The WRP Notebook

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WRP Technical Note SD-CP-2.1
May 1994

Surface Water Sedimentation Processes in Wetlands

PURPOSE: This technical note summarizes the sedimentation processes which control erosion, deposition, and transport of sediment in wetland environments. Related terminology is explained for those lacking specific experience in sedimentation when faced with the evaluation of wetland permits. Future technical notes will cover detailed information on the evaluation of sedimentation in wetlands.

BACKGROUND: Sedimentation in a wetland environment is affected by the hydrology and hydraulics of the wetland and surrounding area. The wetland cannot be isolated from the surrounding environment as erosion and/or deposition on areas outside the wetland may have a profound effect on the sedimentation characteristics within the wetland. The wetland type (i.e. riverine, tidal, depressional, bottomland hardwood, etc.) is also important when evaluating sedimentation. In a riverine bottomland hardwood environment inflowing sediment loads may be transported through the wetland with little deposition. In a depressional wetland all sediment inflow is retained, reducing in wetland size and/or depth.

FACTORS AFFECTING WETLAND SEDIMENTATION: The major factors affecting sedimentation in wetlands include:

- Inflowing Sediment Load. The amount of sediment moving into the wetland when considered with the hydraulics determines the location and amount of sedimentation. Generally, the higher the load and the coarser (larger grain sizes) the material, the more deposition will occur in the wetland.

- Size Distribution of Inflowing Sediment and Wetland Bed Material. The size distribution (percentages of sands, silts, and clays) will determine where deposition will occur within the wetland. If the sediment sizes are primarily in the sand range, deposition can be expected in and near channels and nearby areas where velocity is reduced. For clay and silt sizes, deposition can be expected throughout the wetland. Erosion will normally occur only in areas of high velocity or high turbulence, usually near outlets or along channels and concentrated flow paths in the wetland.

- Velocity and Turbulence of Water. The velocity of the water in the wetland will be the major factor in determining which sediment sizes will be deposited there and where deposition takes place. The amount of turbulence within the flow will have an effect and is correlated with the velocity structure. For erosion, soil type, amount of plant cover, degree of soil compaction, and velocity and turbulence determine the amount and size distribution that will be eroded. The eroded size distribution will be controlled by the bed material of the wetland and the flow velocity.

- Wave Action. Waves within a wetland from wind or boat traffic will have an effect on sedimentation. The usual effects are to redistribute sediment that has been deposited by other means and to cause bank failure/erosion due to wave induced forces. Wave erosion can be significant where large areas of open water exist or where boat traffic is uncontrolled.

- Wind Erosion and Deposition. Wind can be a major driving force of either erosion or deposition in wetlands that are dry for portions of the year. Large depressional wetlands in North Dakota have drifts of aeolian sediment up to 3 feet deep in vegetation around the edges of the dry wetlands. Sediment appears to originate from the dry areas in the wetland where there is no cover to prevent wind erosion. Deposition in vegetated areas can also occur when soil is blown from nearby unprotected non-wetland areas.

- Residence Time. The amount of time water spends in a wetland will affects the deposition of silts and clays. The longer the residence time, the higher the percentage of sediment that can be settled from the water. If significant turbulence is present in the flow (flow through vegetation for example) fine particles such as silts and clays may not deposit even though residence time in the wetland may be considerable.

- Density and Type of Vegetation. The type of vegetation in the wetland, i.e. hardwood trees with little undergrowth or dense cattails or bulrushes, will be important in determining the velocity of flow through the wetland as well as deposition patterns. Studies on a dense growth of bulrushes (*scirpus validus*) indicated that sediment deposited both upstream of and within the bulrush stand. This is apparently due to higher velocities and turbulence within the stand of bulrushes as compared to the relatively still water upstream. The volume of the channel occupied by the bulrushes was about 4 percent of the total volume.

CONCLUSIONS: This technical note reviews important factors in the determination of sedimentation in wetlands. When these factors are used in combination with hydraulic parameters an estimate of expected sedimentation can be made using standard engineering procedures. Several methods are available for estimation of historical, current or future sedimentation such as those discussed in WRP Technical Note SD-CP-4.1 (Jan 93) as well as many computer models.

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Kleiss, B. A. (Jan 1993). *Methods for Measuring Sedimentation in Rates in Bottomland Hardwood (BLH) Wetlands*, WRP Technical Note SD-CP-4.1, U.S. Army Waterways Experiment Station, Vicksburg, MS.

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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

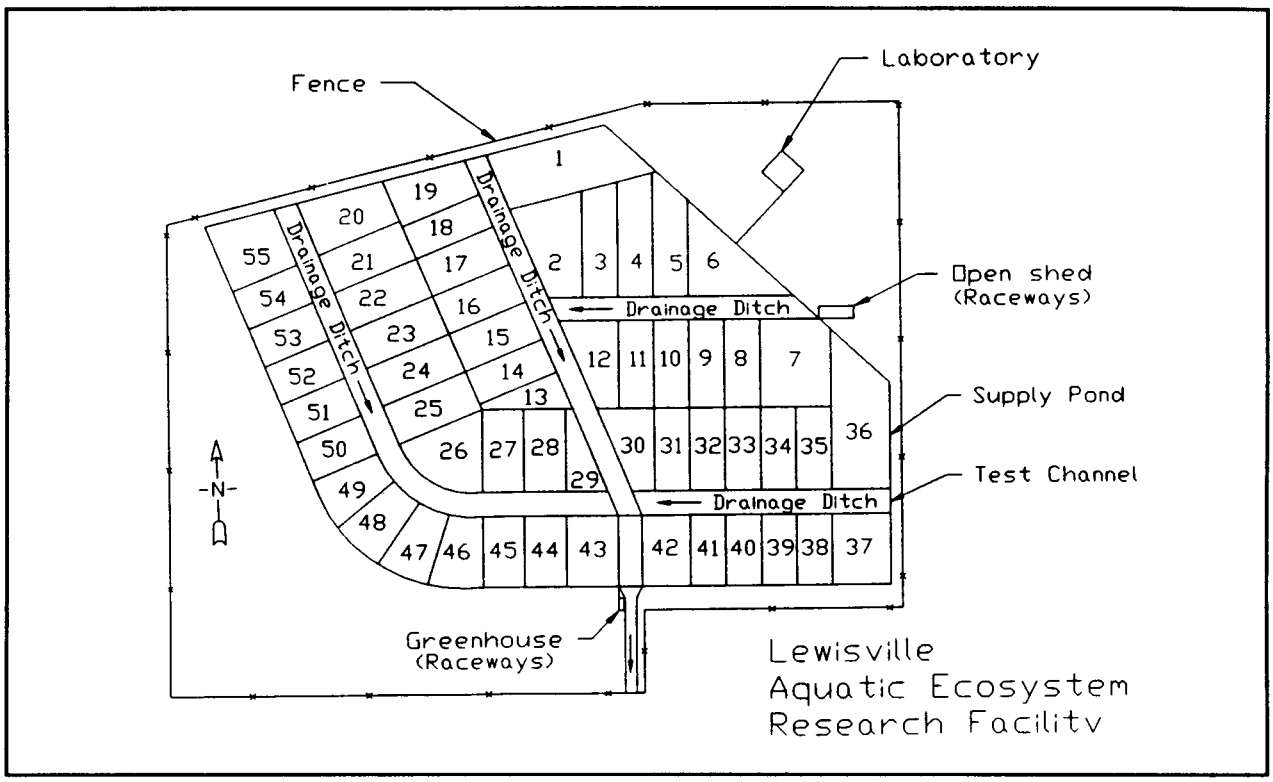

Figure 1. Layout of Aquatic Ecosystem Research Facility in Lewisville, TX showing location of supply pond and test channel

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.

