA
****** Deflection From Vertical (in) -				
Average force required to pull the center of stem horizontal -	NA	NA	NA	NA

DRAG AND VELOCITY DATA

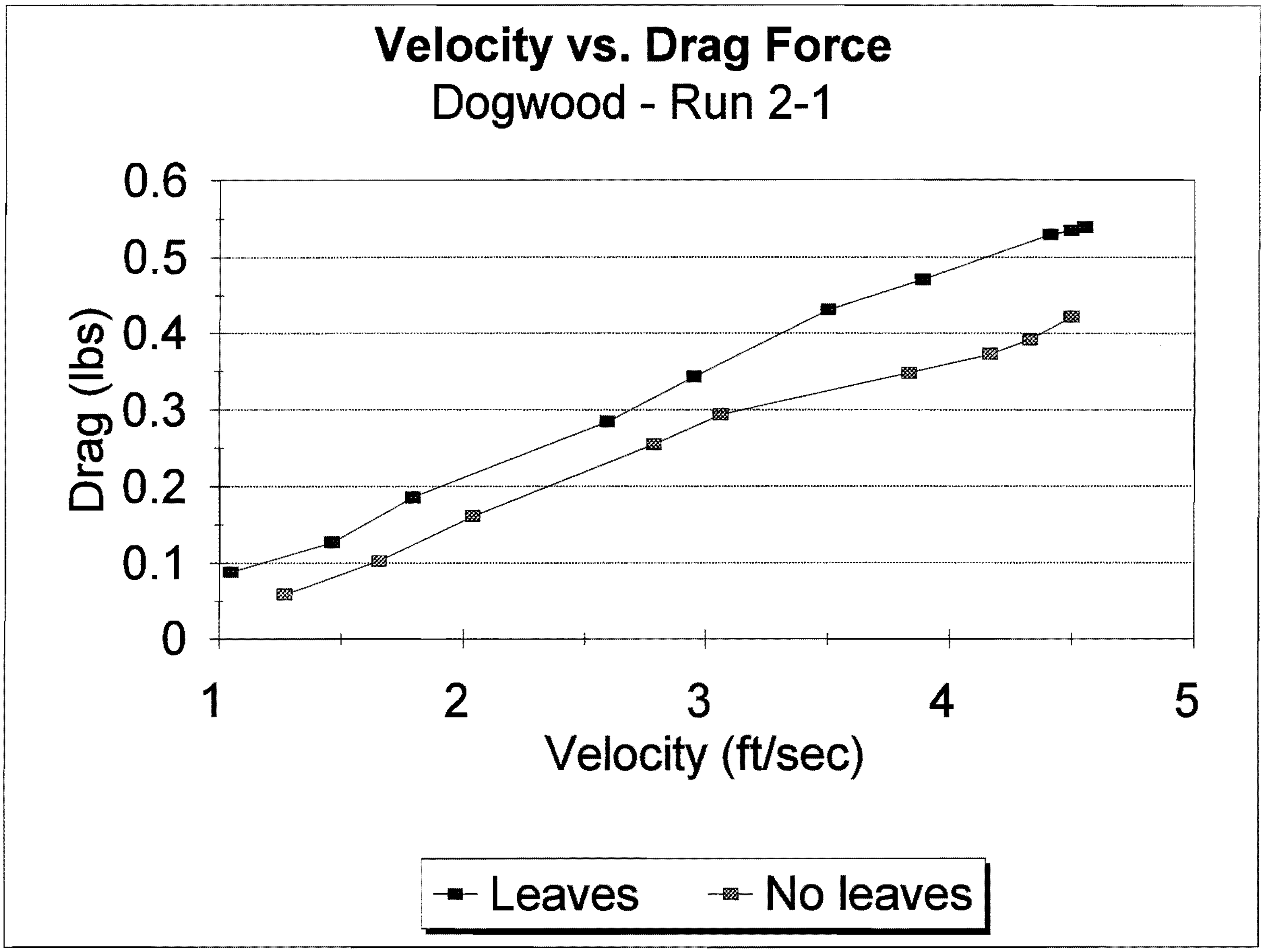
Run #	Deflection (deg - horiz)	With Leaves Counter	With Leaves Time (sec)	With Leaves Strain	Without Leaves Counter	Without Leaves Time (sec)	Without Leaves Strain
1		37	30	18	45	30	12
2		52	30	26	59	30	21
3		64	30	38	73	30	33
4		93	30	58	100	30	52
5		106	30	70	110	30	60
6		126	30	88	138	30	71
7		140	30	96	138	30	71
8		159	30	108	150	30	76
9		162	30	109	156	30	80
10		164	30	110	162	30	86

