X. Watersheds: Sediment Yield and Sediment Control, Remote Sensing and GIS Applications

X. WATERSHEDS: SEDIMENT YIELD AND SEDIMENT CONTROL, REMOTE SENSING AND GIS APPLICATIONS

NORTHERN WASATCH FRONT PRE-FIRE MITIGATION STUDY WITH GEOGRAPHIC INFORMATION SYSTEM APPLICATIONS DAVIS AND WEBER COUNTIES, UTAH

ROBERT C. RASELY, GEOLOGIST, NORMAN C. EVENSTAD, GEOLOGIST, MARK M. PETERSEN, RESOURCE CONSERVATIONIST; NATURAL RESOURCES CONSERVATION SERVICE, SALT LAKE CITY, UTAH

ABSTRACT: Communities are encroaching rapidly into the base of the steeply rising Wasatch Front because of the high quality views. The increased growth has significantly increased the risk of wildfire damage. This study includes the cities between North Salt Lake and Pleasant View, Davis and Weber Counties, Utah.

Wildfires are only the initial hazard. Fire makes the burned areas susceptible to hazards from the next intense storm flow. The resultant excessive sediment delivery represents a significant hazard to downstream urban areas. The main objective of this study was to provide quick access to quantitative post-fire sediment delivery data for cities and counties. This will facilitate a rapid response in post-fire emergency mitigation action. Previously, these assessments took from two to ten days to complete.

Geographic Information System (GIS) layers were developed to deliver this procedure to city and county planners and emergency response staffs. Sediment yield rates were developed for each individual canyon-fan drainage way and the interfluve areas for the before-fire, post-fire low intensity burn and post-fire high intensity burn conditions. The GIS layers developed for this study include sediment yield, slope failure, vegetation, soil, slope and watershed sub-basins. These GIS databases can be updated in the future and can also be manipulated for more detailed analysis of natural resources or hazards.

The use of GIS in this assessment will save critical reaction time during the post-fire hazard mitigation assessments. Damage potential was based on sediment yield volume and a risk assessment rating of low, medium or high was developed.

<u>INTRODUCTION</u>: The escalating development of communities along the western slopes of the Wasatch mountain range has become an increasingly important issue to city, county, state and federal officials concerned with public safety and land management. A major portion of Utah's population lives along the Wasatch Front corridor. Davis and Weber counties account for 20 percent of the state's population on 1 percent of Utah's surface area. This represents a significant population affected by land management policies developed for the urban-wildland interface and National Forest System Land. Some of the biggest hazards confronting landowners along this corridor involve debris flows, debris floods, debris slides and wildland fires. These hazards not only affect people living in the urban-wildland interface but also people living along the many drainage corridors further downstream of the canyon outlets.

Wild fires along the Wasatch Front pose a two fold threat to landowners. There is the obvious fire hazard and then a flood and debris hazard from storm events that impact the burned watershed. A steep area impacted by a wildfire can create a "loaded-gun" situation if a rainstorm occurs before the vegetation is reestablished. This set of circumstances became reality with the Affleck Park Fire, September 1988, (Nelson and Rasely, 1990) located east of Salt Lake City in Emigration Canyon. In this case, emergency measures to collect debris and sediment in the upper watershed prevented heavy damage to houses downstream. However, precious time was lost because sediment yield modeling had to be performed before an informed decision could be made on the extent of needed emergency watershed protection. The information developed from this study will allow for a more rapid response in the development of an emergency watershed protection plan in the event of a watershed degrading wildfire along the Wasatch Front.

LOCATION: The study area encompasses the Wasatch Mountain Front in Davis and Weber counties. It contains about 63,000 acres of steep, rugged terrain with alluvial fans and steep, confined drainage channels. The study area is subject to intense summer thunder storms that produce flash floods and a heavy snowpack which can create periods of high runoff during the spring thaw. The western extent of the study area terminates approximately along the boundary of the ancient Lake Bonneville shoreline at an elevation of 5,200 feet (Fig.1).

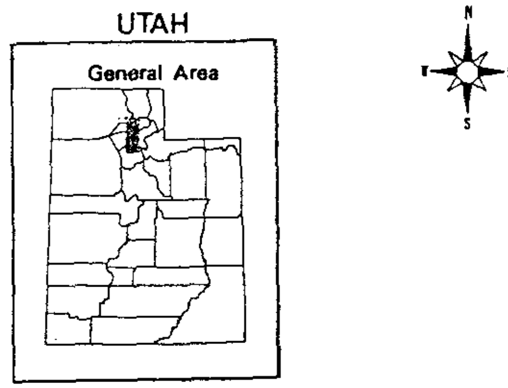


Figure 1
General Location

PURPOSE AND SCOPE: The purpose of this study was to identify and characterize the potential post-fire sediment yield rates from drainages in the study area. A total of 93 separate watersheds were evaluated.

Another purpose of this study is to provide a means for rapid response to post-fire emergency mitigation through use of a Geographic Information System (GIS) database. The database includes information needed to model the post-fire sediment yield potential from a single watershed or series of watersheds depending on the extent of the burn.

Almost every town in Utah was built on an alluvial fan at the mouth of a canyon in order to obtain irrigation water, so this database can be useful throughout Utah.

METHODS USED: A model developed by the Pacific Southwest Inter-Agency Committee (PSIAC) 1968 (revised 1991), Factors Effecting Sediment Yield in the Pacific Southwest, was used to model the sediment yield from 93 watersheds in the study area. The PSIAC method consists of rating a watershed on the basis of nine factors shown listed as follows: Surface Geology, Soils, Climate, Runoff, Topography, Ground Cover, Landuse and Management Quality, Upland Erosion, and Channel Erosion.

Each soil unit received a numerical rating for the present condition, a low intensity burn, and a high intensity burn. This rating corresponds to the upland sediment yield from that watershed in units of tons per acre, assuming an average sediment density of 90 pounds per cubic foot. The post-fire sediment yield ratings assume a burn over the entire watershed for a worst-case scenario.

Sediment yields were calculated at the canyon outlet area. Routing of the sediment through the fan area and channel reaches below the apex will have to be performed on a site by site basis if this information is needed. The GIS capabilities can assist with the routing of sediment. This routing would involve detailed topography, hydrology, sedimentation and stream mechanics information to perform and is beyond the scope and intent of this study.

The interfluve areas (small triangle-shaped areas between main watersheds) generally do not have a single discrete drainage, so transport of sediment from these areas is generally by overland flow processes without a defined point of impact. These areas involve very small drainages and sediment volume and were not considered in this report.

Another factor considered with the sediment yield evaluation was the extent of previously mapped debris flows, debris slides, landslides and other related slope failures in each of the watersheds. This helped in determining which watershed would have a higher relative hazard rating if a wildfire occurred in any of the watersheds. On an areal basis, partly-detached landslides identified in 1983 were statistically significant as sources for debris flows in 1984 in Utah *(Wieczorek, Lips, Allen, 1989).*

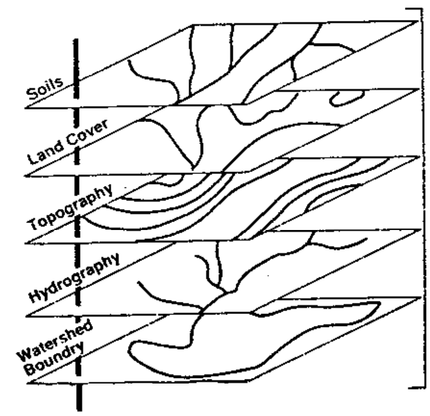
USE OF THE STUDY: The information derived from this study can be used by city, county, state and federal planners and specialists as a source of information and guide for general planning and the preparation of an emergency watershed protection plan. Users of this report and database will have access to reliable information including rangeland sediment yield, slope, vegetation, watershed sub-basins, and present slope failure areas.

Data developed from this study was incorporated into a geographic information system (GIS) for analysis and used to illustrate the utility of a GIS system in handling the large amounts of spatial and tabular data involved with natural resource planning or hazard mitigation. The GIS database resulting from this study will allow the user to estimate sediment yield from a burned area by digitizing the burn area and assigning burn intensities. The burn intensity assigned to a burn area will dictate which sediment yield rate the software uses to generate the modeled, total post-fire, upland sediment yield. The software can then produce a report of the modeled sediment yield from the watersheds within a burned area. This data can be generated as soon as a fire is declared "contained" instead of waiting days until the fire is declared out. The potential sediment yield can be used to determine the need for emergency protection for life and property. The database developed with this study can be copied to a single 8-millimeter data cartridge.

GEOGRAPHIC INFORMATION SYSTEM (GIS) DATABASE

A GIS is a computerized system for inputting, managing, manipulating, analyzing and displaying spatially referenced data. GIS technology is used to measure, overlay, compare, and analyze geographic data such as vegetation, soils, streams, roads, land use, land ownership, land cover, slope etc.

Figure 2



The GIS work for this study involved an arrangement between the USDA-Natural Resources Conservation Service, Salt Lake City and the Region IV USDA-Forest Service GIS office located in Ogden, Utah. This arrangement facilitated the sharing of data, hardware, software, expertise and work space with NRCS project personnel at the regional Forest Service office in Ogden, Utah.

PRESENT CONDITION SEDIMENT YIELD MODEL: The present condition sediment yield was modeled to establish a baseline condition from which to develop a low intensity burn and high intensity burn sediment yield rate. Most of the area in the study rated as either Low (< 0.6 tons/acre, < 0.49 cubic yards/acre) or Moderate (0.6 to 1.49 tons/acre, 0.49 to 1.2 cubic yards/acre). The southern section of the study area contains relatively more erosive rock types (Tertiary Conglomerate) and so contains a larger percentage of area in the moderate sediment yield category. The rating classifications were taken from the PSIAC sediment yield procedure.

The triangular shaped areas between the 93 main watershed outlets were not separated for tabulation and illustration of the sediment yield. However, the database contains the sediment yield rates based on the landtype-soil units in those zones. These interfluve zones typically contain a large amount of trails and dirt access roads and are frequented by off-road vehicles. The Davis County Planning Commission report (1980) suggested that these trails and access roads increase the overland flow and concentrate these flows enough to cause erosion and deposit sediment in ephemeral channels. Most of this sediment will not be transported to main-stem drainages but can impact properties directly downslope of these interfluve areas.

POST-FIRE SEDIMENT YIELD MODELS: A post-fire sediment yield rate for a burned area can help planners prioritize emergency mitigation by targeting those areas determined to have the highest hazard to life or property. Post-fire sediment yields were modeled assuming: 1) a low-intensity burn of the entire watershed and 2) a high-intensity burn of the entire watershed. A burn over the entire watershed is considered a worst-case scenario. This scenario for the sediment yield estimates seemed appropriate given the proximity of the watershed outlets to a large population and a history of some watersheds to produce damaging debris flows.

The post-fire sediment yield hazard is compounded by the additional hazard of debris (rock, silt, sand, gravel, organics) currently stored in channels along the Wasatch Front. Most of the debris flows observed in 1983-84 picked up a high percentage of their volume from the channel banks and bottom *(Wieczorek, Lips & Ellen,1989).* They also contend that for the short-term, partly detached slopes, along with an increase in ground-water levels, appears to increase the potential for further movement which could lead to debris flows and hyperconcentrated floods. Hyperconcentrated floods, or debris floods are less stratified, and have lower clay content than debris flows. They also usually do not form levees and the woody debris does not have a preferred orientation *(Lips, 1983).*.

Watersheds in a burned area typically develop rills and gullies which increase the delivery ratio and volume of sediment yield off the watershed slopes to the tributaries and main drainages. Studies of mountain streams after watershed disturbance suggest that the sediment transport rate is a function of the supply of soil or sediment in the stream rather than increased runoff (Rice & others, 1979).

<u>BURN INTENSITY</u>: Various definitions have been used to define burn intensity (fire intensity). Vierick and Schandelmeir (1980) defined it as the effect of the fire on the ecosystem, whether it effects the forest floor, tree canopy, or some other part of the ecosystem. Sediment yield data was developed for low and high intensity burns.

The PSIAC rating factors that are affected in the event of a fire are: Runoff, Ground Cover, Land Type & Management, Upland Erosion, and Channel Erosion and Sediment Transport. The other factors, Geology, Soils, Climate and Topography will not change with altered watershed or management conditions. The average PSIAC factor ratings for the soil units evaluated are listed in Table 1.

Table 1 - *Average PSIAC factor ratings for soils in the study area.*

PSIAC Factor	Present Condition	Low Intensity Burn	High Intensity Burn
Geology	0.8	0.8	0.8
Soils	3.0	3.0	3.0
Climate	6.0	6.0	6.0
Runoff	3.9	5.0	7.0
Topography	19.0	19.0	19.0
Ground Cover	-4.0	-0.8	5.7
Land Type & Management Quality	-6.0	1.6	8.0
Upland Erosion	3.5	8.5	17.0
Channel Erosion & Sediment Transport	4.5	8.0	14.0
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Totals	**30.7**	**51.1**	**80.6**

The present condition, low intensity burn and high intensity burn factor ratings equate to an average annual sediment yield from sheet and rill erosion of 0.75 tons per acre, 1.6 tons per acre and 4.6 tons per acre respectively. An average sediment density of 90 pounds per cubic foot was used to calculate tons per acre.

<u>LOW INTENSITY BURN SEDIMENT YIELD MODEL</u>: Typical low intensity burn characteristics were used for each of the PSIAC ratings to stay consistent and enable the relative comparison of the watersheds in the study area. The criteria for a low intensity fire is as follows: a) Perennial roots and vegetation intact, b) Crowns of trees burned, c) Scorched trees, d) Low plants and grasses still somewhat moist and viable, e) Leafy litter consumed, f) 50% of the duff layer consumed, g) Loose grass consumed and sticks and stumps still intact.

The Low Intensity Burn can greatly effect the hydrologic character of a watershed. A study performed by the Davis County Public Works Department showed that deterioration of only 17 percent to 45 percent of the vegetation of a watershed can tremendously increase the runoff and concluded that watershed conditions are probably the most important variable in modeling mountain hydrology and effectively planning mitigation for flooding *(Williams, 1991).*

PSIAC estimates of the sediment yield rates from an area impacted by a Low Intensity Burn generally show an increase of 2 times the present condition yield rate given the assumptions listed above.

HIGH INTENSITY BURN SEDIMENT YIELD MODEL: Criteria used for modelling the sediment yield potential from a High Intensity Burn are listed as follows: a) Litter burned, some larger sticks remain, b) Organic layer consumed (upper 2"), c) Some stumps would burn leaving a hole, roots burned, d) Water repellent layer created in areas with high percentage of organics and extreme temperatures.

The PSIAC model data showed that sediment yield potential from a High Intensity Burn area should be expected to increase an average of six times the Present Condition sediment yield rates. Map 1 is the map of the high intensity burn rate values for the project area and represents an example of the GIS mapping results of this project. The watersheds which contain the highest sediment yield potential in a high intensity burn area #24, #32, #48, #59, #69 (Rudd Creek), #80, and #82. The watersheds were numbered starting in the northern end of the project area and include many unnamed watershed areas.

INTERAGENCY COOPERATION: Interagency cooperation between the USDA-Natural Resources Conservation Service and USDA-Forest Service played a pivotal role in the completion of this study. The field work and GIS compilation were accomplished by interagency teams with valuable field input from Roy Sidle, Research Hydrologist & Heidi George, Hydrologist, both with the Forest Service in Logan, Utah. Sponsorship for the project came from cities, towns, counties, and the State of Utah, Division of Comprehensive Emergency Management. Funding for the study was developed through the River Basin Program of the USDA Natural Resources Conservation Service.

SUMMARY: The watersheds with the highest sediment yield potential after a fire along the Wasatch Front in Davis and Weber Counties are: #32, #48, #59, #69 (Rudd Creek), #80, #82 and #24.

The modeled low intensity and high intensity burn sediment yield rates presented in this study can provide ready answers to concerned agencies about the potential sediment load contributions from range slopes within a burn area. The modeled sediment yield data can be accessed through the use of a GIS. The GIS software then can calculate the total upland sediment yield potential from the burn area. The mapped burn area will need to be entered into the system before any sediment loads are computed.

Emergency mitigation involves identifying the primary goal whether it be protecting homes and other property from the impacts of accelerated erosion and sedimentation, protection of the existing storm drain network or controlling sediment transport on upland slopes. Past emergency seeding of burned slopes in Utah has been considered successful even though there is no quantitative data at this time to document this. The University of Utah is presently conducting a study of the effects of seeding the burned slopes after the Midway Fire near Heber City, Utah in 1992.

Recent trends show that urban development in steep, rugged and fire-prone terrain is occurring not only along the Wasatch Front but also throughout Utah and the rest of the West. Development will likely continue and even accelerate along the other mountain fronts in Utah which have similar characteristics to the Wasatch Front, so, it is up to the agencies involved with resource management and public safety to continue public education concerning the hazards involved with building and living in steep mountain areas.

Steps toward a coordinated, cost-effective, documentable and environmentally sensitive emergency mitigation plan can best be summed up by the steps taken by emergency watershed protection teams during and after the 1993 fires in California. The GIS database developed for this study can help complete the steps listed as follows: 1) IDENTIFY THE ISSUES AND CONCERNS, 2) DEVELOP GOALS AND OBJECTIVES, 3) PERFORM AN EROSION POTENTIAL STUDY LOOKING AT: Sediment Sources & Volumes, Surface Geology, Soils, Runoff, Topography, Vegetative Cover, Land Use, Channel Morphology & Sediment Load and Climate, 4) OUTLINE SELECTION CRITERIA FOR MITIGATION ALTERNATIVES: Ease of Installation, Cost-Effectiveness, Environmental Sensitivity, Other Based on Area of the Burn, 5) EVALUATE MITIGATION ALTERNATIVES.

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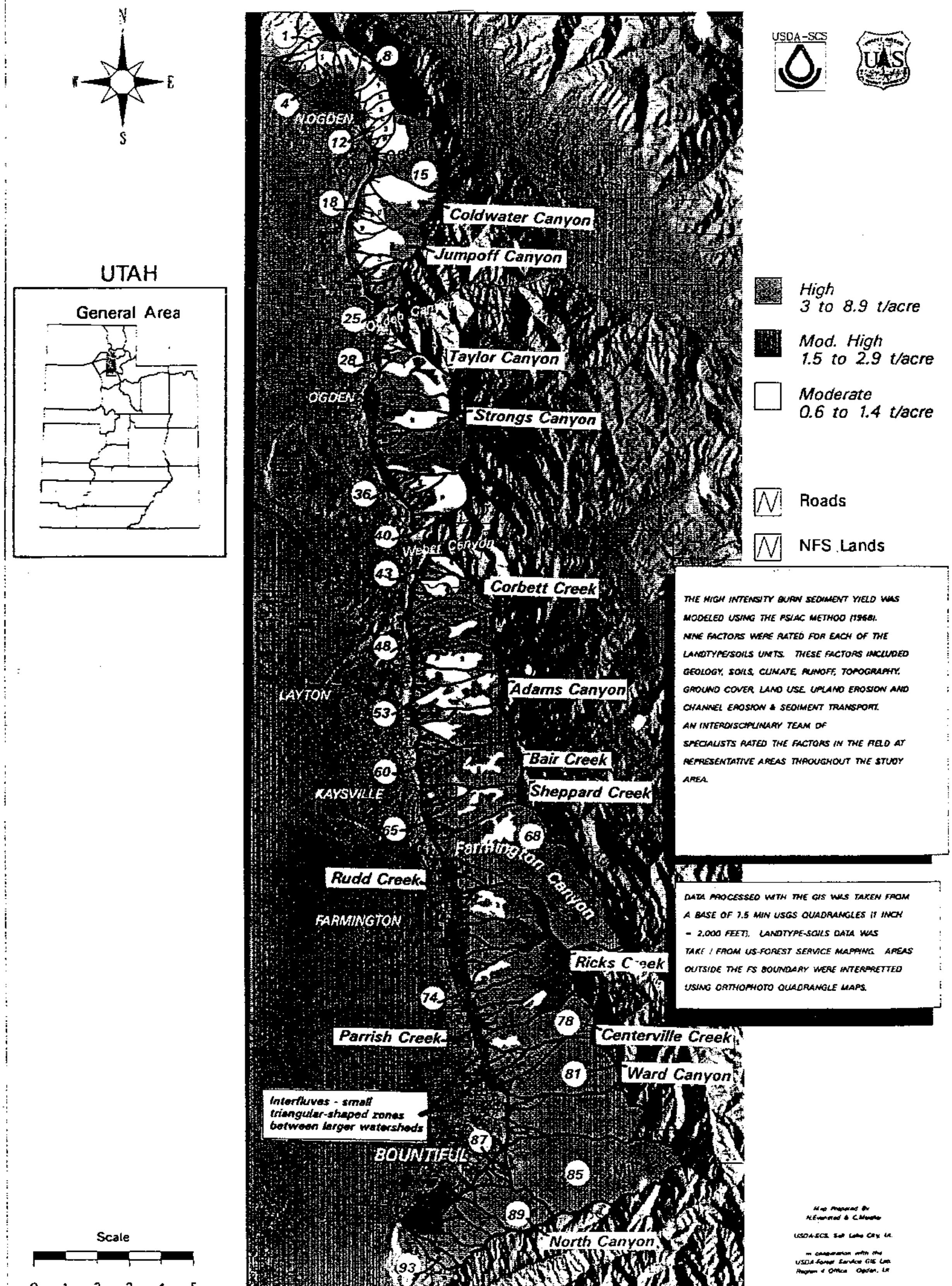
NOTE: This paper is an attempt to create an awareness of the Pre-Fire Sediment Yield Mitigation project accomplished by the Natural Resources Conservation Service in Utah. A more detailed paper elaborating on procedures and results with appendices and maps is available from: Robert C. Rasely, USDA Natural Resources Conservation Service, PO Box 11350, Slat Lake City, UT 84147.

Wasatch Front Pre-Fire Mitigation Study

High-Intensity Burn Sediment Yield Model



MAP - 1
HIGH INTENSITY BURN
SEDIMENT YIELD

INTERACTIONS OF SOUND WITHIN AGRICULTURAL SOILS

By James M. Sabatier, Carl K. Frederickson, Craig J. Hickey and James P. Chambers, National Center for Physical Acoustics, Dept. of Physics, University of Mississippi, University, MS 38677; M.J.M. Römkens, USDA Sedimentation Lab, P. O. Box 1157, Airport Road, Oxford, MS 38655

Abstract: Acoustic phenomenon related to soils have broad applications in agricultural research. The reflection and transmission of acoustic waves from and into the pore spaces of soils depend upon air-porosity, pore tortuosity and air-permeability. The propagation of sound above rough soils is controlled by additional parameters, shape, size and packing density of the roughness elements. Acoustic-to-seismic coupling refers to the coupling of acoustic energy from the atmosphere into the poro-elastic soil matrix. Because of the multi-phase nature of soils wave types in addition to those of single phase materials exist. The characteristics of these waves propagating in the soil are controlled by the above parameters and the soil matrix elastic moduli and bulk density. Work at our laboratory exploiting these phenomena to study the acoustics of soils will be reviewed as well as the possibility of using these techniques to produce in-situ images of these properties on the scale of a few to one hundred centimeters.

INTRODUCTION

Acoustic measurement techniques are widely used in medicine, materials manufacturing and the automotive industry (to name only a few) as an imaging tool. Acoustic imaging techniques require measurements of acoustic wave speeds and attenuation in the material of interest. Although acoustic imaging techniques are successfully used in geophysics to probe deep earth materials and to a much lesser extent the first ten meters or so of the earth's surface, very little work has been done on only the first meter or less of the ground or soil. This is so because of the high attenuation of acoustic waves in soils. The soil, as a consequence of the high attenuation, is seen as a hindrance to deep acoustic probing. This paper specifically addresses acoustic measurement techniques in and theoretical models of agricultural soils which are useful in describing phenomena of interest in the agricultural community. The research described provides the basic information necessary to map or image such properties as soil strength, layering, roughness and porosity.

Acoustic Soil Probes: The soil physical properties tortuosity and air permeability can be determined from measurements of sound wave propagation in soils (Moore, 1992; Sabatier, 1990). Probe microphones have been used to study the coupling of airborne sound into the ground for many years. Attenborough (1986) compared measured acoustic pressure below the ground surface in washed sand to rigid matrix theory. Sabatier (1986) applied Biot's (1956) poro-elastic wave model to describe coupling of sound into the soil. This model predicts two compressional waves, which have been referred to as "fast" and "slow" waves. Much information exists in the literature related to this phenomenon. For most soils and sands, probe microphones a few centimeters below the surface respond to the slow wave, which propagates primarily in the air-filled pore spaces and is highly damped or attenuated with propagation distance. At 100 Hz, attenuation coefficients of 10^2 dB/m are common in soils. The phase velocity of the slow wave varies strongly with frequency from only a few tens of meters per second at 100 Hz to almost the speed of sound in air at 1000 Hz.

Capillary models (Attenborough, 1983) of the pore structure allow for the pore tortuosity and effective air-flow resistivity to be written in terms of the frequency dependent wave speed and attenuation. The measured acoustic data can therefore be inverted to yield model dependent, acoustic probe measurements of these soil properties.

The tortuosity and effective flow resistivity for a soil can be determined by measuring the attenuation or signal loss and the change in phase of the acoustic wave with distance in that material. In order to effectively measure the sound attenuation and phase shift in soils, measurements of sound waves at different depths in the soil profile are necessary.

To understand how tortuosity (τ) and effective flow resistivity (σ_{eff}) are calculated, consider first, the transfer function measured by the probe microphone between two depths d_1 and d_2 when the speaker is directly overhead:

$$T_{d_2 d_1} = e^{ik_b (d_2 - d_1)} \qquad \text{Eq. (1)}$$

where k_b is the complex acoustic wave number ($k_b = k_r + ik_i$) in the soil.

The model (Attenborough, 1983) used to describe acoustic propagation in the ground relates the bulk propagation constant k_b to tortuosity (τ) and effective flow resistivity (σ_{eff})

$$k_b (f) = \frac{2\pi f}{c_o} \sqrt{\gamma} \left[\alpha \tau + \frac{i\, 2\sigma_{eff}}{\pi f \rho_o} \right]^{1/2}, \qquad \text{Eq. (2)}$$

where $a = \frac{4}{3} - \left(\frac{\gamma - 1}{\gamma}\right) N_{pr}$, γ is the ratio of specific heats, N_{pr} is the Prandtl number, c_o the speed of sound in air, and ρ_o is the density of air.

Equations (1) and (2) can be used to calculate τ and σ_{eff} for each frequency measurement. A second method has also been developed that fits the real and imaginary parts of k_b^2 to quadratic and linear functions of f, respectively. The coefficient of f^2 in the fit of $\mathrm{Re}\left(k_b^2\right)$ is proportional to τ, and the coefficient of f in the linear fit to $\mathrm{Im}\left(k_b^2\right)$ is proportional to σ_{eff}. The two methods are discussed by Frederickson (1995) along with the performance of the model being using.

Probe attenuation measurements were made in loess soils, *in situ*. The locations of these measurements were an experimental farm near Senatobia, MS and Pendleton, OR. A herbicide was used to keep the soil surface free of vegetation. At the time the acoustic measurement core samples were taken, the water content and dry bulk density were determined. In this consolidated soil, the coring tool and viscous fluid had to be used to insert the probe and achieve an acoustic seal at the probe entry. Probe measurements at depths of 0.08 m were made on these soils. The spots were chosen because there were no obvious cracks or vegetation on the surface or other obvious visual differences. The acoustic data were taken between 16-100 Hz. Above this frequency, the slow wave is attenuated enough that the fast wave pressure is significant. From Eq. (2) when $\sigma_{eff} >> 1$, $k_r \cong k_i$. Using this σ_{eff} can be calculated between 16-100 Hz. The values range between 2–3 x 10^6 $\mathrm{Nsm^{-4}}$. This approximation does not allow a calculation of the tortuosity.

Similar probe measurements were made in disked loess soils. The measurements show the effect of the tillage depth on the probe pressure as was observed in prepared layer soils by Radke (1995) or Attenborough (1995a).

Acoustic Level Difference: The typical measurement setup for acoustical determination of ground properties using short-range propagation is a point source and a receiver each positioned approximately 0.5 m above the ground surface and at a horizontal range of a few meters. A second reference microphone is positioned 0.1 m above the ground surface and beneath the upper microphone. The total pressure received at either microphone is composed of a direct (r_1) and a reflected (r_2) sound ray.

The *level difference* is the difference in the pressure between two vertically separated microphones, and is equal to the total field at the upper microphone minus the total field at the lower microphone:

$$P_{diff} = 20 \times \log_{10} \left| \frac{[\exp(ik_o r_{1t})]/r_{1t} + Q_t[[\exp(ik_o r_{2t})]/r_{2t}]}{[\exp(ik_o r_{1b})]/r_{1b} + Q_b[[\exp(ik_o r_{2b})]/r_{2b}]} \right| \text{ dB}, \qquad \text{Eq. (3)}$$

where Q_t and Q_b are the spherical wave reflection coefficients for the top and bottom microphones calculated using Eqs. (40) and (41) from Attenborough (1980). Since this is a relative expression, it is not necessary to know the absolute source level. Ideally, the lower microphone should be positioned on the ground where $r_{1b} = r_{2b}$, but, due to steep temperature gradients close to the ground, it is better to put it just above the ground surface, i.e., 0.10 m. Strictly, the influence of atmospheric absorption should be considered, but it is negligible for the short ranges employed.

In Eq. (3) above, it is necessary to specify the impedance of the ground. Frederickson shows

$$Z = \frac{1}{\gamma^{1/2}} \frac{\left[\frac{4}{3}t' + i s'/\rho_o \omega\right]}{\left[\alpha t' + i s'/\rho_o \omega\right]^{1/2}} \qquad \text{Eq. (4)}$$

where s' and t' are the ratios of air-flow resistivity and tortuosity to porosity, respectively.

In this last expression, the surface impedance of the ground is a function of two variables valid for low frequency and/or high flow resistivity. The approximation is valid for most naturally occurring homogeneous soil surfaces.

The values of s' and t' for a ground surface are determined by minimizing the least-square error between the level difference measurement and the level difference predicted using Eq. (3) and Eq. (4).

The frequency location and form of the first minimum in this acoustic-level (or amplitude) difference spectrum are indicators of the soil physical properties. As the σ_{eff} is increased, the first minimum in the level difference spectrum is shifted to higher frequencies and deepened. Attenborough has recently shown that the air-flow resistivity can be determined from the frequency of the first interference dip, only.

Acoustic Propagation over Rough Surfaces: For a porous surface, Attenborough (1995b) has suggested that the roughness can be replaced by introducing an effective admittance. His Eq. (15) is

$$\beta_3{}^* = -ik_o \frac{\sigma_v}{2} + \beta_s(1 - ik_s\sigma_v), \qquad \text{Eq. (5)}$$

where $\beta_3{}^*$ represents the effective admittance for a 3-D roughness. k_o is the wavenumber in the upper fluid, β_s is the admittance of the porous material, k_s is the complex wavenumber of the porous material, and σ_v is a roughness parameter given as the project volume of the roughness per unit area of the surface.

The propagation of sound over flat, smooth grounds of finite impedance has been reported extensively elsewhere (many refs. i.e., Embleton et al.). It is repeated here for ease of reference. The pressure is given as

$$\frac{p}{p_o} = \left(e^{ik_o r_1} / k_o r_1\right) + Q\left(e^{ik_o r_2} / k_o r_2\right) , \qquad \text{Eq. (6)}$$

where,

$$Q = R_p + (1 - R_p) F(w) , \qquad \text{Eq. (7)}$$

$$R_p = \frac{cos(\theta) - \beta}{cos(\theta) + \beta} , \qquad \text{Eq. (8)}$$

$$F(w) = 1 + i\pi^{1/2} w^{1/2} e^{-w} erfc\left(-i\sqrt{w}\right) , \qquad \text{Eq. (9)}$$

and

$$w = \frac{ik_o r_2}{2}\left(cos(\theta) + \beta\right)^2 . \qquad \text{Eq. (10)}$$

In these equations, p_o is the reference pressure at a distance given by $k_o r_o = 1$. Thus, to solve for the propagation of sound over a rough finite impedance surface, it is necessary to determine the wavenumber and admittance of the original surface, as well as the roughness parameter σ_v. Equation 5 yields the effective admittance $\beta_3{}^*$ which can be used in Eqs. (6) to (10) to solve for the pressure.

