WRP Technical Note SD-CP-2.2
May 1994

Effects of Vegetation on Hydraulic Roughness and Sedimentation in Wetlands

PURPOSE: This technical note summarizes available literature and experimental findings to date on the effect of dense wetland vegetation on sedimentation in wetland environments.

BACKGROUND: Sedimentation processes in wetlands include erosion, deposition, and transport of sediments within and through the boundaries of the wetland. Sedimentation tests conducted on a dense stand of bulrushes (*scirpus validus*) indicate that sediment deposition rates may be lower than anticipated when using average velocities in sediment transport equations.

INTRODUCTION: The calculation of Manning n values has been of interest since the Manning equation was presented in the late 1800s (Henderson, 1966). While estimation of n values for normal channels has been fairly well standardized, the estimation of n values in areas of dense vegetation continues to be subject to large variations depending on the experience of the engineer and the perceived density of the vegetation. Flow resistance and sedimentation in bulrush environments is important in design of constructed wetlands, flood routing through existing wetlands, and determination of flood heights for flood damage studies.

The United States Geological Survey (USGS) published a "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains" in 1989. This publication indicates that a base n value of from 0.026 to 0.032 should be used for straight uniform channels in firm soil. The guide recommends adding a maximum of 0.100 for "dense cattails growing along channel bottom". Dense cattails and dense bulrushes could be assumed to be similar in hydraulic characteristics. Other adjustments would be for channel irregularity, variation in cross section, and obstructions in the channel. All of the other factors would be zero for the case being tested in this experiment. When using the maximum values from the above range, the n value for a test channel with bulrushes would be 0.132.

EXPERIMENTAL SETUP FOR A WRP STUDY: The facility used to test n values and sedimentation rates in bulrushes consisted of a 1.2 meters wide and approximately 150 meter long concrete lined drainage channel at the Lewisville Aquatic Ecosystem Research Facility in Lewisville, TX (Fig. 1). The channel has 0.67 m high vertical sidewalls with banks above the concrete sloped at about 1V:3H to a height of 3 to 4 m. The test section, approximately 15 m of the drainage channel, was modified by placing a bulkhead at the downstream end of the test section. This allowed the placement of a 0.05 × 0.15 m stoplog and the retention of approximately 0.15 m of soil on the floor of the channel. The bulkhead was constructed such that the tail water depth could be controlled by the placement of additional 0.05 × 0.15 m stoplogs. Tests were made for backwater conditions where the downstream water condition was increased by either one or two stoplogs. This increased water depth in the bulrushes by 0.15 or 0.30 m above the level of the soil in the test section.

A weir was placed in the channel 77 meters upstream from the test section to allow free flow at the weir for all flow and backwater conditions (shown in Fig. 2). A triangular weir was used for flows up to 0.044 cubic meters per second, abbreviated as cms in this technical note and a contracted