Additional Notes -

Analysis Dogwood 2-1

Run #	With Leaves Velocity (ft/sec)	With Leaves Drag Force (lbs)	Without Leaves Velocity (ft/sec)	Without Leaves Drag Force (lbs)
1	1.05	0.088	1.27	0.059
2	1.46	0.127	1.65	0.103
3	1.79	0.186	2.04	0.162
4	2.59	0.284	2.79	0.255
5	2.95	0.343	3.06	0.294
6	3.50	0.431	3.84	0.348
7	3.89	0.471	3.84	0.348
8	4.42	0.529	4.17	0.373
9	4.50	0.534	4.33	0.392
10	4.55	0.539	4.50	0.422

Drag force (lbs) at 2 ft/sec 0.212


Velocity vs. Drag Force
Dogwood - Run 2-1
0.6
0.5
0.4
0.3
0.2
0.1
0
Drag (lbs)
1
2
3
4
5
Velocity (ft/sec)
Leaves
No leaves

Plant Parameters Date - 7-9-94
Prop # - 84574 Run - 2-2

NOTE: Plant data collected with the strain gauge set in tension and held horizontal
Flume data obtained with strain gauge set in compression.

Strain Gauge Settings - HORIZONTAL IN TENSION
Gauge factor 1.10
5 lbs = 1020 micro-inches / inch

Plant Type - Euonymus		Number of leaves -	90
		Leaf Thickness (in) -	
Plant Height (in) -	8	Leaf Width (in) -	1.5
Stem to First Branch (in) -		Leaf Length (in) -	2
Stem Diameter (in) -	0.25	Avg. Branch Diameter (in) -	
Number of Stems -	2	Height of effective leave area (in) -	8
Number of branches -	9	Width of effective leave area (in) -	10

	micro-inches/inch Around Stem	Force	With String	Force
Average force required to pull the topmost part of stem horizontal -	30	0.147	NA	NA
Average force required to pull the center of stem 45 degrees -	110	0.539	NA	NA
****** Deflection From Vertical (in) -				
Average force required to pull the center of stem horizontal -	NA	NA	NA	NA