In order to verify the applicability of Attenborough's analogy, a set of experiments (Chambers, 1995) was conducted. Initial experiments were done on porous, rough foams in an anechoic chamber. These experiments were performed indoors in a well-controlled environment to eliminate environmental factors such as wind noise and temperature gradients from the analysis. The acoustic pressure was measured for a variety of frequencies as a function of distance from the source. These experiments were conducted over a smooth and rough surface of the same material in order to examine the combined effect of roughness and finite impedance as compared to the effects of the impedance alone.

Convoluted foam used in experiments had a peak to trough height of 1.6 cm. Using Attenborough's formulation for the roughness parameter yielded a result for σ_v of 0.008 m. The normalized impedance for the smooth foam was determined by a fit to a level difference experiment as described by Sabatier et al. (1995). The wavenumber of the foam was determined by a probe microphone measurement using tone bursts at each of the four frequencies. By analyzing the amplitude and arrival times between two microphones buried in the foam, the wavenumber can be evaluated. The time differences are used to evaluate the sound speed of the slow wave which is in turn used to evaluate the real part of the wavenumber. The amplitude change is used to determine the attenuation which is then used to determine the imaginary part of the wavenumber. It should be recalled that the impedance, wavenumber and roughness parameter are necessary to evaluate the effective admittance and hence to predict the acoustic data.

In the acoustic data for the same frequencies over the rough surface, the trends in the data are similar to those in the smooth surface data. There is excess attenuation as a function of distance that increases with increasing frequency. However, the attenuation of the rough surface is greater than the smooth surface. This difference increases with increasing frequency (up to 18 dB). At low frequencies, there is not much difference between the rough and smooth surfaces in the distance range examined here. In essence, the sound does not "see" the roughness. However, as the range is increased, the rough and smooth signals should diverge since the effects of roughness are cumulative. As the frequency increases, the roughness becomes a more significant fraction of the acoustic wavelength and therefore, the effects of roughness are seen at a closer distance from the source.

In an attempt to validate Attenborough's analogy, the material parameters presented earlier were used in Eqs. (6) to (10) in order to predict the acoustic data over the smooth and rough surface. The agreement between the theory and data over the smooth surface is quite good. The data attenuates less than the theory indicates at low frequencies and more than the theory indicates at higher frequencies. It is possible that the level difference method used to determine the impedance has underestimated the impedance at the lower frequencies and overestimated the impedance at the higher frequencies. However, the agreement between the smooth theory and data is satisfactory in the frequency range examined.

These measurements were repeated at agricultural sites in Mississippi and Oregon. Rough surfaces were created using moldboard plows, chisels and disks. In these measurements, the roughness results in an increased attenuation over the smooth surfaces. Further analysis is forthcoming.

Acoustic-to-Seismic Coupling: Strictly speaking, when sound is incident upon the soil surface, energy is couple into both the soil matrix and the pore fluid. Thus far, the motion of the soil matrix has been neglected in the measurements described. This assumption is valid as long as the soil vibrational energy is much smaller than the vibrational energy of the pore fluid. If, however, sensors which couple to the soil matrix (geophones for example) are used, the motion of the gas can be neglected. Alternatively, if a microphone probe is at such a distance from a source that the pore fluid wave is attenuated significantly, the probe microphone can be used as a sensor of the soil matrix motion or energy.

In a series of measurements in sand, Hickey (1995) has shown that either geophones or probe microphones can measure the fast and slow compressional waves in air-filled poro-elastic materials. Figure 1 shows data for three sensors used to measure wave speeds in sand at 1 kHz. The low speed wave of 145 m/s is the slow Biot wave detected by geophones and probe microphones. The high wave speed of 260 m/s is detected after the slow wave decays much deeper in the sand. Tables I and II show measured wave speeds and attenuations and bulk moduli deduced from these speeds. Further work will allow these measurements in varying soil tillages and inversion of this data to determine soil compaction or elastic moduli.

Using arrays of microphone probes, velocity and attenuation images in the first meter of the soil can be accomplished.

Frequency (Hz)	Phase velocity (m/s)	Attenuation (m^{-1})	μ_m (Pa)	μ_m (elastic) (Pa)
750	119.0	7.2	2.5E+07	2.4E+07
1000	117.8	9.9	2.4E+07	2.3E+07
1500	119.8	10.5	2.5E+07	2.4E+07

Table I. Measured values of S wave phase velocity and S wave attenuation using the pulse transmission method. Also, the values of the material shear modulus obtained by inversion.

Frequency (Hz)	Phase velocity (m/s)	Attenuation (m^{-1})	K_{ud} (Pa)	K_{ud} (elastic) (Pa)
750	260.6	16.0	4.9E+08	8.2E+07
1000	251.0	15.4	1.4E+08	7.5E+07
1500	248.0	10.7	7.9E+07	7.1E+07

Table II. Measured values of type I P (fast) wave phase velocity and type I P (slow) wave attenuation using the pulse transmission method. Also, the values of the undrained bulk modulus obtained by inversion.

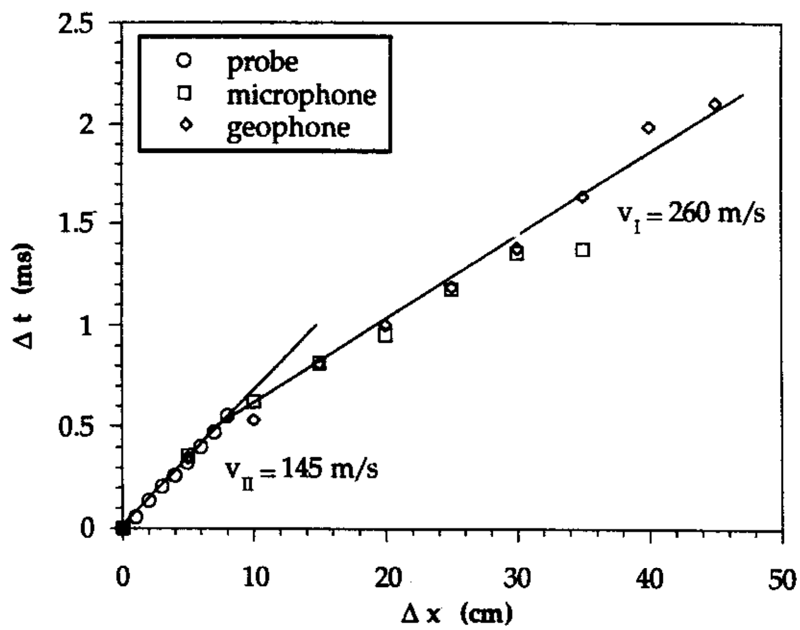


Figure 1. Travel time versus receiver location measured by pulse transmission using a loudspeaker source. Receivers include the probe microphone, in-situ microphones and in-situ vertical component geophones. The reference location, t=0 and x=0, for the probe is 1 cm depth whereas for the in-situ sensors it is the sensors at 5 cm depth. The signal, i.e. pressure and displacement, is dominated by type II P (fast) wave at shallow depths and type I P (slow) wave at the deeper depths. The transition occurs near 12 cm depth.

CONCLUSIONS

Acoustic measurement techniques applicable in determining many soil properties have been described. The acoustic properties of soils may play an important role in understanding erodibility of soil to water and wind and certain aspects of water infiltration at the air/soil interface.

The acoustic transmission and reflection measurements used to measure air-flow resistivity, tortuosity and air-porosity sample the first ten centimeters of the soil. The excess attenuation measurements are good indicators of the roughness of the soil surface. Scale sizes are naturally built into wavelength or frequency dependent acoustic scattering from rough surfaces.

Acoustic-to-seismic coupling measures acoustic wave speeds and attenuations in both the pore-air and the soil matrix. The acoustic attenuation in soils will strongly depend on the contact strength between soil grains, while wave speeds will be more significantly affected by the soil compression and shear moduli.

Finally, these notions give the basic information necessary to design imaging measurements and algorithms.

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SEDIMENT DEPOSITION IN JENNINGS RANDOLPH RESERVOIR, MARYLAND AND WEST VIRGINIA

Margaret Burns, Hydraulic Engineer, U.S. Army Corps of Engineers, Baltimore District, Baltimore, Maryland; Robert MacArthur, Principal, Northwest Hydraulic Consultants, Sacramento, California

Abstract The watershed of the Jennings Randolph Reservoir covers 263 square miles of mountainous terrain in western Maryland and West Virginia. Sedimentation studies performed prior to impoundment predicted along-term average sedimentation rate of 20 acre-feet per year, or 0.08 acre-feet per square mile per year. After three years of operation, large volumes of sediment were observed in the headwaters of the reservoir. Field measurements showed that sediment was accumulating at a rate of three to four times that anticipated. Additional field measurements after the flood of record in 1985 showed that this one event had contributed approximately 600 acre-feet of sediment, or approximately 30 years of predicted sediment inflow. this study was initiated in response to the observed high rates of sedimentation in the reservoir, with the goal of predicting the average annual sediment yield to the reservoir. Several different sediment prediction techniques were used in combination to come up with a range of predicted annual average sediment yields of 0.23 to 0.50 acre-feet per square mile per year, or from three to five times the original estimate.

INTRODUCTION

The Jennings Randolph Reservoir is located in the Appalachian highlands on the North Branch of the Potomac River (NBPR) on the state line between western Maryland and northeastern West Virginia. Portions of the watershed lie in Garrett County, Maryland and Grant and Mineral Counties, West Virginia. The watershed above the reservoir drains an area of approximately 263 square miles. It is roughly rectangular in shape and is about 23 miles long and 12 miles wide. The main channel is relatively steep with a representative channel slope of approximately 0.3 to 0.8 percent. The hills and valleys bordering the NBPR are steep, narrow and heavily wooded. Much of the lands around the project area have been mined for coal, with some clear cutting for hardwood products also occurring in the basin. Generally the water draining from the hillsides is heavily polluted with acid mine wastes, thus affecting the water quality of the river and reservoir. Over 60% of the basin is covered by forest. Farming in the project area is limited due to the steep terrain and poor soils.

Based on several sediment studies conducted prior to impoundment (as well as extensive measured data at Kitzmiller and other locations in the Potomac River Basin), the annual sediment yield to Jennings Randolph Reservoir was estimated to be approximately 20 acre-feet per year. 2065 acre-feet of reservoir storage was allocated to sediment for the 100-year life of the reservoir. The dam was completed in May 1981, and the conservation pool was filled in May 1982. A large amount of deposited sediment was noticed in the headwaters of the reservoir in the fall of 1984, after the pool was drawn down. Reconnaissance sediment survey performed by District personnel in November 1984 and January 1986 (after the flood of record, Tropical Storm Juan) yielded a computed deposition of 270 and 900 acre-feet respectively (total deposition since impoundment). Since the measured sediment inflow thus far seems to exceed the initial estimate, there has been a continued interest in accurately assessing the amount of sediment deposition, and if necessary, computing a revised annual average sediment yield to the reservoir.

SEDIMENT TRANSPORT MECHANISMS, SOURCES AND SINKS

From the field inspections and subsequent review of available reports and documents, it can be concluded that the amount of sediment in the streams in the basin varies according to its source, the local streamflow characteristics, the antecedent watershed conditions and the seasons of the year. Streams draining the heavily forested lands in the headwater areas generally have low sediment production and delivery to the main river channel, except during a severe event. Normal (during low or medium flows) basin sediment yield is primarily limited to suspended load and wash load materials that enter the NBPR from surface erosion, road cuts, rilling and gullying processes. Sediment loading to the main channel is supply limited during low and medium flow periods and the river is capable of carrying the fine sands and silts supplied to it by naturally occurring and man-induced activities throughout the basin. Areas where agriculture, active mining, clear cutting and heavy industry occur have higher sediment loads. Urbanizing areas with high densities of roads, railroads, cleared lands and urban drainage facilities will most likely have the highest sediment production rates, especially if the urbanized lands are in steep sloping valleys. The availability of transportable material is a major factor in explaining the variations of sediment discharge within the basin. Sediment delivery to the main channel is also affected by sediment trapping and local storage that occurs along the way to the main river. The sediment delivery ratio for the NBPR has been estimated by the Soil Conservation Service to be approximately 6 to 8 percent for average annual sediment production. Therefore, far more sediment materials are trapped and go into storage throughout the system (approx. 92-94 %) than go through the system on an average annual basis. Steep pool-riffle and boulder-step channels (typical of the tributaries) are capable of storing and accumulating sediment materials over many years during periods of relatively low to medium runoff. Once the critical threshold of the system is exceeded during a large storm event, large volumes of colluvial and alluvial materials can flush from storage into the high transport capacity main channel. Fine to medium sized sediments that enter the main channel are easily transported through the system to the reservoir during high flows where the main channel velocities average from 10 to 17 feet per second.

COMPARISON OF SEDIMENT DATA FROM VARIOUS SOURCES

The average annual sediment yield to Jennings Randolph Reservoir was determined after review of many methods and published reports. A total of ten different references were compared. Of these, six references were regional studies predicting sediment loads for either the Potomac River basin or the Appalachian region (items 1 through 6 in Table 1). Measured reservoir deposition data for both large and small drainage basins in the nearby area was included as items 7 and 8 in Table 1. The Baltimore District's computation of sediment deposition in Jennings Randolph Reservoir based on a comparison of the 1991 hydrographic surveys and the pre-impoundment aerial topographic mapping is included as item 9 in Table 1.

A computation of sediment yield using the Pacific-Southwest Inter-Agency Committee (PSIAC) method is included as item 10 in Table 1. Figure 1 and Table 1 summarize estimated and published annual sediment yields from these numerous sources. Note the wide range of scatter and the width of the confidence band (approximately one log cycle). This is typical of these types of basins and is a direct result of the episodic processes described above.

In general, the information from the regional studies (items 1 through 6 in Table 1) agreed very closely with the Corps design sediment yield of 0.076 acre-feet per square mile. These regional studies were published during the 1960s. The Corps design value was based on suspended sediment measurements on the Potomac River at Kitzmiller, MD during 1961-1962. All these data were collected for river discharges less than 5000 cfs, which corresponds to a recurrence interval of approximately one year. Therefore, extrapolation of a sediment rating curve based on this data to higher events may not provide an accurate indication of sediment production and delivery processes in the basin during less frequent runoff events.

Regional published yields were generally in the low range (0.05 to 0.09 acre-feet per year per square mile). Measured single event sediment accumulations were generally much higher, ranging from 0.49 to 1.05 acre-feet per square mile. The PSIAC computation (item 10 in Table 1) produces estimated yields of approximately 0.33 acre-feet per square mile. According to the literature, the PSIAC method produces reasonable yield estimates for drainage basins of the size and character of the Jennings Randolph watershed. The PSIAC method is based on nine physically-based parameters which depict watershed characteristics.

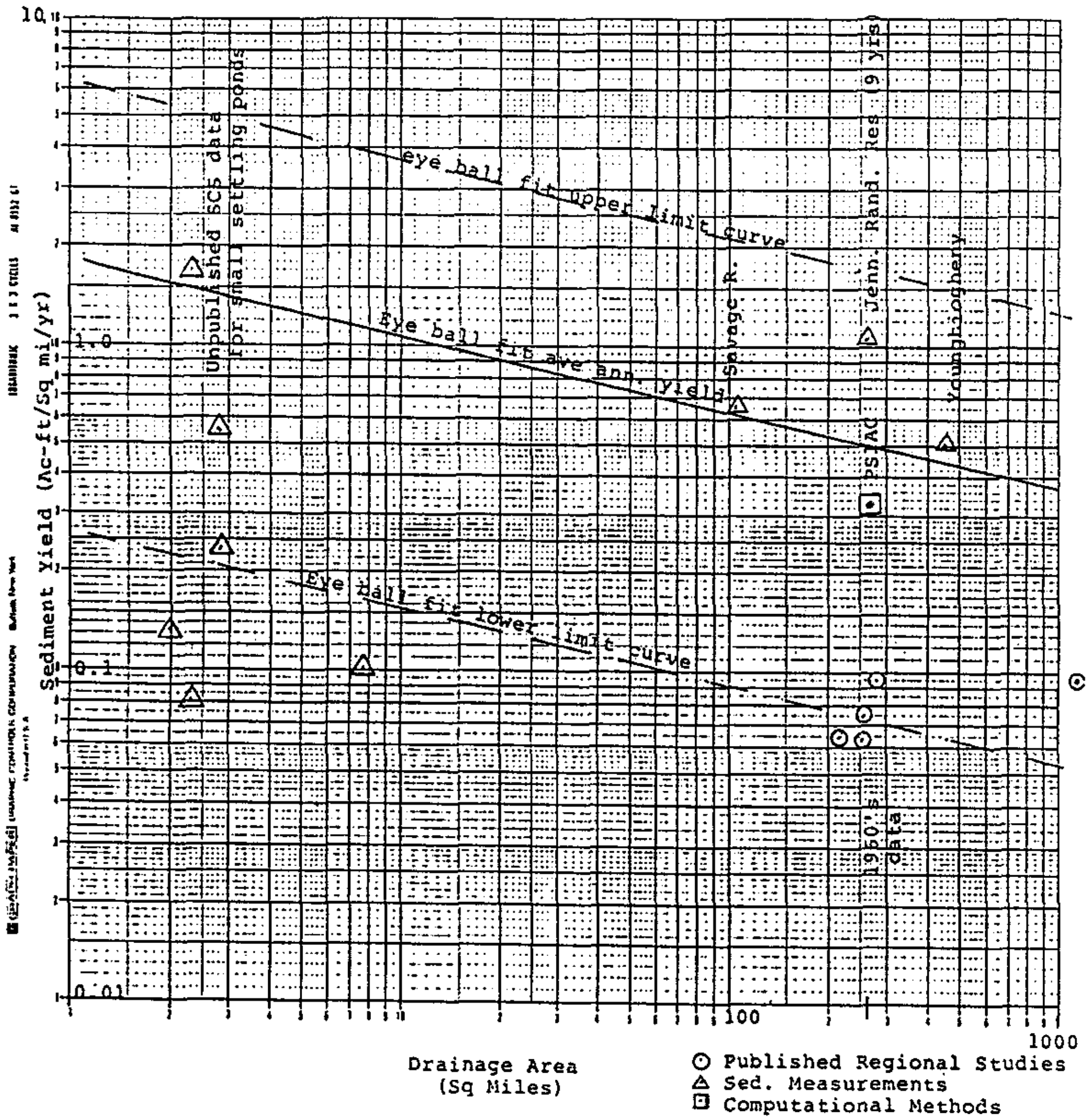
A best fit through the data as shown in Figure 1 indicates that the approximate average annual sediment yield at the reservoir is 0.5 ac-ft/sq mi/yr. During very wet years with high runoff, the yield can be as high as 1.75 ac-ft/sq mi/yr. Conversely, during dry low flow periods the yield can reduce to 0.075 ac-ft/sq mi/yr or less. This variation is common. A basin will not have a constant sediment production or delivery year after year. The actual yield to the Jennings Randolph Reservoir is a function of event sequencing, basin characteristics, sediment availability, transport capacity, and the specific magnitude and duration of single event storms.

Table 1. Summary of Methods Used and Yields.

No.	Reference	Drainage Area (sq.mi.)	Average Annual Sediment Yield (ac-ft/sq mi)	(tons/sq mi)
1.	Reconn. of Sed.& Chem Quality of Surface Water in the Potomac R. Basin USGS 1961 (p.47)	287	0.09	150
2.	Appendix Q, Erosion and Sed., North Atlantic Regional Water Res. Study Coord. Comm. (Table Q-8, p. Q-29)	263	0.07	118
3.	Prelim. Study of Sed. Sources and Trans. in the Potomac R. Basin, Interstate Comm. on the Potomac River Basin, 1963 (Fig. 6)	225	0.06	94
4.	Water Resources in the Appalachian Region, Pennsylvania to Alabama, Atlas HA-198, USGS, 1965	263	0.06	95
5.	Preliminary Appraisal of Stream Sedimentation in the Susquehanna River Basin, USGS, 1968	263	0.06	90
6.	Geomorphology, by Chorley et al, Methuen, 1984 (p. 63, Fig. 320)	1500 ave.	0.09	141
7.	Sediment Deposition in U.S. Reservoirs, ARS Misc. Pub. 1362, Feb. 1978			
	a. Savage River	105	0.64	840
	b. Youghiogheny River	428	0.49	516

Table 1. Summary of Methods Used and Yields (cont.)

No.	Reference	Drainage Area (sq.mi.)	Average Annual Sediment Yield (ac-ft/sq mi)	(tons/sq mi)
8.	Small Reservoir Surveys, West Virginia SCS, 1985 (unpublished data)	2.3	1.68	2379
		2.8	0.55	779
		2.8	0.23	326
		2.0	0.13	184
		7.7	0.10	142
		2.3	0.08	113
9.	Jennings Randolph Reservoir, Sediment Survey, COE, 1991 (see Appendix B)	263	1.05	1714
10.	Report of Water Management Subcomm., Pacific-Southwest Inter-Agency Committee, Oct. 1968 (computed yield for the Jennings Randolph watershed using the PSIAC method)	263	0.33	539



Sediment Yield Versus Drainage Area From Various Sources

Figure 1

ANNUAL SEDIMENT YIELD TO JENNINGS RANDOLPH RESERVOIR

Depending on the analytical approach and the interpretation of the data, the annual sediment yield to Jennings Randolph Reservoir ranges from a low of 0.06 to a high of 1.75 acre-feet per square mile per year. Based on this study, a recommended long-term range is 0.23 to 0.50 acre-feet per squ·e mile per year. A value of 0.35 acre-feet per square mile per year would be a reasonable figure for planning purposes, and corresponds to an annual sediment yield to the reservoir of 92 acre-feet per year. This is much higher than the pre-impoundment estimate of 20 acre-feet per year.

As part of this study, it was verified that the original estimate of 20 acre-feet per year was based on valid data, was computed using accepted methods, and was in concurrence with numerous other studies performed for this basin and similar areas. However, the sediment transport in this mountainous watershed tends to be dominated by extreme events (flood flows). During normal and low flows, the streams in the watershed are supply-limited and carry low sediment loads. Flood flows, however, mobilize large volumes of stored sediment in both the main channel and tributaries, and dislodge the upper layer of streambed material to expose the finer material underneath. In addition to the materials in the main stem of the NBPR becoming mobilized, another, perhaps more significant source of sediment materials comes from tributary flushing during high flows. Above a critical discharge the tributaries will flush (unload) significant volumes of materials that have been accumulating over many years of lesser flows. The lesser flows only have sufficient energy to get the materials to the tributaries where they are trapped until a large enough event can flush them through to the main channel. This is a natural process of storage and release that occurs in steep gradient, coarse bed and/or bedrock controlled systems. Watersheds such as these are high producers of sediment for very short periods of time (during major events), and low producers of sediment for long periods of time during normal flows. A single extreme event may produce one to two orders of magnitude more sediment than a typical two-year event. Because the nature of the sediment transport process changes after a certain threshold is reached, a sediment-discharge rating curve based on data up to the two-year event (as used in the pre-impoundment studies) cannot be accurately extrapolated to reflect the sediment discharge for major flood events. The traditional and accepted methods for computing sediment yield may greatly underestimate the sediment yield of a basin dominated by episodic and extreme events. This conclusion may be applicable to other reservoirs in similar terrain.

Author contact points:

Margaret Burns
Hydrology & Hydraulics Section
Baltimore District, USACE
P.O. Box 1715
Baltimore, MD 21203-1715

phone: 410-962-6761
E-mail: margaret.j.burns@usace.army.mil

Robert C. MacArthur
Northwest Hydraulic Consultants
3950 Industrial Blvd., Suite 100-C
West Sacramento, CA 95691

phone: 916-371-7400

SEDIMENT BUDGETS -- THEIR PREPARATION AND USE IN WATERSHED PLANNING

by Rob Cheshier, Geologist, United States Department of Agriculture, Natural Resources Conservation Service (formerly Soil Conservation Service), Columbia, Missouri.

Abstract: As part of the watershed planning process conducted in Missouri by the Natural Resources Conservation Service (formerly the Soil Conservation Service), it is important that erosion and sedimentation be evaluated and quantified. Source areas of erosion are identified and estimates are made with respect to the amount of sediment leaving those areas. Depositional areas are also located and the amounts of sedimentation approximated. Various data collecting and analyzing tools, such as the Universal Soil Loss Equation (USLE), Ephemeral Gully Erosion Model (EGEM), procedures for calculating classical (permanent) gully and stream channel erosion, sediment delivery ratio curves, landowner/operator interviews, airphotos, topographic and soil survey maps, and reconnaissance and detailed fieldwork are utilized to generate and interpret data. Organization, management, and interpretation of these data can be made easier through development of sediment budgets using Lotus spreadsheets. This paper provides a general overview of methodologies used to collect and analyze relevant erosion and sedimentation data, and describes how sediment budgets are developed. An example sediment budget is presented to help clarify what types of information they provide and how they can be valuable assets to the planning of watershed projects.

INTRODUCTION

The processes of erosion and sedimentation are significant factors that need to be documented and analyzed when conducting watershed studies. For nearly 40 years, the Missouri Water Resources Staff of the USDA Natural Resources Conservation Service (formerly the Soil Conservation Service) has been preparing watershed plans. These plans are prepared under authority of Public Law 83-566 - Watershed Protection and Flood Prevention Act (USDA, 1992).

The staff geologist has responsibility for evaluating and quantifying erosion and sedimentation occurring within the study area. Source areas of erosion need to be identified and quantities of sediment produced must be derived and documented. Where the sediment is transported and where it is deposited, either within the watershed or off-site, must also be given consideration. One way to organize, manage, and aid in interpreting the numerous and sometimes large volumes of sediment is through the use of sediment budgets in the form of spreadsheets. The purpose of this paper is to identify some of the procedures and tools used in collecting erosion and sedimentation data and explain how sediment budgets are prepared.

SEDIMENT SOURCE AREAS

In the watersheds that have been studied in Missouri, source areas for sediment generally fall within the following categories: sheet and rill erosion, ephemeral gully erosion, classical (permanent) gully erosion, stream channel erosion, and floodplain scour. However, watersheds can vary significantly and sediment source areas other than these may be present and should be adequately represented in the final sediment budget.

Various methods are utilized to identify sediment source areas. The staff geologist conducts a reconnaissance field investigation of the watershed early in the planning process. This can be in conjunction with visits to the local Natural Resources Conservation Service (NRCS) field offices. The NRCS district conservationists can be extremely helpful in providing information related to erosion and sedimentation in their particular area. Public scoping meetings are generally held at the beginning of project activities. These provide an excellent opportunity to meet with landowners and operators who are oftentimes very knowledgeable concerning where erosion is occurring and where sediment is being deposited.

As part of the planning process, the project planning engineer randomly selects drainage areas (sample sites) that are representative of the watershed's total drainage area. These sample sites are utilized by the staff geologist to derive erosion and sedimentation data. Air photos, USGS topographic maps, NRCS soil surveys, and geologic maps, as well as any other available literature, can also be helpful in the data collection process.

Sheet and Rill Erosion

Sheet erosion is defined as the removal of a thin, fairly uniform layer of soil from the land surface by runoff water. Rill erosion is an erosional process whereby numerous small channels only a few inches deep are formed (Soil Conservation Society of America, 1982). Generally speaking, sheet and rill erosion accounts for 50 to 80 percent of the total sediment produced within the watersheds studied in Missouri. The actual value is largely dependent upon landuse and the extent to which conservation practices and land treatment have been applied to the land.

Much of the data concerning sheet and rill erosion is obtained through consultation with the local NRCS district conservationist and from information contained in individual farm plans. Information not attainable through these sources is derived by on-site examinations. Landuse information is obtained from the field office and from landuse maps compiled by the planning staff. In all cases, a prediction of the longtime average sheet and rill soil losses in runoff from specific areas in specified cropping and management systems is calculated using the Universal Soil Loss Equation (USDA, 1978).

Ephemeral Gully Erosion

Ephemeral gullies are small channels formed in crop fields by concentrated flow. These small gullies are routinely obliterated by tillage operations but form again in the same location following runoff events (USDA, 1988). Ephemeral gullies generally form in crop fields that do not have adequate land treatment and therefore exhibit sheet and rill soil losses above tolerable limits. Soil losses from this type of erosion can be quite significant and losses of 10 to 15 tons per acre per year are not uncommon in some north Missouri watersheds.

The methodology currently used to estimate the amount of erosion from ephemeral gullies incorporates the Ephemeral Gully Erosion Model (EGEM). Data entered into the model are obtained from various sources including: the EGEM User Manual, soil surveys, airphotos, USGS topographic maps, farm plans, NRCS district conservationists, and in-field (site specific) data collection. Working with the district conservationist, the staff geologist selects representative sample sites (farm fields) from which to develop the variables that are utilized by the model. The model output provides an average annual estimate of the amount of erosion in tons.

Classical (Permanent) Gully Erosion

Classical gullies are channels cut by concentrated flow to such a depth that they are not obliterated by normal tillage operations. Classical gullies in Missouri can range from as little as a foot deep to as much as 40 feet or more. Predicting rates of classical gully growth and the amount of sediment produced is at best an educated guess. Numerous factors affect the rate of gully erosion including such variables as soil type, geology, topography, land use, land treatment, rainfall, and the presence of livestock. The staff geologist is to a large extent guided by experience and good judgement.

Methodologies outlined in Technical Release 32 (USDA, 1966) and the National Engineering Handbook, Section 3 (USDA, 1983) provide general guidelines by which gully erosion rates can be approximated. The staff geologist also relies on procedures that have been developed from personal field experience. Also helpful are interviews with landowners/operators, sound fieldwork including mapping of gullies, and comparison of airphotos from differing time periods.

Stream Channel Erosion

Stream channel erosion, including both the removal of material from streambanks and streambed degradation, is another example of concentrated flow erosion. Streambanks in Missouri watersheds can exhibit lateral recession rates ranging from nearly stable to extremely severe. Landowners in north Missouri have reported losing 16 rows of corn along streambanks in just one storm event (a lateral recession of about 40 feet).

Procedures for calculating the amount of erosion occurring in stream channels are similar to those used for classical gullies. To determine erosion rates, estimates are made for the width, depth, and length of the eroded areas and for the length of time over which the erosion has occurred. Information is available in the Guide to Sedimentation Investigations (USDA, June 1976). Comparison of airphotos, topographic maps, and cross sections of varying dates can be extremely informative. Interviews with landowners/operators can be an invaluable source for determining erosion rates. Oftentimes they can relate the time it took for a streambank to move from point A to point B. They may know how much of a field has been lost to erosion and over what time frame. Again, common sense and good judgement should be utilized.

Floodplain Scour

Floodplain scour is erosion of the floodplain surface by flowing floodwaters. This can result in the formation of channels or depressional areas where soil material has been removed. Sheet scour can also occur where a relatively uniform layer of soil is removed. Volume of the eroded portion of the floodplain, determined by the length times width times depth method, is multiplied by the appropriate volume weight of the soil material to determine tons of soil loss. The gross soil loss is then divided by the number of years over which the erosion took place to arrive at an average annual rate.

As with other forms of erosion mentioned previously, airphotos, field reconnaissance, and interviews with local people can be valuable sources of data.

SEDIMENT DEPOSITION AREAS

Upland Areas

Only a portion of the soil material eroded annually from upland areas is transported into the stream system. The remainder is deposited in upland ponds and lakes and at various enroute locations, (e.g., fields, areas of reduced gradient, sediment sinks, overbank areas along gullies). Sediment delivery ratio curves are used to estimate sediment yield to the point of concern - in this case, the stream system. Once the sediment yield to the stream system is established, it plus the amount of sediment deposited in upland ponds and lakes is subtracted from the gross soil loss. The result is the amount of sediment deposited at the various enroute locations.

Delivery ratio curves, and guidance in estimating delivery ratios, can be found in the National Engineering Handbook, Section 3 (USDA, 1983) and Guide To Sedimentation Investigations (USDA, June 1976). Many factors, including shape of drainage area, drainage area topography, soil texture, and landuse must be considered when selecting delivery ratios. It should be emphasized that delivery ratios are approximations at best and that judgement, experience, and good common sense must be utilized.

Ponds and Lakes

Many watersheds in Missouri are located in rural areas where there are numerous ponds and small lakes located in the upland areas. These impoundments provide efficient sinks (trap efficiencies in excess of 90 percent are common) where sediment enroute to the stream system can be deposited.

Sedimentation surveys, which measure the amount of sediment stored in a reservoir, provide excellent information from which annual rates of sedimentation can be derived. Unfortunately, these data are seldom available. The most common method to determine sediment yield is to compute gross erosion within the drainage area of each impoundment and then apply appropriate delivery ratios.

Stream Channels

A portion of the gross soil loss derived from all sediment source areas is eventually transported into the watershed's stream system. Part of this sediment load is deposited within the stream channels, either on the stream bottom or on sediment bars. The remaining sediment load is deposited on floodplain areas or is transported off-site through the watershed outlet.