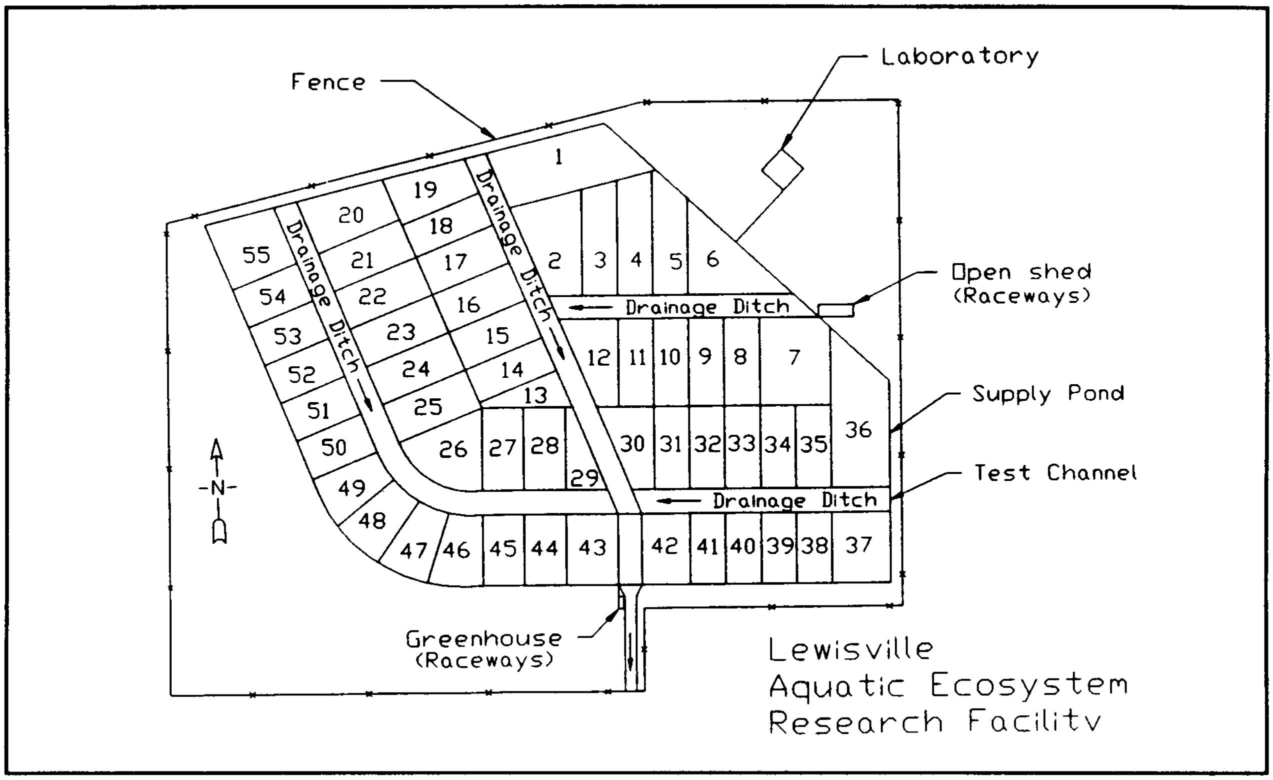

Figure 1. Layout of Aquatic Ecosystem Research Facility in Lewisville, TX showing location of supply pond and test channel

rectangular weir for higher flows. Drainage and/or seepage was present in the channel from ponds located between the weir and the test section. This drainage/seepage flow was measured at the downstream end of the test section prior to each test using a Marsh-McBirney Model 2000 velocity meter. Channel inflow was then adjusted to account for the seepage flow.

Water for the series of tests was obtained from ponds adjacent to the upstream end of the drainage channel. Water was taken primarily from Pond 36 shown in Fig. 1. Pond volume was sufficient to allow a 2 to 3 hour test for each run with a nearly constant flow rate in the test channel. The maximum flow rate that could be obtained using Pond 36 (including channel seepage) was 0.057 cms. A flow of 0.057 cms was sufficient to just overtop the vertical portion of the channel for the high backwater condition. Tests to determine Manning's n values and sediment retention rates were run at flow rates of 0.009 cms, 0.026 cms, 0.044 cms, and 0.057 cms including seepage from the surrounding ponds.

Soft stem bulrushes (*Scirpus validus*) were planted in late April 1992 in soil placed in the bottom of the concrete channel and retained in place by a stoplog at the downstream end of the test section. The bulrushes were allowed to grow from late April until late July 1992. The bulrushes had a continuous supply of water due to seepage and releases from nearby ponds used in ecosystem research. After the test to determine Manning's n values in July 1992, bulrush samples were taken and analyzed for stem count, stem diameter, and dry weight of the plants. The sampled area consisted of nine sample sections each 40.5 cm by 82.3 cm.