DRAG AND VELOCITY DATA

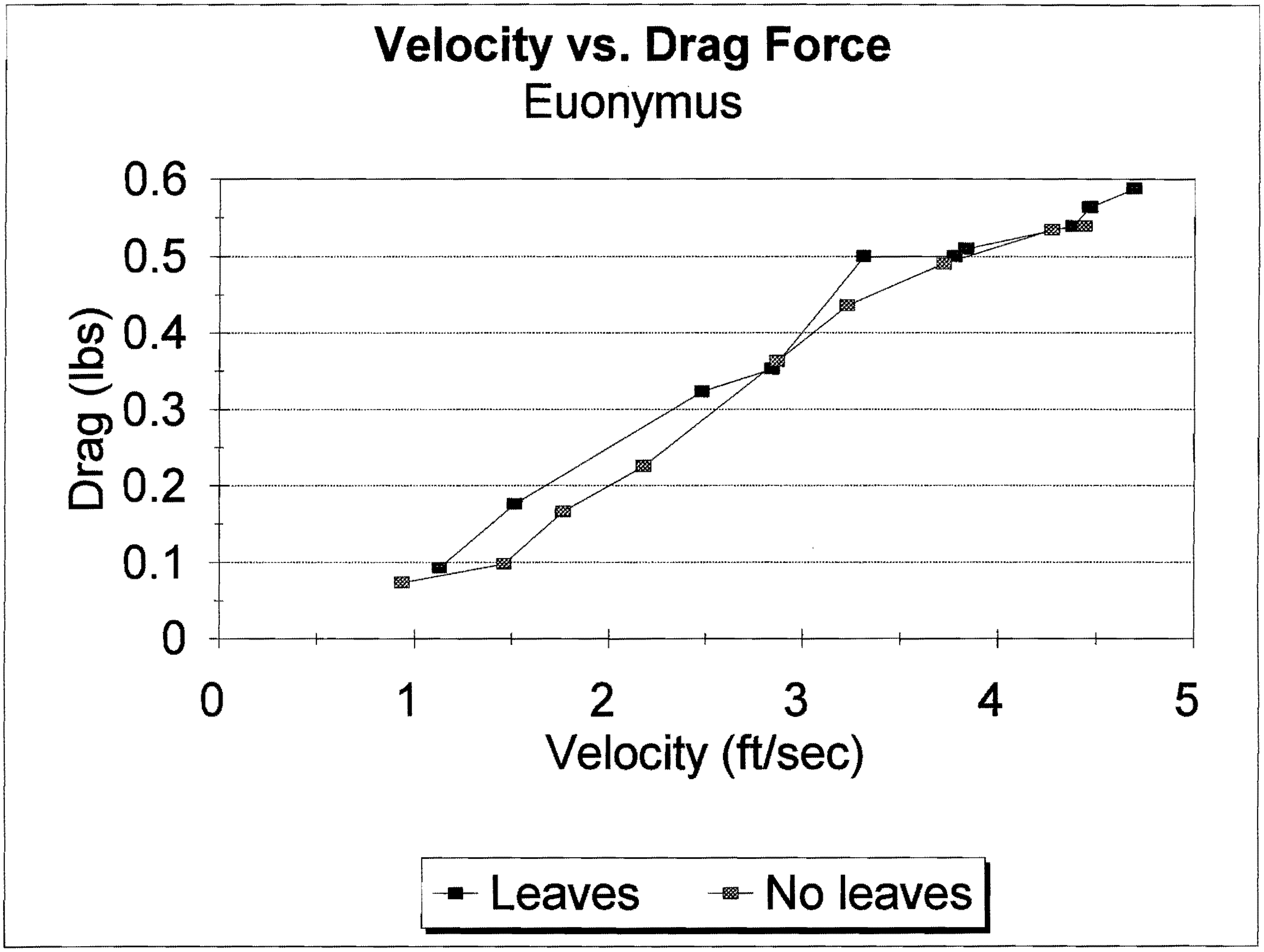
Run #	Deflection (deg - horiz)	With Leaves Counter	With Leaves Time (sec)	With Leaves Strain	Without Leaves Counter	Without Leaves Time (sec)	Without Leaves Strain
1		40	30	19	33	30	15
2		54	30	36	52	30	20
3		89	30	66	63	30	34
4		102	30	72	78	30	46
5		119	30	102	103	30	74
6		136	30	102	116	30	89
7		138	30	104	134	30	100
8		158	30	110	154	30	109
9		161	30	115	160	30	110
10		169	30	120	NA	30	NA

Additional Notes -

Analysis Euonymus

Run #	With Leaves Velocity (ft/sec)	With Leaves Drag Force (lbs)	Without Leaves Velocity (ft/sec)	Without Leaves Drag Force (lbs)
1	1.13	0.093	0.94	0.074
2	1.52	0.176	1.46	0.098
3	2.48	0.324	1.77	0.167
4	2.84	0.353	2.18	0.225
5	3.31	0.500	2.87	0.363
6	3.78	0.500	3.23	0.436
7	3.84	0.510	3.73	0.490
8	4.39	0.539	4.28	0.534
9	4.47	0.564	4.44	0.539
10	4.69	0.588	NA	NA

Drag force (lbs) at 2 ft/sec 0.250


Velocity vs. Drag Force
Euonymus
0.6
0.5
0.4
0.3
0.2
0.1
0
Drag (lbs)
0
1
2
3
4
5
Velocity (ft/sec)
Leaves
No leaves

Plant Parameters Date - 7-10-94
Prop # - 84574 Run - 3-1

NOTE: Plant data collected with the strain gauge set in tension and held horizontal
Flume data obtained with strain gauge set in compression.