The amount and texture of sediment deposited and stored within the stream channels is determined by field examination of representative stream reaches. During summer months, many stream bottoms can be walked in order to note the extent of sediment present. Thickness of the deposits can be estimated using a hand-held soil probe. The volume of sediment is computed and converted to tons.

Floodplains

When the water-carrying capacity of stream channels is exceeded, sediment laden floodwaters move onto the floodplains. As the water slows, sediment is deposited as overbank deposits (natural levees), sediment fans, and blanket deposits. In many Missouri watersheds, these deposits are referred to as modern, post settlement sedimentation. Since the introduction of agricultural activities in Missouri, erosion and sedimentation rates have accelerated when compared to rates associated with natural, geologic processes. These "modern" floodplain deposits oftentimes constitute a significant portion of the total sedimentation occurring within a watershed.

The volume and texture of these deposits is obtained by conducting borings with a hand-held soil probe. Probings are made along ranges established at randomly selected sites throughout the floodplain. In general, "modern" deposits can be distinguished from the developed, older, buried soil profile based on features such as texture, color, and stratification (USDA, June 1976). Volume and bulk density of the sediment is used to calculate total tons which are divided by the estimated time required for deposition in order to derive an average annual rate of deposition.

Off-site

A portion of the total (gross) soil loss produced within a watershed is not deposited enroute to the watershed outlet. This portion (sediment yield to the watershed outlet) is equal to the gross erosion calculated for the watershed minus the sediment deposition that has been referred to above. This remaining sediment load is moved out of the watershed and is deposited at off-site areas. This remaining volume can be compared to a sediment yield derived using sediment delivery curves applied to the watershed's drainage area. If the two values do not coincide, which they seldom will, a compromise needs to be made.

SEDIMENT BUDGET WORKSHEETS

After sediment source areas have been identified and the appropriate equations for calculating soil losses, delivery ratios, trap efficiencies, etc. have been established, it is helpful to display the information in a spreadsheet format. Lotus 123 has proven quite useful for this purpose. Specific equations used in the worksheet are up to the discretion of the preparer. Each individual, state or federal agency, or organization may use different techniques and methodologies to derive the necessary erosion and sedimentation values. Equations are oftentimes subjective and should be selected to fit the particular watershed and conditions that are being analyzed. Figure 1 shows a sediment budget spreadsheet for an imaginary watershed typical of those found within the agricultural areas of Missouri.

Figure 1 displays both the present (existing) conditions within the watershed, as well as the predicted future conditions after the installation of project measures. In this particular example, the subject watershed represents a drainage area of 170,000 acres consisting of 148,000 acres of upland and 22,000 acres of floodplain. For this example, it is assumed that project measures will consist of 200 small floodwater retarding structures (permanent pools of 5-10 acres), 3 multiple-purpose reservoirs (permanent pools of 100-350 acres), 300 grade stabilization structures, and an accelerated land treatment program.

Column (a) of the spreadsheet lists the sources of sediment that have been identified within the subject watershed. Column (b) shows the acreages from which sheet and rill soil losses are occurring. These have been categorized into acres with adequate protection and those that are not adequately protected. Land that is adequately protected refers to land that is subjected to sheet and rill erosion over a sustained period at a rate which does not result in reduced crop productivity. Column (c) lists gross (total) soil losses in tons per year for each sediment source. Total soil loss for the entire watershed is given at the bottom of the column.

The spreadsheet allows for a quick comparison of the total (gross) soil loss between the present conditions (2.19 million tons per year) and the future with project conditions (1.18 million tons per year). The significance of each sediment source with respect to its contribution to total sediment production is also easily noted. From Figure 1, it is clear that sheet and rill soil erosion from cropland that is not adequately protected is the major contributor to gross soil loss. Under present conditions, this one source provides 45 percent of the sediment produced. With the installation of project measures, it can be seen from the spreadsheet that soil loss from sheet and rill erosion on land not adequately protected is estimated to reduce from 974,200 tons annually to 261,900 tons - a 73 percent reduction. Soil losses from other sediment sources under present and future with project conditions can also easily be compared by examining the spreadsheet.

Columns (d) and (e) show tons of sediment deposited in ponds, lakes, and reservoirs, as well as upland areas. Upland sedimentation includes overbank deposits along gullies, deposits in gully bottoms, and sediment fans at field edges. The spreadsheet illustrates the significant sediment trapping efficiency of project structures. Under present conditions, existing ponds and lakes trap an estimated 179,900 tons of sediment annually. With the installation of project structures, this figure increases to nearly 327,000 tons. Looking at Column (e), a very significant reduction in sediment deposited in upland areas is apparent following installation of project measures. Sedimentation decreases from 743,700 tons per year to 308,800 tons - nearly a 60 percent reduction.

Column (f) displays average annual tons of sediment entering the stream system from the various sediment source areas. The data in this column are probably some of the most important information with respect to watershed and natural resource planning. Sediment entering the stream system is deposited on streambeds, as overbank deposits on floodplains, or is transported to off-site areas outside of the subject watershed's drainage area. The resulting sedimentation can have significant negative impacts on channel capacities, floodplain crops and pastures, productivity of the soil resource, riparian areas, fisheries, and water quality. Column (f) clearly shows a substantial reduction in sediment entering the stream system under the future with project conditions.

Columns (g) and (h) document the amounts of sediment deposited within stream channels and on floodplains. The spreadsheet format allows the reader to easily determine how much sediment is delivered from each sediment source area. Reductions in delivered sediment due to project measures are also clearly displayed.

Tons per year of sediment transported through the subject watershed's outlet and delivered to off-site areas is shown in Column (i). In this example, sediment leaving the watershed is reduced from nearly 670,000 tons annually to 278,800 tons. The ability to readily observe these data on the worksheet makes the reader aware that a significant decrease in the negative impacts of sedimentation will result in off-site areas.

SUMMARY

Erosion and sedimentation are active processes occurring in watersheds throughout the state of Missouri. Substantial negative impacts on the natural resource base result from these processes. During watershed planning activities conducted by the Water Resource Staff of the USDA Natural Resources Conservation Service, the staff geologist is responsible for collecting and analyzing erosion and sedimentation data. Over the past years, various charts, tables, and graphs have been utilized to display erosion and sediment information. The worksheet in Figure 1 has evolved from earlier tables which were first included in Missouri watershed plans in the mid-1980s. These early tables were generated to provide a readily understood reference concerning tons of soil loss, sediment deposition, and sediment yield within the subject watershed (Finney, 1995).

The current sediment budget worksheet has proven to be an efficient and organized method for displaying erosion and sedimentation data. It can assist landowners, farmers, city and county officials, other watershed residents, and natural resource professionals in understanding the extent of present erosion and sedimentation problems and show what effects project measures will have within the watershed.

The present condition portion of the worksheet serves to stratify areas of erosion and sedimentation so the weight of each to the overall problems can be readily identified. This can assist watershed planners in determining where the installation of project measures will prove most effective, as well as where project funds can best be spent.

The sediment budget information can help in identifying and understanding numerous sediment-related problems. For example, the fact that considerable amounts of sediment, along with adsorbed chemicals, are entering the stream system points to the need to address water quality issues. Excessive sedimentation in the streams also raises issues related to increased flooding due to decreased channel capacities and to detrimental effects to the aquatic habitat. The spreadsheet makes clear that substantial amounts of sediment are being deposited on floodplains. This should raise questions about what damages are occurring to growing crops, the productivity of the soil resource, riparian areas, and wetlands. Having this information summarized in a simple, organized manner helps watershed planners understand the scope of sediment-related problems and hopefully provides some guidance in formulating effective, sound-minded solutions.

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FIGURE 1 - SEDIMENT BUDGET WORKSHEET

Sediment Sources[1]		Upland Acres	Gross Soil Loss	Deposited		Sediment[3] Entering Stream System	Deposited		Sediment Leaving Watershed
				Lakes[2]	Upland		Stream Channels	Flood Plain	
			Tons Per Year[4]						
Column a		b	c	d	e	f	g	h	i
PRESENT CONDITIONS									
CROPLAND									
Sheet & Rill	(A)	19,100	77,300						
	(N)	34,800	974,200	98,000	381,400	572,100	8,200	123,100	440,800
GRASSLAND									
Sheet & Rill	(A)	68,300	150,600						
	(N)	4,900	37,200	18,100	101,800	67,900	1,200	34,500	32,200
FOREST LAND									
Sheet & Rill	(A)	16,600	43,300						
	(N)	2,200	15,800	5,700	42,700	10,700	200	3,900	6,600
OTHER		2,100	8,400	600	4,700	3,100	100	1,000	2,000
CLASSICAL GULLY			327,000	18,500	61,700	246,800	12,200	172,300	62,300
EPHEMERAL GULLY			417,600	39,000	151,400	227,200	7,300	147,700	72,200
STREAMBANK			28,000			28,000	14,600	4,900	8,500
SCOUR			108,900			54,500	4,900	59,400	44,600
TOTAL		**148,000**	**2,188,300**	**179,900**	**743,700**	**1,210,300**	**48,600**	**546,800**	**669,200**
FUTURE WITH PROJECT CONDITIONS									
CROPLAND									
Sheet & Rill	(A)	39,200	151,600						
	(N)	25,300	261,900	107,900	122,200	183,400	3,400	50,900	129,100
GRASSLAND									
Sheet & Rill	(A)	57,500	132,800						
	(N)	3,500	26,600	41,500	70,700	47,200	500	14,200	32,500
FOREST LAND									
Sheet & Rill	(A)	16,900	44,800						
	(N)	1,600	11,500	15,100	33,000	8,200	100	1,600	8,200
OTHER		4,000	8,400	3,100	3,200	2,100	0	400	2,100
CLASSICAL GULLY			253,300	97,700	31,100	124,500	5,000	71,200	48,300
EPHEMERAL GULLY			183,000	61,600	48,600	72,800	3,000	61,000	8,800
STREAMBANK			21,000			21,000	6,000	2,000	13,000
SCOUR			81,700			40,900	2,000	42,900	36,800
TOTAL		**148,000**	**1,176,600**	**326,900**	**308,800**	**500,100**	**20,100**	**244,200**	**278,800**

1. (A)-Land adequately protected from erosion; (N)-Land not adequately protected from erosion.
2. Includes ponds, lakes, and single and multiple-purpose PL-566 structures.
3. Represents gross soil loss minus sediment deposited in upland areas and in ponds.
4. All figures rounded to nearest 100 tons.

BASELINE SEDIMENT YIELD FROM DISSIMILAR HEADWATERS RESEARCH WATERSHEDS

Charles W. Slaughter[1], Research Leader; Keith R. Cooley[1], Hydrologist; Clayton L. Hanson[1], Agricultural Engineer; F.B. Pierson[1], Hydrologist; Ron.L. Hartzmann[2], Hydrologic Techni ian; A.L. Huber[1], Mathematician; J.B. Awang[1], Hydrologist

[1] **Northwest Watershed Research Center, USDA Agricultural Research Service, Boise, Idaho**
[2] **Institute of Northern Forestry, USDA Forest Service, Fairbanks, Alaska**

Abstract

Research watersheds are used in study of hydrologic processes and for establishment of baseline characteristics for hydrologic and ecosystem variables. Sediment yield reflects geologic, geomorphic, climatic, soil, plant cover, stream channel and land use influences within a watershed, and may vary markedly in response to differences in any or all these factors. This is illustrated by two upland research watersheds that receive similar total annual precipitation, each dominated by seasonal snowfall, but with very different hydrologic and sediment yield regimes. Patterns of sediment yield and streamflow have been determined for upland semi-arid rangeland watersheds in southwestern Idaho (Reynolds Creek Experimental Watershed) and for upland boreal forest watersheds in central Alaska affected by discontinuous permafrost (Caribou-Poker Creeks Research Watershed). The research programs of these contrasting headwaters research sites were independently established, but have similar aims and approaches and are contributing to knowledge of hydrologic and sediment processes in their respective biogeographic settings.

INTRODUCTION

Fluvial erosion and sediment production is a major concern in natural resource management. Loss of topsoil causes progressive and almost irreversible reduction in site productivity, while downstream sediment deposition can damage floodplain agriculture and structures. The National Research Council (1994) recently identified control of erosion and maintenance of the soil resource as key to managing and sustaining overall rangeland site productivity.

Research watersheds in rangeland, forest and agricultural settings are widely employed in fundamental research on hydrologic processes, to develop methods for hydrologic prediction, to determine the effects of changing conditions on hydrologic processes and to develop long-term records of basic hydrologic data, and for experimental research (typically whole-basin manipulation of vegetative cover) on hydrologic processes and regimen (Toebes and Ouryvaev 1970, Leopold 1971). Extensive research on sediment production, transport and yield has been accomplished in research watersheds (e.g. Leaf 1966, Borges and Bordas 1988, Wicks et al 1988, Renard et al 1991). Nevertheless, Shen (1991) suggested that watershed sediment yield is "...perhaps, the most difficult problem facing us in the field of sedimentation...," due to complex interactions of heterogenous landscape, soils, precipitation, climate and management conditions. However, the "population" of established research watersheds is shrinking due to shifting agency priorities and diminished fiscal resources. This paper briefly describes some results of erosion research at two long-term watershed research facilities, and suggests opportunities which they provide for process research and detailed analysis of interacting landscape, climate, and resource management factors in production, yield and disposition of sediment within watershed systems.

The Research Watersheds

Reynolds Creek Experimental Watershed (RCEW) was established in 1960. The objective was to develop a comprehensive basin-scale research program to address growing concerns about water supply, flooding, erosion, and rangeland management in the extensive mountainous rangelands of the interior Pacific Northwest. The USDA-ARS Northwest Watershed Research Center selected the 234 km^2 Reynolds Creek basin (Figure 1), at 43° 10' N, 116° 46' W, as a long-term study site which is representative of interior Pacific Northwest mountainous rangelands, characterized by high relief, predominantly rangeland vegetation, and winter precipitation with seasonal snow .

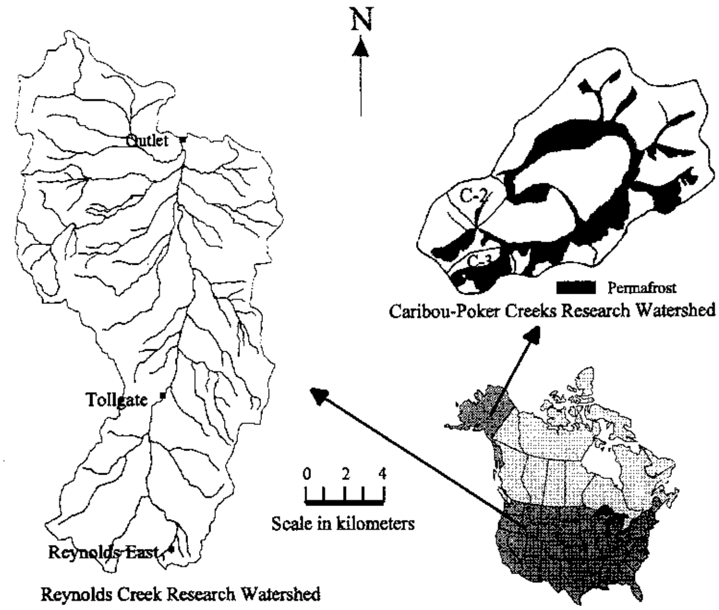

Figure 1. Reynolds Creek Experimental Watershed and Caribou-Poker Creeks Research Watershed.

Reynolds Creek is a north-flowing perennial stream, directly tributary to the Snake River, draining the north flank of the Owyhee Mountains in southwestern Idaho. The watershed is situated in a region of late Tertiary sedimentary and volcanic rock overlying Cretaceous granitic basement rock. The elevation range within RCEW is 1098 m to 2241 m msl; annual precipitation varies from 23 cm at the lowest (northernmost) elevations to over 110 cm at the highest locations, where over 75% of annual precipitation is received as snow. Mean annual temperature varies from 8.4°C in the lower valley to 4.4°C at the highest elevations. Seasonal soil freezing is common and strongly influences hydrologic regimen and sediment production (Hanson, Burton and Molnau 1988). Soils range from shallow desertic at xeric lower-elevation sites to deep organic and podzolic in mesic high-elevation forest sites. RCEW is a rangeland watershed: big sagebrush (*Artemisia tridentata, wyomingensis*) is dominant below 1375 m; low sagebrush (*Artemisia arbuscula*) dominates above 1375 m on harsh sites; mountain big sagebrush (*Artemisia tridentata, vaseyana*) is common at high elevations on deep well-drained soils with deep snow accumulation. Other shrubs found throughout the watershed include shadscale (*Atriplex confertifolia*), greasewood (*Sarcobatus vermiculatus*) and spiny hopsage (*Grayia spinosa*) in areas of low precipitation and alkaline soils; bitterbrush (*Purshia tridentata*) is found at mid- to upper elevations on coarse-textured soils, and mountain mahogany (*Cercocarpus ledifolius*) is often associated with granitic outcrops. The most common grasses on the watershed are bluebunch wheatgrass (*Agropyron spicatum*), Idaho fescue (*Festuca idahoensis*) and bottlebrush squirreltail (*Sitanion hystrix*), with cheatgrass (*Bromus tectorum*) and sandberg bluegrass (*Poa sandbergii*) common at low and mid-elevations, respectively. Small stands of second-growth Douglas fir (*Pseudotsuga menziesii*) and subalpine fir (*Abies lasiocarpa*) occur on north and east slopes at high elevations sites having persistent snowpacks; groves of aspen (*Populus tremuloides*) are found in moist higher-elevation sites, and juniper (*Juniperus occidentalis*) is locally common in some drier upper-elevation locations.

RCEW is comprehensively instrumented to measure precipitation, climate, snowpack, soil moisture and streamflow over a wide range of elevation and site conditions (Flerchinger, Hanson and Burgess 1994). Precipitation is measured with an array of 18 dual-gauge (shielded/unshielded gauges) sites, and snow is monitored at eight locations. Streamflow is monitored with nine weirs from headwaters to basin outlet, with capacity up to 200 m^3/s. Comprehensive meteorological data are collected at low-, mid- and upper-elevation sites and directly telemetered by VHF radio to the Northwest Watershed Research Center in Boise, Idaho, 63 km northeast of RCEW. Precipitation chemistry is monitored at a central valley location in collaboration with the National Atmospheric Deposition Program.

Caribou-Poker Creeks Research Watershed (CPCRW) is a 104 km^2 basin 45 km north of Fairbanks, Alaska, at 64°10' N, 147°30' W. CPCRW (Figure 1) was established as a collaborative project by the Inter-Agency Hydrology Committee for Alaska (with the Institute of Northern Forestry, USDA-FS, as Lead Agency) in 1969, to address hydrologic and ecosystem process questions in the discontinuous-permafrost boreal forest of central Alaska.

CPCRW lies in a region of uplifted Precambrian schist overlain by a thin mantle of loess derived from glacial outwash floodplains to the south. The watershed encompasses more than a dozen first-, second-, and third-order basins over an elevation range from 210 m to 826 m msl, permitting research within a stream system continuum from headwaters through fourth-order streams. CPCRW is in the "Interior" climatic zone of Alaska, characterized by large diurnal and annual temperature extremes and low precipitation. The mean annual temperature varies from -4.9°C in lower valleys (240 m msl) to as warm as -1.2°C at mid-elevation (480 m msl) south-facing slopes (Haugen et al 1982). Mean annual precipitation at CPCRW ranges from 25 cm in lower valleys to over 50 cm at upper elevations. More than 50% of annual precipitation comes as snow, which occupies the landscape for six to eight months of the year (Slaughter and Benson 1986). The soil mantle is seasonally or perennially frozen; CPCRW is in the zone of discontinuous permafrost (perennially frozen soil) where warmer south-aspect slopes generally lack permafrost, while shaded valleys and north-aspect slopes are underlain by frozen ground at shallow (<100 cm) depth. Permafrost temperatures are in the range of -0.5 to -2.0°C, and the frozen soils are therefore susceptible to warming and thaw if disturbed (Slaughter 1993).

The vegetation of CPCRW is typical of the subarctic boreal forest: north slopes support predominantly black spruce (*Picea mariana*) stands with ericaceous shrubs, a thick feather moss/sphagnum moss/lichen ground cover and deep surficial organic matter layer; south slopes support mixed stands of aspen, birch (*Betula papyrifera*), and white (*P. glauca*) and black spruce. Valley floors are generally poorly drained, underlain by permafrost, and support dense stands of shrub birch (*B. glandulosa*, blueberry (*Vaccinium uliginosum*), willows (*Salix* spp.), occasional stands of larch (*Larix laricina*), and associated shrubs and forbs. The vegetation is a mosaic reflecting elevation, aspect, soils, and successional stages following wildfire (Viereck et al 1986).

CPCRW is comprehensively instrumented for hydrologic research. Precipitation is measured with continuously-recording gauges over a transect from valley to treeline. Seasonal snowpack is measured with three standard snow courses and one snow pillow. Streamflow from first- and second-order basins is measured with prefabricated Parshall flumes installed to minimize permafrost disturbance (Slaughter 1981), and with natural channel controls in downstream sites. Comprehensive climate data are collected at valley, mid-slope and treeline locations. Precipitation chemistry is monitored in CPCRW at the northernmost National Atmospheric Deposition Network site in the US.

PATTERNS OF SEDIMENT YIELD

RCEW and CPCRW are operated by different agencies, for different goals, in dissimilar biogeographic regions of North America. Rather than drawing direct comparisons of sediment yield patterns between the two watersheds, we offer examples of the types of information available and conclusions drawn from the two research watersheds, to indicate the potential for future research into questions of hydrologic regime and sediment production.

Reynolds Creek Experimental Watershed

The primary objective of early sediment measurements at RCEW was to determine sediment yields from semiarid rangeland watersheds, emphasizing storm runoff. Monitoring locations selected in the mid-1960's have been continuously operated to the present time. Bedload transport was measured at selected locations during early years using Helley-Smith bedload samplers and sediment detention ponds; it was estimated that bedload contributed about 20 percent of total sediment yield (Johnson and Hanson, 1976).

Strong spatial and interannual variation in sediment yield was immediately evident at RCEW. Johnson and Hanson (1976) reported that average sediment yields from RCEW and individual subwatersheds (3200 to 23000 ha) ranged from 1.14 to 1.9 tonnes/ha/year. Unit-area sediment yield from six upland source areas (0.9 to 83 ha) was only one-third or less of that measured from the larger downstream watersheds. Most sediment is produced by a small percentage of yearly runoff, and (contrary to normal expectations) sediment concentrations and unit-area sediment yield appeared to increase with drainage area, apparently due to streambank erosion and channel flushing.

Precipitation is highly variable at RCEW. Major frontal rainfall events occasionally produce runoff and sediment from the entire watershed, but it is far more common that runoff events at lower elevations are caused by high-intensity rainstorms, often on frozen soil, and runoff events at higher elevations are caused by snowmelt. Johnson and Gordon (1986) reported that sediment measured at sites below 1400 m msl was produced mainly from rainfall events, while snowmelt-runoff was responsible for most sediment production at higher elevations. In drought years sediment production was negligible, while flood years produced high sediment yields. Sediment yields were more than ten times higher in wet years than in dry years, and about 90 percent of average yearly yield at the RCEW Outlet occurred in winter, during January through March. In 4 of 18 years, the single largest storm event contributed over 50 percent of annual sediment yield at RCEW Outlet. Pronounced spatial variability of sediment yield among small watersheds in this high-relief terrain is illustrated by two small basins only 7 km apart, Nancy and Flats. The Nancy catchment is 220 m higher and receives 38 mm more precipitation than the Flats catchment. The Nancy watershed experiences three times the number of snowmelt runoff events, 75 percent more snowmelt runoff, and about the same snowmelt sediment yield as Flats. Rainfall-runoff events are about the same at both sites, but runoff is nearly six times greater and sediment yield from rainfall events is over three times greater at the Flats catchment (Johnson and Gordon, 1986).

Continuing sediment research at RCEW builds on the original watershed, subwatershed and upland catchment work discussed above, and incorporates plot and laboratory studies to isolate erosion and sediment transport processes. The spatially and temporally variable nature of sediment yield has been underscored by recent research; total annual suspended sediment yields from the Reynolds Mountain East (RME) and Tollgate (TOL) catchments (Figure 1) and the entire RCEW vary widely, with high-year yields being ten to 200 times greater than yields in low years (Table 1). The smaller, higher elevation RME (streamgauge elevation 2019 m msl, drainage area 40 ha) shows more variability than does TOL: total annual suspended sediment yield during the period 1969-1987 varied from near zero (1977) to 20 tonnes (0.5 tonnes/ha); during the same period the downstream TOL (streamgauge elevation 1403 m msl, drainage area 54 km^2) had total annual suspended sediment yield from near zero (1977, 1987) to over 9000 tonnes (1.7 tonnes/ha) in 1969. Years of highest or lowest sediment production do not necessarily correspond between the two catchments. High sediment yields from the smaller upstream catchment are often overshadowed by or diluted by contributions from other sectors of the larger TOL; storm precipitation or snowmelt patterns may be quite variable across the TOL catchment.

Table 1. Suspended sediment yield from Reynolds Creek Experimental Watershed (tonnes)

Year	Outlet, 234 km^2	Tollgate, 54 km^2	Reynolds Mt., 0.4 km^2	Year	Outlet, 234 km^2	Tollgate, 54 km^2	Reynolds Mt., 0.4 km^2
1967	12214	8270	-	1978	7488	2068	6
1968	3931	1425	-	1979	10588	1506	5
1969	35679	9427	10	1980	3843	1456	8
1970	13941	5253	20	1981	1693	1035	5
1971	26404	7092	3	1982	29494	5744	8
1972	33921	6436	11	1983	19771	6638	14
1973	2300	972	6	1984	14247	6791	17
1974	5227	2023	10	1985	1814	371	4
1975	8942	5348	8	1986	8325	871	6
1976	2638	1995	7	1987	333	80	3
1977	2954	46	1	-	-	-	-
Mean Annual Yield (tonnes)					11702	3564	8
Unit Area Mean Annual Yield (tonnes ha^{-1} yr^{-1})					0.5	0.66	0.2

Sediment yield for the complete RCEW (drainage area 234 km^2) also varied greatly, from very low amounts during the drought years 1981, 1985 and 1987 to over 35,000 tonnes (1.5 tonnes/ha) in 1969. While earlier short-term (8 to 10 years) studies had suggested that up to 90% of annual sediment yield occurred in the January-March period, the longer 21-year record indicates that only 72% of annual sediment is yielded during this period. Differences in the patterns of sediment yield between TOL and the composite RCEW are less pronounced than between RME and TOL; the high and low years tend to correspond more closely. Over 21 years of record, suspended sediment yield averaged 0.5, 0.66, and 0.20 tonnes/ha/yr for RCEW, TOL and RME respectively. Even between TOL and RCEW the primary type of events causing runoff and erosion and thus sediment production can vary. In the lower portions of RCEW rain on snow or frozen soil often produces the major events. In the higher-elevation TOL, while rain events do occur and can produce significant runoff and sediment production, the predominant runoff and sediment yield come from spring snowmelt.

It is generally accepted that vegetative cover influences runoff and sediment yield. Johnson and Blackburn (1989) conducted experimental vegetation removal trials, in which bared plots showed about 20 times greater soil loss than did naturally vegetated plots. On a very detailed spatial scale, Johnson and Gordon (1988) determined that the interspace areas between rangeland shrubs produced 250% more runoff and 800% more soil loss than did soil beneath the shrub canopy, leading them to emphasize "...the importance of understanding spatial variability in infiltration and the wide differences in potential erosion from shrub and interspace areas when predicting sagebrush rangeland erosion and applying erosion models on rangeland." Blackburn, Pierson and Seyfried (1990) and Blackburn and Pierson (1994) subsequently identified significant micro-scale differences in sagebrush rangelands, with interrill erosion highest between coppiced shrubs, and greatest during the late winter/early spring period of diurnal freeze-thaw cycles. This micro-scale spatial variability of runoff generation, soil movement and erosion in semiarid rangelands was described in detail by Pierson et al (1994).

Caribou-Poker Creeks Research Watershed

Streamflow and suspended sediment have been monitored in CPCRW since the mid-1970's, utilizing fiberglass Parshall flumes which are operated during the ice-free summer streamflow season following spring ice breakup and snowmelt runoff. Acquisition of data during spring breakup has been hindered by extensive aufeis accumulation at the gauges (Slaughter and Benson 1986). Suspended sediment samples taken within the flumes utilize both weekly grab samples and automated pumped samplers set to obtain hourly or six-hourly storm samples.

Measurements discussed here are from two contrasting first-order catchments, C-2 (5.2 km^2, south aspect, 3.5% permafrost) and C-3 (4.5 km^2, northeast aspect, 53% permafrost). These basins differ primarily in the presence of permafrost (Figure 1), which is a function of aspect and which strongly affects vegetation (Viereck et al 1986) and hydrologic regime (Dingman 1975; Slaughter et al 1983). Permafrost can act as an aquaclude, restricting aquifer recharge and discharge; this effect becomes more pronounced with increasing proportion of permafrost in a catchment. Permafrost-underlain slopes yield water more rapidly to streamflow than do permafrost-free slopes, contributing to more "flashy" storm hydrographs: permafrost-dominated catchments have higher unit-area peak flows, lower base flows, and steeper hydrograph recessions than nearby permafrost-free catchments. This is evident in unit-area hydrographs and flow-duration curves (Slaughter et al 1983); the permafrost-dominated C-3 basin consistently has more rapid storm response, higher peaks, and higher runoff volumes than does the C-2 basin which is almost permafrost-free.

The influence of permafrost is reflected in sediment regime of upland catchments (Slaughter and Collins 1981). Summer-season sediment yields from first-order basins with varying influence of permafrost over three years, selected to represent low flows (1978, 1980) and high flows (1981), are given in Table 2. Sediment yield during relatively dry years is low from both permafrost-dominated and permafrost-free basins, averaging less than 0.4 g $m^{-3}km^{-2}day^{-1}$ in both cases. During years of high flow such as 1981 the effects of permafrost are evident in accelerated sediment yield. C-3 (permafrost-dominated) yielded 11.2 kg $km^{-2}day^{-1}$ vs 3.0 kg $km^{-2}day^{-1}$ from the nearly permafrost-free C-2 basin (Slaughter et al 1983). The corresponding seasonal sediment production totals were ca. 5600 kg and 2200 kg, respectively. The sediment values reported do not include the primary hydrologic event of the year, spring breakup; these values are therefore conservative with respect to total annual yield.

Table 2. Ice-free season suspended sediment yield from Caribou-Poker Creeks Research Watershed (tonnes).

Year	Ice-free Season	Basin C-2, 5.2 km^2	Ice-free Season	Basin C-3, 4.5 km^2
1978	June 22-Oct. 1 (102 days)	0.0502	June 22-Oct. 1 (102 days)	0.0481
1980	June 17-Sept. 23 (99 days)	0.2996	June 17-Sept. 9 (85 days)	0.2768
1981	May 20-Oct. 7 (141 days)	2.2205	June 4-Sept. 23 (112 days)	5.6044
	Seasonal Mean (tonnes)	0.8234		1.9764
	Unit Area Mean (tonnes/ha)	0.0016		0.0043

Vegetation affects sediment yield from boreal forest landscapes, as in more temperate regions. Aldrich and Johnson (1979) manipulated test plots on permafrost-free forested sites in CPCRW and demonstrated that complete vegetation removal resulted in erosion 18 times greater than on an adjacent naturally-forested (aspen/white spruce) site. Vegetation disturbance without complete removal, such as created by off-road recreational vehicle traffic or wildfire control activities, can result in soil warming, thaw and erosion on permafrost sites (Slaughter and Aldrich 1989).

CONTRASTS AND COMMONALITIES

Sediment production from high-elevation basins in Southwestern Idaho rangelands is produced mainly by snowmelt, although rain-on-snow events are occasionally important. At lower elevations (below 1400 m msl) sediment production is mainly by rain falling on snow and/or frozen soil. About three-quarters of the average annual sediment production occurs in winter, during January - March. There is great spatial variability in sediment production at both the landscape scale, evidenced by the variation among high and low years in the nested watershed system, and at the micro-scale as evidenced by the large contrast between sediment yield from beneath and between plants.

In central Alaska's boreal forest uplands wintertime suspended sediment concentrations (in the absence of snowmelt from October through March) are low and stable. Following spring breakup, major sediment production events are the product of summer storms when the landscape is free from seasonal snow. The interacting effects of landscape position and permafrost on streamflow and sediment yield are evident: warmer south-aspect headwaters basins have less permafrost influence than similar north-facing basins; streamflow and sediment yield are more variable and "flashy" in permafrost-dominated settings, with higher peak flows and sediment concentrations, and with lower minimum flows and sediment concentrations, both associated with increasing permafrost presence. Spatial variability in open-water-season sediment production at the landscape scale is at least partially a function of the amount and location of permafrost. Vegetation and land use can significantly affect sediment production at smaller scales.