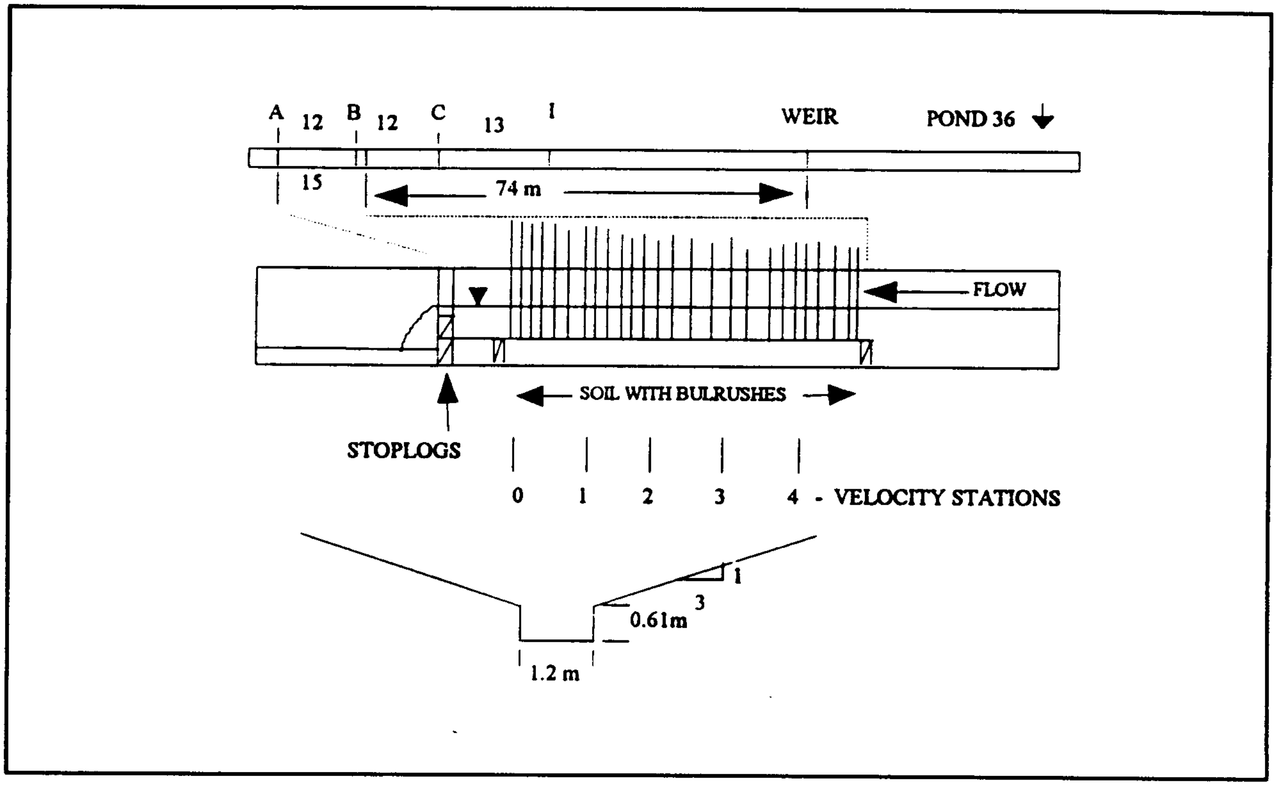

Figure 2. Schematic View of the Lewisville Aquatic Ecosystem Research Facility Test Channel showing test set up and sampling/measurement locations

The planted area was then allowed to continue growing from July until late November 1992 when additional tests were run to determine the ability of the bulrushes to trap fine sediments. The areas sampled after the July tests were not populated as densely as the unsampled area but were located at the extreme lower end of the test section and did not affect the flow except at the extreme downstream end of the test section.

Sediment Testing Apparatus: In late November 1992 the bulrushes were tested for sediment trapping efficiency by introducing a fine grained sediment into the flow upstream of the bulrushes. The sediment consisted almost exclusively of silts and clays with very little sand. Sediment used in the tests consisted of a loessial soil from the Vicksburg, MS area that was transported to Lewisville for the tests. The use of the Mississippi soil allowed easy visual identification of areas where deposition had occurred due to the difference in color between the nearly black soil at Lewisville and the light brown soil from Vicksburg. Approximately 150 liters of sediment material was transported and proved to be adequate for the series of tests.

The experimental setup for the analysis of fine sedimentation in the bulrushes consisted of a mixing tank for mixing a sediment slurry, a pump for injecting the slurry into the channel, and turbulence producing devices (cinder blocks) which were placed in the channel to create turbulence and speed sediment mixing. Sediment deposition was indirectly measured by sampling sediment concentrations at three points in the test channel using a standard DH-81 suspended sediment sampler. The test points (labeled A, B, and C) are shown in Figure 2 as well as the location of the sediment injection apparatus (I). The sediment samples were then analyzed for sediment concentration and a grain size analysis was performed using an Elzone model 112 LSD particle size analyzer.

EXPERIMENTAL RESULTS:

- Bulrush Growth and Density. The bulrush stand as tested for the Manning's n value determinations was well established in late July with an average of 403 stems per square meter. The average diameter for the bottom 50 cm of the stems was 0.7 cm and the volume of stems in the lower 50 cm of water was 8,704 cm^3/m^2 or 1.7 percent of the total channel volume. Sedimentation testing was performed 4 months after the initial Manning's n value testing. By the November test date, plant densities had doubled from an average 402 $stems/m^2$ to 807 $stems/m^2$. Stem diameter had also increased from 0.70 cm to 0.76 cm. The bulrushes occupied an average of 4.0 percent of the channel volume in November compared with 1.7 percent in July. Plant dry matter content (for the entire plants) had increased from 442 grams per square meter in July to 1502 grams per square meter in November.