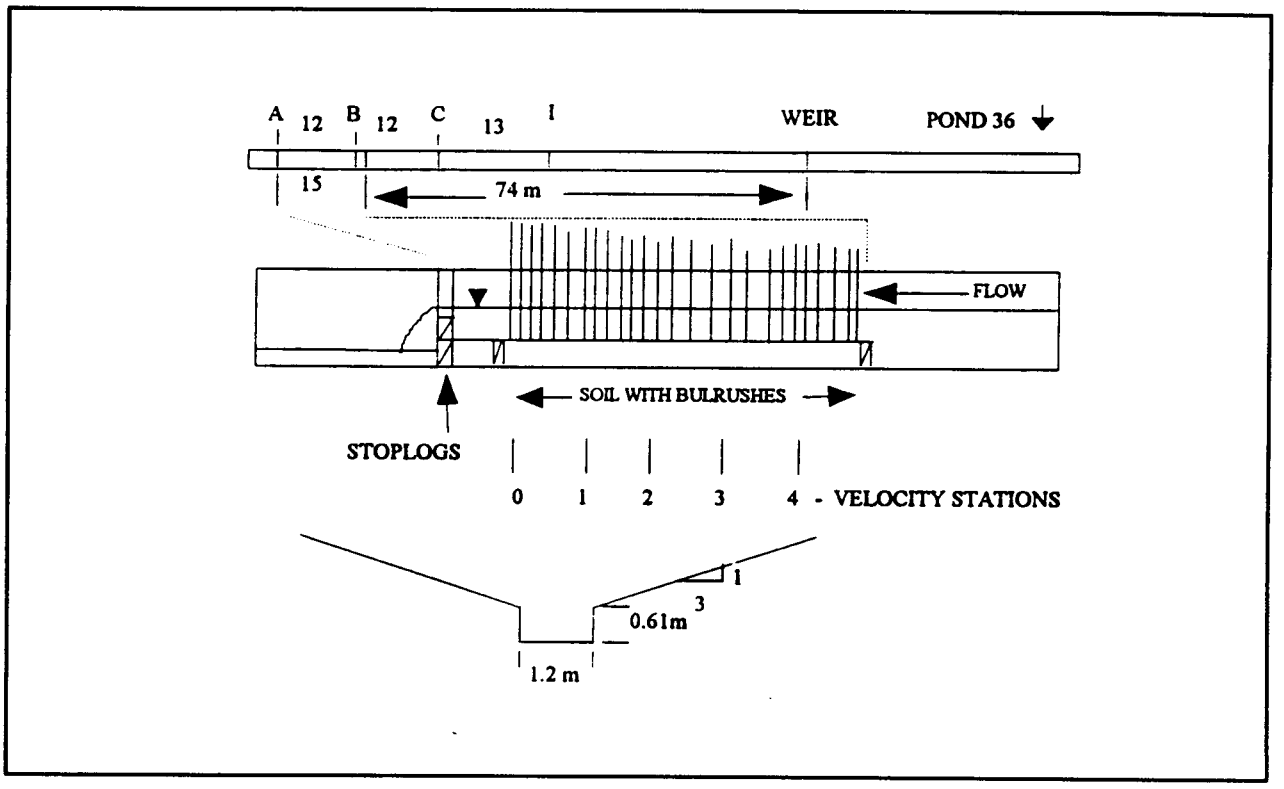

Figure 2. Schematic View of the Lewisville Aquatic Ecosystem Research Facility Test Channel showing test set up and sampling/measurement locations

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 $\frac{O-C}{C}$
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.