A few major events produce most of the annual sediment yield at both locations. While snow constitutes half or more of the annual precipitation in both watersheds, rainfall events produce the majority of the basin sediment yield from these watersheds (except for the high-elevation Reynolds Mountain sub-basin in RCEW). Vegetation has a significant impact on sediment production. Sediment yield is low in drought years and much greater in high-flow years.

The value of sediment data is enhanced by ancillary information about the hydrologic processes involved and by knowledge of the landscape in which sediment is detached, transported and deposited. Sediment yield, although not universally monitored in hydrologic research programs, provides a useful indicator of landscape stability under current and past management practices, and provides a basis for evaluating watershed response to changing land use or climate.

While dissimilar in location and climate, these two long-term research watershed programs each provide (1) research data with which to characterize hydrologic regime and sediment yield of the respective landscape settings, (2) sustained, long-term documentation of hydrologic and climate variables, providing baselines for study of watershed response to changes in forcing functions (incoming energy, precipitation and pollutants, land use or land cover change), and (3) a context and physical facility for detailed process research and model validation in the larger biogeographic settings represented by these respective research catchments. Diminishing resources available for long-term landscape-level research accentuate the value of long-term, sustained watershed programs which comprehensively monitor climate, landscape, streamflow and sediment yield.

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SEDIMENT DELIVERY TO HEADWATER STREAM CHANNELS FOLLOWING ROAD CONSTRUCTION AND TIMBER HARVEST IN THE BLUE MOUNTAINS, OREGON

By Robert E. Gill, Fisheries and Watershed Program Manager, A. G. Crook Company, Beaverton, Oregon

INTRODUCTION

Many studies have focused on improving our understanding of the effects of timber harvesting activities on soil, water, and fisheries resources. Much of this work has led to the development and widespread use of soil erosion prediction models by land managers. This use has resulted in model applications that are outside the bounds in which the models were developed, for example, different soil and geologic types, and different hydrologic and climatic regimes.

There is currently no validated method for predicting the quantity of sediment delivered to first and second order channels following road construction and harvesting in areas of ash-influenced soils. Ash-influenced soils are common throughout central and eastern Oregon. It is commonly held that sedimentation increases with increasing slopes and with increasing amounts of surface soil disturbance. There is, however, little (if any) available data of actual quantities of ash-influenced soil moved from disturbed sites to stream channels.

It is commonly accepted that sediment eroded from road fill-slopes contributes a very large proportion of the total sediment reaching streams. It has been shown that the surface condition of a road fill and the distance to a stream channel controls the amount of sediment actually reaching the stream. The application of this concept in a soil erosion model requires that the amounts and conditions be measured in the field and delivery coefficients derived for typical conditions.

The R1-R4 Sed Model (Cline et al. 1981) was adapted for use on the Wallowa-Whitman National Forest. This adaptation, known as WWSED, has been widely used to support management decisions but has never been validated. The WWSED model produces quantified estimates of sediment yields prior to management (natural sediment yield) and sediment yields for seven years in response to various management scenarios. The types of management activities included in the model are roading, logging, and fire. The model estimates on-site erosion for a given management activity, modifies the amount of erosion according to general land unit characteristics, delivers the eroded material to the stream system, and routes it through the watershed to a critical stream reach. Here interpretations are intended to be made by qualified professionals on the potential effect of the delivered sediment.

The WWSED model simplifies an extremely complex physical system and is developed from a limited data base. Although it produces specific quantitative values for sediment yield (i.e., tons/sq. mi./year), the results are intended to be treated as relative indicators of how real systems may respond. Values currently produced by this procedure are probably only useful as comparisons where large differences among alternatives are produced and not for predicting specific quantities of sediment yielded. Validation of the sediment delivery coefficients of this model will allow for improved prediction of sediment yield and reduced error associated with current predictions.

Study Objectives The objectives of this study were: (1) to determine the amount and rate of sediment delivery to ephemeral (first and second order) stream channels following road construction and logging, and (2) to evaluate the WWSED sediment yield predictions.

DESCRIPTION OF STUDY AREA

The Syrup Creek study watershed is located in the Starkey Experimental Forest and Range near La Grande, Oregon (Figure 1.). The watershed is approximately 3.5 square miles in size and is drained by a fourth order channel (2.4 miles) which is fed by numerous first (14.2 miles), second (6.2 miles), and third order (3.2 miles) streams. All the drainages within the study area are ephemeral with the majority of the water coming off the area in early spring (April and May). The rather open nature of this country, especially the southerly ponderosa pine

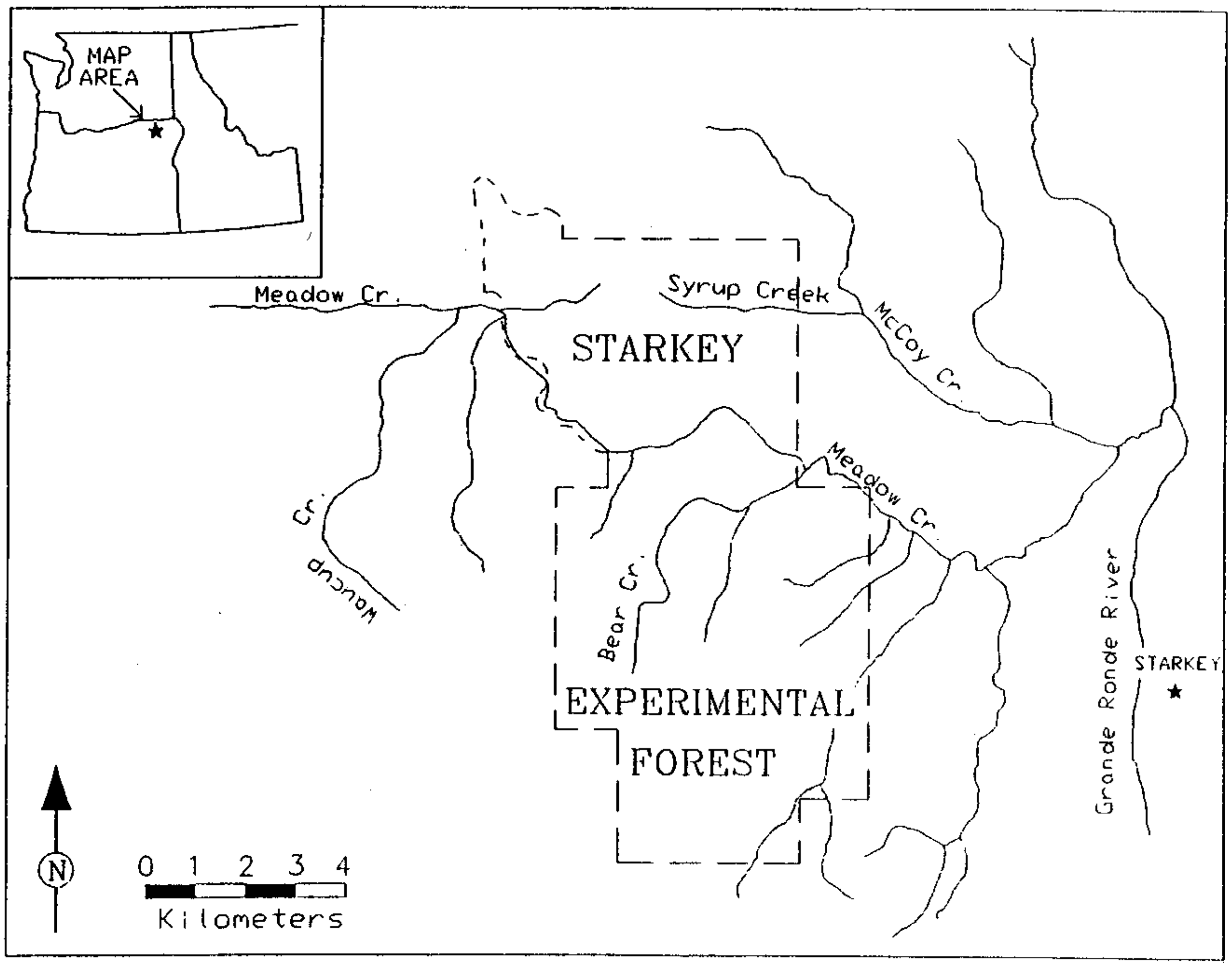


Figure 1. Project study area. Upper Grande Ronde River Watershed in the Blue Mountains of northeast Oregon.

types and open grassland communities result in rapid snow melt events and an early water loss from the area. The 2230 acre study area has a mean elevation of 4190 feet, a mean slope of about 16 percent and a 100 degree aspect (southeast).

<u>Climate</u> The climate in the Blue Mountains is characteristic of the snow dominated inland conifer type described by Swank et. al. (1989). Precipitation in this area averages approximately 20 inches per year. More than half of the annual precipitation occurs as snow during the winter months. However, summer rainfall does occur. Storms may be of short duration, high intensity convectional type.

<u>Geology and Soils</u> The Syrup Creek area is underlain by Columbia River Basalt which is a hard, relatively competent rock type. The landscape is rolling, relatively non-dissected, and stable. Ridge tops are broad and trend in an East-West direction. Current erosion problems are associated with roads, overland flow on open grassland communities and stream bank erosion during spring runoff events.

The soils and their related productivity potentials have been defined here based on the presence or absence of volcanic ash. Volcanic ash dominated sites can be characterized as having higher water holding capacities, greater effective rooting depths and higher productive potentials. The deeper deposits of volcanic ash can be identified by the presence of grand fir and larch with the grand fir usually creating a closed canopy. These deep ash deposits occur on northerly, toe slope positions. The moderately deep ash deposits usually contain lodgepole pine, larch, and occasionally Douglas-fir and ponderosa pine in transition zones. The moderately deep ash deposits occur on broad ridge tops and on slopes with a northerly aspect.

Non-ash soils developed in loess and residuum and colluvium derived from basalt. These soils can be characterized as having low to moderate effective water holding capacities, shallow rooting depths and moderate to low productive potentials. These sites are dominated by ponderosa pine and Douglas-fir. The sites with the least soil development are grassland communities followed by those with marginally productive ponderosa pine communities (10-20 inches of effective rooting depths).

<u>Logging</u> A major modification of the forest vegetation occurred in the Syrup Creek watershed beginning in 1991. Silviculture objectives for this area, in addition to harvesting mature and overmature trees, was to develop healthy, fully stocked and productive timber stands, composed primarily of budworm and Douglas-fir bark beetle resistant species, ponderosa pine and Western larch. Silvicultural treatments emphasized regeneration harvest methods due to the extensive insect damage.

Harvest prescriptions included 925 acres of clear-cut with reserve trees, 81 acres of shelterwood, 291 acres of intermediate harvest and 10 acres of individual tree selection. Logging systems included 1095 acres of tractor, 175 acres of skyline and 37 acres of tractor swing to skyline. Post harvest cultural work included 800 acres of broadcast burning, 150 acres of grapple piling, 100 acres of pre-commercial thinning and stand cleaning, 150 acres of gopher baiting, and 900 acres of planting. Implementation resulted in harvesting 11.3 MMBF of timber from 1307 acres treated. To facilitate harvest, 2.9 miles of the existing road system were reconstructed and 25.6 miles of new road were constructed.

METHODS

<u>Local Characteristics</u> The rate of soil erosion for a given geographic area is a function of climate, vegetation, and soil physical characteristics. In order to establish a reference point in which to compare results of this study with current and/or future information, characteristics of the local environment were measured.

The area contributing runoff and sediment to the in-channel trapping locations was characterized in terms of elevation, area, length of stream channel, slope, and aspect. These characteristics are important in understanding the conditions in which sediment transport occurred. Basin area was measured by standard traversing methods and recorded in acres.

Precipitation measurements were obtained from the weather station located approximately five miles east at the Starkey Experimental Forest and Range Headquarters. Mean elevations, slope and aspect were measured by Digital Elevation Modeling in Geographic Information Systems (GIS).

Disturbance factors, such as roads, logging and fire, were measured. The lengt of road potentially contributing sediment to stream channels above sediment traps were measured using a hip-chain and recorded to the nearest foot. The amount of area being disturbed by logging and fire was estimated from mapping exercises and recorded to the nearest acre.

<u>In-Channel Sediment Sampling</u> An in-channel sediment trap was installed in each of twelve ephemeral drainages representative of the watershed in the fall of 1990. Six were installed within the north aspect of the watershed and six within the south aspect of the watershed. Site specific placement of sediment traps was based on specific characteristics that facilitated construction and reduced the risk of trap failure. It was necessary for the sediment trap location to be sufficiently incised as to provide a large enough catch basin volume (approximately 2 - 5 cubic yards) and to have sufficient quantities of woody materials (logs) available for construction and maintenance of sediment traps.

These were constructed utilizing woody materials, straw bales and filter cloth perpendicular to the channel to act as a filter dam. Construction consisted of placing logs perpendicular to the stream channel secured by wiring them to steel fence posts driven into the ground downstream of the log. Straw bales were then placed upstream of the secured log structure, approximately to the height of the top log (3+ feet). Filter cloth was then placed to line the entire catch basin area. Style 3401 Typar Brand filter fabric was selected because of its strength and filtering abilities. This fabric has a thickness of 15 mils., an Equivalent Opening Size (FOS) of 70 - 100 U.S. Std. Sieve (0.17 mm), a flux of 230 gal./ft.^{2}/min. at 10 inches of water head and a coefficient of water permeability (K) of 2 x 10^{-2} cm./sec.. These catch basins were designed to function as filters as well as settling ponds, and were designed to trap all sizes of material from all sources above the traps, both bedload and suspended load. The goal was to have no stream flow over the catch basin, but to allow all water to filter through the fabric.

Materials (organic and inorganic) were collected from the traps annually following each spring runoff period (between July 01 and September 15) in 1991, 1992 and 1993. Sampling took place following spring runoff but before significant fall rains occurred. The majority of materials were collected by sweeping and shoveling into storage containers. Some quantities of materials were too fine in structure to be collected by sweeping and shoveling due to the ash content in many of the soils. For this reason, a generator-driven vacuum cleaner was used to collect the remaining fine material, as well as retrieve the fine materials entrained in the fibers of the filter cloth. Where feasible, all of the material from each sediment trap was then transported to the laboratory for sample analysis.

<u>Sample Analysis</u> A laboratory analysis was necessary to determine the relative quantities of sediment (inorganic material) found in the samples. Collections from each sampling location were spread out on a table and allowed to air dry. Samples were then sieved through a 0.5 inch screen to separate the large organic materials such as tree needles, sticks and twigs and any large inorganic particles such as large pebbles. The separations were then weighed to the nearest 0.01 grams and recorded. Stones larger than 0.50 inches were very rare. The sample portion passing the 0.5 inch screen was processed through a series of "splitting" to attain a well mixed representative subsample. Depending on the size of the sample, up to eight splits were performed. Small samples were not processed through the splitting procedures.

The subsample from each sampling location was placed in eight (8) tared crucibles. The eight crucibles were then re-weighed and placed in the drying oven for approximately 24 hours at 105^{o}C. Crucibles were allowed to cool for one hour before re-weighing to determine the relative amount of water in each crucible sample. The difference between the initial weight and the post-drying weight is the amount of water in the sample. To express as a percentage, the following equation was used for each crucible (C1-C8) measured:

Equation 1. Amount of water expressed as a percent.

$$\frac{\text{Initial Weight (g) - Post-Drying Weight (g)}}{\text{Initial Weight (g)}} = \text{\% Water Content}$$

Following drying, crucibles were placed in the muffle furnace for 6 hours at 425-450°C and again re-weighed to determine the relative amount of organic material in each crucible sample. The difference between the post-drying weight and the post-muffle furnace weight is the amount of organic material in the sample. To express as a percentage, the following equation was used for each crucible (C1-C8) measured:

Equation 2. Amount of organic material expressed as a percent.

$$\frac{\text{Post-Drying Weight (g) - Post-Muffle Weight (g)}}{\text{Initial Weight (g)}} = \text{\% Organic Content}$$

All recorded measurements were entered into a spreadsheet, where calculations were performed to determine the relative amounts of moisture, organics and inorganics (sediment) in each of the eight crucibles for each of the sampling collections. The eight measurements were averaged to determine an average percent content of moisture and organic material for each sampling location.

The Hydrometer Method of grain size analysis was performed on selected sampling locations to obtain an estimate of the distribution of soil particle sizes (Bowles 1978). This data was plotted on a semilog plot of percent finer vs. grain diameters.

The average moisture and organic content was then extrapolated back to the weights of the initial samples. This determined the total amount of organic and inorganic material caught at each sampling location.

Sediment Yield Predictions Changes in sediment yield due to road construction, logging and fire in the Syrup Creek study area were predicted using the WWSED model. Modeling was performed with the same assumptions and intensity to be consistent with past modeling efforts on the Wallowa-Whitman National Forest, La Grande Ranger District. Analysis of data from sampling methods and site characterizations determined the quantity and rate of sediment delivered to Syrup Creek. These measurements were compared to those predicted by the WWSED model.

RESULTS AND DISCUSSION

The average annual and monthly precipitation for the period of record (1984-1993) was 20.76 inches and 1.48 inches, respectively. Precipitation was found to be variable throughout the study period of 1991 through 1993. Precipitation in 1991 was characterized by an above average year with an annual total of 23.85 inches. Maximum monthly precipitation was 5.28 inches occurring in November. Of particular interest to this study was the occurrence of an estimated 15 to 20 year runoff event in Meadow Creek. This was the result of days of rain following a warm period in which soils were saturated from recent snow melt. The second and third weeks of May, 1991 had 1.08 and 2.76 inches of rain respectively. The majority of which fell in a one to two day period.

Precipitation in 1992 was below average with an annual total of 17.15 inches. Maximum monthly precipitation was 3.05 inches occurring in November. Precipitation in 1993 was again above average yielding an annual total of 22.28 inches. Maximum monthly precipitation was 3.46 inches in April and 3.48 inches in June.

The following tables list the inherent properties of the 12 in-channel sediment trap contributing areas (Table 1), and also the management disturbance factors associated with the 12 sediment trapping locations (Table 2). Sample location number 5 was a control basin in which no ground disturbing activity was to take place. The site logging plan changed to include this area into an adjacent harvest unit. As a result, the in-channel sediment trap was destroyed. A different control (number 5A) was located outside of the analysis area.

Location	Area (ac)	Elevation, m	Slope (deg)	% Area >30% Slope	Aspect (deg)
1	10.02	1210	6.9	0	88
2	10.15	1272	7.3	3.7	87
3	33.84	1252	8.6	0	35
4	36.82	1320	10.5	5.8	32
5	9.38	1337	10.3	1.5	30
5A	63.31	1381	2.9	6.2	87
6	13.15	1292	9.8	0	17
7	29.78	1300	7.2	0	164
8	24.88	1293	7.6	0	175
9	8.68	1264	8.6	1.3	148
10	3.72	1272	8.6	0	167
11	18.67	1247	9.5	0	169
12	17.86	1225	7.2	0	156

Table 1. Inherent properties associated with the in-channel sediment sampling locations.

Location	Roads (ft)		Distance	Stream	Harvest (ac)		Rx Fire (ac)
	Existing	New	to trap (ft)	Channel (ft)	Tractor	Skyline	
1	0	267	164	199	2	0	0
2	0	0	319	90	3	0	0
3	0	0	275	664	42	0	18
4	0	471	477	361	10	13	0
5	0	0	0	n/a	9	0	9
5A	0	0	0	235	0	0	0
6	0	266	74	195	13	0	13
7	0	85	660	902	8	7	0
8	0	70	545	1082	16	0	0
9	0	0	445	230	12	0	0
10	0	0	0	100	0	0	0
11	0	346	246	492	5	0	0
12	0	526	737	737	0	0	0
Total	0	2031	3942	5287	120	20	40

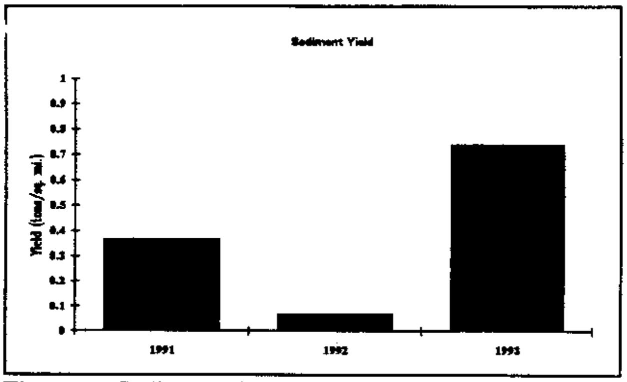
Table 2. Management disturbance factors associated with the in-channel sediment sampling locations.

Grain size analysis was conducted on samples from locations 3, 8 and 10. Results show a range of diameters from 0.001 mm to 0.048 mm. Grain size distribution curves show clay content ranging from 0 to about 30 percent.

Total sediment yield in tons per square mile are illustrated in Figure 2. No statistically significant relationships between the quantity of sediment yielded versus either inherent or management disturbance factors could be concluded from this data set. Precipitation and sediment yield (Figure 3) did not show a significant relationship, based on t-test results with 43 degrees of freedom and the 5% level of significance (Figure 4).

The inherent factors described in Table 2 did not show a relationship to the amount of sediment yielded, correlation coefficients ranges from 0.05 to 0.45. Management disturbance factors illustrated in Table 3 did not show a significant relationship to sediment yield, r-Squared ranges from 0.0004 to 0.45.

While there appears to be no significant relationship between inherent or management induced disturbance factors and sediment yield, there has been a two-fold increase in sediment yield when comparing 1993 to 1991 sediment yields, and a ten-fold increase in sediment yield when comparing 1993 to 1992 sediment yields. The r-Squared values for 1993 sediment yield versus inherent values were considerably higher than 1991 or 1992 values.



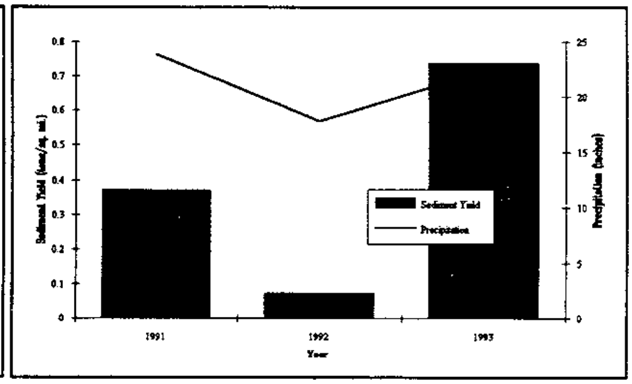
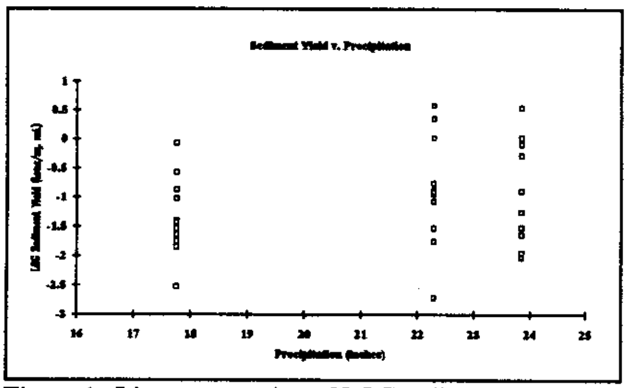


Figure 2. Sediment yield in tons/sq. mi. for the Syrup Creek study area.

Figure 3. Sediment yield and precipitation for the study period of 1990-1993.

The WWSED Model predicted 32.95 tons/sq. mi. of sediment would be produced in 1991. This prediction included natural erosion and management induced increases. Measured yields were 0.37 tons/sq. mi. with a maximum measured yield of 3.57 tons/sq. mi.. The model predicted that 25.06 tons/sq. mi. and 24.92 tons/sq. mi. would be produced in 1992 and 1993, respectively. However, measured values were 0.07 tons/sq. mi. and 0.74 tons/sq. mi., with maximum yields of 0.87 tons/sq. mi. and 3.85 tons/sq. mi., respectively. Figure 5 compares predicted and measured values.



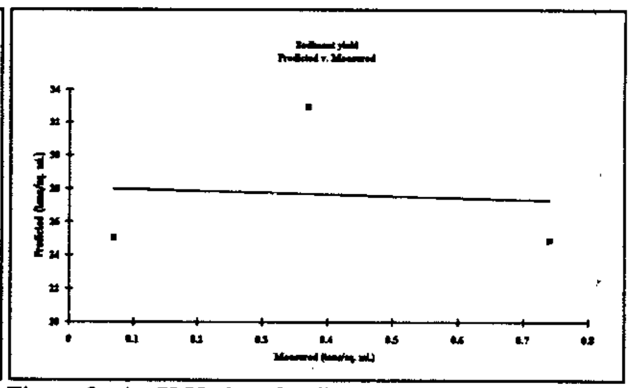


Figure 4. Linear regression of LOG sediment yield versus precipitation for the study period (1990 to 1993).

Figure 5. An X-Y plot of sediment yield predicted by the WWSED versus average sediment yield measured from the study area.

Disturbance by animals was visible at many sites within the small basins and on-slope sediment traps. Cattle, elk and deer populations create some soil disturbance. Succulent forage persist late into the summer near the channels and cattle and elk both use these areas heavily. An animal damage index was not developed with this study. Gophers may also be a significant factor as their populations increase rapidly when the forest canopy is reduced and large increases in grass, forbs and brush species occur.

The use of in-channel catch basins as described in this study was not present in the literature. Methods commonly being employed focused primarily on suspended sediment sampling. These methods included but are not limited to, splitters of various kinds, Coshocton Wheels and pumping water samplers.

Qualitatively, the in-channel sediment catch basins proved to be highly effective in meeting the objective of trapping sediments. The small grain sizes recovered suggest that a substantial enough velocity break in stream flow existed as to settle out and filter these fine sediments. Only three catch basins showed evidence of over flowing. This was not a significant concern in the sampling effectiveness since the potential fraction lost was likely extremely fine in nature and probably would not have added significantly to the total sample.

Measurements were conducted relatively high (upstream) in ephemeral and intermittent stream channels. It is speculated that if sampling were conducted lower (downstream) in the stream channel, a larger increase in sediment yield would have been measured. This is in part due to the increased volumes of discharge able to detach and transport additional sources of sediment, such as stream bank and channel scour, and additional management related sources missed by the sampling frequency used. For example, culvert failure occurred at a stream crossing not associated with one of the 12 sampling locations.

CONCLUSION

It can be concluded that while there was an increase in sediment yield in the Syrup Creek Study Area, there is no statistically significant relationship between this increase and inherent or management factors. This may be due, in part, to the limited data set with only three years of observations. It is likely that there are other inherent and management factors which would help explain the variation in sediment yields.

It has also been shown that the WWSED Model drastically over-estimates the sediment yield from this area. From this, we can conclude that the variability of natural systems is far more complex than can be simplified into a prediction model.

Several additional years of measurement are necessary. The WWSED model predicts sediment yield for a seven year period. Data for 1994 and 1995 has been collected. Data from 1991 through 1996 will be analyzed with results expected in the fall of 1996. Measurements should continue for an additional two years and preferably longer. This may provide a more robust data set in which to evaluate the WWSED model.

An expanded version of this paper is available from the author (Gill 1994).

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SEDIMENT YIELD AND QUALITY IN TWO SMALL SEDIMENT DEBRIS BASINS IN THE TUCANNON WATERSHED IN SOUTHEAST WASHINGTON

Frank F. Reckendorf, Engineering Geologist, Reckendorf and Associates, Salem, Oregon

Abstract: Two small sediment basins were constructed in October 1987 as one phase of a water quality demonstration project. The evaluation to size the basin for sediment storage capacity was based on using the USLE modified to reflect frozen ground, and sediment delivery ratios. Sediment accumulation rates were 0.28 ac-ft./sq-mi. and 0.31 ac-ft./sq-mi in basins one and two respectively, for the 1988 survey and declined to .22 asnd .20 ac-ft/sq-mi in the 1989 survey. Basin two's rate declined to 0.08 ac-ft/sq-mi in 1990, and had this rate again when measured in 1993. Sediment reduction is attributed to a combination of : (1) reduced tillage and other conservation measures implemented through the Food Security Acts of 1985 and 1990; (2) application of demonstration plots of various rotations with no-tillage seeding in basin one; and (3) very low winter precipitation, especially when soil was unfrozen. Water and sediment sampling for pesticides and nutrients was done in both basins in the spring of 1989. Pesticide results showed that the common pesticides used in these watersheds in the prior year had either essentially expended their half lives by the time of spring sampling, or had not reached the offsite location of the basins. However there is evidence of accumulation of total organic carbon and phosphate in the sediment.

INTRODUCTION

The Tucannon River is a 500 sq-mi. tributary of the Snake river in SE Washington. Based on seven years of suspended load data, including one 1% chance flood event, the river has an average sediment yield of 613,510 tons/yr to the USGS gage site (431 sq-mi). The particle size of the suspended sediment measured four times between 12/22/64 and 1/30/65, averages 89 % silt and clay. Runoff high in small particle sizes, has a high potential to yield agricultural chemicals. To evaluate sediment loads, two sediment basins located on unnamed tributaries to the Tucannon River were constructed in Nov. 1987, as demonstration projects in cooperation with the Washington Department of Ecology, and the Columbia Conservation District. The upper watersheds consists of sloping loess soil profiles (Table 1) utilized as dry cropland. Steep escarpments fringe the upland areas and consist of shallow soil profiles of loess, volcanic ash, and weathered basalt. These steep areas are used primarily as rangeland. Annual precipitation varies from 16-20 inches, with most significant runoff events occurring when frozen and thawing ground conditions prevail. However other runoff conditions occur. Most of the sub-watersheds in the Tucannon have been farmed up through the late 1980's with conventional tillage. Several rotations have been historically used, with one of the most erosive being winter wheat followed by summer fallow. Generally farm and ranch operations are aware of methods to better manage the land they operate. However there is a financial risk as well as a capital investment cost associated with implementation of conservation practices which reduces the attractiveness associated with additional conservation. In addition many farmers. use interrelated management of cropland and rangeland. For example livestock utilize crop aftermath and unfenced odd areas in the cropland and riparian areas. If conservation practices such as strip cropping is applied to cropland, thus limiting aftermath grazing on cropland, the rangeland must be capable of providing adequate forage to replace the aftermath grazing.

EROSION EVALUATION

The cropland soils present in the upper watersheds of both basins are the Athena and Palouse soil series. There are six rangeland soils present with the larger areas being the Gwin, Asotin, Tucannon, and Kuhe soils. The upper two inches of the Athena, Gwin, Kuhe, and Palouse soils were sampled for particle size distribution as shown in Table 1. The results shown reflect the coarser nature of the rangeland soils.

Basin one and two contain 1084 ac and 1796 ac of cropland, and 1204 ac and 1236 ac of rangeland (Table 2). On these areas, sheet and rill erosion was determined using the Universal Soil Loss Equation (USLE) but adjusted using the R, L, and S values for frozen soil conditions (McCool and George, 1983). K factors for the different soils in the basin were weighted based on area to arrive at a composite estimate of soil erodibility. C factors for various crop management conditions evaluated were based on the Columbia Conservation District Technical Guide. P factors were assumed constant at 1.0. A winter wheat summer fallow condition was assumed for the background cropland condition. Sheet and rill erosion rates on cropland were

TABLE 1

SOIL PARTICLE SIZES

SOIL	SLOPE %	GRAVEL %	SAND %	SILT %	CLAY %
ATHENA	20		11	51	38
GWEN	43	38	37	12	13
KUHL	31		27	49	24
PALOUSE	22		7	43	50

determined to be 11 tons/ac above basin one and 17 tons/ac above basin two. The total annual sheet and rill erosion from cropland and rangeland are calculated to be 26,630 tons and 38,657 tons for basins one and two respectively, as shown in Table 2.

SEDIMENT DELIVERY RATIO (SDR)

This erosion evaluation includes only sheet and rill and streambank erosion, as they were the predominant sources. Formulas, such as those by Lee and Molnau (1979), have been developed to represent SDR. Lee and Molnau (1979) developed relationships in the Palouse of SDR to drainage area and to relief length ratio. The equations were developed for suspended load measured in southeast Washington along three small watersheds above weirs and for one larger watershed. Data from the SDR evaluation varied from an average of 42.8 % for the small drainage areas (8.2 ac) to 8.3 % for the largest drainage area (17,593 ac). All of the areas had predominantly sheet and rill erosion on dry cropland as the source of the measured sediment.