- Manning's n Value Determination. The water surface profile was measured for each test flow rate for two different tailwater conditions. The first condition tested in July was with one additional stoplog in place (total stoplogs equal to 2 - one to retain soil and second to raise tail water above channel bed). This condition is noted as the low tailwater condition in the following tables and discussions. The second condition for the July tests used two stoplogs in addition to the base stoplog and is referred to as the high tailwater condition. Water surface elevations and velocity measurements were taken at five stations along the test section. The stations are shown in Fig. 2 and are located at the upstream and downstream ends of the section and at every 3 meters along the test channel between the ends of the bulrushes (labeled as 0 to 4 on Fig. 2). One set of water surface profile measurements was also taken for the November sedimentation tests for a flow rate of 0.044 cms. During the remaining November tests only the water surface elevation values at the upstream and downstream end of the test channel were recorded, but the water surface slope was relatively constant along the channel for the high tailwater cases during July testing.

  The results of the five cross sectional velocity and depth values obtained in the July tests were averaged for each flow rate and the averages are presented in Table 1. Tests listed under "Observed" columns are the velocity values measured in the channel using a Marsh-McBirney Model 2000 velocity meter. The velocity measurements were taken at a standard 20-, 60-, and 80-percent depth measured from the water surface. Values used in these calculations are the 60 percent observations. Velocity values shown under "Calculated" headings were obtained using the flow rate divided by the wetted area to obtain an average velocity. It can be seen that there is a wide scatter in the computed Manning's n values for these tests. The n value varies from a low of 0.164 to a high of 0.929. The differences between using the observed and calculated velocity values also show wide variation in n values with differences of 1.1 percent to 149.7 percent. It should be noted that the calculation of n values normally uses the average velocity for the cross section and not point measurement values. This indicates possible problems in measuring velocities in bulrush flow areas and calculating flow rates by multiplying measured velocities by measured cross sectional areas.

  The calculated values show a definite trend towards reduction in n value with increasing velocity as shown in Figure 3. This decrease cannot be construed as a result of bending of the bulrush stems since all velocities are well below threshold velocity where the stems would begin to bend. The November tests with double the number of bulrush stems show a similar trend at a significantly higher range. The difference in n value as a result of using the calculated average velocity versus an average of observed velocities can also be seen in Figure 3. At the very low velocities, the accuracy of the velocity meter and the inability to measure slope extremely accurately may account for much of the difference between observed and calculated values.

Table 1. Manning's n Values for Soft Stem Bulrushes.

Flow	Tail-water	Slope m/m or ft/ft	Observed Velocity (Average) mps (fps)	Calculated Velocity (Q/A) mps (fps)	Obs n	Calc[a] n	% n Diff (O-C)/C
July 1992 Test							
0.009	low	.0088	0.067 (0.22)	0.073 (.24)	.297	.261	13.8
	high	.0010	0.015 (0.05)	0.024 (.08)	.929	.372	149.7
0.026	low	.0105	0.107 (0.35)	0.101 (.33)	.423	.291	45.4
	high	.0035	0.073 (0.24)	0.064 (.21)	.329	.339	-2.9
0.044	low	.0145	0.152[b] (0.50)	0.137 (.45)	.180	.271	-33.6
	high	.0040	0.095 (0.31)	0.091 (.30)	.262	.265	-1.1
0.057	low	.0145	0.180 (0.59)	0.155 (.51)	.164	.254	-35.4
	high	.0050	0.293 (0.96)	0.110 (.36)	.178	.282	-36.9
Average					.345	.292	18.3
November 1992 Test							
0.010	high	0.0028		0.024 (0.08)		.697	
0.026	high	0.0085		0.058 (0.19)		.585	
0.044	high	0.0120	0.119[c] (0.39)	0.088 (0.29)	.367	.501	
0.064[d]	high	0.0198		0.119 (0.39)		.497	

[a] Using calculated velocity (Q/A).
[b] Velocity value of 0.54 (1.77) not included.
[c] Only test where velocities were measured during November testing.
[d] Flow is higher due to seepage from rainfall just previous to test.

When the November test began it was found that the upstream 3 m were filled with debris, trash, and moss that had been washed down the channel. This debris had caused some of the upstream bulrushes to bend downstream and created a large head loss in the upstream portion of the test section. For this reason the first 3 m of bulrushes were removed from the channel and the sediment and n value tests were performed with only 12 m of bulrushes.

The effect of bulrush density can be seen in Fig. 4 where the n value for a condition with no bulrushes in the channel has been estimated using Henderson (1966). The n value for the channel without bulrushes was estimated to be 0.03 (0.32 from USGS 1989). The data indicates that the increase in n value with increasing plant density is nearly linear for the range tested. The ratio of this increase in n averaged 182 percent for a doubling in plant density from 403 to 807 stems per square meter. The factor by which the n value increased due to the increase in plant density was rather stable varying from 1.76 to 1.89 and showing no pattern with regards to increasing velocity.