Strain Gauge Settings - HORIZONTAL IN TENSION

Gauge factor	1.10	
5 lbs =	1020	micro-inches / inch

Plant Type -	Dogwood 3-1	Number of leaves -	45
		Leaf Thickness (in) -	
Plant Height (in) -	20	Leaf Width (in) -	2
Stem to First Branch (in) -		Leaf Length (in) -	3
Stem Diameter (in) -	0.4375	Avg. Branch Diameter (in) -	
Number of Stems -	1	Height of effective leave area (in) -	13
Number of branches -	9	Width of effective leave area (in) -	10

	micro-inches/inch			
	Around Stem	Force	With String	Force
Average force required to pull the topmost part of stem horizontal -	90	0.441	NA	NA
Average force required to pull the center of stem 45 degrees -	128	0.627	NA	NA
****** Deflection From Vertical (in) -				
Average force required to pull the center of stem horizontal -	NA	NA	NA	NA

DRAG AND VELOCITY DATA

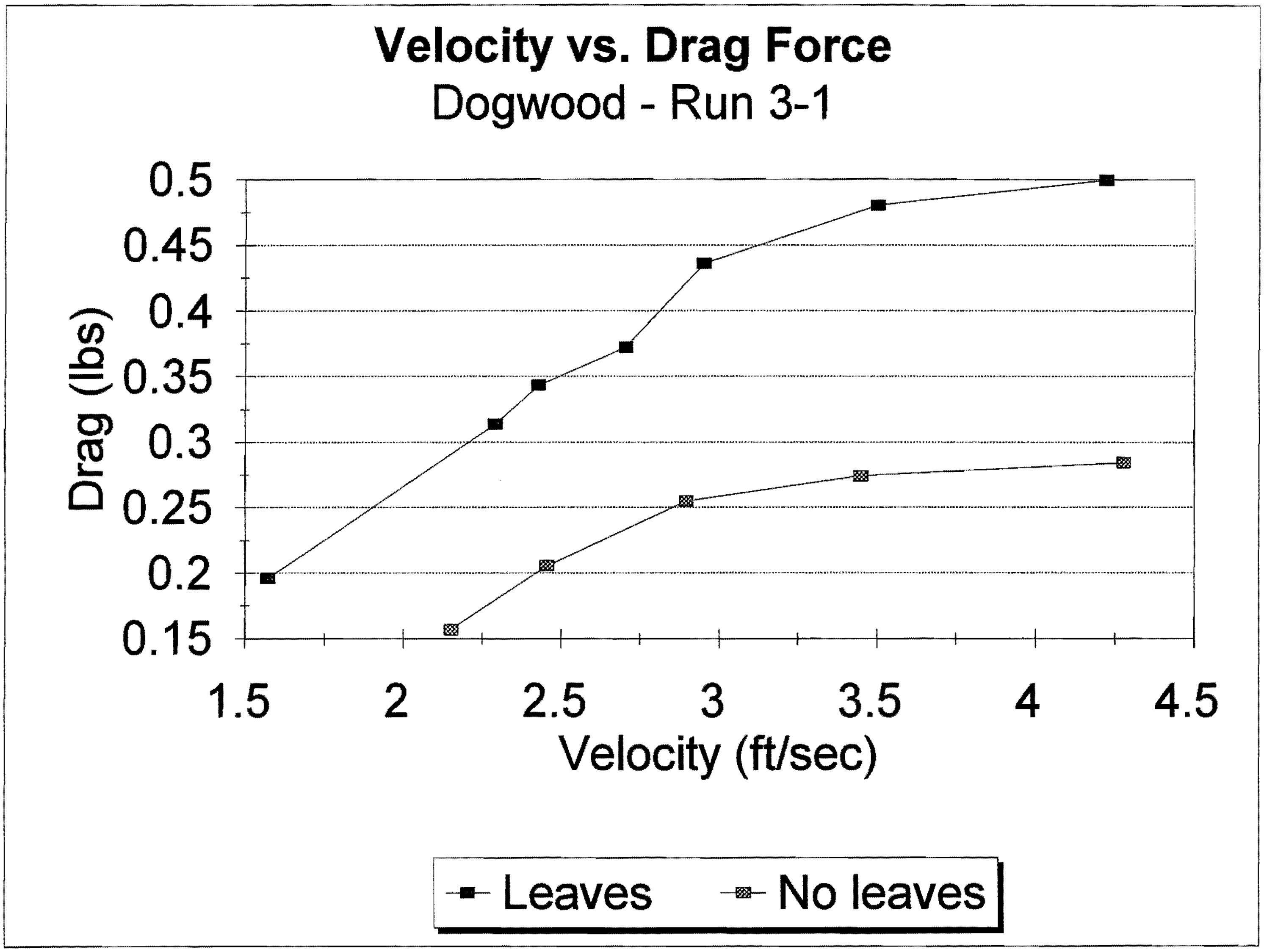
	Deflection	With Leaves			Without Leaves		
Run #	(deg - horiz)	Counter	Time (sec)	Strain	Counter	Time (sec)	Strain
1		56	30	40	77	30	32
2		82	30	64	88	30	42
3		87	30	70	104	30	52
4		97	30	76	124	30	56
5		106	30	89	154	30	58
6		126	30	98	NA	30	NA
7		152	30	102	NA	30	NA
8		NA	30	NA	NA	30	NA
9		NA	30	NA	NA	30	NA
10		NA	30	NA	NA	30	NA