A field evaluation was made that visually compared the Lee and Molnau (1979) basins to one and two in this study, and SDR's were assigned to the two study basins. The assigned values applied to sheet and rill erosion, were weighted based on drainage area. These values and those calculated using the Lee and Molnau equations (1979), are shown in Table 3.

SEDIMENT YIELD (SY)

The sediment yield of a watershed can be estimated from: (1) measured sediment transport or accumulation; (2) gross erosion and SDR's as previously discussed; (3) predictive equations such as Flaxman (1971), or Renard (1980); (4) rating procedures such as PSIAC; and (5) compare unmeasured data to measured data. For the two basin in question the estimated SY's to size the basins was determined using the USLE modified for frozen ground and SDR's, along with streambank erosion and the associated SDR's. The results (Table 2), are the calculated SY's to the sites. For basin one sediment yield is 5,517 tons/yr , and for basin two 8,215 tons/yr.

SEDIMENT STORAGE

The quantity of sediment trapped in ponds, debris basins, and reservoirs usually does not represent (except for large capacity COE, and BOR), the sediment yield to the site. The principal spillways may passes significant quantities of sediment while the debris basin is filling and even higher quantities of sediment may pass the dam if the emergency spillway operates. The trap efficiency (TE) of the structure must be estimated and the sediment yield modified to determine sediment yield to the site. The TE's for the two basins studied were determined on the basis of the ratio of the capacity of the reservoir to the average annual inflow (Chapter 8, USDA, SCS, 1983). The capacity inflow relationship for both basins was determined to be 0.0247. Since the particle size of the suspended load in the Tucannon River was determined to be 89 % silt and clay, the curve for "primarily colloidal and dispersed fine grained sediment" was used. The TE was determined to be 53 %. With the low TE the sediment storage needed at the two sites was calculated to be 2,924 tons/yr for site one and 4,354 tons/yr at site two. The rate of storage was calculated to be 1.28 tons/ac/yr or 0.52 ac-ft/sq-m for basin one, and 1.44 tons/ac/yr or 0.59 ac.ft/sq-mi for basin two. For the evaluation of potential sediment storage it was assumed that 20 % of the sediment would be submerged, and have a volume weight of 1,307 tons/ac-ft. The remainder would be aerated and has an estimated volume weight of 1,634 tons/ac-ft.

Sediment storage began in November 1987, so less than one full runoff year was available prior to measurement in August of 1988. However, there was a 1.5 inch precipitation event on frozen soil on January 11, 1988 that resulted in a high sediment yield. The event sediment was essentially confined to the basin one (i.e. 100% TE), and mostly confined (80% TE) in basin two. The measured rates are shown in Table 2. The presence of frozen soil was based on freeze tube records of the Columbia Conservation District. Sediment accumulation rates were 0.28

TABLE 2
SEDIMENT YIELD FOR PROJECTED AND MEASURED CONDITIONS

PAREMETER	UNITS	BASIN 1	UNITS	BASIN 2	AV PREC inches
Drain Area Cpld.	ac	1084	ac	1796	
Drain Area Rng.	ac	1204	ac	1236	
Total Drain Area	ac	2288	ac	3032	
Calculated Val.					
Co. Sh. & Ri. Er.	tons/yr	26,630	tons/yr	38,657	
Sh. & Rill SDR	%	20.6	%	21.2	
Str-bnk Eros.	tons/yr	34	tons/yr	22	
Str-bnk SDR	%	90	%	90	
Sed. Yld. Site	tons/yr	5517	tons/yr	8215	
	ton/ac/yr	2.41	ton/ac/yr	2.7	
Trap Efficiency	%	53	%	53	
Sed. Yld. Stor.	tons/yr	2924	tons/yr	4354	
	tons/ac/yr	1.28	ton/ac/yr	1.44	
	ac-ft/yr	1.88	ac-ft/yr	2.8	
	ac-ft/sq-mi	0.52	ac-ft/sq-mi	0.59	
Measured					
Sed. Yld. Stor.					
August, 1988	ac-ft/yr	C 99	ac-ft/yr	1.47	15.67
(<1 yr precip.)	ac-ft/sq-mi	0.28	ac-ft/sq-mi	0.31	
August, 1989	ac-ft/yr	0.78	ac-ft/yr	0.95	19.18
	ac-ft/sq-mi	0.22	ac-ft/sq-mi	0.2	
August, 1990	ac-ft/yr	0	ac-ft/yr	0.38	16.89
			ac-ft/sq-mi	0.8	
August, 1991	ac-ft/yr	0	ac-ft/yr	0.05	20.61
			ac-ft/sq-mi	0.01	
August, 1992	ac-ft/yr	0	ac-ft/yr	0	13.9
August, 1993	ac-ft/yr	0.03	ac-ft/yr	0.37	20
	ac-ft/sq-mi	0.01	ac-ft/sq-mi	0.08	

ac-ft/sq-mi and 0.31 ac-ft/sq-mi for basins one and two which are about half of the protected rate of accumulation (Table 2). Even though it was a short runoff year the measured precipitation of 15.67 inches at Pomroy applied to the site was about the same as the 16 inches of average annual precipitation used in the McCool and George (1983) equations for determining R value for frozen soil conditions.

Sediment accumulation rates in 1989 decreased to 0.22 ac-ft/sq-mi for basin one and 0.20 ac-ft/sq-mi in basin two. Most of the sediment was associated with runoff from a four day precipitation event (January 7-10, 1989) of 2.74 inches on unfrozen ground based on freeze tube records. However, there was four inches of snowfall recorded at nearby Pomroy Wa., on January 7 and 8, when maximum temperatures were below freezing, but by January 9 and 10 max./min. temperatures were 43/15 and 42/33 degrees Fahrenheit, associated with precipitation amounts of 0.34 inches and 0.91 inches, which is when most of the runoff occurred.

In 1990, 1991, and 1992 no measurable sediment reached the surveyed cross sections locations in pond one. In the 1989-90 runoff year there was very low winter precipitation (6.03

TABLE 3

FIELD AND FORMULA SDR'S

Wtr-Shd	Fld-SDR RNG.	Fld-SDR CPLD.	Wgt-SDR	SDR R/L	SDR Drn-Area
One	0.3	0.1	0.206	0.26	0.111
Two	0.3	0.15	0.211	0.21	0.112

inches from Dec.-April), as contrasted to 10,75 inches the prior year for the same time period ((NRCS, WNTC, 1995)). No daily precipitation value exceeded 0.5 inches throughout the winter and no significant snowfall occurred until late February, when soils are assumed to be unfrozen because of the long period of above freezing minimum temperatures recorded at Pomroy. In the 1990-91 runoff year there were two days (January 6 and 7) of high precipitation (1.13 and 1.07 inches) but this is assumed to be primarily from snowfall. Surface maximum temperatures at Pomroy were below freezing for a period of time before snowfall, but maximum temperatures increased to well above freezing throughout the remainder of January, and well into the spring. Therefore there was little opportunity for runoff as the soils unfroze (if they had been frozen) during the low precipitation period. In addition after 1989 overall the surface residue increased to at least 1000 lb/ac, and soil pulverization decreased from fines or dust to clods. This was associated with reduced tillage (mostly chiseled winter grain stubble but some no till).

In pond two sediment accumulation rates continued to decline from 1989 values to 0.08 ac-ft/sq-mi in 1990 to 0.01 ac-ft/sq-mi in 1991, and than up slightly to 0.08 ac-ft/sq-mi in the 1993 runoff year. No sediment accumulated during the 1991-92 very low winter runoff years. The 1992-93 winter runoff year was high (12.51 inches), although about one third of this occurred in April. No daily precipitation values exceeded 0.35 inches except for one day in January which was 0.60 inches. Based on surface temperatures at Pomroy the ground appear to be frozen in January, but no significant runoff occurred because of the low precipitation. The highest precipitation of the year occurred in late April when, based on high max./min temperatures, the ground should have been unfrozen. The same type of reduced tillage and increased residue occurred after 1989 in basin two as in basin one. However, peas were still used in the rotation in basin two, so those field had higher erosion rates and higher SY's.

WATER AND SEDIMENT QUALITY

During two runoff events in February 1988, and 1989 the Columbia Conservation Dist. obtained grab samples for measuring water quality at the the forest/ cropland boundary of the Tucannon River (Camp Wooten Br.), and at the inlet and out of the basins. No discharge measurements were taken, so the actual value rather than the loading values are shown in Table 4.

In August of 1988, the upper four inches of the sediment from both basins were sampled and tested for total organic carbon. Basin one had a value of 7.4% and basin two 5.1%. At the time of sampling it was observed that there was a large amount of floating pea residue in both basins.

In April of 1989, this author sampled the water and submerged sediment in both basins for residuals of DDT, DDD, and DDE , as well as for Metribuzin and Bromoxynil which are commonly used pesticides for weed control. These are useful as late fall pre and post plant herbicides. Similar test were made on other herbicides used to control broadleaf weeds in small

TABLE 4

SUSPENDED SEDIMENT GRAB SAMPLES

Paremeter	Units	Basin 1 Inlet	Basin 1 Outlet	Basin 2 Inlet	Basin 2 Outlet	Tucann R. Cmp. Woot.
1988						
pH		8.11	7.47	7.94	7.94	7.61
Sulfate	mg/l	2.81`	2.62	2.85	5.89	0.92
Nitrate N	mg/l	1.73	2.16	2.07	1.6	0.05
OrthoPhos	mg/l	0.08	0.16	0.24	0.21	0.07
1989						
pH		7.3	6.7	7.4	8.5	7.8
Sulfate	mg/l	2	3	3	2	<2
Nitrate N	mg/l	2.8	7.58	3.06	2.4	3.35
Ammn. N	mg/l	0.09	0.14	0.14	0.2	0.12
OrthoPhos	mg/l	0.15	0.17	0.11	0.1	0.02

grains (wheat and barley) and peas in the watersheds of both basins. These were MCPA, Dinoseb, and Triallate. During the 1989 crop year barley, wheat and peas were grown in the watersheds of both basins. As shown in Table 5 all samples gave none detectable results. Total organic carbon, nitrate nitrogen, ortho-phosphate, and total phosphate were also evaluated. The average pounds of ortho-phosphate per ton of sediment for the two basins is 0.003. The average for nitrate nitrogen was 0.0000117. The average for total organic carbon was 2.2%.

TABLE 5
PESTICIDES AND NUTRIENTS IN SEDIMENT AND WATER

Paremeter	Detection Lim-Sed mg/kg	Detection Lim-Water ug/l	Basin One Sed.	Basin One Water	Basin Two Sed.	Basin Two Water
DDT	0.002	0.05	ND	ND	ND	ND
DDD	0.002	0.05	ND	ND	ND	ND
DDE	0.002	0.05	ND	ND	ND	ND
Metribuzin	0.02	1	ND	ND	ND	ND
Bromoxynl	0.02	1	ND	ND	ND	ND
Dinoseb	0.02	1	ND	ND	ND	ND
MCPA	0.2	65	ND	ND	ND	ND
Triallate	0.02	1	ND	ND	ND	ND
pH			6.7		7.1	
TOC(%)	0.1		2.3		2.1	
Nitrate-N	0.07		2.33		2.8	
OrthoPhos	0.1		384		424	
Total Phos	1		920		730	

CONCLUSION

This study shows that the erosion estimates, SDR's , and TE's were on the conservative side. More sediment storage was allowed for than has occurred. This is acceptable from a design point of view as it allows for fewer cleanouts. The evaluation was based on a 25 year basin life with five year cleanout. However, the basins were built to the maximum capacity available at the site which exceeded the capacity needed. Therefore estimating a lower rate of deposition would not have changed the design. In addition sediment storage based on average annual conditions should be conservative as most of the sediment will be produced by storm events.

The data indicates the importance of frozen ground to accelerate erosion/sedimention if sufficient precipitation occurs, as little erosion/sedimentation occurred with the low winter runoff years from 1990-1992. The increased runoff in the winter of 1993 did not appreciably increase erosion/sedimentation. Crop residue on the land in the watersheds increased from 1989 through 1993, which appears to be a factor in reducing the runoff, erosion and sedimentation to much lower levels in recent years, especially by 1993 in basin one. In other words increased precipitation in basin one did not significantly increase erosion and associated sedimentation. However in basin two, where there were peas in the rotation in some fields, erosion rates increased somewhat and there was some sediment transported to the basin.

The water and sediment sampling in 1989 for pesticides and nutrients, indicates that the common used pesticides for weed control expended their half life before the time of sediment and water sampling. In addition the lack of DDT or its metabolites DDD, and DDE indicates that there is no evidence of DDT use in these sub-watersheds.

The concentration of ortho-phosphate in the sediment is not unusually high, for a nutrient that tends to be sediment bound. The nitrate nitrogen concentration in the sediment is also low which is to be expected. The total organic carbon content of the sediment is of some concern as sediment intrusion into spawning gravels in the Tucannon River would cause increases biological oxygen demand as the organic material in the sediment decomposes. This will have the effect to reduce the dissolved oxygen available for the eggs in the salmonid redds. There was a large amount of floating pea residue in both basins at the time of sediment measurement in August of 1988 The high pea residue was likely responsible for the high values of total organic carbon for that sample time period.

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HILLSLOPE EROSION, CHANNEL ROUTING, AND SEDIMENT YIELD IN SMALL SEMIARID WATERSHEDS, SOUTHERN CALIFORNIA

Peter M. Wohlgemuth, Geographer, Pacific Southwest Research Station, USDA Forest Service, Riverside, CA

Abstract: This paper reports first-year measurements of intrabasin erosion and sedimentation in four small semiarid watersheds on the San Dimas Experimental Forest, located in the tectonically active San Gabriel Mountains near Los Angeles, California. Three of these watersheds are covered with native chaparral vegetation (one of which had contour trenches carved into the hillsides and check dams constructed in the channels), while the fourth has been type converted to annual grass. These mechanical and vegetative treatments were established as part of an erosion control experiment following a wildfire in 1960. In 1993-94, the watersheds were instrumented with sediment collector traps, colored rock tracers, and permanent stream channel and debris basin cross sections to monitor hillslope erosion, delivery of sediment to channels, movement of channel sediment, and watershed sediment yield. Storms produced 1229 mm of precipitation over the 1994/95 hydrologic year, 172 percent of normal, generating surface runoff in the ephemeral channels not by hillslope overland flow but by soil mantle exfiltration. Hillslope erosion and sediment delivery to channels were an order of magnitude less under type converted grass vegetation than under natural chaparral plant cover. There was no relationship between painted rock tracer travel distance along the channels and rock size. Most of the tracers were too large to be entrained by the flow, however, and many were buried in fine material transported through the drainage network. Small watershed sediment yield was negligible. Most of the differences in both watershed morphology and sediment cycling appear to be related to the previous erosion control treatments.

INTRODUCTION

The USDA Forest Service, along with other agencies, is charged with responsible management of publicly owned lands. Yet, our knowledge and understanding of wildland ecosystem dynamics, including upland erosion and sedimentation, are inadequate to accurately predict the outcomes of different land management practices. Often the consequences of management treatments are poorly understood in the short term and virtually unknown in the long term. Postfire watershed rehabilitation is an especially controversial management issue with serious legal ramifications in southern California, as the urban wildland interface encroaches on adjacent steep mountain fronts. There is general agreement that watershed protection measures are necessary to reduce postfire erosion and sedimentation, but the utility and wisdom of many erosion control practices are being questioned. Ultimately, the problem reduces to the fact that there is too little quantitative information available, for either sediment dynamics or the effects of management treatments, on which land managers and policymakers can base their decisions.

The purpose of this study is to document and quantify erosion and sedimentation in four small semiarid watersheds in the tectonically active San Gabriel Mountains of southern California. Using sediment collector traps, repeated surveys of permanent cross sections, and colored rock tracers, this project monitors 1) surface sediment transport on hillsides, 2) hillslope sediment delivery to channels, 3) channel sediment movement, and 4) small watershed sediment yield. Concomitantly, this investigation may provide some indication of the long-term (35-year) effectiveness and consequences of several specific postfire emergency rehabilitation treatments (type conversion, contour trenching, and channel checks) whose persistence and influence are still apparent on the landscape. This paper reports the first-year measurements of a multi-year study that includes future burning treatments.

The results of this project should serve as fundamental building blocks for a comprehensive predictive model of small watershed sediment yield for southern California catchments subjected to several land management treatments. They will also provide benchmark data against which the performance of existing models can be evaluated. The resulting information on erosion and sedimentation behavior in small semiarid watersheds, along with the long-term effects of postfire emergency rehabilitation treatments, should aid public agencies in making land management decisions.

BACKGROUND

Semiarid geomorphic systems can exhibit extremely high rates of sediment production (Langbein and Schumm, 1958). The steep San Gabriel Mountains of southern California are an extreme example in which the high natural erosion rates are accentuated by management practices and wildfire (Sinclair, 1954; Scott and Williams, 1978). Weathered rock debris combines with organic litter to form thin, colluvial soils (DeBano, 1974). This sediment, stored on the hillslopes, is shed quasi-continuously by the processes of granular transport and mass movement (Rice, 1974), and accumulates on the banks and bed of ephemeral channels at the base of the hillsides. The stored channel sediment is then periodically scoured by surface runoff and debris flows, generated by infrequent high-magnitude storms, and routed primarily as bedload to the watershed outlet (Scott and Williams, 1978). Fire dramatically accelerates these landscape processes (Rice, 1974; Wells, 1981; Florsheim et al., 1991), prompting emergency rehabilitation treatments on the part of land managers.

Fires render the landscape susceptible to flooding and massive erosion, which endangers downstream life and property. Land management agencies strive to control the adverse impacts of accelerated erosion to both on-site environmental quality and off-site resources. While many possible options for erosion control are available (USDA Forest Service, 1992), land managers have learned from experience that it is most cost-effective and realistic to attempt to reduce erosion at the source (Rice et al., 1965).

STUDY AREA

The study area is located in the San Dimas Experimental Forest (SDEF), about 45 km northeast of Los Angeles, California (Figure 1). Situated in a front range of the San Gabriel Mountains, the SDEF is a 6945-ha research preserve administered and operated by the USDA Forest Service. The SDEF has been the site of extensive hydrologic monitoring for over 60 years (Dunn et al., 1988).

The San Gabriel Mountains, part of the Transverse Ranges geomorphic province, are an upthrust crustal block resulting from the continuing regional compression associated with local tectonic plate collision (Atwater, 1970). Uplift rates in the Transverse Ranges have been estimated to be 7.6 m/1000 years, compared to a regional denudation rate of 2.3 m/1000 years (Scott and Williams, 1978). Lithologies in the study area consist exclusively of crystalline rocks, primarily Precambrian metamorphics and Mesozoic granitics (Rogers, 1967).

Topography in the SDEF consists of a highly dissected mountain front with narrow, steep-walled canyons. Elevations in the study area range from 750 to 1050 meters. Slope profiles exhibit both summit convexities and basal convexities, as the hillslopes meet the channels in an inner gorge (Wohlgemuth, 1986). Mean slope gradients in the study area are 35 degrees. The drainage network and hillslope morphology characteristics are considered to be as much a function of the tectonic activity as denudational process (Scott and Williams, 1978).

The SDEF experiences a Mediterranean climate, characterized by hot, dry summers and cool, moist winters. Precipitation, falling almost exclusively as rain, is produced by mid-latitude cyclonic winter storms and rare late summer tropical hurricanes. Mean annual precipitation for the study area is 714 mm (62-year record), but rain during individual years can range from 1595 mm to 258 mm. Over 90 percent of the annual precipitation falls between the months of November and April, with 10 percent of the storms producing over 50 percent of the total rain (Wohlgemuth, 1986).

The soils in the SDEF are poorly developed, rocky, and highly porous. Distinct soil horizons are often lacking and the boundary between soil and regolith is very gradual (DeBano, 1974). The soils are well-drained, as the underlying decomposing rock can absorb large amounts of moisture. Particle size analysis of the surface soil material reveals the average texture to be a loamy sand (Wohlgemuth, 1986).

Vegetation in the SDEF consists primarily of California chaparral. Plant cover on south-facing slopes ranges from dense stands of chamise (*Adenostoma fasciculatum*) and ceanothus (*Ceanothus* spp.) to more open stands of chamise and sage (*Salvia* spp.). North-facing hillsides are dominated by scrub oak (*Quercus berberidifolia*) and ceanothus, with occasional woodland trees--live oak (*Quercus agrifolia*) and California laurel (*Umbellularia*

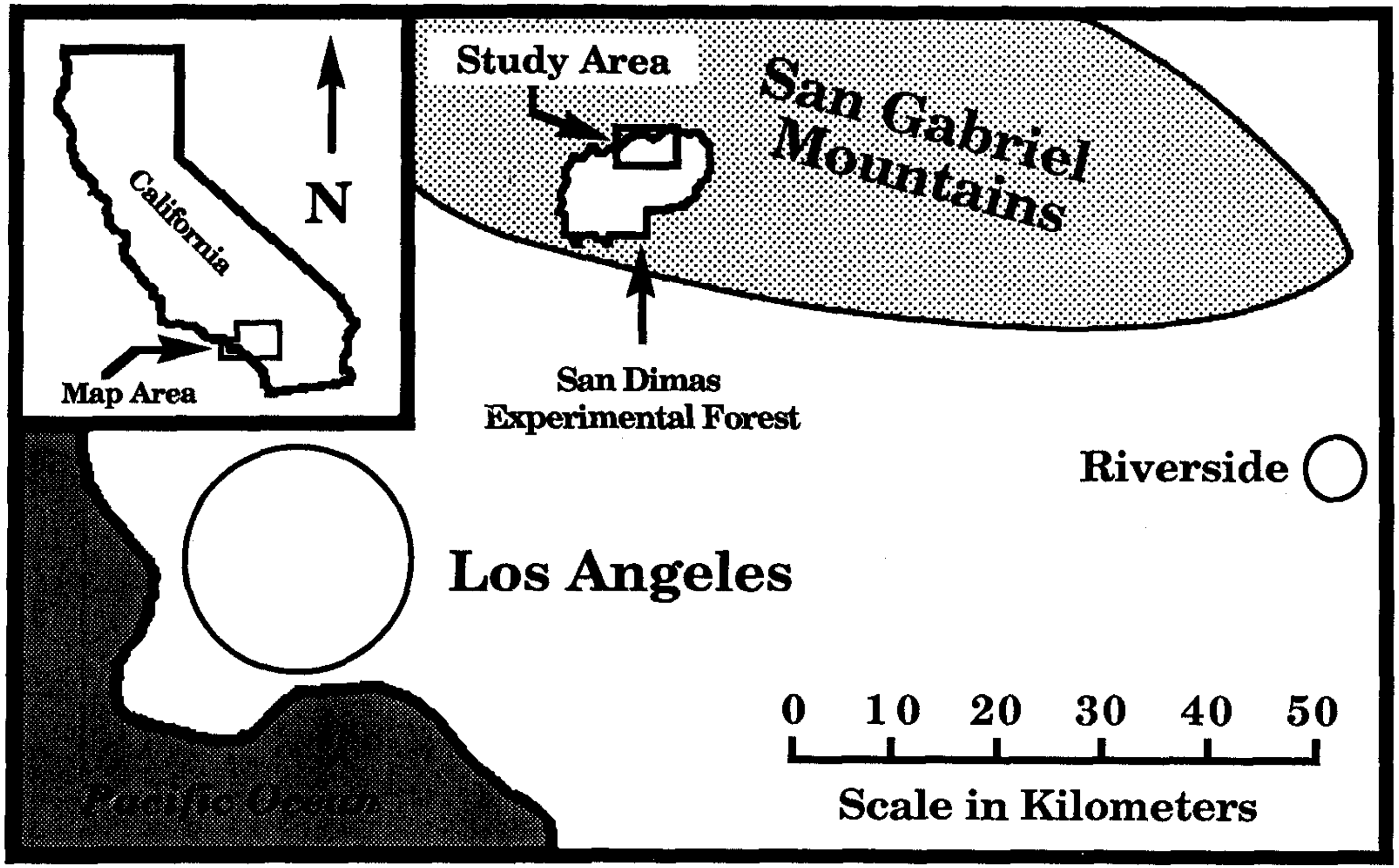

Figure 1 - Location map of the San Dimas Experimental Forest showing the study area.

californica)--occurring on the moister shaded slopes (Hellmers et al., 1955). The height of the chaparral vegetation canopy is 1-5 meters, and projected crown cover ranges from 30 to 100 percent (Wohlgemuth, 1986).

Nearly the entire SDEF burned in a wildfire in 1960, providing an opportunity to evaluate the following postfire emergency rehabilitation treatments: 1) type conversion by herbicide spraying followed by grass seeding to produce a rapid ground cover; 2) contour trenching at 12-m vertical intervals, creating platforms to interrupt overland flow and encourage onslope storage; and 3) stream channel stabilization with check dams to prevent downcutting that could undermine adjacent colluvial slopes (Rice et al., 1965). Small replicate watersheds were selected for treatment that were as similar as possible in size (0.8 to 3.6 ha), shape (elongate), aspect (south to southeast), and potential erodibility (slope, channel gradient, rockiness, and amount of colluvial soil). These watersheds were each instrumented with a debris basin to capture sediment outputs (Rice et al., 1965). Unfortunately, the subsequent winter was the driest storm season on record, so definitive results on the effects of these management treatments were never produced. Four of these small watersheds were re-activated for the current study: two in chaparral vegetation without mechanical treatments; one in type converted grass vegetation; and one in chaparral with both contour trenches and channel check dams. As only two of the watersheds are replicates of each other, the four essentially become case studies whose results are not necessarily generalizable.

METHODS

The amounts of both hillslope erosion and sediment delivery to channels were sampled using sheet metal collector traps with a 30 cm aperture on unbounded plots (Wells and Wohlgemuth, 1987). Within each of the four study watersheds, fall-line transects (from ridgecrest to channel) were established on randomly selected slope facets. Twenty five traps to document the magnitude and downslope disposition of hillslope surface sediment transport were randomly laid out *en echelon* along the fall-line transects with the constraint that at least two traps were deployed on each transect. Fifty traps to sample the amount of hillslope sediment delivered to channels were randomly laid out along the slope/channel interface of each watershed. The traps were installed in summer 1994 and allowed to equilibrate with the local ground surface. Trapped sediment was collected in February and May of 1995. Material was transported to the laboratory where it was dried and weighed.

Stream lengths were measured and channel patterns were mapped in the study watersheds following the near record storms of winter 1993, when the drainage networks were at their maximum extent. Permanent cross sections to document changes in channel bed elevation were established using notched rebar monuments. Ten cross sections were established in each of the four watersheds, distributed proportionately to the length of Strahler stream orders for each drainage network (Strahler, 1957). Initial surveys were performed in summer 1994 by measuring the horizontal distance and vertical relief from a reference pin to breaks in slope which define cross-section configuration using standard sag tape protocol (Ray and Megahan, 1978). The cross sections were resurveyed in March 1995, following the winter storm season.

Presence or absence of surface runoff in channels was determined by field inspection and mapped for the entire drainage network of each watershed. In most instances it was obvious whether or not runoff had occurred: scour was evident, fresh deposition was apparent, and/or organic debris marked the position of high water at crest stage. In a very few cases subjective decisions were made based on oriented vegetation on the channel bed surface.

Movement and routing of channel sediment were documented by measuring the distance moved by painted tracer rocks of various sizes (Keller, 1970). Tracers were laid out just downstream of the permanent channel cross sections, which served as reference lines to measure travel distance. Axial diameters, weights, and identification numbers were recorded for each rock. Tracer rocks ranged in intermediate axis diameter from 11.3 mm to 64 mm in five size classes according to the phi scale (Krumbein and Pettijohn, 1938). Five rocks of each size class were deployed at each channel cross section in summer 1994; rocks were located and their travel distance measured in March 1995.

Channel sediment outputs were captured in the debris basins at the bottom of the watersheds. Sediment yields were calculated using an engineering end-area formula (Eakin, 1939) based on the repeated sag tape surveys of permanent cross sections spaced 1.5 meters apart. Debris basin cross sections were established in summer 1993, surveyed in winter 1994, and resurveyed in summer 1995.

RESULTS

Many of the morphological differences between these four watersheds result from the persistent effects of the management treatments following the 1960 wildfire. The vegetation in the type-converted watershed is still mostly grass, although many slopes have undergone succession to buckwheat (*Eriogonum fasiculatum*) and sage. The contour trenches persist, effectively shortening the slope lengths. These contour trench platforms continue to trap sediment, but many have been breached at channel crossings, exposing the unprotected sediment prism to the agents of erosion. Most of the channel check dams are still intact. An accretionary wedge of sediment has accumulated behind these dams, radically altering upstream channel morphology. These observations cannot be generalized, however, as the watershed treatments were not replicated.

Storms during the 1994/95 hydrologic year produced 1229 mm of rainfall, 172 percent of the long-term average and the sixth largest annual accumulation on record (the 90th percentile). Nearly half of the total rain fell in January, with a secondary peak in early March.

Preliminary analysis of the weight of trapped sediment revealed that the raw data were strongly right-skewed, but the distributions were effectively normalized using a logarithmic transformation. Summary statistics of the transformed data for both the hillslope plots and the channel interface plots for each of the four small catchments are arrayed in Table 1. T-tests confirm the tabulated results: the plots in the type converted grass watershed are very highly significantly different from the plots in the chaparral vegetation ($p=0.000$), but that the chaparral watersheds do not differ from each other. Because of the lack of watershed treatment replications, however, the dramatic differences between grass and chaparral vegetation types should be taken with caution. Curiously, more sediment was captured in the hillslope traps than the channel interface traps in chaparral vegetation, although this was statistically significant ($\alpha= 0.05$) only in watershed 0508.

Evidence of surface runoff occurred in 45 to 63 percent of drainage network lengths and four to seven of the permanent cross sections in the four study watersheds (Table 1). Continuous flow was experienced along nearly the entire mainstem and at least one tributary of each watershed. Discontinuous flow was documented in most of the tributaries, with scour apparent at the flow initiation site and deposition evident at the local flow termination site. As there was no evidence of extensive hillside surface wash or rilling, the source of the water at the initiation sites was not hillslope overland flow. Rather, evidence of sapping at the head of discontinuous gullies suggests that the source of surface runoff was exfiltration of soil mantle throughflow. However, neither violent discharge nor seepage was directly observed. Several tributaries experienced no surface water flow.

The general pattern of changes in channel bed elevation for the permanent cross sections that experienced surface flow was one of filling with fine material followed by scour through these new deposits. However, in several instances, gullies incised below the original channel level. Incision and deposition in the grass watershed were absent or very subdued. In the chaparral watersheds, local gullying occurred in the steeper channel reaches, while deposition occurred in the flatter gradient reaches.

The patterns of painted rock tracer movement for those channel cross sections experiencing surface runoff are arrayed in Table 1. Overall, most of the rocks were located (~90 percent), although several individual tracer lines had recovery rates as low as ~60 percent. Many of those rocks (~35 percent) were buried in fine sediments deposited during the winter storms. These were carefully excavated then re-buried. Presumably, the rocks that were not recovered are buried at some downstream location and may be unearthed in the future. Most of the rocks exhibited little or no movement, although one tracer was located 21 meters downstream from its point of origin and several others traveled more than five meters. Plots reveal no relationship between travel distance and rock size, although recovery was less complete for the smaller size classes. Fewer tracer rocks moved and fewer were buried in the type converted grass watershed than in the chaparral catchments.

Table 1. First Year Summary Data by Watershed.

Watershed				
Identification Number	0507	0508	0542	0560
Treatment	Type Converted Grass	Chaparral with Contour Trenches and Check Dams	Chaparral with no Treatment	Chaparral with no Treatment
Area (hectares)	3.21	2.35	2.12	1.32
Stream Length (meters)	777	730	815	446
Hillslope Sediment Traps[a]				
n	25	25	25	25
Mean ($\log_{10}$ grams)	1.773	3.085	2.895	2.894
Std. Dev. ($\log_{10}$ grams)	0.617	0.472	0.282	0.341
Channel Interface Sediment Traps[a]				
n	50	50	50	50
Mean ($\log_{10}$ grams)	1.870	2.799	2.856	2.744
Std. Dev. ($\log_{10}$ grams)	0.561	0.492	0.387	0.480
Surface Water Flow[b]				
Percent of Drainage Network	59	63	49	45
Number of Cross Sections	7	6	6	4
Painted Rock Tracers[bc]				
n	175	150	150	100
Number Located	169	140	119	89
Number Buried	35	69	59	36
Number Moved	24	38	30	33
Mean Distance[d] (meters)	0.06	0.14	0.08	0.78
Median Distance[d] (meters)	0.12	0.10	0.19	0.16
Maximum Distance[d] (meters)	2.50	9.75	2.60	21.0
Debris Basin Sedimentation[b] ($meters^3$)	0	0	3	0

a - cumulative values (October 1994 - May 1995)
b - winter 1995 storm season
c - for channel cross sections with surface water flow
d - of those located

All of the debris basins filled with water from the storm runoff, but there was little evidence of new sediment accumulation. Comparison of repeated surveys of the permanent cross sections reveals that one sediment reservoir (in watershed 0542) received ~ 3 m^3 of new material, while the others recorded no changes (Table 1).