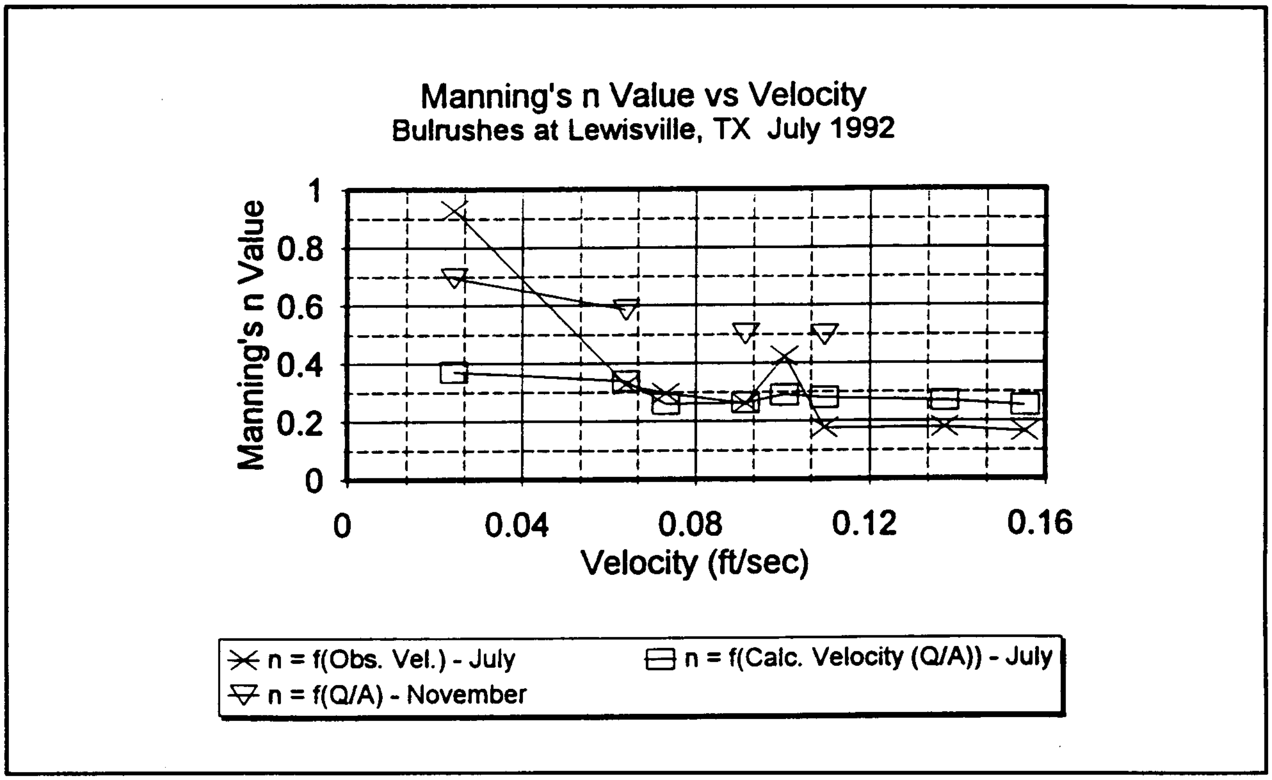

Figure 3. Manning's n Value Versus Velocity for Bulrushes

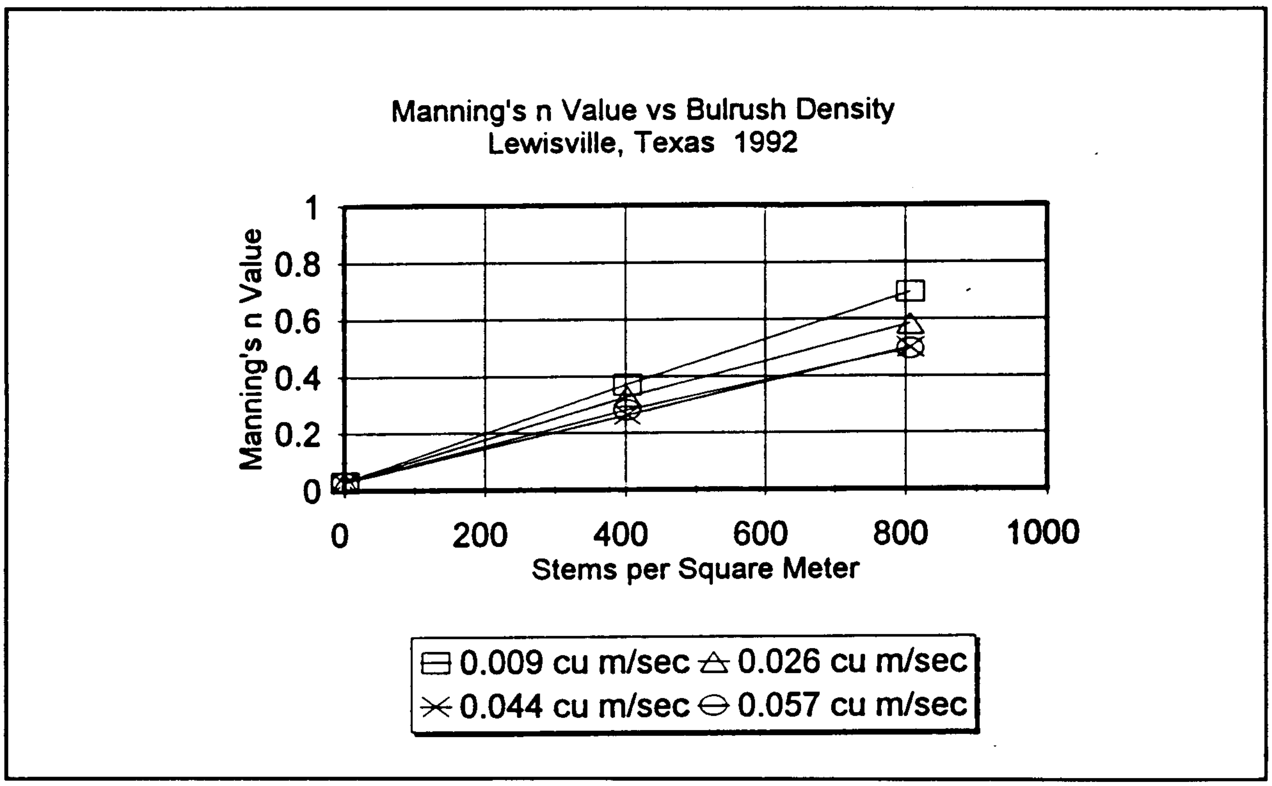

Figure 4. Manning's n Value Versus Bulrushes Density

It was thought that perhaps a change in the coefficient of drag (C_d) could be responsible for the change in Manning's n values due to changing Reynolds numbers or due to the reduction of C_d with increasing Reynolds number. Accordingly, Reynolds number for the various flows were calculated. Stem Reynolds numbers ($Re=\rho*Vel*Dia/\mu$) range from a low of 661 for the 0.009 flow rate in July to a high of 3171 for the 0.0064 flow in the November test. These Reynolds numbers are in the range of a laminar boundary layer and are significantly below the range of the transition to a turbulent boundary layer for flow around a single cylinder. The Reynolds number is high enough to indicate a turbulent wake behind a single cylinder (Schlichting, 1979). These Reynolds numbers are all at a very stable point on the Reynolds number vs coefficient of drag (C_d) curve and the range of Reynolds numbers encountered in this study produce a constant value for C_d. This indicates that the drag coefficient would not account for the variation in Manning's n value when velocities were varied. This was also true when n was compared to velocity multiplied by the hydraulic radius of the channel.

It may be that the reduction in n values with increasing velocity has to do with the effect of turbulence from upstream bulrush stems on flow around the downstream bulrush stems. This effect may reduce flow resistance by causing early transition to a turbulent boundary layer at the downstream bulrush stem or perhaps a cycling between laminar and turbulent, thus reducing drag from the stems and lowering flow resistance.

- Sedimentation. Sediment for the test was introduced 25 m upstream from the channel section where the bulrushes were growing. With the introduction of turbulence at the injection point, 25 m of flow allowed adequate time for mixing of the sediment and water prior to the first sampling point. The first sampling point was located 12 m upstream from the bulrushes.

Based on the desired concentrations of 250 to 500 mg/liter and the desired test flows, sediment was mixed with 460 liters of water to create a slurry in the mixing tank. This slurry was continuously stirred to prevent settling of the sediment. This proved to be extremely important for the higher flow rates when sediment content of the slurry was very high. For the initial test Q=0.010 cms a propeller mixer was used to agitate the sediment slurry. This proved to be very difficult and resulted in an increasing concentration with time as shown in Figure 5. For the second test Q=0.026 cms the propeller mixer was also used for the initial portion of the test. About a third of the way into the test the mixer quit and agitation was accomplished using a shovel. This method was used for the remainder of the tests and resulted in high concentrations for the end of the 0.026 cms test and rather variable inflow concentrations for the 0.044 cms test. For the 0.057 cms test the results were less variable. A partial analysis was done on a sample of the soil and is shown in Fig. 6 and labeled as SOIL ANAL.