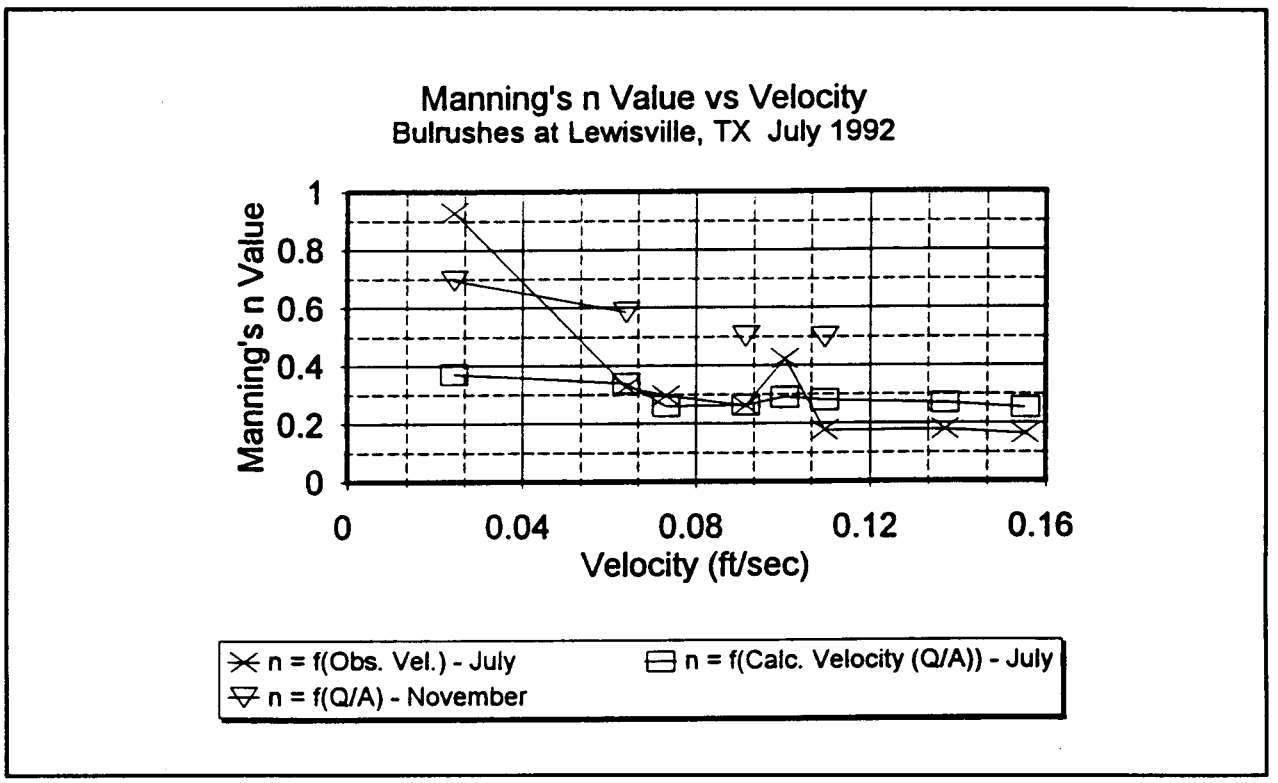

Figure 3. Manning's n Value Versus Velocity for Bulrushes

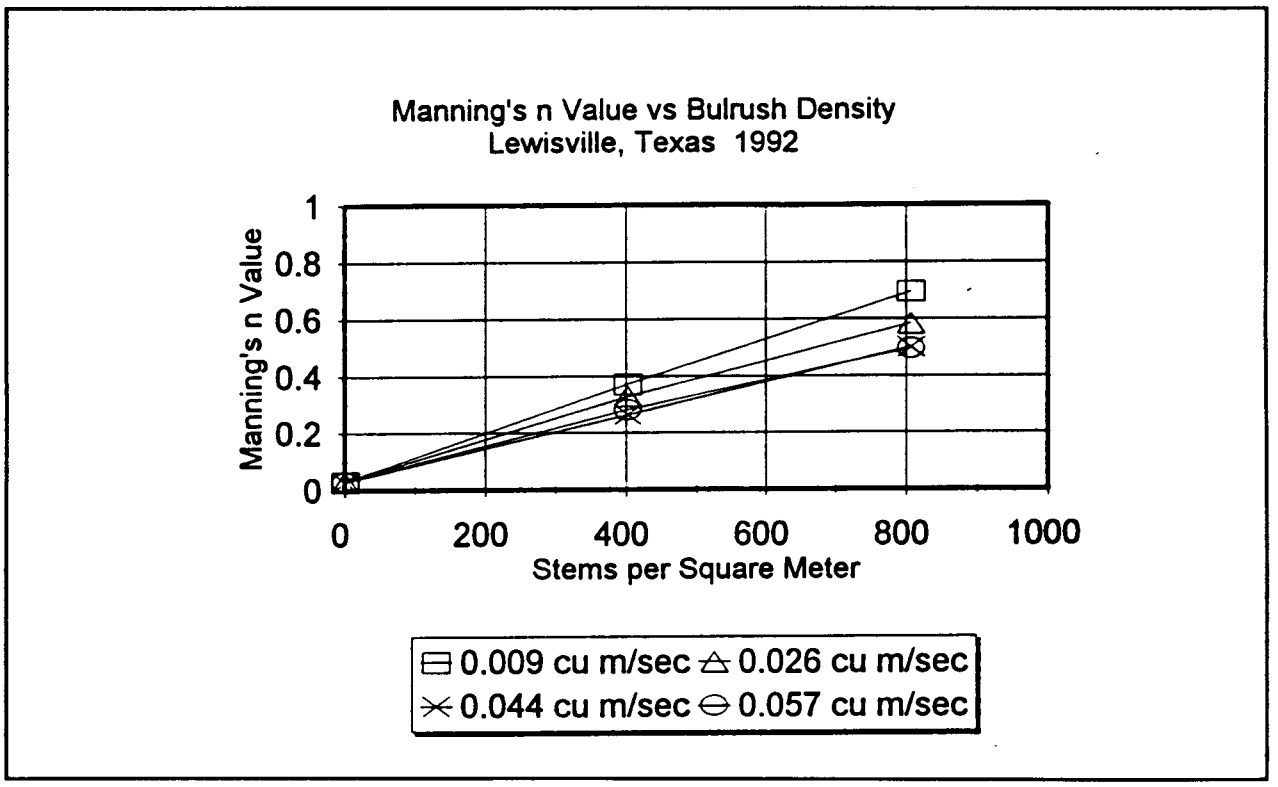

Figure 4. Manning's n Value Versus Bulrushes Density

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.