DISCUSSION

Surface sediment transport on hillslopes and sediment delivery to channels are an order of magnitude smaller in the type converted grass watershed than in catchments with chaparral vegetation. This indicates there has been a fundamental change in slope erosion behavior, presumably reflecting differences in the surface and subsurface growth habit of the dominant vegetation types, and confirms previous research findings from an adjacent watershed (Wohlgemuth, 1986). Although the hillslope erosion rates are similar in the chaparral catchments, the slightly larger values in watershed 0508 may reflect the presence of the contour trenches., It is unclear why the amount of captured debris on the hillslope plots exceeds the catch for the channel delivery plots in the chaparral watersheds.

The source of surface runoff in channels was not overland flow but rather soil mantle exfiltration. The spatial distribution of channel flow may therefore reflect a limiting depth to local bedrock, forcing subsurface water above ground. The lack of local gullying in the type converted grass watershed may reflect the presence of a larger number of bedrock channel reaches. Future surveys of channel sediment storage may confirm these ideas.

Most of the painted rock tracers did not move, even though they were subjected to relatively high-magnitude runoff. The fact that many tracers were buried in fine material indicates that sediment was indeed being transported through the drainage network, but that it consisted of particles much smaller than those represented by the tracers. Fewer tracer rocks were buried in the type converted grass catchment, possibly reflecting diminished delivery of fine material from the hillslopes. The larger travel distances of tracer rocks in watershed 0560 may have been due to runoff generated on an access trail on the catchment perimeter. This 'extra' water was conveyed into the lower third of the mainstem via a local tributary in what amounts to an unnatural extension of the drainage network.

Despite a hydrologically active storm season, sediment yield from these watersheds was negligible. The 30 cm aperture collector traps sample a slope/channel interface that is twice the total stream length. Assuming a bulk density of 1.0 g/cm^3 for the trapped debris and using the appropriate figures from Table 1, approximately 2.6 to 4.8 m^3 of sediment was delivered from the hillslopes to the channels in the chaparral watersheds, compared to ~0.5 m^3 in the grass catchment. Although much of this sediment was routed down the channel, little material reached the debris basin. Presumably, most of this newly delivered sediment filled channel storage sites flushed clean by the storms of winter 1993.

Land management treatments 35 years ago to mitigate postfire erosion and sedimentation appear to have resulted in wholesale changes in watershed morphology and perhaps sediment cycling behavior. A type converted grass watershed currently exhibits an order of magnitude less hillslope erosion and sediment delivery to channels than two comparable catchments in chaparral vegetation. A slight increase in hillslope erosion in a third chaparral watershed may stem from the presence of contour trenches. Channel morphology is dramatically different upstream of small check dams than in comparable stream sections lacking these structures. Sediment yields following the 1960 fire have long since stabilized, yet the effects of the management treatments still persist. Although these changes are not necessarily deleterious, they were certainly not anticipated. The foregoing information illuminates the consequences of several management practices in semiarid chaparral ecosystems and should aid public agencies in making more informed land management choices.

SUMMARY

This project has documented erosion and sedimentation in four small semiarid watersheds in southern California chaparral ecosystems during one hydrologically active storm season, using sediment collector traps, painted rock tracers, and repeated surveys of permanent cross sections. Findings based on first-year measurements are 1) type converted grass hillslopes seems to have transported and delivered less sediment to channels than comparable chaparral hillsides, 2) sediment grains smaller than 11.3 mm in diameter were readily scoured and deposited in the channels, and 3) sediment yield to the debris basins was inconsequential. Much of the difference in intrabasin erosion and sedimentation between these watersheds appears to be related to previous management treatments.

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Peter M. Wohlgemuth, USDA Forest Service, Riverside Forest Fire Laboratory, 4955 Canyon Crest Drive, Riverside, CA 92507, (909) 276-6274, FAX (909) 276-6426.

STIFF-GRASS HEDGES
A VEGETATIVE ALTERNATIVE FOR SEDIMENT CONTROL

S. M. Dabney, Agronomist, Oxford, MS; L. D. Meyer, Agricultural Engineer (Collaborator), Oxford, MS; G. H. Dunn, Soil Scientist, Fort Collins, CO; G. R. Foster, Hydraulic Engineer, Oxford, MS; and C. V. Alonso, Hydraulic Engineer, Oxford, MS, USDA-Agricultural Research Service

Abstract: Grass hedges are narrow strips of stiff, erect, dense grass planted close to the contour. When planted across concentrated flow zones, they can retard and spread out surface runoff, cause deposition of eroded sediment, and prevent ephemeral gully development. Coarse, hedge-forming grasses can withstand concentrated flows that would bend and overtop finer vegetation. Strips of switchgrass, vetiver grass, eastern gamagrass, eulalia, and fescue were studied in specially designed flumes to develop a stage-discharge relationship based on vegetation properties and to evaluate the sediment-trapping effectiveness of hedges in concentrated flow channels. Backwater depths were increased by the introduction of sediment into the flow as plant residues accumulated on the hedges. Vetiver grass and switchgrass demonstrated the greatest ability to withstand high flows, and 0.3-m wide hedges of each ponded backwaters as deep as 0.4 m. For slope of 0.05 and flow rates ranging from 0.005 to 0.04 $m^3sec^{-1}m^{-1}$, almost all sediment coarser than 0.125 mm was trapped in a delta formed downslope of a hydraulic jump, while 80% of sediment finer than 0.032 mm passed through the hedges. Trapping of intermediate sizes depended on the flow rate, ponded depth, and sediment density. Ongoing field trials have highlighted several practical aspects of applying this emerging erosion control technology.

INTRODUCTION

Vegetative barriers are narrow permanent strips of stiff, erect, dense, perennial vegetation established along the general contour of slopes but crossing concentrated flow areas at convenient angles for farming (Dabney et al., 1993). Stiff-grass hedges are a subset of vegetative barriers and have potential for reducing sheet, rill, and ephemeral gully erosion and trapping sediment on cropland (Kemper et al., 1992; McGregor and Dabney, 1993; Meyer et al. 1995). The design spacing and the lateral extent of vegetative barriers in concentrated flow zones depend on runoff rate, sediment load, topography, and the density of the vegetation being established (Dabney et al., 1993).

Conventional grass buffer strips and filter strips can often fail where flow concentrates because the grass becomes submerged or inundated with deposited sediment. Stiff erect grasses extend the range of conditions where grass strips can control runoff and sediment yield by withstanding higher flow rates and deeper sediment deposits. In situations where sediment loads are high, deposition upstream of hedges can significantly flatten concentrated flow areas over time, further spreading and dispersing runoff. The ability to regrow after sedimentation enables stiff grass hedges to restore their trapping capacity after each deposition event.

Although stem stiffness may have only secondary effects on flow resistance once vegetation is overtopped, stem stiffness clearly is important in determining when tall vegetation will fail and become inundated by the flow (Dunn and Dabney, 1996). The product of stem density (M) with stem modulus of elasticity (E) and moment of inertia (I) reflect the overall resistance of a grass to bending under the forces of flowing water. Both drag forces and hydrostatic forces, caused by a much shallower flow depth on the downstream side than on the upstream side, are involved when flowing water bends stiff-grass hedge stems. Sediment depositing on non-vertical stem and leaf surfaces further adds to the forces causing grass stem bending (Dabney et al., 1995).

The objective of this report is to provide an overview of recent research findings and experience concerning the role of stiff-grass hedges in soil and water conservation.

STANDARDS

A U.S. working group composed of scientists from several agencies (Kemper et al., 1992) began evaluating grass hedges in 1988. The working group prepared a draft interim standard for "vegetative barriers" and submitted it to USDA-Natural Resources Conservation Service (NRCS; then the Soil Conservation Service) in the summer of 1993 (Dabney et al., 1993). NRCS distributed the draft standard to all its National Technical Centers and seven states (Virginia, New Jersey, South Carolina, Mississippi, Puerto Rico, Hawaii, and Iowa) were identified to develop interim state standards and conduct field evaluations.

Purposes: As set forth in this standard, vegetative barrier systems may be designed to:

1. Reduce soil loss by causing deposition of eroded sediment on hill slopes.
2. Facilitate benching of sloping topography.
3. Retard and reduce surface runoff by promoting detention and infiltration.
4. Disperse concentrated flow and prevent ephemeral gully development.
5. Divert runoff to a stable outlet.
6. Entrap sediment-borne and soluble contaminants and facilitate their transformations.

Criteria: Design criteria were suggested for each of the six purposes (Dabney et al., 1993). Minimum mature barrier tiller density of 2000 stems m^{-2} and minimum mature barrier width of 0.3 measured 0.05 m above the soil surface were specified. Vegetation must be managed to maintain a standing height of at least 0.2 m.

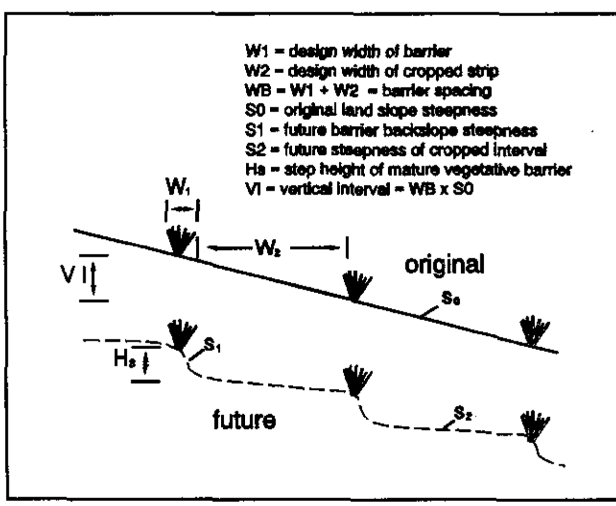

Figure 1 Schematic definition sketch of grass hedge system illustrating expected changes in land slope over time resulting from tillage and erosion/deposition processes.

Figure 1 is a definition sketch of a system of vegetative barriers. The size (design width of barriers in the downslope direction, W_1 in Fig. 1) and spacing (WB, width of barrier plus cropped interval) of a system of vegetative barriers depend on a number of factors. The maximum vertical interval ($VI = WB \times S_0$) in the standard is the lesser of 2 m (USDA-Soil Conservation Service, 1954) or the spacing calculated from terrace formulas (NRCS Practice Standard 600-1). Barriers should be parallel and as near the contour as practicable. Following the NRCS practice standard CONTOUR FARMING (330), average barrier grades should not exceed 0.4 percent. Deviations with gradients of 1 percent over continuous distances of up to 60 m are permissible to improve alignment.

In concentrated flow situations (purpose #4), hedges may be continuous, crossing the entire hillslope, or discreet with length sufficient that design flows do not pass around its ends. In these areas, maximum VI is reduced to 1.3 m, hedges must be at least two rows wide, vegetation must be maintained at a height of at least 0.4 m, and stem diameter must be at least 3 mm at 0.4 m height. No along-hedge gradient restrictions apply within the area of impounded water for the 10-yr design storm after 20 yrs of sediment deposition.

EXPERIMENTAL METHODS AND RESULTS

Stage-Discharge Relationship: Dabney et al. (1996) conducted a series of flume experiments to develop an equation to predict backwater depth as a function of flow and grass hedge characteristics. Strips from 0.15 to 0.5-m wide of switchgrass (*Panicum virgatum* L.), vetiver grass (*Vetiveria zizanioides* (L.) Nash.), eulalia (*Miscanthus sinensis* Anderss.), and eastern gamagrass (*Tripsacum dactyloides* (L.) L.), plus tall fescue (*Festuca arundinacae* Schreb.) for comparison, were studied in specially designed flumes. Backwater elevations were determined for clear-water flows, **q**, ranging from 0.001 to 0.093 $m^3sec^{-1}m^{-1}$, typical of those occurring in upland runoff channels. Slopes of 0.03, 0.05, and 0.07 were initially tested for flows above 0.023 $m^3sec^{-1}m^{-1}$. Backwater depth was found to be nearly independent of flume slope, and all other tests were conducted with slope a of 0.05. Preliminary analysis of the data indicate the increased water depth at the upstream edge of a grass hedge can be expressed as:

$$\textbf{Increased STAGE}(\text{cm}) = 0.000341\ \textbf{RE}^{1.07}\ \textbf{VEG}^{0.17}\ \textbf{LEAF}^{0.47}, \qquad \textbf{RE} < 11{,}700$$

$$\textbf{Increased STAGE}(\text{cm}) = 0.0762\ \textbf{RE}^{0.49}\ \textbf{VEG}^{0.17}\ \textbf{LEAF}^{0.47}, \qquad \textbf{RE} > 11{,}700 \qquad [1]$$

where **RE** = **q**/ν, Reynolds Number, dimensionless (ν is kinematic viscosity of water, q is the specific flow rate); **VEG = DIAM*M*WIDTH**, dimensionless (**DIAM** = stem diameter (cm), **M** = stem density (number/cm^2), and **WIDTH** = hedge width (cm), all measured at 5 cm height above ground); **LEAF** = dimensionless number related to the number of leaves of a specific grass relative to the number for "typical" grass (**LEAF** = 0.5 for switchgrass, 2.0 for vetiver grass, and 1.0 for the other grasses studied). Equation [1] indicates that the stage-discharge relationship was a bimodal function of flow, being nearly a linear function of Reynolds number up to 11700 and a 0.49 power function at higher values. Backwater depth was also a fractional (0.17) power function of stem density, stem diameter, and hedge width.

In subsequent studies, backwater depths were found to be increased by the introduction of sediment into the flow as the hedges became loaded with plant residues (Meyer et al., 1995; Dabney et al., 1995). For field applications, crop residues and duff expected to be caught on hedges can be accounted for by modifying the value of **LEAF** in equation [1]. The **LEAF** value may need to be more than doubled depending on the normal number of leaves, the amount of residue involved, and the uniformity of the hedge.

Sediment Trapping: Deposition of sediment upslope of the grass is the primary mechanism for trapping sediment by grass hedges (Dabney et al., 1995). Grass hedges do not filter sediment because they have relatively large flow spaces. Only large material such as fibrous plant residues are trapped by filtration. Sediment trapping efficiency depends on the ponded depth (hedge density and flow rate), backwater length (slope), flow rate, and sediment size and density.

Hillslopes: Grass hedges generally trap about 2/3 of the sediment generated on small plots (McGregor and Dabney, 1993; Dabney et al., 1993). Observation of field plantings indicate that hedges and associated parallel tillage marks cause considerable redirection of runoff flows to localized low areas. Thus, hedges act somewhat like terraces in reducing effective slope lengths and can thus reduce erosion as well as sediment yield.

Concentrated Flow Situations: Where flows concentrate, slope has a major impact on the length of the ponded area, and hence on sediment trapping. Meyer et al. (1995) showed that for 0.05 slope and flows between 0.005 and 0.04 $m^3 sec^{-1} m^{-1}$, trapping efficiency of effective hedges was above 90% for sediment particles larger than 125 μm diameter and about 20% for sediment smaller than 32 μm. Between these sediment sizes, trapping effectiveness decreased with increasing flow rates. The 20% trapping of sediment finer than 16 μm reported by Dabney et al. (1995) was greater than predicted by settling theory, suggesting some unidentified mechanism was operative in removing fine sediment.

Hedge Failure Prediction: A hedge's strength is related to its stem density, its stems' moments of inertia and modului of elasticity, and, to the extent that stems interact, its width. Dunn and Dabney (1996) found that the modului of elasticity of stems of several hedge grasses increased with stem age until maturity, becoming similar to that for wood. In flume studies, vetiver grass and switchgrass had the greatest ability to stand against high flows; 0.3-m wide hedges of each stood against backwater depths as great as 0.4 m. Vetiver grass developed its strength from large diameter stems, whereas switchgrass hedges were stable because of the high modulus of elasticity of its mature stems and and the smaller hydrostatic loads resulting from lower leaf density. To avoid localized failure, a balance between a hedge's resistance to flow (causing hydrostatic loading) and strength (to resist bending) is needed.

DISCUSSION

Practicality of Narrow Contour Strips: The relaxation of along-hedge grade restrictions in concentrated flow areas makes layout of and farming between hedges easier than following true contours through incised areas. However, successive parallel hedges cannot remain on the contour when they cross areas of variable slope steepness. Similarly, allowable hedge spacing, WB, will vary with slope. In designing hedge systems for variable landscapes, one approach is to select a constant hedge spacing based on the steepest 30% of the field that is a convenient multiple of the working width of the field equipment. Keeping the hedges parallel is important to facilitate field operations. Where variable slopes cause excessive deviations from the contour, extra hedges can be included on the gentler slopes in order to keep hedges on steeper slopes close to the contour. If planting direction is reversed around the end of each extra hedge, and the subsequent hedge is continued across the steeper area in parallel with the previous hedge, only a small area of cropland will be lost and no point rows will be created.

Need for Tile Drainage: Where hedges cross swale areas, sediment deposition will result in reduced slopes and loose, unconsolidated sediment. Wheel ruts in this sediment, combined with residues trapped on the hedges, have been observed to significantly impede surface drainage, thus lowering cropland productivity and interfering with field operations. A porous drainage tile may be buried perpendicular to grass hedges near the location where they cross concentrated flow areas to avoid these difficulties.

Maintenance Requirements: Any vegetative erosion control practice requires maintenance. However, grass hedges generally require less maintenance than waterways, buffer strips, or filter strips because sediment deposits do not need to be redistributed throughout the field. Also, repair of washouts is restricted to a narrow area of vegetation. When hedges are established from seed, washouts are likely to occur in concentrated flow areas during the establishment year. These areas can be repaired with transplanted vegetation the following year (Dewald et al., 1996).

Allowable Erosion: Erosion control by grass hedges increases progressively over time. In the establishment year, hedges afford little erosion control beyond the area planted to grass and the near-contour tillage marks created between them. Hedges and tillage marks tend to redirect flows and cause flow concentration to occur higher in the landscape.

Considerable soil movement must occur to bench landscapes. A planner must decide at the outset how much erosion will be temporarily tolerated with the understanding that runoff and erosion control will increase with time.

Tillage Erosion: Away from concentrated flow areas, soil movement by water erosion will be greatly reduced by grass hedges. In these areas, movement of soil by tillage (Lindstrom et al., 1992; Govers et al., 1994) will be the predominant factor causing benching of agricultural lands. In no-till situations, little landscape benching will occur.

Landscape Evolution: As hedges become established, they begin to trap sediment and the slope of the landscape between the hedges becomes reduced as a result of tillage erosion and erosion/sedimentation processes. Incised areas where flows concentrate are most rapidly filled as sediments from large areas are deposited in localized deltas. Flows immediately below hedges crossing swales may retain considerable erosive power and cause rills to develop. Tillage will smooth these areas, but the net effect will be an accelerated benching of the landscape (Fig. 1) in concentrated flow areas. This benching will continue until the backwater from a downslope hedge submerges the base of the next hedge upslope. The steepness of a stable backslope of the mature hedge (S_1, Fig. 1) will determine the required design hedge width.

Hedge Regrowth: Grass hedges are not static. After sedimentation, future growth of the grass can renew its stem density and height, and thus its flow retarding and ponding capacity. As sediment deposits in the deltas, depth of rooting increases, as does the ability of the soil to store the supplemental water carried to swale areas with runoff. These conditions may facilitate more plant growth than occurred previously in the ephemeral gully area, or possibly than is occurring on the rest of the watershed. This increasing vegetative growth adds to the stability of the delta and further slows flow over its surface allowing more sediment to settle. These propitious conditions for diffusion of the flow, increased plant growth, and sediment deposition are contingent on the long term ability of the grass hedge to tolerate the growing head loss across it, while preventing development of erosion channels down the steep slope which it occupies.

As an equally or more robust hedge grows on top of a broadening deposited delta (i.e. Fig. 2), future sediment trapping capacity of the hedge will be greater than that of the initial hedge because the flatter slope and broadened flow area result in larger water and sediment storage capacities, increased settling opportunity time in the longer backwater, and lower specific flow rates through the hedge.

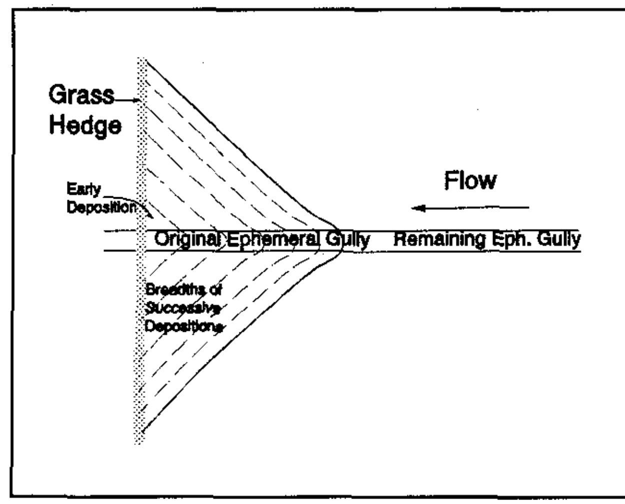

Figure 2 Progressive delta development and flow dispersion where stiff grass hedges impede a concentrated sediment-carrying flow.

Accurate estimation of long-term barrier sediment trapping performance requires that consideration be given to how evolution of the slopes affects hedge density and hydrology. Current generation erosion models have not yet been configured to allow for the dynamic modification of slopes needed for the long-term simulation of these processes.

Trapping Fine Sediment: Trapping of fine sediment is of particular concern because this fraction is frequently associated with contaminants which impair water quality. The capacity of any grass barrier to trap sediment depends on its hydraulic resistance, on the particle size distribution of the sediment source (Foster et. al, 1985; Meyer et al., 1992), on flow rate, and on the topography of the flow area. If flattening of the land caused dispersion of the flow sufficient to reduce a specific flow rate from 0.043 to 0.0055 m^3/sec-m, trapping of 23μm sediment could be increased 10 fold (Dabney et al., 1995). Further, if lower slope steepness caused settling distances to be longer than 7 m, trapping of 12 μm sediments could be increased to 50%.

Applicability to Flood Plain Situations: Grass hedges can be utilized on flat lands where water quality is an important concern. Hedges can be placed along field borders or near the top of slope breaks to ensure uniform over-bank flow. Utilization of subsurface drainage and drop-pipe inlets to facilitate drainage is especially important in lands with small slope.

Application to Construction Sites: Grass hedges offer an attractive and effective alternative to silt fences on construction sites. The need for rapid establishment and the high value of the area being protected make vegetative establishment most practical in these areas. While it is easy to kill or remove grass hedges to bring construction sites to final grade, a more efficient approach would be to cut areas close to final grade prior to hedge establishment, bury a porous tile under the hedges to facilitate drainage, and allow the hedges, with any benches that form from trapped sediment, to remain as part of the permanent landscaping.

Using Hedges with Other Vegetative Conservation Measures: Grass hedges are not a complete conservation system by themselves. They can be used most efficiently in conjunction with other practices such as conservation tillage and terraces. Following are some of the ways that hedges can be used with other vegetative erosion control technologies.

Waterways: Waterways are designed to remove water from a field under controlled conditions. In some situations, grass hedges can preform the same function even though their alignment is perpendicular to the direction of runoff flow. Hedges "step" water down the slope, relying on deposition of sediment to cause progressive leveling that disperses and slows runoff. Waterways to some extent preclude optimal hedge functioning because they prevent deposition of sediment in the lowest parts of the swale. Where flow conditions do not exceed hedge strength, a suitable merging of these technologies may be to leave small sodded areas below each hedge to control local erosion on hedge backslopes while allowing crop production above each hedge to facilitate benching. Where flow conditions exceed the capacity of hedges alone, hedges may serve to help stabilize waterways and to prevent flow parallel to but outside the waterway.

Buffer Strips: Buffer strips are similar to hedges except that they are wider, have less stringent contour alignment criteria, and require sediment berms to be periodically removed and redistributed on the land. Hedges established just upslope of buffer strips where they cross swale areas could reduce failure of buffer strips caused by flow concentration.

Filter Strips: Filter strips are graded areas of vegetation located along field boarders. Grass hedges incorporated into the upslope portion of filter strips could minimize grading requirements by vegetatively ensuring dispersal of flows entering the filter strips. Hedges would also increase filter strip longevity by promoting sediment deposition above the filter strips.

Riparian Buffer Zones: Riparian buffer zones are similar to filter strips but usually include woody vegetation as well as grasses. Grass hedges could again be used to advantage at the upslope edge of such vegetation zones.

Soil Bioengineering: To date most soil bioengineering technology has been restricted to the utilization of woody vegetation (USDA-SCS, 1992). The purposes of soil bioengineering are very similar to those of grass hedges so these technologies should be coordinated. More research is needed to identify the most compatible combination of woody and grass plants for each local condition.

CONCLUSIONS

Cross-slope grass hedges are an emerging technology that can help control erosion and sediment yield from cultivated fields and disturbed sites. Their greatest potential appears to lie in their use as a guide for near-contour cultivation, as a method of trapping sediment and controlling ephemeral gully development in concentrated flow areas, and as a leading edge to buffer strips and filter strips to ensure more uniform entry of runoff into these more extensive areas of vegetation. Where runoff concentrates, leading strips of tall stiff grasses can augment and extend the life of wider riparian filters by increasing sediment deposition above such filters and by spreading-out runoff to reduce preferential flow through such filters.

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SEDIMENTATION POND AND WATER QUALITY CONTROL STRUCTURE McGHEE TYSON AIRPORT KNOXVILLE, TENNESSEE

Authors: **Tom Lindquist, P.E., Director of Engineering, McGhee Tyson Airport, Knoxville, TN; K. Flint Holbrook, P.E., Manager, Stormwater Section, SC Department of Health & Environmental Control, Columbia, SC; John C. Hayes, P.E., Professor, Agricultural & Biological Engineering, Clemson University, Clemson, SC; Bob Steele, Hydrologist, The LPA Group, Inc., Columbia, SC**

Abstract: The events leading to the construction of a sedimentation pond and water quality control structure at a major air carrier airport in Tennessee will be discussed. During the placement of 4.8 million cubic yards of compacted earth fill for a 3,000 foot runway extension, sediment-laden storm water was discharged into the Tennessee River. The sedimentation pond controls the quality and quantity of storm water being discharged from the airport. In addition, the pond provides flexibility in the event of a major chemical spill. Design, construction and operation details are discussed.

INTRODUCTION

McGhee Tyson Airport is located 15 miles south of Knoxville in East Tennessee. The airport serves four major passenger airlines, seven commuter airlines, three cargo airlines, a wing of the Tennessee Air National Guard and extensive corporate and general aviation users. In May 1989, the Airport Authority entered into a contract with Metric Constructors for a 3,000 foot extension to runway 5R. This involved placement of 4.8 million cubic yards of earth fill, relocation of a roadway and extensive utility and storm sewer system improvements. Approximately one million cubic yards of material was to be removed from property adjacent to the extension and the remainder from a borrow area a mile away. The main site excavation and fill area included 267 acres. Fort Loudon Lake, the impounded Tennessee River, is three-fourths of a mile downstream of the project. The lake extends from Lenoir City up river 61 miles past the City of Knoxville. There is extensive residential and commercial development adjacent to the lake, plus significant recreational use.

During the summer and fall of 1989, the contractor began excavation in the entire 267-acre main site, with plans to cease operations for the winter. The month of December was unusually cold for the Knoxville area, and the exposed soil froze several inches deep. In January 1990, heavy rains caused excessive erosion, which exceeded the capacity of the erosion control measures and allowed sediment-laden flow to enter Fort London Lake.

DESIGN

Watershed description: The watershed consisted of nearly 1,500 acres with the lowest one-third disturbed. Initially, best management practices only were evaluated to control the disturbed area. This was not feasible due to off-site flow passing through the construction area. Therefore, it was determined that one structure should be constructed to control the discharge. An investigation of the watershed was conducted to set the design considerations. There were four major drainage patterns within the watershed. The land use was primarily air operations area, agricultural, residential and construction. The Airport Authority owns almost the entire drainage area.

Soils in the watershed had not been mapped by the Natural Resource Conservation Service. A field investigation and soil sampling of the disturbed area were done. A rainfall simulator and pipette of a nondispersed sample were used to estimate the eroded particle size distribution. The hydrologic soil group was determined to be C. The two conditions evaluated were during construction with the soil disturbed and post construction when stabilization was achieved. These conditions set parameters for design of the structure for sediment control and flow control.

Regulatory Considerations: The Airport Authority's engineering consultant, The LPA Group, prepared initial calculations for a sedimentation control pond. In February 1990, the State of Tennessee requested a more detailed qualitative sedimentation study. At that point, the Airport Authority authorized their engineer to retain expert sedimentologists and hydrologists. The Tennessee Department of Environment and Conservation initially required a 70 mg/l sediment concentration limit for the peak flow of a 10-year, 24-hour design storm. Further investigation found that the agricultural land use generated well in excess of this level. Therefore the existing condition could not meet this standard. A compromise was reached with the department to design for a 0.5 ml/l settleable solid concentration in the peak flow rate of the 10-year, 24-hour design storm. This standard was typical for coal mining activities in eastern Tennessee. Therefore, a volume of sediment yield was calculated and a clean out period set as well as a single storm yield to determine the effluent concentration.

The dam is of sufficient size to require a safe dam permit from the Tennessee Department of Health and Environment, Division of Water Supply. This is a small, category 2 dam that poses significant hazard and was designed to pass one-third of the PMP through the emergency spillway.

Design of the Structure: The structure was to be designed for three primary objectives. The first was for sediment control during construction of the runway extension. Second, was to attenuate peak flow rates after the construction was completed. Third, the dam would be a point of control for any chemical spills that occur at the airport. It would be a primary part of the NPDES storm water pollution prevention plan. Also, future expansions and NPDES storm water considerations were taken into account.

The watershed contained approximately nine areas where detention would occur. These included culverts under roads where temporary rock rip rap structures could be installed to gain significant storage of sediment. These areas were mapped, and several hydrologic configurations were evaluated. Soil Conservation Service methodology was used to calculate peak flow rates. Army Corps of Engineers HEC models were used to evaluate the structures. SEDCAD3+ was used to determine the sediment trapping efficiency of the controls. Design storms with a 24-hour duration were used for the calculations. Runoff from the 10, 25, 50, 100 year and one-third of the probable maximum precipitation were calculated and used for design.

During construction, a permanent pool was desired to control sediment at the required levels. However, the basin had to remain dry post-construction to prevent waterfowl from interfering with air traffic. The principle spillway is a 60-in. diameter corrugated metal pipe (CMP) perforated riser connected to a 42-in. reinforced concrete pipe (RCP) barrel. Also, connected to the barrel with 18-in. CMPs are dual 24-in. CMP perforated risers with the top capped. A 24-in. slide gate with screw rod mechanism is attached to drain the pond. During construction, this gate was closed to provide a permanent pool of two and one-half feet. Figure 2 shows details of the principle spillway. This configuration trapped 76% of the sediment influent volume in the pond and discharged a settleable solid concentration of less than 0.03 ml/l. Peak inflow for the during construction period was 1,200 cfs with an outflow of 166 cfs. Sampling of selected storm events in July of 1991, indicated that the structure was collected fine silt and larger particles. The basin trapped particles 0.011 mm and larger. This means that particles smaller than fine silt were passed through the system.

Energy Dissipator: The energy dissipator at the discharge of the principle spillway is a reinforced concrete structure. During the initial design, a rip rap stilling basin was planned. Due to the close proximity of a 12-in. high pressure natural gas line down stream of the dam, it was necessary to install the concrete energy dissipator. A type XI, Bureau of Land Reclamation, outlet structure was designed. This structure is 10 ft tall, 15 ft wide, 17.5 ft long and 2.5 ft deep. It discharges to an open channel with rip rap lining. A detail of the energy dissipator structure is shown in Figure 3. This design reduced discharge velocities to non-erosive levels for protection of the downstream channel. Further protection was provided by obtaining permission for the Airport Authority to rip rap line the channel to the intersection with agricultural land use down stream. The peak rate of discharge was reduced for the design storms as shown in the following table. The results are from a model calculated by the SCS TR 20 program.