The sediment concentration was sampled at point C, 12 m upstream from bulrushes, point B (before bulrushes), and point A (after bulrushes). Results for the four tests are shown in Figure 6. The sediment concentrations drop noticeably between points C and B while dropping only slightly between points B and A. Two of the tests were also run for approximately the last 20 minutes of the test at a concentration of approximately double that of the previous portion of the test. Results of these partial tests are also shown in Figure 7 at the end of the tests for flows of 0.026 and 0.057 cms.

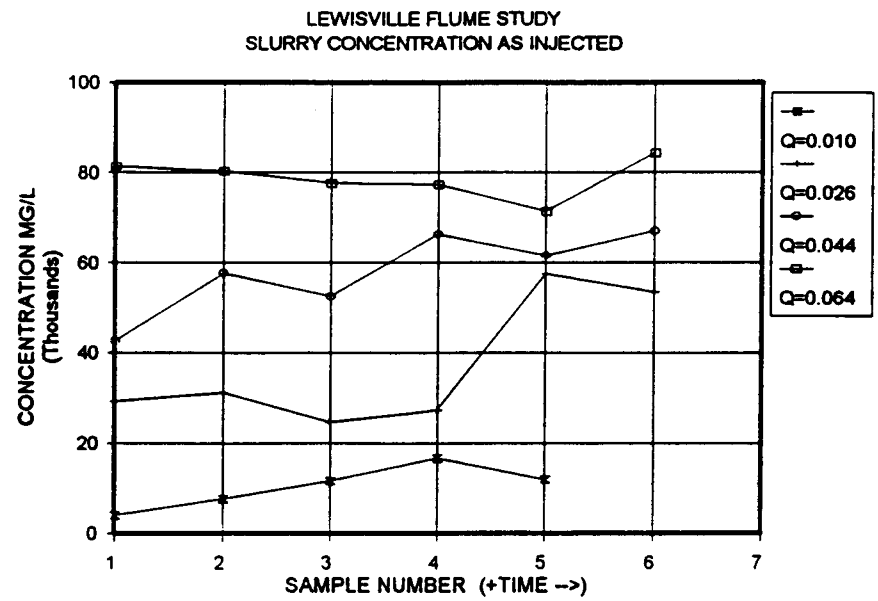

Figure 5. Sediment Concentration of Injected Sediment Slurry

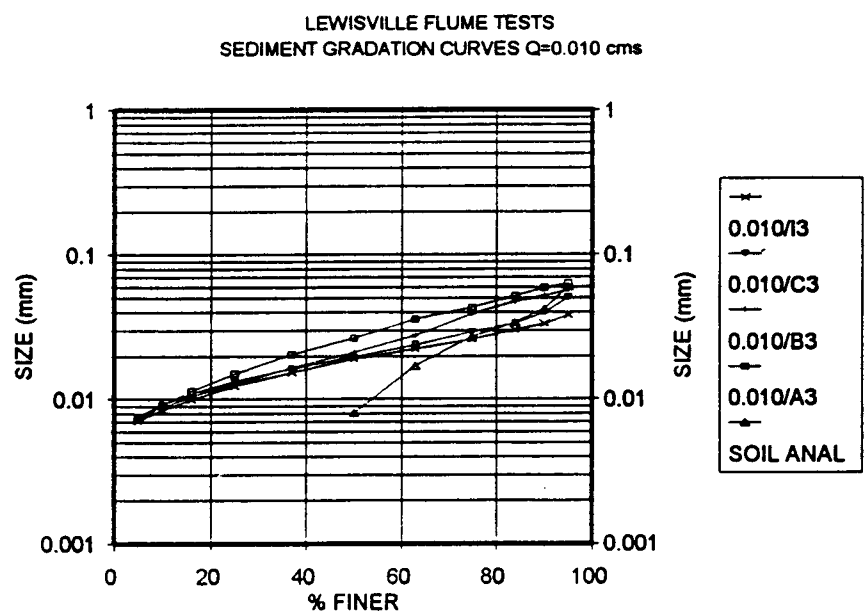

Figure 6. Particle Gradation for Original Soil, Injected Sediment (I), and Collected Sediment Samples (A-C) for Sample Series 3 for Q = 0.010 cms