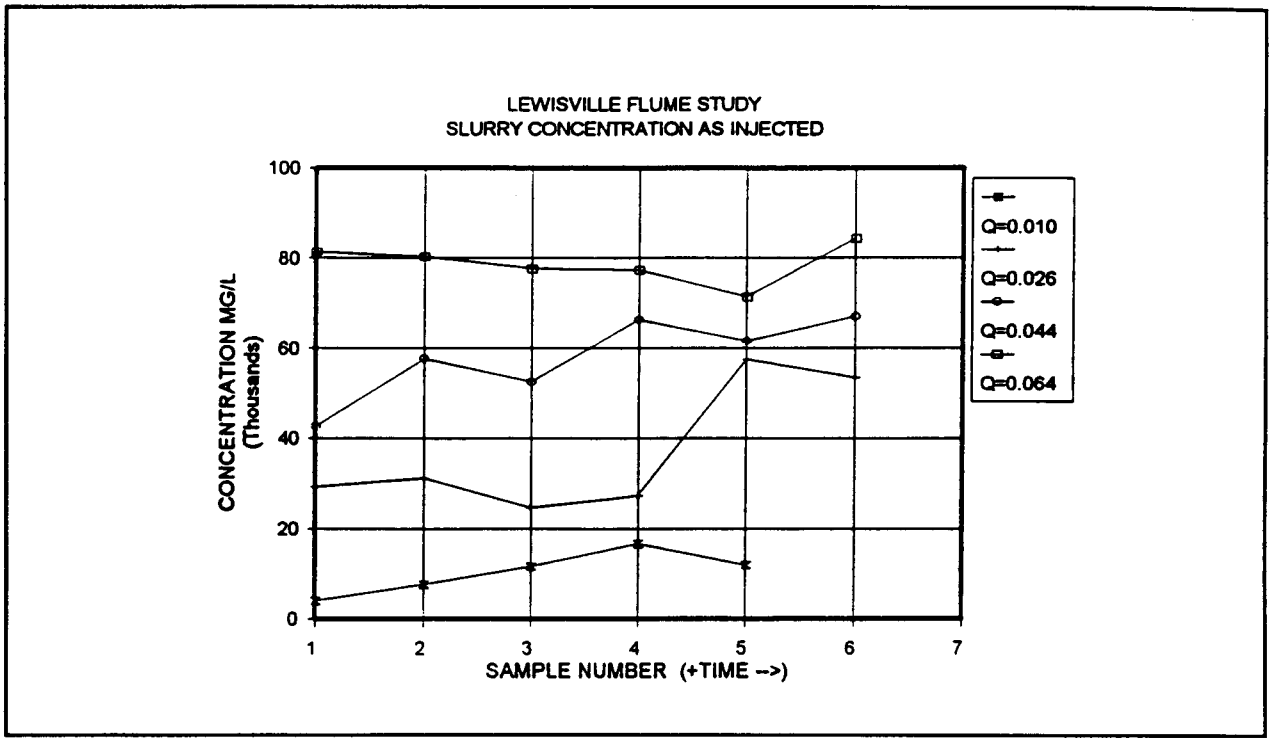

Figure 5. Sediment Concentration of Injected Sediment Slurry

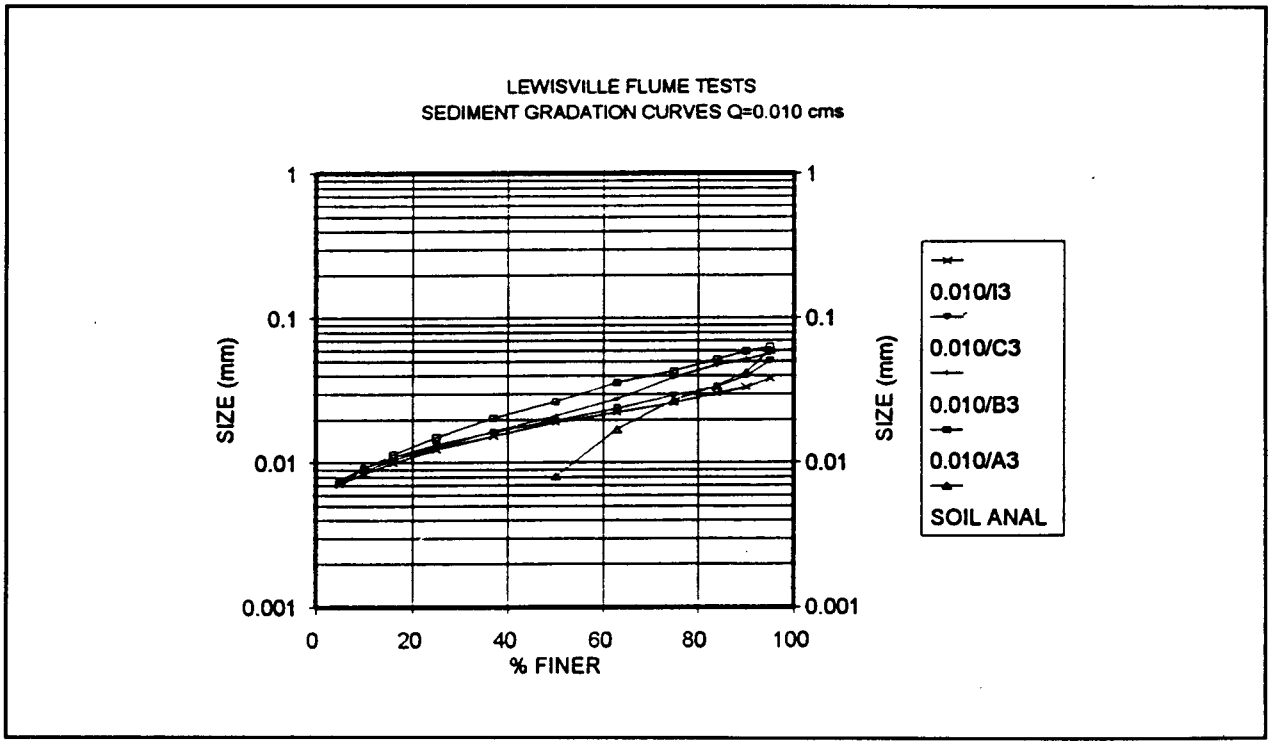

Figure 6. Particle Gradation for Original Soil, Injected Sediment (I), and Collected Sediment Samples (A-C) for Sample Series 3 for Q = 0.010 cms

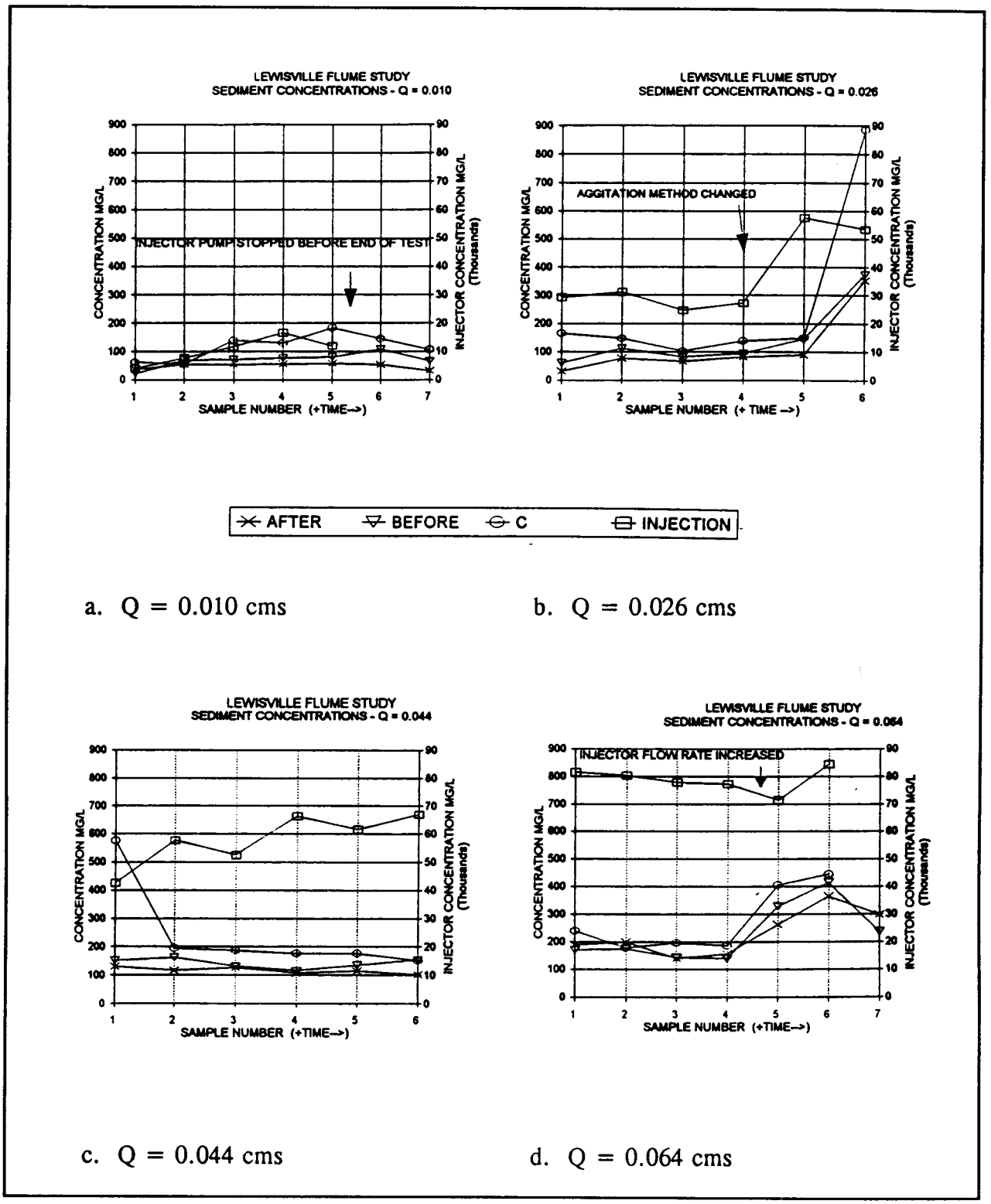

Figure 7. Sediment concentrations for flows of 0.010, 0.026, 0.044, and 0.064 cubic meters per second at sampled locations

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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WRP Technical Note SD-CP-2.3
May 1994

Predictive Techniques: Wetland Sedimentation Due to Surface Water Flow

PURPOSE: This Technical Note presents conditions for which existing sedimentation technology can be used in wetland areas. Although the term sedimentation embodies the processes of erosion, entrainment, transportation, deposition, and compaction of sediment, this technical note addresses waterborne sediments.

BACKGROUND: Sedimentation processes should be grouped into the broad categories of "local" and "general" processes. Local processes are those occurring over a relatively small space resulting in driving mechanisms that are highly three dimensional in space and dynamic in time. General sedimentation processes are those occurring over relatively large-scale space resulting in driving mechanisms, and response of sediment particles, that can be adequately predicted using one-dimensional dynamic or analytic steady state equations. General sedimentation processes will be discussed below.

SEDIMENTATION PROCESSES: Sediment investigations to date have focused on inorganic material. Particle size has been the key parameter in classifying sediment behavior. The Subcommittee on Sediment Terminology of the American Geophysical Union proposed the classification system in use today (Lane, 1947).

Particle Size, mm	Classification
< 0.004	Clay
0.004 to 0.0625	Silt
0.0625 to 2.0	Sand
2.0 to 64.0	Gravel
64.0 to 256.0	Cobbles
> 256.0	Boulders

Because the behavior of sediment particles is so sensitive to their size, Lane partitioned these broad ranges into class intervals using a geometric progression of 2.

The emphasis in existing reservoir sedimentation studies was on volume depletion in the reservoir pool. Research attention was focused on the deposition and compaction processes involving the finer sediment particles characterized as sand, silt, and clay. Hydrodynamic forces systematically decreased as flow entered the reservoir and once deposited, sediments remained immobile.

In riverine sedimentation, however, the historical research interest has included the processes of erosion, entrainment, transportation, and deposition. The research emphasis has focused on sand and gravel size particles because the forces in riverine systems do not permit the finer silt- and clay-sized particles to deposit.