Table A

Hydraulic Performance Table					
	Storm Return Period				
	10 Yr	25 Yr	50 Yr	100 Yr	1/3 PMP
Precipitation (Inches)	4.8	5.6	6.2	6.6	9.8
Inflow (CFS)	1415	1634	1766	1851	2673
Outflow (CFS)	160	304	645	805	1722
Water Surface Elevation (MSL)	854	856	857	857.5	858.8
Top of Dam (MSL)		860			
Principle Spillway (MSL)		60" - 850	24" - 843.5		
Emergency Spillway (MSL)		856			
Pond Bottom (MSL)		838			

Design of the Dam: The earth fill dam is designed to Soil Conservation Service standards. The top is 20 ft wide to permit access to the principle spillway by maintenance equipment. The side slopes for the dam are 5 to 1, to permit ease of mowing. A clay core was not specified since native material available for construction is impervious, a key-way was specified and the width of the dam is much wider than minimum standards. Also, the pond is operated as a dry pond. The emergency spillway is designed to pass the 1/3 PMP storm without overtopping the dam.

In May 1990, the consultants had completed studies, fine tuned a hydrologic model and conducted dam-break analysis. On June 19, 1990, the state issued final comments and a permit to construct the dam. During the summer, geotechnical studies revealed large quantities of rock in the area of the pond, requiring a redesign. In October, the runway extension contractor submitted his initial price proposal. This exceeded the funding available within the runway extension project. Negotiations through the end of the year were not fruitful in producing a project that could be funded. Late in 1990, the pond and dam construction became a stand-alone project, and the Airport Authority requested funding from the FAA. In spring 1991, the FAA issued a grant in the amount of $1,406,063, and bids were received in July. The Airport Authority and The Daniel Company signed the contract, and construction started in September 1991. The project layout is shown in Figure 1.

CONSTRUCTION DETAILS

Pond and Dam Construction: The sequencing was phased to permit the construction of the dam in the fall of 1991 and complete the excavation of the pond in the spring of 1992. The dam is 22 ft high and 1,400 ft long. The key-way for the dam was excavated to a minimum cross section of 20 ft wide by 7 ft deep and replaced with select material. The key-way and dam required 95,000 yds^3 of fill, placed in 8-in. lifts, compacted to 95% of its Standard Proctor dry density. Moisture was controlled within minus 2% to positive 3% optimum moisture content. The principle spillway conduit is a 42-in. reinforced concrete pipe with rubber gaskets. The pipe is laid on a portland cement concrete cradle, with anti-seep collars every 20 ft. The detention pond covers 28.4 ac, impounds 538 ac ft, and required the relocation of 400,000 yds^3 of soil and rock. Figure 4 shows details of the dam cross section.

Principle Spillway Structure: The principle spillway consists of one, 60-in. and two, 24-in. perforated risers to provide required detention. The top of the 24-in. risers is covered, diverting discharge to the 60-in. riser. Control is provided with four gate valves in the principle spillway. One, 24-in. gate valve permits the pond to be completely drained and operated as a dry pond, which is the normal post-construction condition. During construction, this valve was closed, creating a 2.5 ft deep permanent pool. This requires flow to pass through the perforated riser pipes. The 24-in. risers may be removed from the system by closing 18-in. gate valves on each side of the central riser. This creates a permanent pool 6 ft deep. In the event of a major fuel spill or similar emergency, the entire flow from the pond can be turned off with the 42-in. gate valve downstream from the principle spillway. This valve has been turned off once when a service contractor spilled jet fuel on the air carrier ramp; however, the fuel was collected before reaching the pond. All gate valves are easily accessible by way of a timber cat walk. With the pond completely full, it would require 3.4 days to empty with the 24-in. gate valve open.

The final cost of the dam is approximately $261,000, and the cost of the pond is $1,479,000.

Performance problems: The pond and dam have made a significant improvement in the quality of the storm water being discharged from the airport. Sedimentation deposits in Fort Loudon Lake have been reduced, peak discharge rates moderated and the factor of safety in the event of a major spill improved. Given the opportunity for improvements, the following revisions would be made:

- Install a paved invert from the three principle inflow points to the principle spillway, with the pond bottom sloped at a minimum of 1.5% to the paved invert. This would improve drainage and access for mowing the bottom of the pond.
- Increase the size of the rip rap in the energy dissipators located at the principle inflow points to prevent the rip rap from being relocated during heavy rainfall.
- Install a permanent erosion fabric adjacent to the paved invert. The paved invert in the ditches upstream of the pond are too narrow in some locations, allowing flow to erode the bank outside the defined channel.
- Install paved, small energy dissipators to prevent erosion at the location where slope drains discharge to the lateral ditches.
- Employ a temporary erosion mat on the dam to improve establishment of a good stand of grass.
- Extend the rip rap lining of the emergency spillway to the lined discharge channel. During the March 1994 storm, erosion problems were experienced when water was discharged through the emergency spillway.

CONCLUSION

This has been a worthwhile project for the Airport Authority, and we are a better neighbor in the Knoxville area because of it. The Blount County Soil Conservation District granted the Airport Authority a special conservation award in 1992 for their efforts. During a 50-year storm event in March 1994, the pond was completely full and water discharged through the emergency spillway approximately one foot deep. The pond performed according to design. The most significant improvement would be to include this type of structure in the original design of the runway extension and have it in place sooner.

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Authors: Tom Lindquist, P.E., Director of Engineering, Metropolitan Knoxville Airport Authority, PO Box 15600, Knoxville, TN, 37901, phone 423-970-2773, fax 423-970-4113, Internet tomlind@waun.tdsnet.com

K. Flint Holbrook, P.E., Manager, Stormwater Section, SC Department of Health & Environmental Control,2221 Devine Street, Suite 222, Columbia, SC, 29205, phone 803-734-9251 fax 803-??????, Internet wpo#123#dhec4005.columb35#c#holbrokf#125#@gm0.state.sc.us

John C. Hayes, P.E., Professor, Agricultural & Biological Engineering, Clemson University, Clemson, SC, phone 803-656-40777, fax 803-734-5593, Internet jhayes@prism.clemson.edu

Bob Steele, Hydrologist, The LPA Group, Inc., 2530 Devine Street, P.O. Box 5850, Columbia, SC 29250, phone 803-254-2211, fax 803-779-8749

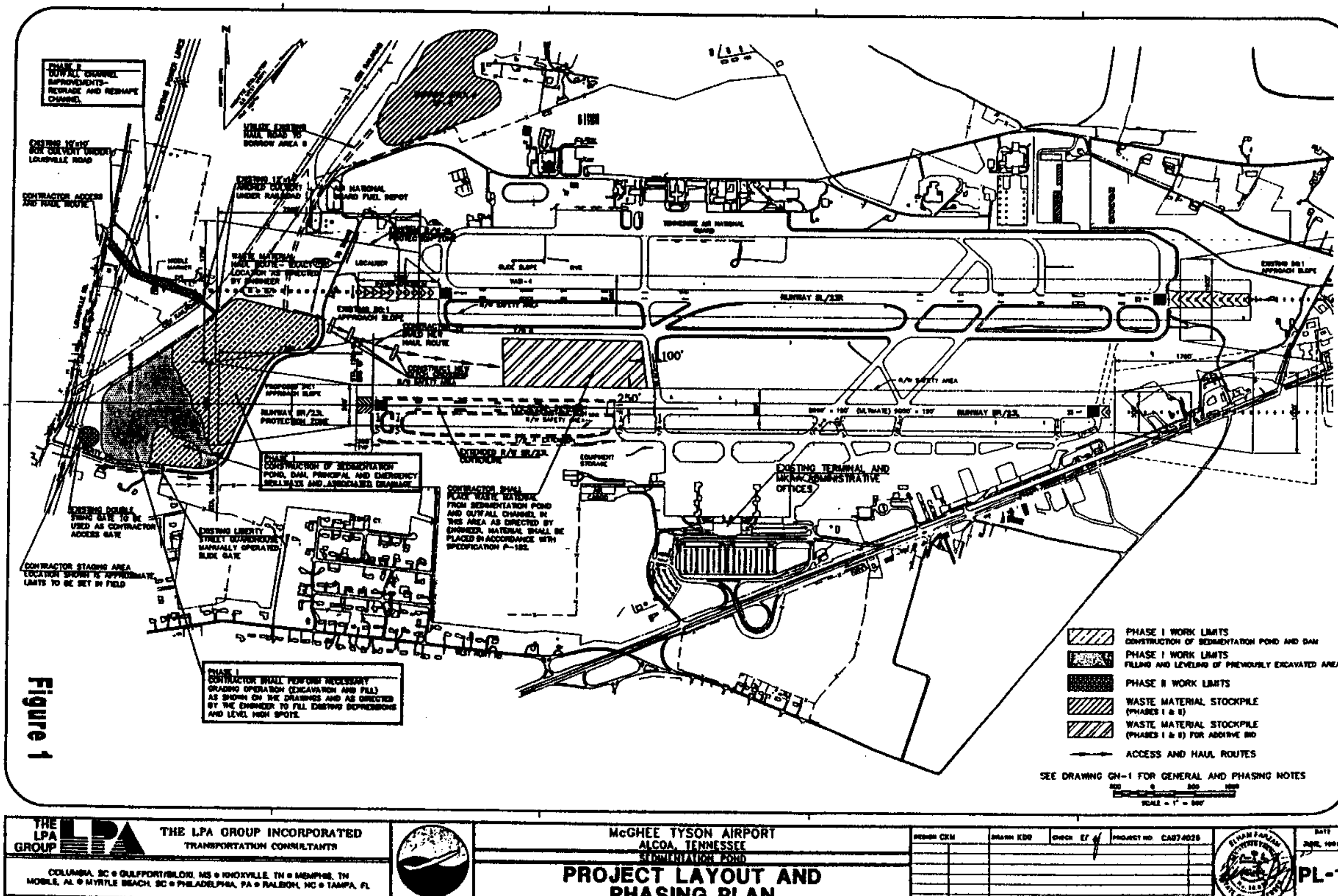
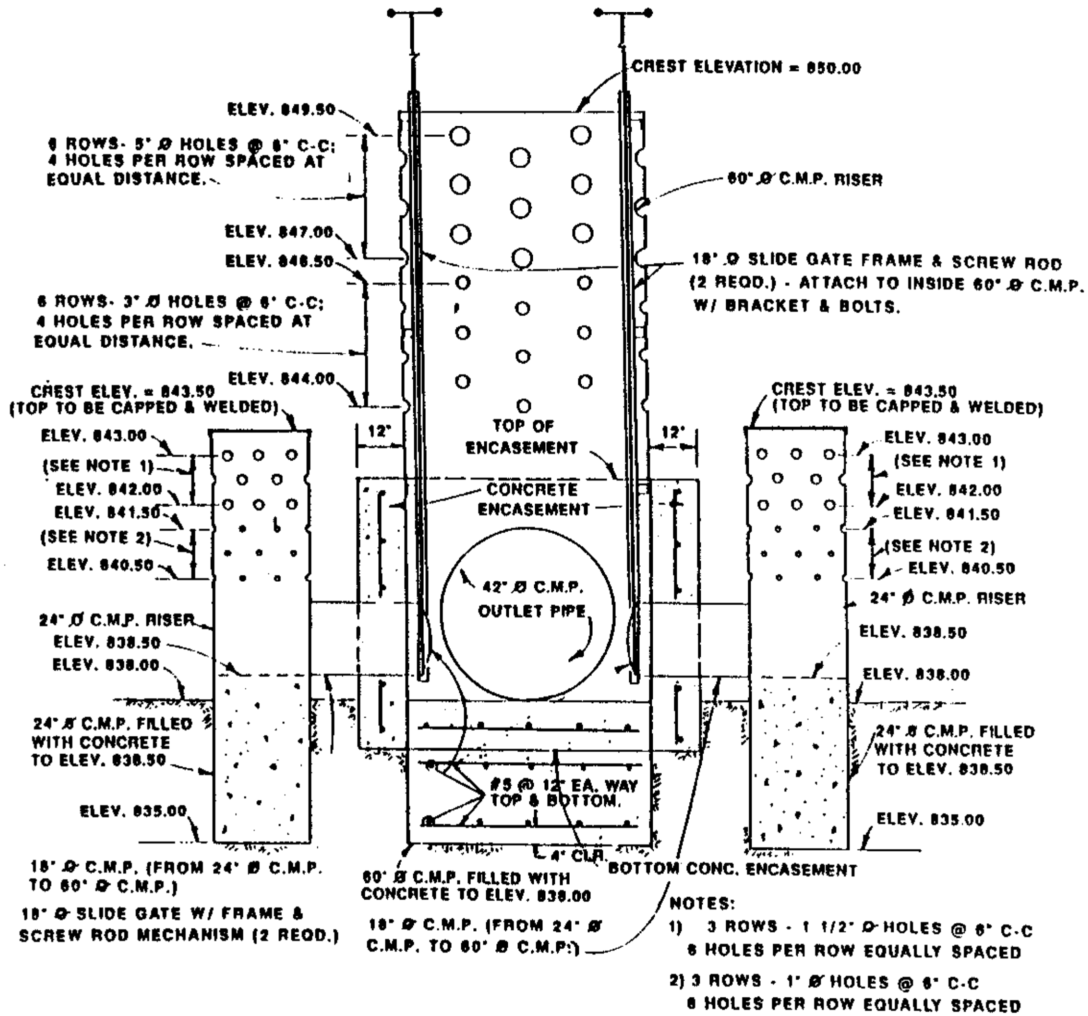
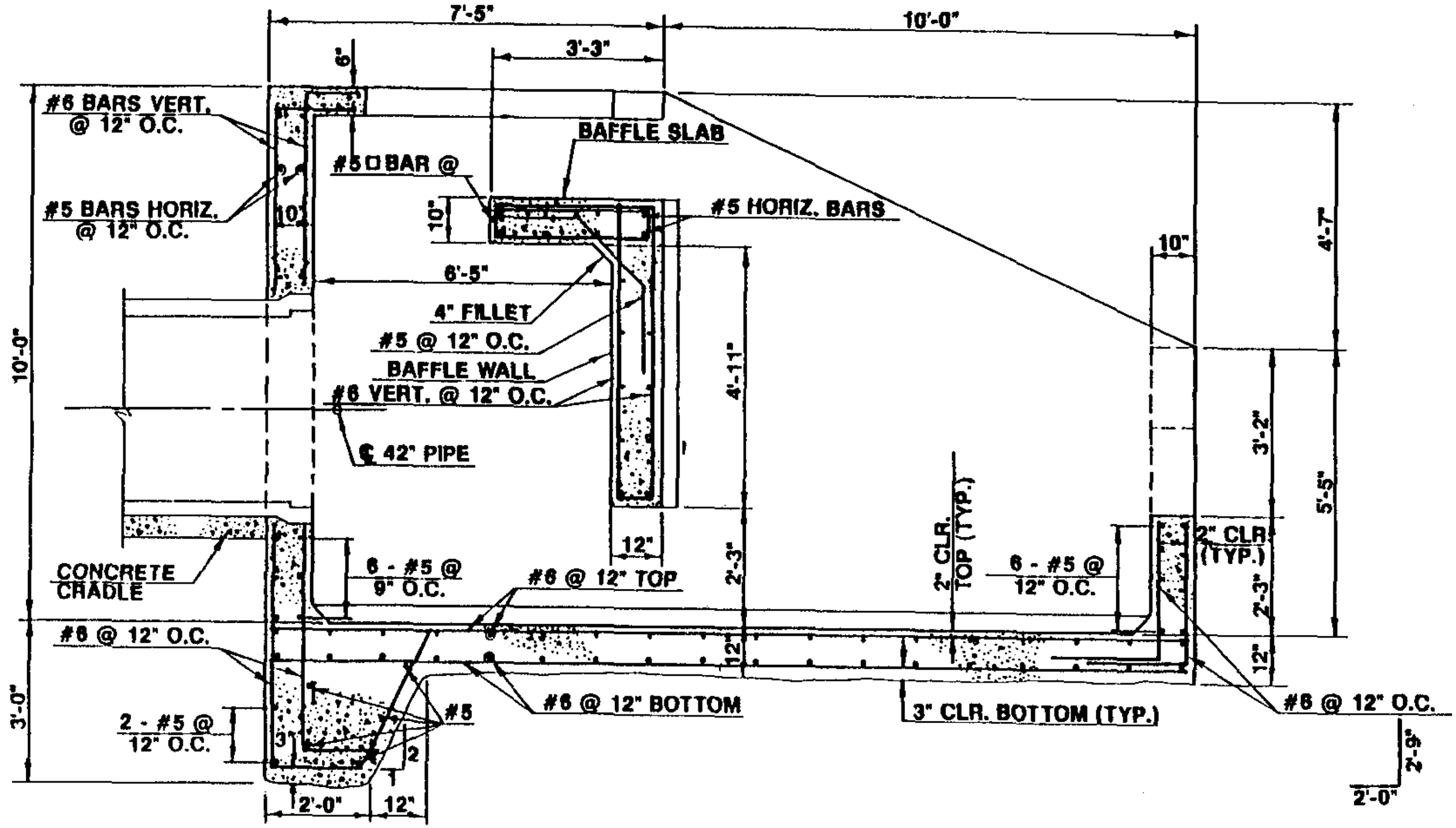


Figure 1
PHASE I WORK LIMITS
CONSTRUCTION OF SEDIMENTATION POND AND DAM
PHASE I WORK LIMITS
FILLING AND LEVELING OF PREVIOUSLY EXCAVATED AREA
PHASE II WORK LIMITS
WASTE MATERIAL STOCKPILE
(PHASES I & II)
WASTE MATERIAL STOCKPILE
(PHASES I & II) FOR ADDITIVE BID
ACCESS AND HAUL ROUTES
SEE DRAWING GN-1 FOR GENERAL AND PHASING NOTES
EXISTING TERMINAL AND MKAA ADMINISTRATIVE OFFICES
RUNWAY 5L/23R
100'
250'
THE LPA GROUP INCORPORATED
TRANSPORTATION CONSULTANTS
COLUMBIA, SC • GULFPORT/BILOXI, MS • KNOXVILLE, TN • MEMPHIS, TN
MOBILE, AL • MYRTLE BEACH, SC • PHILADELPHIA, PA • RALEIGH, NC • TAMPA, FL
McGHEE TYSON AIRPORT
ALCOA, TENNESSEE
SEDIMENTATION POND
PROJECT LAYOUT AND
PHASING PLAN
PL-1



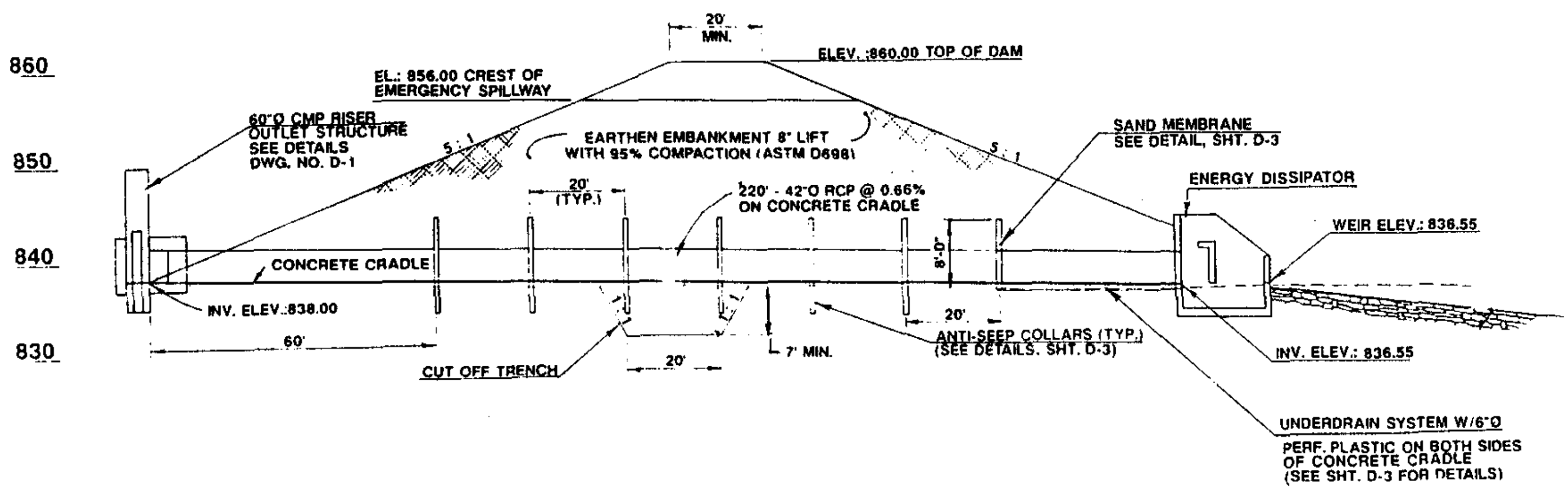
Principle Spillway

Figure 2



Energy Dissipator

Figure 3



Section Through Dam

Along Centerline of 42" Discharge Pipe

Figure 4

SEDIMENT AS A NONPOINT SOURCE POLLUTANT CAN BE CONTROLLED DURING HARVESTING OF NORTHERN HARDWOOD FORESTS

C. Wayne Martin and James W. Hornbeck, Research Foresters,
Northeastern Forest Experiment Station, Durham, NH 03824

__Abstract__: Sediment yields from undisturbed northern hardwood forests of New England are among the lowest in North America. Data from the Hubbard Brook Experimental Forest in the White Mountains of central New Hampshire indicate that sediment yields from mature forests average 40 kg/ha/yr. However, annual yields may range from 1 to 150 kg/ha/yr. Sediment yields are not related to watershed size and are not well correlated between watersheds. They are highly variable and are related more to the occurrence of individual large storms than to annual precipitation. Research at Hubbard Brook indicates that erosion and sedimentation during and after logging can be maintained within these natural background levels by strict use of Best Management Practices. Watershed 5 at Hubbard Brook was commercially whole-tree clearcut with 96% of the biomass removed and 70% of the forest floor disturbed. Yet, during the year of logging, sediment yields were the same as before logging. Sediment yields did increase significantly the following 3 years, but levels were below precutting maximums for 2 of those years, and the third year was a modest increase.

INTRODUCTION

Northern hardwood forests of New England are within a one-day drive for 100 million residents of eastern United States and Canada. Thus, streams draining these forests are highly prized for aesthetics, recreation, drinking water, municipal water supplies, and fish habitat. Maintaining high quality water in these streams has long been a priority for the general public, environmental organizations, and government agencies.

Fortunately, the soils of northern hardwood forests, especially in New England, are resistant to erosion. Organic horizons of the forest floor allow rain and snowmelt to infiltrate rapidly into the mineral soil, even in extreme rainfall events. The mineral soils are generally well-drained, coarse-textured sandy loams with high infiltration capacities. As a result, erosion rates and sediment yields from undisturbed forest lands are among the lowest in the country (Patric 1976) and erosive overland flow seldom occurs (Patric et al. 1984, Pierce 1967). Megahan (1972) showed that average stream sediment rates in New England were the lowest of 12 geographic regions in the United States. A reasonable long-term average erosion rate for undisturbed forests in New England seems to be about 30 to 40 kg/ha/yr (Bormann et al. 1974, Patric et al. 1984).

Careless logging practices, especially the poor design and maintenance of truck roads, log landings, and skid trails, can cause considerable erosion which may lead to severe sedimentation of streams (Patric 1976, 1978). Sedimentation from logging operations is the major form of water quality degradation in forest streams in the Northeast today. However, forest research over the last 4 decades has produced guidelines to help loggers, foresters, and landowners harvest timber without causing unacceptable erosion and degradation of streamwater quality (Trimble and Sartz 1957, Haussman 1960, Kochenderfer 1970, Hornbeck et al. 1986, Irland and Conners 1994). These guidelines have been incorporated in best management practice (BMP) regulations in all states in the Northeast.

Our paper uses research from the Hubbard Brook Experimental Forest to show that if these well documented guidelines are carefully followed, harvesting of forest products need not lead to excessive erosion and sedimentation.

METHODS

The Hubbard Brook Experimental Forest is located in the White Mountains of central New Hampshire. Hubbard Brook was initiated in 1955 as a watershed management research center and several stream gaging stations were established to measure streamflow from watersheds forested with northern hardwoods. The gages are sharp-crested, v-notch weirs. Each year the sediment that collects in the stilling basin behind the v-notch is measured, excavated, sampled, dried and weighed. Oven-dry weights are then calculated for all of the sediment removed from the basin and extrapolated back over the watershed as mass of soil material lost per unit area. The data presented in this paper includes both organic and mineral material that collects in the basins. On the basis of intensive studies of dissolved solids and suspended sediment, Bormann et al. (1974) suggested that, for Hubbard Brook data, an additional 2% should be added to these values to account for particulates that flowed over the notches during high flows, and 25% should be added to account for suspended sediment. The data presented in this paper do not include these additions. Annual precipitation and sediment values presented in this paper are for a water year which at Hubbard Brook is from June 1 through May 31.

The Hubbard Brook watersheds discussed in this paper are adjacent and all have south-facing aspects. They range in elevation from 450 to 800 m above sea level. Slopes average 20 to 30% with some grades approaching 70% near the ridge tops and incised stream channels. Precipitation averages 1400 mm/yr occurring at the rate of 2 storms per week. From mid-December to mid-April, precipitation occurs as snow and accumulates as a snow pack. The soils of the watersheds are generally fine sandy loams classified as Typic or Lithic Haplorthods derived from coarse-textured glacial till.

Watershed (WS) 1, 3, and 6 are reference watersheds. They are forested with mature northern hardwoods that have not been logged since 1920. Ninety percent of the basal area of these forests is sugar maple (*Acer saccharum*), yellow birch (*Betula alleghaniensis*) and beech (*Fagus grandifolia*). WS 1 is 11.8 ha in area; WS 3 is 42.4 ha; and WS 6 is 13.2 ha. All watersheds are drained by 1st- or 2nd- order streams.

WS 5 was mechanically whole-tree clearcut in the winter of 1983-84. Cutting began in October 1983 and was completed in May 1984. Skidding was not finished until June 1985. Trees were felled using a track-mounted, swing-to-tree, feller-buncher and forwarded to the landing in tree-length (including boles, branches, and tops) with articulated, rubber-tired, cable skidders. There were no truck roads on the watershed. All trees greater than 5 cm dbh were felled, and 96% of the aboveground biomass was removed from the watershed during the logging.

WS 5 is 21.9 ha in area. Skid trails were steep and occasionally exceeded 15% grade. Where they ran up and down the slope, skid trails were located on the crest of the ridges between streams on the dryest sites with convex crowns to shed water. Broad-based dips were employed, and temporary waterbars were installed as soon as the logger finished a section of the trail. Permanent water bars were installed, spaced according to percent slope, as soon as the skidding was complete. Culverts or bridges were required at all live stream crossings. Logging slash was removed from the streams by the logger. Landings were located off the watershed on dry convex sites. The operation was temporarily closed several times due to bad weather.

Soil disturbance created during the logging was measured using 81 transects, each 10 m long. After harvesting, the soil surface along 0.1 m intervals of each transect was classified into one of the following disturbance types: "undisturbed", "depressed" where the soil surface was undisturbed but depressed by a wheel or falling tree, "scarified" where mineral and organic soil were mixed, "scalped" where organic horizons were scraped off the mineral soil, "mounds" of either mineral or organic soil, wheel "ruts" lined with either mineral or organic soil, "vegetation" consisting of slash or stumps, and "bare rocks" more than 10 cm across.

RESULTS

Undisturbed Watersheds: Sediment yields from three forested watersheds at Hubbard Brook that have not been logged since 1920 are presented in Table 1.

Table 1. Annual sediment yields and precipitation for 3 undisturbed watersheds at the Hubbard Brook Experimental Forest in New Hampshire.

Year	WS 1	WS 3	WS 6	Precip.
	--------------kg/ha	--------------		mm
1975	68	35	18	1308
1976	20	10	15	1769
1977	62	29	79	1402
1978	131	37	18	1532
1979	61	47	25	1362
1980	141	64	32	1194
1981	41	25	34	1355
1982	47	28	10	1585
1983	10	11	3	1410
1984	84	47	35	1638
1985	7	5	4	1200
1986	52	45	17	1425
1987	108	71	52	1311
1988	6	4	1	1290
1989	18	19	7	1234
1990	13	24	13	1553
Mean	54	31	23	1411
C.V.(%)	81	65	87	12

The average sediment yields from these watersheds is close to the predicted long-term average erosion rate of about 40 kg/ha/yr for undisturbed forests in this region (Patric et al. 1984). Sediment yield from these neighboring watersheds was not related to watershed size. WS 1, the smallest at 11.8 ha, had the highest average yield at 54 kg/ha and consistently had higher sediment yields than the other two watersheds. WS 6, similar in area at 13.2 ha, had the lowest average sediment yield at 23 kg/ha/yr. WS 3, the largest at 42.4 ha, had an average yield of 31 kg/ha/yr.

Annual sediment yields between the three watersheds were not well correlated. The best correlation for the 1975 through 1990 period was between WS 1 and WS 3 with an r^2 of 0.849. WS 1 and WS 6 were poorly correlated with an r^2 of 0.508; as were WS 3 and WS 6 at r^2 of 0.547. Also, there was considerable variation from year to year. Sediment yield from WS 1 ranged from 6 to 141 kg/ha/yr with a coefficient of variation (CV) of 81%. WS 3 ranged from 4 to 71 kg/ha/yr with a CV of 65%. WS 6 ranged from 1 to 79 kg/ha/yr with a CV of 87%.

Annual sediment yields were not well correlated with annual precipitation (Table 1). Correlation of annual sediment yield with annual precipitation gave r^2 values of 0.004, 0.013, and 0.000 for WS 1, WS 3, and WS 6, respectively. Sediment yields from all three watersheds were lowest in 1988, which was a dry year, but not the driest year. The highest sediment yield for WS 1 occurred in 1980, the year with the lowest precipitation. Sediment yields from all 3 watersheds were below average in 1976, the year with the highest precipitation.

Harvested Watershed: WS 5 was clearcut in the winter of 1983-1984. Ninety-six percent of the aboveground biomass was removed by rubber-tired, articulated, cable skidders. Such mechanized, whole-tree clearcutting usually results in extreme site disturbance (Table 2).

Table 2. Soil disturbance caused by whole-tree clearcutting of WS 5 by percentage of the watershed in each type of disturbance. SE is standard error of the estimate.

Type	Percent	SE
Undisturbed	30.3	2.8
Depressed	3.8	0.8
Scarified	13.0	1.3
Scalped	0.8	0.8
Organic mound	12.8	1.6
Mineral mounds	5.6	1.1
Organic ruts	10.6	1.4
Mineral ruts	18.1	2.7
Vegetation	1.8	0.4
Bare rocks	3.2	0.7
Total	100.0	

Seventy percent of the forest floor of WS 5 was disturbed (Table 2). After the logging, 25% of the watershed was exposed mineral soil (types: scalped, mineral mounds, and mineral ruts), and 33% of the watershed suffered some compaction (types: depressed, organic ruts, and mineral ruts). This level of soil disturbance is typical of whole-tree clearcutting throughout New England (Martin 1988, Ryan et al. 1992).

Table 3. Annual sediment yields from WS 5, which was whole-tree clearcut with heavy, mechanized equipment in the winter of 1983-1984, and adjacent WS 6, uncut since 1920.

Year	WS 5	WS 6	Ratio 5/6
	---kg/ha---		
	Before harvest		
1975	24	18	1.3
1976	12	15	0.8
1977	134	79	1.7
1978	68	18	3.8
1979	97	25	3.9
1980	89	32	2.8
1981	41	34	1.2
1982	35	10	3.5
1983	14	3	4.7
	After harvest		
1984	64 (71)	35	1.8
1985	112* (23)	4	28.0
1986	129* (43)	17	7.6
1987	208* (97)	52	4.0
1988	6 (18)	1	6.0
1989	15 (28)	7	2.1
1990	44 (37)	13	3.4

Sediment yields from undisturbed WS 6 and whole-tree clearcut WS 5 were compared using two different techniques. First was the calculation of a simple ratio between WS 5 and WS 6 since WS 5 usually produced more sediment than WS 6 (Table 3). Prior to cutting WS 5 produced as much as 4.7 times as much sediment as WS 6. During the 7 years immediately following cutting WS 5 exceeded this ratio 3 times. In 1985, WS 5 yielded 28 times as much sediment as WS 6, but the total annual yield was only 112 kg/ha which was less than the maximum precutting yield of 134 kg/ha of 1977. In 1986, WS 5 yielded 7.6 times as much sediment as WS 6, but again this was well within the precutting range of sediment yield. In 1987, WS 5 yielded 208 kg/ha of sediment which was greater than the precutting peak of 134 kg/ha from WS 5 or the 141 kg/ha from WS 1, but the ratio between WS 5 and WS 6 was only 4.0 or less than the maximum precutting ratio of 4.7.