Additional Notes -

Analysis Dogwood 3-1

Run #	With Leaves		Without Leaves	
	Velocity (ft/sec)	Drag Force (lbs)	Velocity (ft/sec)	Drag Force (lbs)
1	1.57	0.196	2.15	0.157
2	2.29	0.314	2.46	0.206
3	2.43	0.343	2.90	0.255
4	2.70	0.373	3.45	0.275
5	2.95	0.436	4.28	0.284
6	3.50	0.480	NA	NA
7	4.22	0.500	NA	NA
8	NA	NA	NA	NA
9	NA	NA	NA	NA
10	NA	NA	NA	NA

Drag force (lbs) at 2 ft/sec 0.266



Velocity vs. Drag Force
Dogwood - Run 3-1
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
Drag (lbs)
1.5
2
2.5
3
3.5
4
4.5
Velocity (ft/sec)
Leaves
No leaves

APPENDIX C

COMPOUND FLOOD CHANNEL; ANALYSIS AND EXAMPLE

The following is a discussion for computing the flow for a compound flood channel. The two methods of flow conveyance and equivalent resistance (section 3-5, Equations 10 and 12) are compared. The objective of this exercise is to demonstrate the effect of the large resistance values of vegetation found in this study. Figure 16 shows the typical cross section for a compound flood channel used in this example and comparison. A discussion of the methodology to locate cross sections and to select subsections follows.

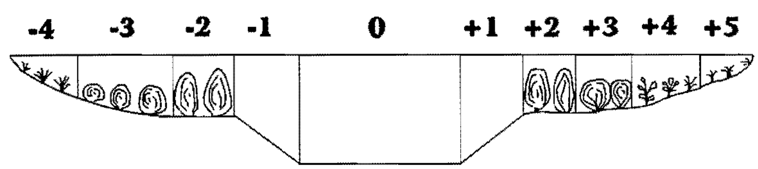


Figure 16 Cross section of a hypothetical channel and flood plains.