Estuarine sedimentation studies require a more complete treatment of the problem since the hydrodynamics are complicated by both baroclinic (buoyancy) forces and barotropic (other) forces.

WETLAND SEDIMENTATION PROCESSES: In wetland studies, analysis is complicated by the hydrodynamic diversity in the system as well as by the difference in behavior of sand, silt, and clay particles. The cohesive characteristics of the clay and fine silt particles further complicate the analysis. Vegetation complicates the physical analysis of the deposition and erosion processes, as well as the transport process by altering the turbulent structure of flow when compared to "normal" boundary roughness dominated flows. In addition, the new "organic" sediment class is introduced. Organic sediments have both physical and chemical influences on sedimentation processes. Turbidity is a condition to be reckoned with in wetland systems and it has not received a great deal of attention analytically in existing sedimentation studies. Aquatic life in the wetland system can introduce turbidity, affecting light penetration and aquatic plant growth. The additional energy source due to aquatic life is one not commonly addressed in sedimentation studies. Finally, the presence of aquatic life may make boundary sediments more difficult to erode compared with the more biologically sterile riverine and flume systems which provided the coefficients for erosion functions currently in use.

APPLICATION IN WETLANDS: These and other factors complicate sedimentation investigations in the wetland environment. However, by carefully identifying goals and objectives, existing technology can give valuable insight into the longevity of a wetland as it responds to the inflowing sediment material. Also, existing technology can give valuable insights into the performance of project features as man attempts to work with and manage the wetland systems.

The Waterways Experiment Station is presently developing and distributing a system of PC based computer programs which calculate hydraulic parameters, sediment transport rates, and long term sediment yields. This application package will be useful for studying the finer silt and clay sediments commonly found in wetland environments, as well as coarser sand and gravel size sediments which occur in the inflowing or exiting channels. The package is called "Hydraulic Design Package for Channels (SAM)" (Thomas, *et. al.*, 1993).

CONCLUSIONS: Sedimentation studies have traditionally focused on riverine, reservoir, or estuarine systems. By recognizing the controlling physical similarities and differences between wetland and other hydrologic systems, application of the appropriate physical description of erosion, entrainment, transport, deposition, and compaction processes is possible.

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Methods for Measuring Sedimentation Rates in Bottomland Hardwood (BLH) Wetlands

PURPOSE: This note describes four methods that can be used to measure sedimentation rates in BLH forests and other wetland systems. These are: a modified sediment trap method, called a sediment disk; use of a feldspar clay marker horizon; use of ^{137}cesium for dating cores; and a dendrogeomorphic method. The advantages and disadvantages of the methods are discussed and their application to wetland regulation and evaluation considered.

BACKGROUND: A comprehensive study examining the physical, chemical, and biological functions of a BLH wetland forest adjacent to the Cache River in eastern Arkansas was initiated by the U.S. Army Engineer Waterways Experiment Station in 1986. It was postulated that in highly turbid waterways such as the Cache River, one of the primary water quality functions of the wetland system involved the removal of sediments suspended in the water column and the subsequent removal of the nutrients and contaminants associated with the suspended sediments. Accordingly, a study was designed to describe the sedimentation patterns occurring within the BLH forest.

APPROACH: Four methods of measuring sedimentation were employed to determine their usefulness in evaluating sedimentation rates in wetlands and to quantify these rates. These methods range from relatively expensive and time consuming to inexpensive and quick, and also differ in the time period they are designed to assess.

- Modified Sediment Trap Method. Numerous reports are available regarding the proper way to design and install sediment traps in limnological and oceanographic research situations. Many of these reports recommend submerging into the water body a cylindrical column that is approximately five times as tall as it is wide. These 5:1 aspect ratio columns are designed to prevent any resuspension of the trapped material.

  It was decided that this design was not appropriate for a BLH system for several reasons. For example, water fluctuations can be so drastic that it would be difficult to install the cylinders at a depth where they stay submerged throughout a sampling period. The fluctuating water levels would also make it difficult to know just what portion of the water column was being sampled. Perhaps, most importantly, the resuspension of materials is a significant aspect of the sedimentation patterns of these wetland types, and high-aspect ratio sediment traps can overestimate net sedimentation.

  Therefore, "sediment plates" instead of sediment traps were designed and positioned in the field. These plates are 15-cm-diameter Plexiglas circles, with about a 1-cm hole in the middle. The upper surface of the plate is sanded so that sediments will not be washed off because of a smooth surface, but natural resuspension can occur. To anchor the disks to the surface, a 30-cm-long threaded steel rod was hammered into the ground, the disk was placed over the rod, and a washer and wing nut were used to secure the disk to the rod (see Figure 1). Minor adjustments can be made to get the disk even with the ground. Each disk was placed a known distance and direction from a PVC rod that had been securely pounded into the ground to aid in relocating the disks later.

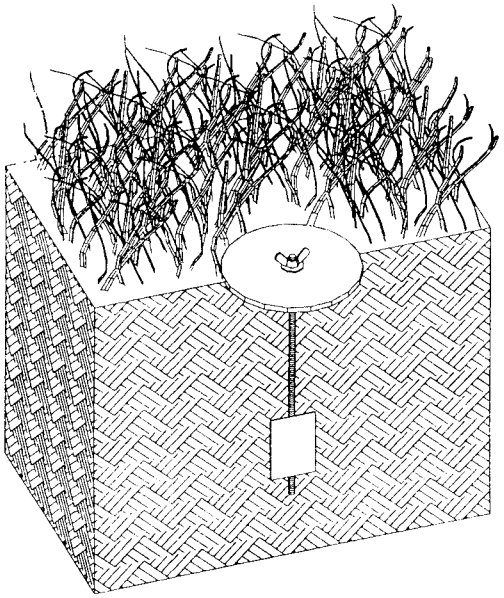

Figure 1. Schematic diagram of Plexiglas sediment disk

The sampling frequency was determined by the hydrology of the system. Annual sampling was used in a BLH system to allow the disks to collect sediment from one low-water period to the next. At sampling sites with high sedimentation rates, the disks were often completely buried (Figure 2). If sediment buried a disk, the approximate location of the disk was determined with a compass and tape measure, and then a sharp object was pushed into the sediment until Plexiglas was "hit." The accumulated material was collected by cutting around the edge of the disk with a knife and scooping the material into a zipper-lock bag with a spatula. The collected sediment was later dried and weighed in the laboratory. The depth of the ground surface above the disk surface was measured in the field, and the ground surface immediately surrounding the disk was smoothed out or the disk elevated to the new ground level so that the old deposition did not erode onto the disk.

This method is simple, provides the possibility of easy replication at each site, and provides a straightforward way of collecting annually deposited sediments for particle size analysis or chemical analysis. The sediment disks are relatively inexpensive to construct and easy to install. There is the disadvantage, however, of having to return to the sites to make repeated measurements. Additionally, while the disks seem to work very well in areas with high sedimentation, there does seem to be a tendency toward underestimation in areas with low sedimentation because small amounts of sediment can be washed off the disks during heavy rainfall.

- Feldspar Clay Marker Horizons. Researchers at Louisiana State University have used the feldspar clay method extensively in the marshes in south Louisiana (Baumann 1980; Baumann, Day, and Miller 1984; Cahoon and Turner 1989). Feldspar clay is a very white material composed of silt and clay size particles and is often used for pottery. It is very inexpensive and can be obtained in bulk.