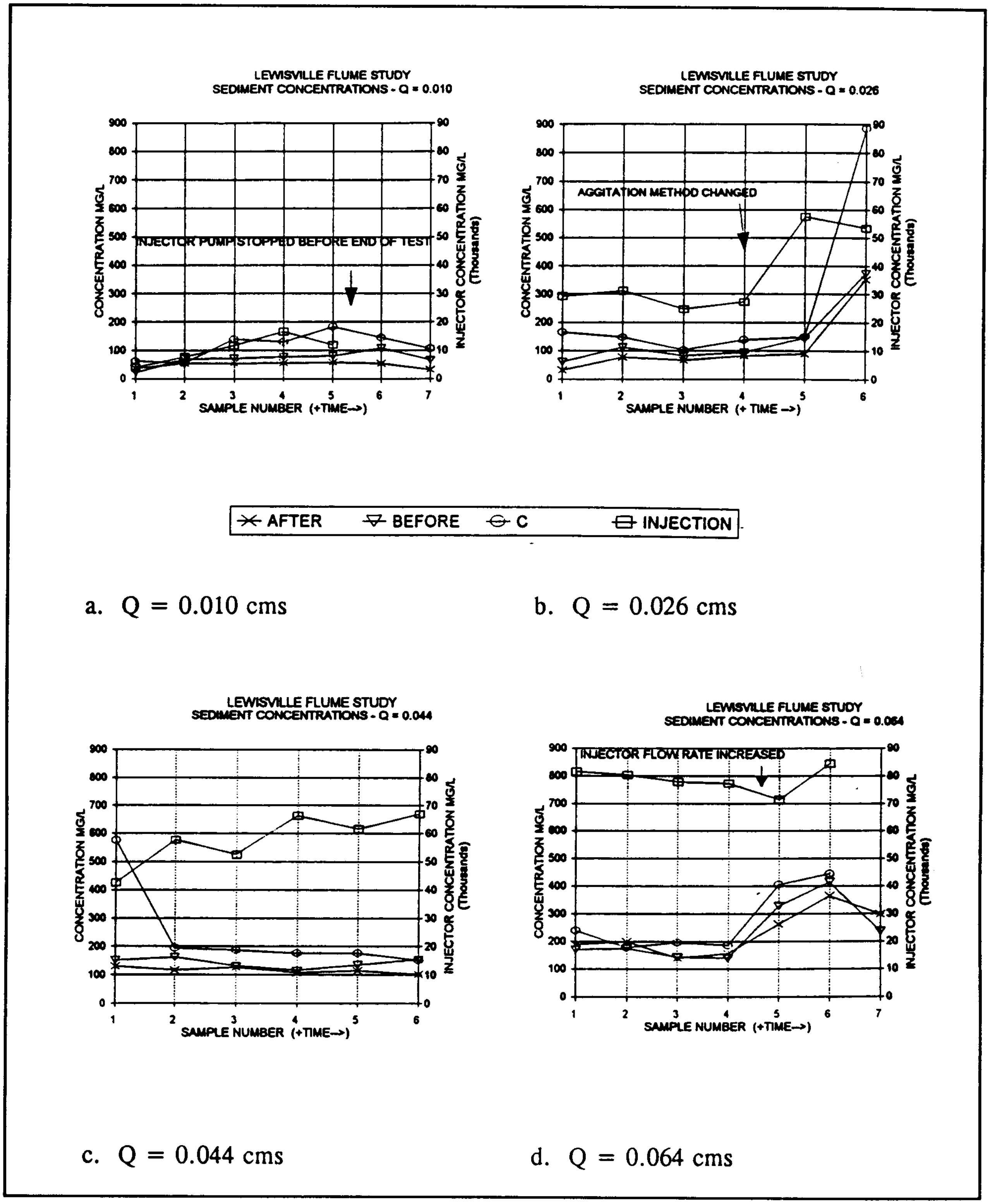

Figure 7. Sediment concentrations for flows of 0.010, 0.026, 0.044, and 0.064 cubic meters per second at sampled locations

Grain size analyses overall showed no significant difference between the injected size distribution and that observed at downstream points, although some tests showed a small trend of grain size fining in the downstream direction. The major difference was a loss of particles at the coarsestend of the distribution. Some differences are noticeable between the soil sample and the collected samples in the 50 percent range and no explanation is available for this difference other than a uncharacteristic sample or possibly a coagulation of slay particles when in contact with the water at the test site. Analysis of the sediment data is continuing.

CONCLUSIONS: Manning's n values were found to be from 2 to 5.4 times as high as indicated by USGS (1989). The n values were found to vary from 0.27 to 0.70 for bulrushes in two differing growth states and with varying flow rates. The n value was found to decrease with increasing velocity for both growth conditions tested for the velocities and flow rates tested. Variations in n value could not be accounted for by changes in the drag coefficient C_d.

Sediment was observed to deposit in the bulrushes but not to the extent that deposition occurred upstream. From this data it appears that less sediment will be retained by bulrush stands than would be predicted due to increased turbulence in the flow in the bulrushes. This increased turbulence and associated maximum velocities is much higher than would be predicted by simply reducing the cross sectional area by the volume of the bulrush stems.

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