Jarrett (1985) lists six criteria for locating cross sections.

1. The cross sections need to be located at major changes in bed or water-surface profiles. If old flood profiles are available, they can be used to locate the breaks in water-surface profiles.
2. The cross sections need to be placed at points of minimum and maximum cross-sectional area, width, or depth. The number of cross sections needs to be greater in expanding reaches and in bends to minimize the relative degree of expansion between cross sections and leave the individual subreaches more nearly uniform.
3. The number of cross sections needs to be greater in reaches that have moderate to severe changes in cross-section shape, even though the total areas may differ only slightly from each other. An example would be sections that change shape from just a main channel to a main channel with overbank flow.
4. The cross sections need to be located at abrupt changes in roughness characteristics, for example, where the flood plain is heavily vegetated in

one subreach, but has been cleared and cultivated in the adjacent subreach. The use of a cross section twice, in close proximity and with different roughness values, must suffice for the present to evaluate the frictional losses.

5. The cross sections need to be located at control sections if critical or supercritical flow conditions exist. These controls include natural and manmade weirs, check dams, rock walls, fences, and severe obstructions.
6. The cross sections need to be located at tributaries where changes in discharge are anticipated. The exact placement of the cross sections varies, depending on the method of analysis and program requirements.

Resistance coefficients apply to individual cross sections, but they must also be typical of the reach of channel that the cross section resides in. If the resistance is not uniform throughout a reach, the average resistance may be used instead. A reach that applies to one cross section is considered to extend halfway to the next cross section. When several discharges are to be analyzed, the reach lengths may need to be increased or decreased so that uniform conditions can be maintained.

Once the cross section has been located, it needs to be subdivided into subsections. As with the reach of channel, the cross section must satisfy the criteria for uniform flow for the whole width of the cross section. Therefore, it will need to be divided into subsections so that the resistance is fairly uniform and the velocity is basically uniform. This applies to the main channel (Arcement and Schneider, 1989) as well as the flood plain. Subdivisions are made at major changes in channel geometry and changes in the roughness. If the resistance is fairly constant throughout the main channel it will not need subdividing, however, this will not likely be the case with a natural flood plain with vegetation.

Subdivisions should be made where changes in vegetation, average plant height, average plant spacing, average stem diameter, or changes in combinations of these occur. The average of these parameters is used since vegetation is very non-uniform and these parameters vary from plant to plant. Also, changes should be made where the landscape changes and becomes dominated by trees (Arcement and Schneider, 1989). Where trees are dominant, subdivisions should also be made when vegetation on the ground surface changes by the same vegetative parameters as cited above.

The hydraulic parameter that needs to be known is the slope of the energy grade line. Since the slope is assumed to be constant throughout the main channel and its flood plains, the slope can be approximated as the slope of the flood plains adjacent to the main channel.

EXAMPLE FOR DEVELOPING STAGE-DISCHARGE RELATIONSHIP

To develop the following example, a the hypothetical channel shown in Figure 16 will be used. The main channel is trapezoidal in shape and the subdivisions are as shown. Typical values will be used and all measurements will be in English units, and a typical energy slope of .001 will be selected. The plant parameters for the flood plains and Manning's n coefficients for the main channel and the soil type of the flood plains as follows:

Table 5. Plant parameters and Manning's roughnesses for a channel and its flood plains.

Section #	H' (ft)	Ps (ft)	Sd (ft)	Ps/H'	Sd/H'	n bed
-4	0.83	0.80	.020	0.96	0.024	.020
-3	1.75	1.80	.031	1.03	0.018	.020
-2	3.33	3.20	.105	0.96	0.032	.020
-1	---	---	---	---	---	.023
0	---	---	---	---	---	.025
1	---	---	---	---	---	.024
2	3.17	3.00	.100	0.95	0.032	.020
3	2.33	2.04	.051	0.88	0.022	.020
4	1.75	1.70	.031	0.91	0.018	.020
5	0.67	0.90	.021	1.34	0.031	.020

The main channel is assumed to be free of vegetation, so the resistance of the man channel is just the bed roughness. Using Manning's n, the hydraulic radius is calculated and with a knowledge of the channel geometry, the area and depth of the subsection can be determined. With this depth, the water surface elevation for the entire channel is calculated and fixed at 1,103 ft. The discharge can be calculated by multiplying the velocity and the area.