  For this procedure, the feldspar clay is spread out on the forest floor, at a rate of approximately 2 L per 0.25 m^2, at a known distance from a PVC marker (Figure 3). Sampling consists of locating the clay pad and taking a small core of the sediments deposited above the clay and the

Figure 2. Plexiglas sedimentation disk anchored to the forest floor with about one third of the sediments scraped off

clay itself. A thin-walled aluminum beverage can works well as a coring device, or a chunk of the ground can be cut out with a large field knife. The amount of material deposited above the bright white marker horizon can be easily measured. As with the sediment disks, sampling frequency depends on the hydrology of the wetland system under study. In the BLH system, samples were taken during the low-water period during the fall when there was the best chance of finding all of the sampling sites exposed and out of the water. In other wetland systems, the sampling frequency should be modified to best reflect the local hydrology and to address the questions to be answered.

Figure 3. Researcher spreading a feldspar clay pad for a marker horizon

The clay-silt nature of the feldspar clay provides a surface for sedimentation that is very similar to the natural sediments in many wetland systems. Also, in areas that are not rapidly eroding, the clay pad stays intact for several years and allows the measurement of net sedimentation rates over a period of several years. Cahoon and Turner (1989) describe several other advantages of the feldspar methodology: (1) it is relatively inexpensive, (2) it provides an estimate of recent sediment accretion events, (3) sampling success is known at collection time because the marker is readily visible in the field, and (4) core collection and processing are relatively simple and fast.

This method can even be used in shallow standing water. Feldspar clay will sink to the bottom and create a good marker horizon. Sampling can be accomplished by pushing a clear Plexiglas tube into the ground, filling it with water, and plugging it to maintain suction while the tube is pulled out. In this manner, the white clay can be seen through the side of the tube, even if the permanently saturated sediments are too unconsolidated to be removed as an intact core.

- ^{137}Cesium Atmospheric Fallout Method. Ritchie and McHenry (1989) reviewed the use of radioactive fallout ^{137}cesium in measuring sediment accumulation rates and patterns in the environment. ^{137}Cesium is a product of nuclear fission reaction, and does not occur naturally in the environment. Widespread global dispersal of ^{137}cesium began with thermonuclear weapons testing in late 1952 (Perkins and Thomas 1980), and measurable amounts began to appear in the soil in 1954 (Wise 1980). Peak quantities occurred in 1963 and 1964 immediately before the Atmospheric Nuclear Test Ban was put into place. Figure 4 depicts a typical ^{137}cesium profile. Maximum activity occurs at the depth corresponding to 1963. The depth at which ^{137}cesium first appears is equivalent to 1954, when the isotope was first detectable. ^{137}Cesium is rapidly adsorbed by suspended particles and the clay components of sediments and soil and therefore, once deposited, establishes a fairly stable marker.

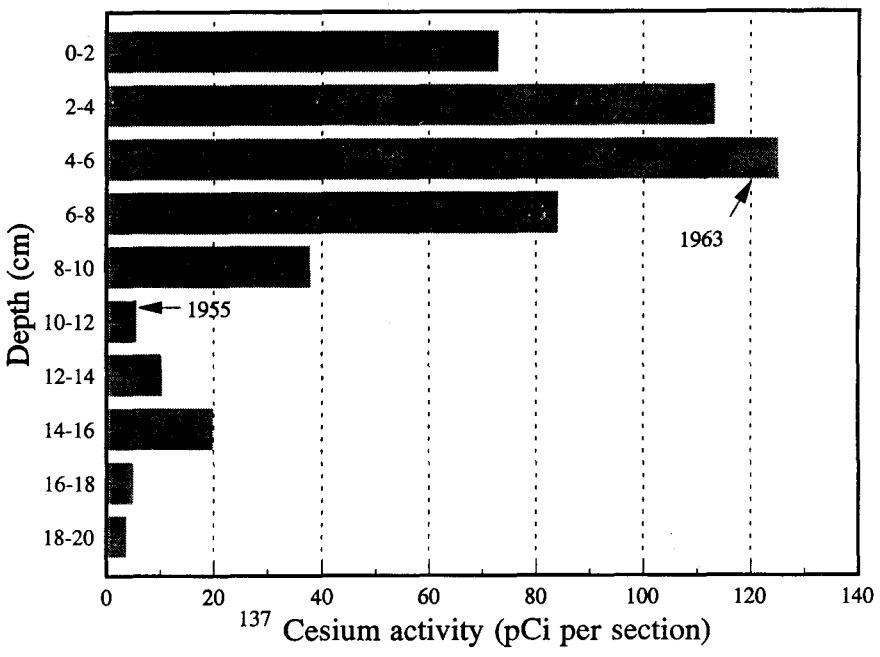

Figure 4. Typical ^{137}Cesium profile showing 1963 peak

To measure ^{137}cesium, sediment cores are taken in a wetland in a manner designed to minimize compaction. The cores are sliced in increments appropriate to the anticipated rate of sedimentation. The sections are dried, and ^{137}cesium activity is counted with a lithium-drifted germanium detector and multichannel analyzer (DeLaune et al. 1989).

DeLaune et al. (1989) have examined the accuracy of ^{137}cesium measurements in wetlands by establishing that the vertical accretion rates using ^{137}cesium were comparable to rates measured with marker horizons in Louisiana Gulf Coast marshes. ^{137}Cesium is also an excellent way to integrate sedimentation rates over a 30- to 35-year period, thereby taking into consideration periods of resuspension or erosion. Also, because estimates of sediment accumulation rates can be made from a single sediment core, repeated sampling trips are not required.

However, there are some limitations to the method. Obtaining cores from wetland locations may be a difficult task, if not impossible in some locations. In some cases, the deposited ^{137}cesium may be reworked, by either bioturbation or hydrologic events, causing the profile to be indistinct. The measuring technique, while relatively straightforward, requires specialized equipment that is available at a limited number of laboratories. The procedure is relatively expensive, and the sample processing can be time consuming.

- Dendrogeomorphic Method. The dendrogeomorphic work done in the Cache River basin was done in conjunction with the U.S. Geological Survey (Hupp and Morris 1990). Dendrogeomorphic analysis is based on both dendrochronologic and geomorphic methodologies. Sigafoos (1964) and Everitt (1968) showed that historic patterns of floodplain deposition could be described through tree-ring analysis with detailed hydrogeomorphic observation. Dendrogeomorphic analysis involves the coring or cross-sectioning of specific trees affected by the geomorphic processes.

Buried stems and associated adventitious tissues are the principal botanical evidence of high sedimentation rates. Initial tree roots form, upon germination, just below the ground surface. These first rootlets eventually form the major root trunks that radiate from the initial germination point. This basal flare or root collar and initial root zone form a distinctive marker of the original ground surface. Trees subjected to substantial sediment accretion typically have the appearance, near the ground level, of a telephone pole, and lack the normal basal flare (Figure 5).

The basic age determination of the tree is made by taking an increment core from near the base of the tree; ring counts are then made from the biological center (first year of growth) to the outside ring (last year of growth). The tree-ring counts may be made in the field or returned to the laboratory for more accurate microscopic examination and cross-dating. Generally, small measurement errors in the tree-ring counts will only have minor effects on the sedimentation calculation rates.

Figure 5. "Telephone pole tree." Sediment deposition has been so great around the base of this tree that the basal root flare has been completely buried

Several trees within the wetland area to be examined, representing a range of ages, are cored. Each sampled tree is excavated near its lateral roots. Measurements are made of the depth of burial of the lateral trunk roots, from the top of the root to the present soil surface. Depth measurements should be taken 0.5 to 1.0 meter away from the tree trunk to ensure that the measurements avoided the influence of the basal flare. Depth measurements are divided by the age of the tree to obtain a sedimentation rate near the tree. This rate is considered to be a conservative estimate of accretion, given that the initial root growth is embedded a few more centimeters into the root.