Second, a regression technique was used to compare sediment yield between WS 5 and WS 6. A linear regression and associated 95% confidence intervals were established between sediment yields from WS 5 and WS 6 for a 9 year, preharvest, calibration period. In the 7 years following harvest, increases in annual sediment yield were attributed to the harvesting operation if they exceeded the 95% confidence intervals. In Table 3, the numbers in the parentheses were determined from the preharvest regression, and are estimates of sediment loss if the watershed had not been cut. Values with an asterisk exceeded the 95% confidence interval about the regression and increases over the predicted values were attributed to the harvesting.

Before cutting, sediment yields from WS 5 ranged from 12 to 134 kg/ha/yr. After cutting, sediment yields ranged from 6 to 208 kg/ha/yr. Regression techniques indicated that sediment yields in 1984, the year of the cut, were similar to precutting levels despite receiving 309 mm of precipitation in May alone. Values for 1985 through 1987 exceeded those that could have been expected if the watershed had not been cut. The 1987 value was twice the predicted value and exceeded the previous maximum by 74 kg/ha/yr.

DISCUSSION

Erosion and sedimentation are natural processes. In the 12,000 years since the last glaciation, the landscape of the Northeast has been shaped by the forces of erosion. Even today, watersheds covered by forests that have not been disturbed by humans for decades are continuously eroding and supplying sediment to streams. Sixteen years of measurements at the Hubbard Brook Experimental Forest (HBEF) in the White Mountains of central New Hampshire indicate that the average erosion rate from watersheds covered with northern hardwood forest undisturbed by humans for more than 70 years is from 23 to 54 kg/ha/yr. Fortunately these erosion rates are among the lowest in the country.

Erosion and sedimentation rates from undisturbed watersheds in the Northeast vary tremendously from year to year, and watershed size has little to do with this variability. Also, erosion and sedimentation rates are not closely related to annual precipitation amounts. At the HBEF, the year with the lowest annual precipitation actually produced the highest annual sediment yield in one watershed. The highest sediment yields from each of the three watersheds occurred in different years and all three years were with below average precipitation. The year with the lowest sediment yield was the same for all three watersheds but it was not the driest year. High sediment yields from undisturbed forest are associated with individual large storms or snowmelt events rather than exceptionally wet or dry years.

It is well known that careless logging practices, particularly the poor design and maintenance of truck roads and skid trails, can cause considerable erosion and sedimentation (Patric 1976, 1978). However, a long history of forest research in the Northeast has produced a series of guidelines to help loggers, foresters, and landowners harvest timber without degrading streamwater quality (Trimble and Sartz 1957, Haussman 1960, Kochenderfer 1970, Hartung and Kress 1977, Martin and Hornbeck 1994).

Silvicultural activities, including logging, were designated potential nonpoint sources of water pollution by the 1972 Clean Water Act and by the 1987 Water Quality Act. To comply with these Acts, all states in the

Northeast have used guidelines produced by forest research to establish Best Management Practices (BMPs) to control erosion and sedimentation from forest lands. For the harvested watershed discussed in this paper, the logging techniques required by BMPs for the state of New Hampshire were used to effectively control erosion and sedimentation, even on a mechanical, whole-tree clearcut where 70% of the soil was disturbed. The BMPs included guidelines for:

1. Steepness of truck roads and skid trails.

2. Water control devices, including the construction and spacing of waterbars and broad-based dips.

3. Culverts, including type, size, spacing, and installation recommendations, such as ditch construction when seeps are involved.

4. Buffer strips of trees along stream channels to provide shade and a source of woody debris.

5. Filter strips of undisturbed land between disturbed sites and streams to trap sediment.

6. Filter devices such as hay bales to prevent sediment from flowing from a road, skid trail, or landing directly into a stream.

7. Minimizing the addition of logging slash and tree tops to streams and removal of this material when necessary.

8. Crossing of streams by roads or skid trails using culverts or bridges.

9. Location of landings, and control of petroleum products and human waste.

10. Closing of logging operations during unfavorable weather.

11. Closing and rehabilitation of roads, landings, and skid trails which often involves grooming, seeding, and mulching.

CONCLUSION

Sediment yields from undisturbed northern hardwood forests of the Northeast are among the lowest in North America. They are not related to watershed size and are not well correlated between watersheds. They are highly variable from year to year and are not particularly related to annual precipitation. They are related to the occurrence of individual large storms. Erosion and sedimentation need not be major concerns in the northern hardwood forests of the Northeast if BMPs are closely followed.

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DESIGN OF BLUNT NOSED CHEVRONS IN THE MISSISSIPPI RIVER FOR SEDIMENT MANAGEMENT

By Robert D. Davinroy, District Potamologist, Potamology Section, U.S. Army Corps of Engineers, St. Louis, Missouri; Stephen L. Redington, Chief, River Engineering Unit, Potamology Section, U.S. Army Corps of Engineers, St. Louis, Missouri; and Claude N. Strauser, Chief, Potamology Section, St. Louis District Corps of Engineers

INTRODUCTION

Sedimentation in a reach of the Upper Mississippi River (Mile 290.2 to Mile 289.0) has caused depth problems in the navigation channel. Annual maintenance dredging has been performed to maintain a reliable project channel. Historically, the dredge disposal material has been placed in the offside portion of the navigation channel, only later to be reintroduced back into the channel after the next high water season. To address this problem, the St. Louis District has designed and implemented new structures called Blunt Nosed Chevrons which serve as both channel improvement structures and permanent dredge disposal holding areas. The structures also create riverine habitat for a variety of fish species.

Project Location. Figure 1 is a vicinity map. Figure 2 is a plan view hydrographic survey showing the location of the first three Blunt Nosed Chevrons placed in the Mississippi River. The structures are located at the entrance of two major side channels. Construction of chevrons number 4 and 5 is planned in the near future.

Flow Splits. Historic discharge measurements have been taken to determine flow distribution trends (flow splits) between the side channels and the main navigation channel. Table 1 indicates the flow split trends have remained fairly constant, with a slight lowering of flow in the main channel in 1994 and 1995.

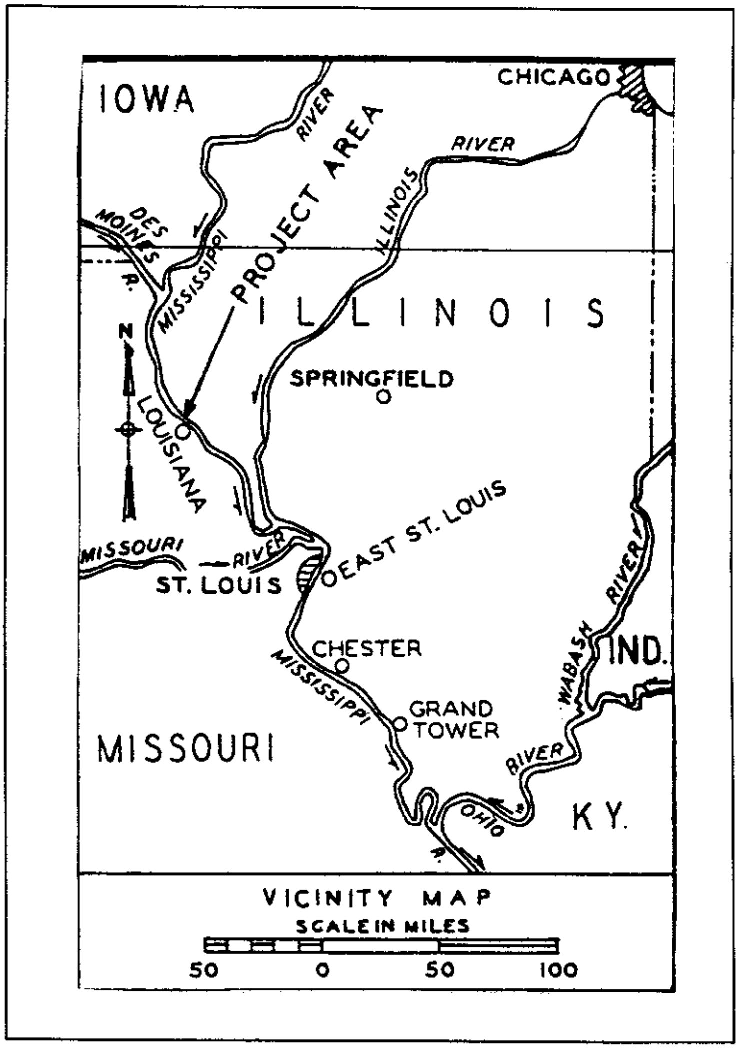

Figure 1. Vicinity Map.

DESIGN

Theory. The three structures were placed in the upper end of the side channel as the first phase of an eventual five chevron configuration plan (Figure 2). This plan theorizes that placement of the Blunt Nosed Chevrons will create "added roughness" in the side channel entrance but not significantly reduce side channel flow as compared to a traditional closure structure design. In theory, increasing the n value at the critical entrance area by this method will subtly lower side channel conveyance thereby increasing main channel conveyance. In this particular reach, the problem was threefold. The structures had to encourage manageable side channel deposition for main channel navigation improvement , the structures had to contain dredge disposal material, and the structures had to improve environmental diversity.

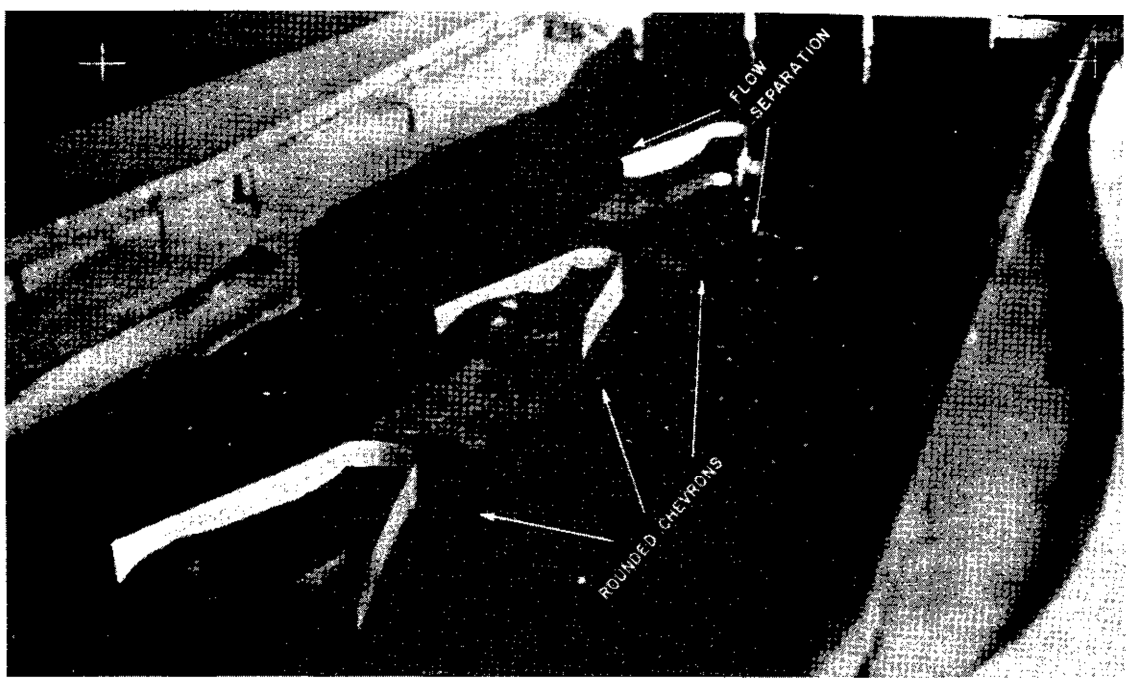

Figure 3. Blunt Nosed Chevrons in the St. Louis Harbor Model at WES

The design was based on movable bed model tests conducted at the Waterways Experiment Station for the St. Louis Harbor Navigation Study of 1986 (2) and from flow conveyance computations using HEC2. Although the model study examined a different reach of river, the study provided a sedimentation information base for the chevron concept. Traditional (pointed nose) and Blunt Nosed Chevrons were both tested in a near straight stretch of the model (Figure 3). The blunt nosed design achieved several important features including:

a. The elimination of excessive scour on the upstream head of the structure. Tests were initially conducted with pointed chevrons. These structures created an excessive amount of upper head scour directly endangering the structural integrity in the prototype. The modified blunt nose shape, although somewhat more complex to build in the prototype, significantly reduced upper head scour. This extends the life of the structure in the river while reducing maintenance costs.

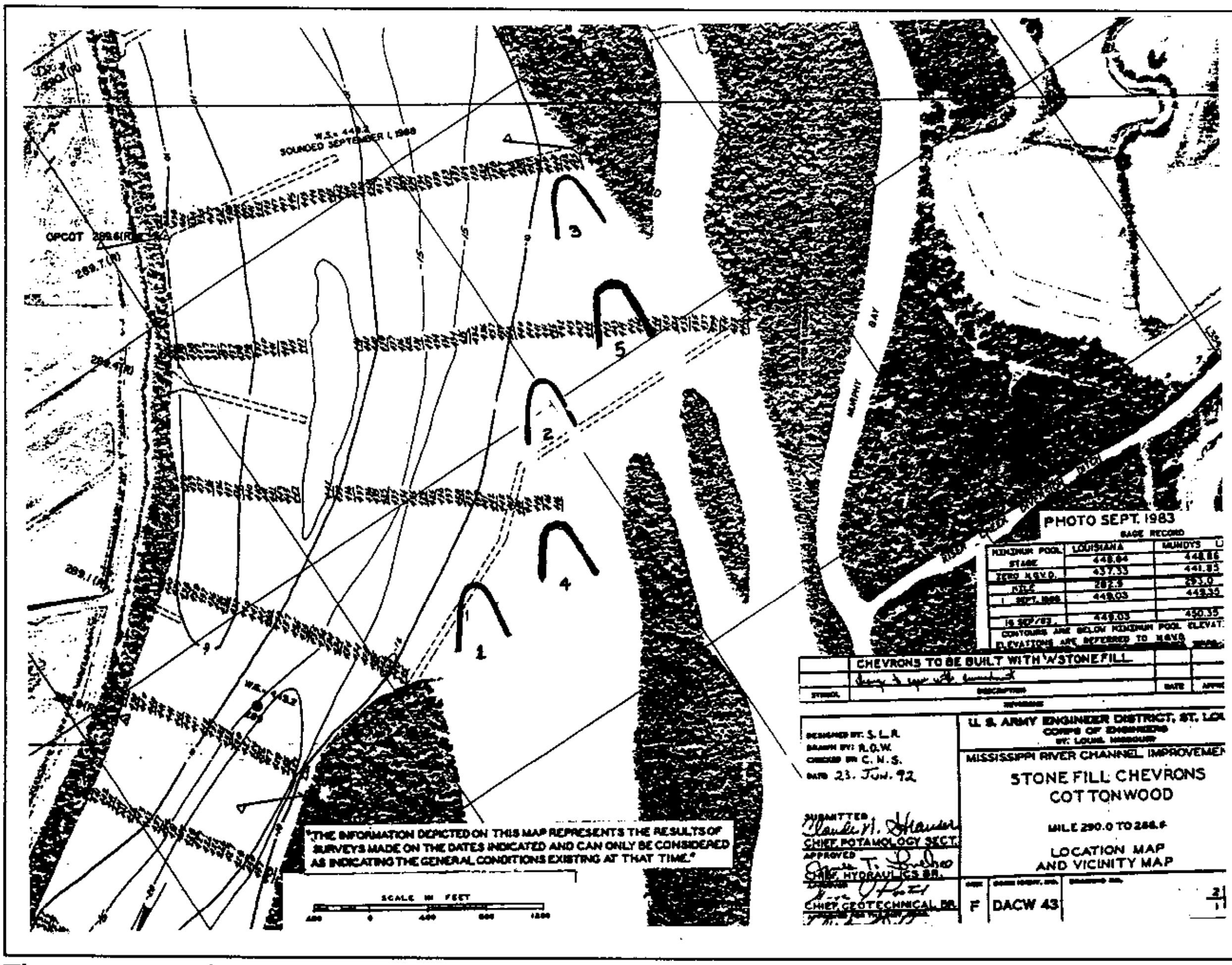

Figure 2. Location Plan of Blunt Nosed Chevrons on the Mississippi River at Cottonwood Island, Mile 289.0

DATE	Main Channel	Boyd-Fritz Side Channel	Fritz- Ill. Side Channel	TOTAL
31 July 1985	53,580 cfs 66%	5,772 cfs 7%	22,049 cfs 27%	81,401 cfs
22 July 1986	75,598 cfs			
3 Sept 1987	71,465 cfs 67%	10,093 cfs 10%	24,726 cfs 23%	106,284 cfs
Chevrons Constructed Fall of 1993				
13 July 1994	61,675 cfs 62%	10,762 cfs 11%	26,397 cfs 27%	98,834 cfs
26 Apr 1995	96,723 cfs 60%	20,863 cfs 13%	42,852 cfs 27%	160,438 cfs
7 June 1995	116,614 cfs 66%	16,329 cfs 9%	43,687 cfs 25%	176,630 cfs

Table 1. Historical Flow Splits at Cottonwood Island during Drawdown Conditions in Pool 24.

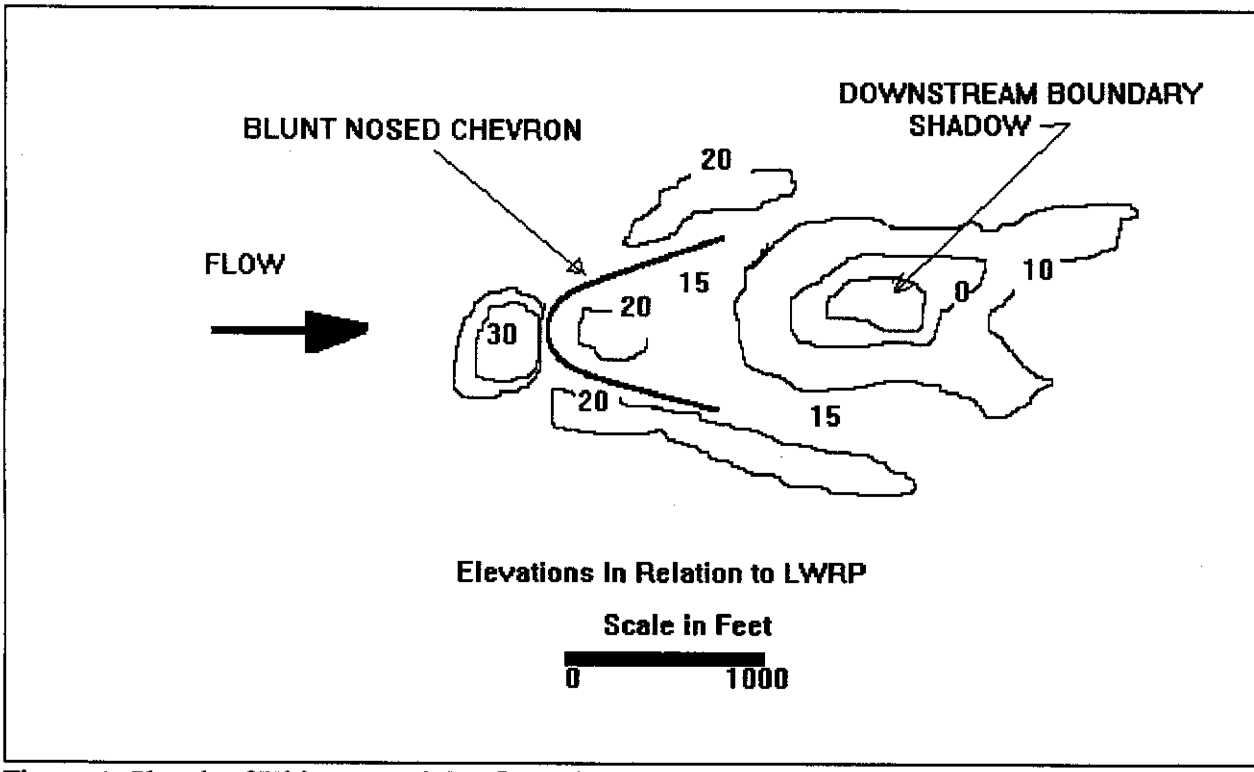

Figure 4. Sketch of Ultimate Bed Configuration Development around Blunt Nosed Chevrons

b. A permanent dredge disposal area within the ordinary high water. The design in the model demonstrated that disposal material placed within the boundary shadow of the structure stabilized (Figure 3). This was a direct result of the chevron boundary effects on the local sedimentation patterns. Placing dredge disposal material in this area will solve the short term dredge disposal problem while accelerating the long term full effect of the structure on the ultimate bed configuration.

c. Creation of habitat diversity. Several important sedimentation patterns resulted from the boundary shape in the model tests. Figure 4 is a schematic indicating the ultimate bed configuration pattern observed around a Blunt Nosed Chevron. This pattern has the potential for serving as excellent habitat for a variety of macro and micro invertebrates, fish, and fauna.

Design Specifications. The Blunt Nosed Chevron design requires the use of standard graded "A" stone or quarry run stone with a maximum top size of 5000 pounds. The typical section is trapezoidal containing the following dimensions:
Height - 2 feet above the maximum regulated pool elevation of Lock and Dam 24 (449.0 msl)
Crown Width - 6 feet
Side Slopes - 1 on 1.5
Bottom Width - Varying with bed topography
Linear Centerline Length - Approximately 1000 feet
Orientation - Angled directly into flow

Construction. Construction began on September 21, 1993 and was completed October 5, 1993. A total of 46,592 tons of stone was used. The method of placement was by floating plant equipment.

Dredging. The Dredge Natchez pumped material into the chevrons during the month of November 1993. A total of 185,959 cubic yards of material was placed on the inside and outside of the chevrons. Much of this material has remained, although some material placed outside the downstream shadow boundary has been carried away. Future dredge material, if needed, will be placed further downstream behind each structure to accelerate development of the ultimate bed configuration. Figure 5 is a photo illustrating the dredge placement within the structures.

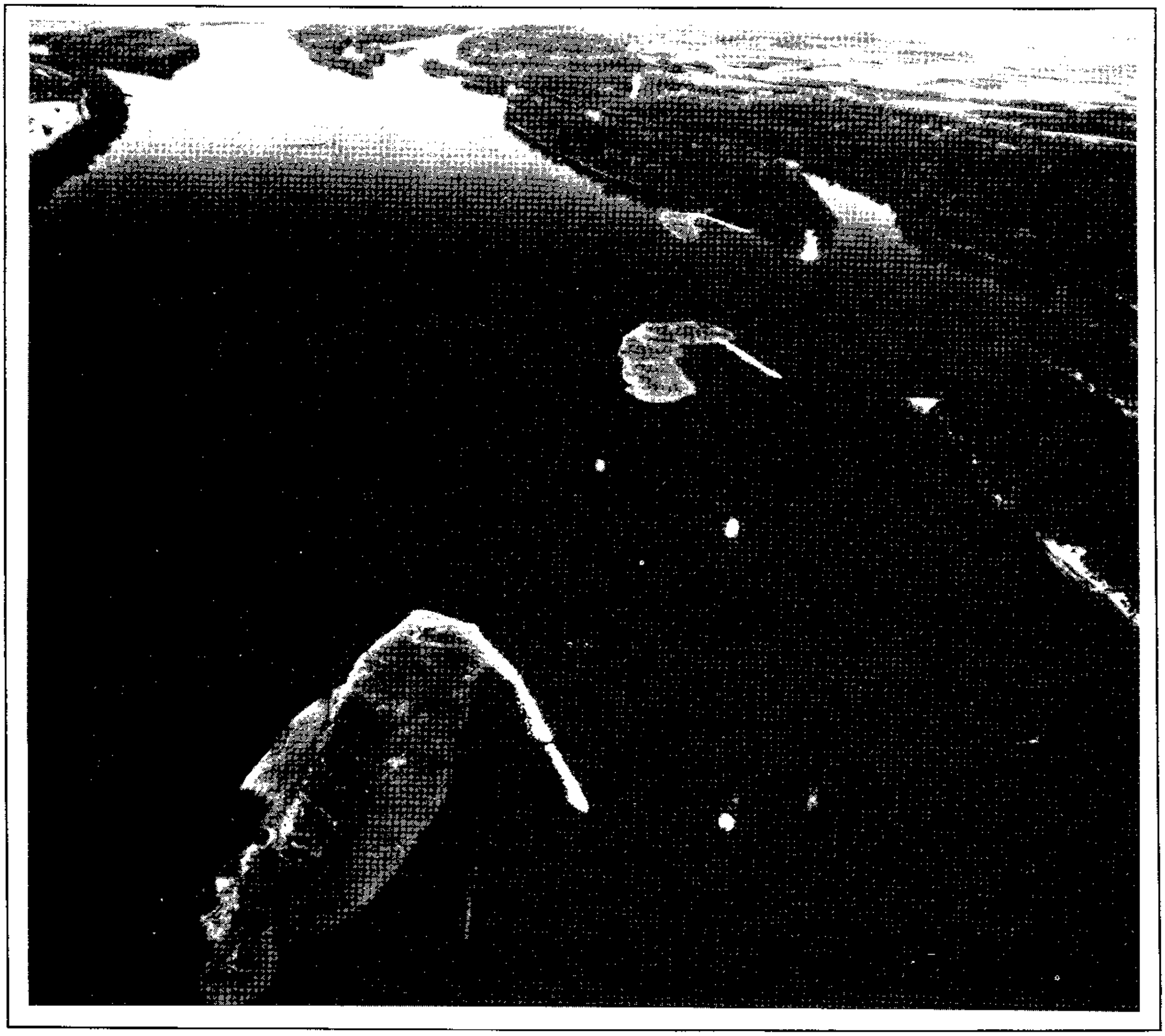

Figure 5. Blunt Nosed Chevrons on the Mississippi River With Placed Dredge Disposal Material, Looking Upstream

MONITORING

Velocity. The velocity patterns around the structures were measured on July 14, 1994 (Figure 6). The graph establishes the fact that the flow pattern is as anticipated. Velocity is smoothly transiting around the structures with no apparent turbulence or excessive velocity occuring at the heads of the structures, thereby ensuring stable, structural integrity. These types of data will continue to be collected on a more intermittent basis as the bed configuration around the structure fully develops.

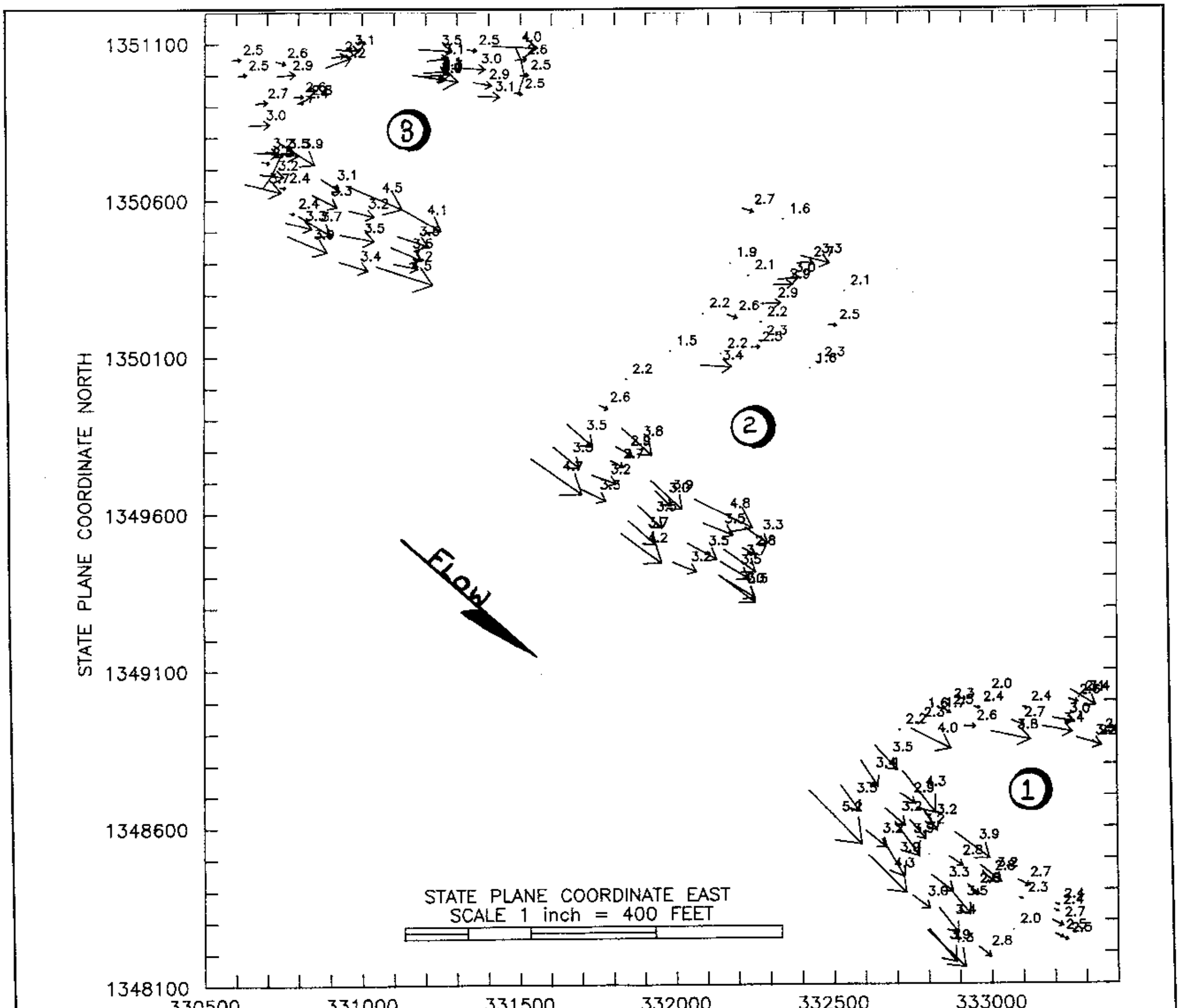

Figure 6. Velocity Magnitudes and Directions around Chevrons During Normal Pool

Water quality. Water quality samples were collected in August, September, and October of 1994 and also in August and September of 1995. A variety of indicators were analyzed. The average results are as follows:

Water temp: 24 degrees Celsius	pH : 8.0
Conductivity : 440(normal)	ORP (Oxygen Reduction Potential): 350 (good)
Silica: 11 mg/liter	Phosphates: 0.2 mg/l
Ortho: 0.1 mg/l	Nitrates: 1.0
Ammonia : less than 0.5	Suspended solids: 40 mg /liter to 10 mg/liter
Volatile SSP: 10 mg/l	Chlorophyll: 50 mg/l
Phenophytin: 6 mg/liter	DO: 10.0 (above average)

Monitoring of this type will continue in the future. The above data indicates that water quality in the chevron fields is excellent and able to sustain aquatic life (Brown 1995).

Macroinvertebrates. A macroinvertebrate study on the three chevrons was prepared in March of 1995 based upon field data collected in November of 1994. A total of 94 taxa were collected in the outside of the structures, 69 taxa were collected on the inside of the structures, and 31 taxa were collected on the surrounding river bed. Invertebrate density was high in the substrate surrounding the chevrons, although species richness and diversity were lower than other areas sampled. Dominant taxa were species generally associated with sandy substrate in large rivers. Diversity and species richness were high on the exterior and interior of the structures. Commonly collected species were those typically associated with fast flowing, rocky streams, and rock or vegetate littoral areas. The high diversity in this area reflected habitat heterogeneity. This is considered beneficial for the development of future fish communities (Miller, T. 1995).

Fish. In August of 1995, an electrofishing study was conducted along both the outside and inside of the middle Blunt-Nosed Chevron. A total of 18 different fish species totaling 199 fishes were reported at a sampling rate of 7.1 fish per minute. These results are above average and indicate that large numbers of fish are utilizing the habitat created by the structure. The data also reveals that the fish community on the inside of the structure is similar to a backwater lake community, while the community on the outside of the structure is similar to a typical river community. Although theses data are by no means conclusive, the early trends indicate these structures are very beneficial to riverine fish communities (Atwood 1995). It was also apparent during the sampling period that the Blunt Nosed Chevron field is serving as a recreational outpost for fishing and boating enthusiast.

CONCLUSIONS

Blunt Nosed Chevrons in the Mississippi River are performing as designed. The structures are reaping the multiple benefits associated with the boundary effects. Chevron design in the future will be modified to create additional environmental diversity. Top elevations may be varied, as well as the addition of notches, changes in lateral slope, etc.

Both engineering and environmental monitoring will continue to quantify the final effects. If favorable trends continue to occur, Blunt Nosed Chevrons may be used in other reaches and in other applications on the Mississippi River.

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