Next, a guess is made for the velocity of an adjoining section and all calculations are made, as described for the main section. The exceptions are, that, if the calculated water-surface elevation is different than the water-surface elevation that is fixed by calculations from the main channel, a new guess for the velocity must be made and all steps repeated. Also, n_{veg} must be calculated for the sections within the flood plains and added to the bed values determined there.

With all these calculations made, the discharges for each section can be summed and the total discharge for that water surface elevation can be obtained. The results of these steps are shown in Table 6 below.

Table 6. Table of Calculations to Demonstrate the Conveyance Method.

Section #	V (fps)	n (veg)	n (total)	R (ft)	A (ft^2)	Depth (ft)	W.S.Elev (ft)	Q (cfs)
-4	1.5	0.039	0.059	2.56	560	3.0	1,103	840
-3	3.0	0.020	0.040	4.01	1135	4.0	1,103	3,405
-2	5.0	0.040	0.060	16.10	2005	5.5	1,103	10,025
-1	15.0	---	0.023	19.89	3010	15.0	1,103	45,150
0	19.0	---	0.025	32.14	4605	20.0	1,103	87,495
1	15.0	---	0.024	21.20	3285	15.0	1,103	49,275
2	5.0	0.040	0.060	15.95	2870	4.5	1,103	14,350
3	4.0	0.026	0.046	7.65	1965	4.0	1,103	7,860
4	3.0	0.021	0.041	4.17	1390	3.5	1,103	4,170
5	2.0	0.037	0.057	3.78	1340	3.0	1,103	2,680

By summing up the discharges for each subsection, the conveyance method calculates the total discharge of the channel is 225,250 cfs.

Finally, this same example will be solved to illustrate using an equivalent roughness which is based on the assumption that each subarea has the same mean velocity. This method proceeds the same as the equivalent roughness method just presented, except that equation (13) will be used instead of equation (15) to solve for the equivalent roughness. Table 7 shows the results below.

Table 7. Table of Calculations to Demonstrate The Equivalent Resistance Method

Section #	V (fps)	n (veg)	n (total)	R (ft)	A (ft^2)	P (ft)	Depth (ft)	W.S.Elev (ft)
-4	1.5	0.039	0.059	2.56	560	219.1	3.0	1103
-3	3.0	0.020	0.040	4.01	1,135	282.7	4.0	11.3
-2	5.0	0.040	0.060	16.10	2,005	124.5	5.5	1103
-1	15.0	---	0.023	19.89	3,010	151.3	15.0	1103
0	19.0	---	0.025	32.14	4,605	143.3	20.0	1103
1	15.0	---	0.024	21.20	3,285	154.9	15.0	1103
2	5.0	0.040	0.060	15.95	2,870	179.9	4.5	1103
3	4.0	0.026	0.046	7.65	1,965	256.8	4.0	1103
4	3.0	0.021	0.041	4.17	1,390	333.3	3.5	1103
5	2.0	0.037	0.057	3.78	1,340	354.2	3.0	1103

The equivalent roughness coefficient is .0457 and solving Manning's equation for discharge gives a total discharge of 106,309 cfs for the entire channel at this water-surface elevation. The average velocity for the entire channel, as used by Chow's first method, is 4.8 feet per second. The equivalent resistance method assumes a constant velocity for all subsections. This method calculated a flow of 106,309 cfs. The conveyance method which does not have to assume a constant velocity, calculated twice the flow of 225,250 cfs. The equivalent resistance method under predicts the channel flow because it proportions too large of flow in the flood plain and too small of flow in the main channel.