This method has the advantage of providing a "quick and dirty" means of estimating sedimentation. Only one visit to each site is required, and it is possible to get the results of the work before leaving the field. The total amount of time required is dependent upon the size of the wetland area to be characterized. Enough trees should be sampled to provide a reasonable average for each hydrologically similar portion of the wetland. The only equipment required for this technique is a tree corer and a shovel, although a calculator and a strong back are helpful. Also, differences in historic versus more recent sedimentation rates can be made by measuring trees in different age groups.

The primary disadvantage of the method is the difficulty in accounting for the variability due to differences in microtopography. Therefore, this method is probably best used where estimates of sedimentation rates are acceptable. Additionally, the method can only be used in forested wetlands, and in areas where there has been a relatively high rate of sedimentation.

- Comparison of Methods. Good success has been achieved with all of the methods discussed above in the Cache River basin in Arkansas. A graph of sedimentation rates taken with all four methods along a transect perpendicular to the Cache River is presented in Figure 6. Mass accretion, measured in kilograms per square meter per year was measured with the sedimentation disks, and vertical accretion, measured in centimeter per year was measured for the other three methods. While general trends are apparent, the actual rates of sedimentation are different for each of the methods, which gives some insight into different sedimentation rates over the time periods measured by each method. For example, the clay marker horizons measure a 3-year period, between 1988 and 1991. There has been little time for compaction of deposited sediments to occur during this period, and the measurements of sedimentation rates for the period are quite high. In contrast, depending upon the age of the trees, many of the measurements taken using the dendrogeomorphic method integrate a time period that begins during the 1930s. There has been a significant increase in agriculture in the drainage basin since that time, which may explain lower sedimentation rates in samples covering a longer time period.

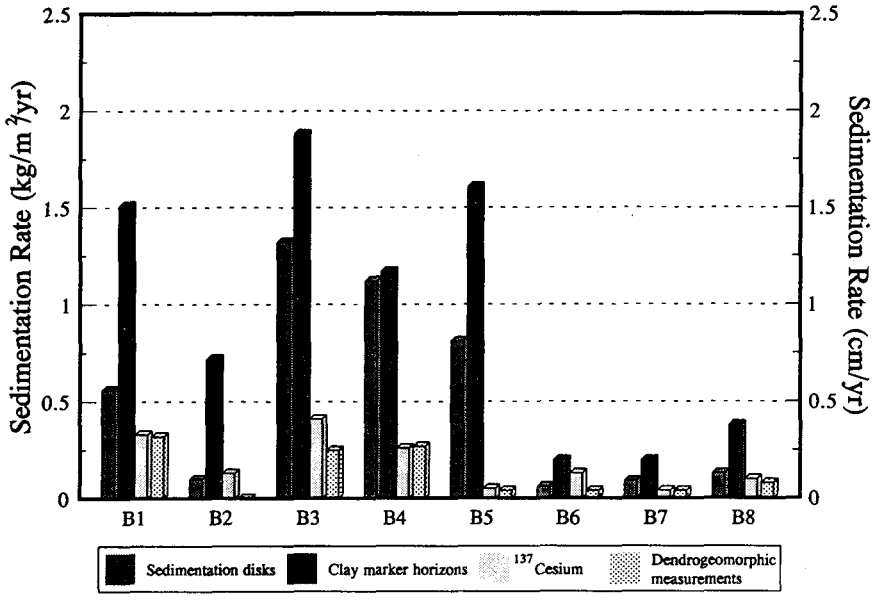

Figure 6. Comparison of results from the four methods of measuring sedimentation at one Cache River transect

Decisions concerning which method to use should be based largely on the question to be answered and the resources available. It would seem that the dendrogeomorphic method is well-suited to wetland regulatory situations in forested wetlands. In a single day, trees could be cored, root flares, uncovered and results obtained in order to estimate a wetland's sediment-trapping capacity. For longer term studies, both the feldspar clay pads and sediment disks offer inexpensive means of estimating annual sedimentation rates. The clay pads have the advantage of allowing the determination of net annual sedimentation rates over a multiple-year period, while the sediment disks are well-suited to situations in which further chemical or physical analysis of the sediments is desired. If funds are available, ^{137}cesium provides a technically respected method with which to determine sedimentation rates over a 30- to 35-year period. By using both recent and long-term sediment dating techniques simultaneously, a comparison can be made of historical and modern sedimentation patterns (Cahoon and Turner 1989).

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Collection of Undisturbed Bulk Wetland Sediment Samples

PURPOSE: This technical note describes how to collect bulk undisturbed sediment samples from wetland areas.

BACKGROUND: Certain sediment analysis procedures require the collection and sectioning of undisturbed bulk sediment samples. Techniques such as Cs^{137} dating of sediments are dependent upon the collection of a bulk sample. Also, analysis of samples for toxicants such as pesticides, herbicides, and heavy metals may require a bulk sample. In order to determine a depth profile for a substance the sample core must be undisturbed; that is, the core must retain its original size and shape until it is sectioned, or cut up, for analysis. Because of the high organic content of wetland sediments, collection of an undisturbed bulk sediment core can be difficult. In addition, many wetland areas are remote; therefore, sampling equipment must be simple, rugged, and lightweight enough to carry by foot or small craft for long distances.

EQUIPMENT: Though seemingly uncomplicated, the equipment used in the collection of the sample is extremely important. For the collection of bulk samples, a 10 cm (4 inch) pipe is used. In order to get an undisturbed sample, a very thin walled pipe is needed. The best pipe material is 10 cm diameter aluminum irrigation pipe, which is thin, light-weight, strong, and smooth walled. If thin walled aluminum pipe cannot be located, then PVC pipe can be substituted. If PVC must be used, drain pipe is superior to the thicker high pressure pipe. Because the aluminum pipe will penetrate the sediment easier than PVC, there is less chance for compaction of the core during collection. Also, samples are more easily removed from the aluminum pipe.

Regardless of the pipe material, the end of the pipe should be beveled with a file to enhance penetration. The sharper the end the better. The length of sampler is dependent upon the depth of water and the length of sample to be collected. For most applications a 2 - 3 meter section of pipe is adequate, though the pipe can be cut into any length necessary. Measuring marks should be placed along the outside of the corer, at 10 cm intervals, so that the length of the core can be determined in the field and compared to the length of the core once it is removed from the sampler.

In order to remove or "pull" a core from the sediment, some type of handle for the pipe is desirable. The hinged bracket, shown in Figure 1, works very well with the aluminum pipe. This design allows the bracket to be easily moved along the pipe and tightened with the wing nut during collection.

In addition to the bracket, caps or rubber stoppers are needed for each end of the corer. The stopper or cap for the top end of the bracket should be fitted with a screw-in stem valve. A small hand-operated or battery-operated air pump is needed in conjunction with rubber stoppers fitted with screw-in valve stems, in order to remove the core from the sampler.

Loose organic cores will also need support while they are being sectioned. A good core holder can be constructed from a 1 meter section of 10 cm diameter PVC pipe by slicing the pipe down the middle and gluing caps on the ends of the half pipe. Holes should be drilled at the ends of the pipe

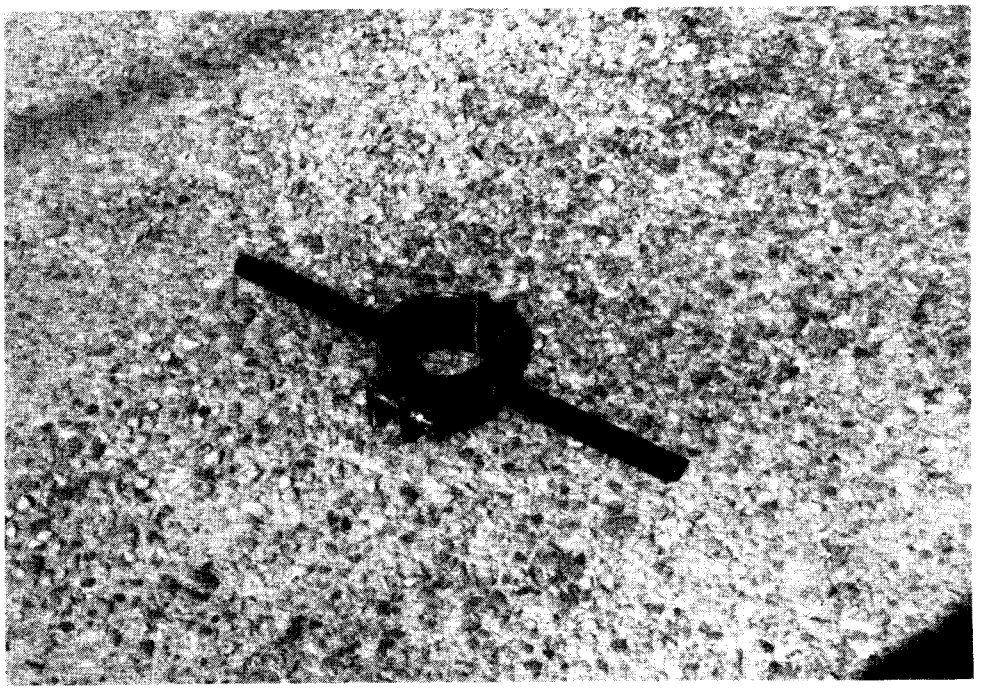

Figure 1. Bracket for sample extraction

to allow excess water to run off the sample. This trough, as shown in Figure 2, will support the sample and hold it in its original form while it is being sectioned.

SAMPLE COLLECTION: The techniques employed in the collection process are designed to collect an undisturbed sample of sediment with a minimum of water above the core. Cores may be collected by either wading or from a small boat. When collecting a core, the bottom cap should be removed and held close by. The bracket with handles is attached to the corer about chest high. The following procedure should be followed:

- Place the top cap tight on the corer. With the top cap tight, vertically lower the corer to the wetland bottom. Keep the top cap on during this step to prevent water from filling the corer. The corer should rest lightly on the bottom without penetrating.

- Remove or loosen the top cap so that air can fill the pipe. Once the cap is removed, quickly push the corer into the wetland sediment. Some water will enter the pipe, but this can be minimized by rapidly pushing the corer into the sediment. Once the corer is in the sediment, water will no longer enter the pipe. The corer should be pushed into the sediment until the bottom of the wetland is struck.

  The bottom is defined as the bottom of the wetland before the deposition of sediments. Normally, the bottom of the wetland will be difficult to penetrate, indicating that the bottom has been found. In wetlands that periodically become completely dry, hard pans may form in the sediment layers where the sediments were allowed to dry. These hard pans will be difficult to penetrate but are usually thin, only a few cm in depth. Once they are penetrated the underlying sediments are usually much softer. Often, if a hard pan is mistaken for the bottom the hard pan will not support the core above it and the core will be lost during extraction. If the material of the wetland bottom is known, then examining the soil at the bottom of the extracted core will help determine

Figure 2. Sectioning of sample in trough

if the real bottom has been reached. Wetlands often form above a clay layer of soil, thus mottled clay at the bottom of the core is a good indication that the wetland bottom has been reached.

- Once the bottom is found, push the corer an additional 10 - 15 cm to obtain a hard plug that will support the soft sediments above during extraction. Care should be taken during the coring process to keep the corer vertical.

- Once the corer has been pushed into the wetland bottom, rotate the corer 360 degrees to break the core loose from the bottom. It may be necessary to rotate the corer additional times. Generally, the corer is much easier to rotate once the core is broken loose.

- After the core is broken loose replace and tighten the top cap. This will provide a suction on the sample during removal and help hold the core in the sampler.

- Remove the sample from the bottom by pulling the corer out vertically. Depending on the sample, the core may be very difficult to remove. The bracket will greatly assist in the removal task.

- Once the bottom of the corer reaches the water surface, quickly cap the bottom to avoid losing the sample.

- Transport the samples in a near vertical position to their final location. This is necessary because the top few inches of the core are often in a near liquid form. Laying the core horizontally will cause this portion of the core to mix and it will no longer represent an undisturbed sample.

REMOVAL AND SECTIONING OF CORES: Samples must be extracted from the corer and sectioned without mixing, stretching, or compacting. Assuming that a good sample has been obtained, the first consideration is whether to section the sample in the field. Sectioning is generally easier in the laboratory but very soft samples may compact during transport. This decision should depend on

the consistency of the samples collected and the accuracy desired. Very soft organic mud samples should be removed from the cores and sectioned in the field.

Very consistent samples may be removed from the corer using a stick with a broad end, approximately the size of the core. According to Andrew Nyman of the Louisiana State University Wetland Laboratory for Wetland Soils and Sediments, this is generally adequate for samples obtained from coastal marshes where the sediments are firm and interlaced with roots from marsh grasses. These samples can be sectioned on a flat table using a serrated knife.

However, sediments found in many freshwater wetlands with high siltation rates are generally very soft and are easily compacted or stretched. Also, these samples may adhere to the inside of the sampler and be difficult to remove. These samples require special techniques and equipment for removal from the corer and sectioning. The following steps are recommended:

- Place the sectioning trough at an approximate 10 degree slope.
- Place the bottom of the corer in the middle of the trough and remove the bottom cap.
- Remove the top cap and replace it with a cap fitted with a screw-in valve stem.
- Use the pump to push the sample from the corer. With one person holding the sampler, another person can operate the pump. Pump the sampler full of air until the sample starts to move, then shut off the pump and allow the sample to slowly move into the trough.
- If the sample stops moving, pump in more air until the sample begins to move again. Most samples will slide down the trough as they are pumped out. However, if the sample starts to compact, or if it is longer than one half the trough length, the sampler may be moved back to remove the sample. Be sure not to move the pipe too quickly, as this may cause the sample to become elongated.
- Using a measuring stick, determine the length of the sample. Discard any sample that is significantly longer or shorter than originally measured in the field.
- Lay the measuring stick on the top of the sample and lightly mark the sample with a knife at the desired sectioning locations. The sample may be cut using a sharp, thin-bladed knife, such as a filet knife. A large spoon can be used to scoop up very soft sections.

  If the samples are to be transported for analysis, each section should be stored in a clearly marked, plastic ziplock bag. Each bag should identify the sample number, location, and depth of the slice. It is helpful to pre-number the bags before sectioning the core.

  For samples requiring small sections, 1 - 3 cm, the first one or two slices may be composed of an organic liquid ooze. It may be helpful to freeze these samples before pumping. If this not possible then it may be necessary to estimate the approximate line of demarcation for these top sections.

CONCLUSIONS: A methodology for collecting sediment cores has been developed that allows scientist to obtain bulk undisturbed cores of soft organic wetland sediments. Such a sample is often needed to determine sedimentation rates or perform other analyses that require a sediment profile. The equipment has been tested and proven effective in both fresh and salt water marshes. Because

the equipment is simple and lightweight it may be easily carried to remote wetlands by foot or small boat.

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