Sediment Storage and Drainage Ditch Excavation on the North Carolina Coastal Plain: A Case Study in Pitt County

Mark Lange
Department of Geography, University of Southern California

Scott Lecce and Patrick Pease
Tobacco Road Research Team, Department of Geography, East Carolina University

The storage component of a fluvial sediment budget is difficult to quantify, yet is critical to understanding the fate of soils eroded from agricultural lands. The drainage systems in eastern North Carolina are heavily modified by human activity and are presently dominated by maintained ditches. The periodic re-excavation of the drainage ditches provides a unique opportunity to investigate the accretion of stored alluvial sediments. This paper presents an initial evaluation of the effects of channel excavation with particular focus on adjustments in channel morphology and sediment characteristics. Sixteen cross-sectional profiles were monitored along a 40m ditch segment over a one year period following re-excavation. The depth and composition of stored bed sediments were measured. Ditch excavation produced a sediment sink that resulted in a significant positive net change in alluvial storage and relatively simple cross-sectional morphology. The stored sediments lacked a fine fraction, suggesting that fines are transported beyond the study reach. Beginning in spring, vegetation growth increased the hydraulic roughness within the ditches and resulted in a decrease in sediment transport and an increase in complexity of cross-sectional channel morphology. We tentatively conclude that sediment eroded from coastal plain agricultural land does not travel very far from its source.

Introduction

Most drainage systems on North Carolina's coastal plain have been heavily modified for agricultural use by channelization. The straightening and deepening of stream segments lowers seasonally high water tables and accelerates the movement of water off agricultural fields. Periodically, the channels are cleared of vegetation and accumulated sediment. This re-channelization provides an excellent opportunity to study sediment storage and the evolution of drainage ditches in coastal plain watersheds. Because the sediments removed from the ditches are spread over adjacent fields, re-channelization also provides an opportunity to investigate sediment recycling which has been suggested as a potential solution to coastal plain agricultural erosion (Phillips, 1985). The purpose of this paper is to present an initial evaluation of the short-term and longer-term effects of channel excavation on stored sediment volumes and channel morphology, and to examine the effectiveness of re-channelization as a mechanism for sediment recycling.

Study Site

The study site is located near the town of Littlefield on the southern edge of Pitt County on the North Carolina Coastal Plain (Fig. 1). This small watershed is part of the larger Neuse River drainage that flows into the Pamlico Sound on the Atlantic Coast. The site is surrounded by a mixture of woodland and cropland and is characterized by low slope gradients (< 0.02) and well drained sandy soils (Slattery et al., 1998). The channel reach investigated is part of a deep (1.5-2 m), straight, 450 m long channel with intermittent flow that drains into a larger ditch exhibiting base flow year round. The drainage basin has been heavily modified for agricultural use with row and furrow cropping patterns that have the effect of concentrating surface runoff down rows to the lower field edge in a pattern common in agricultural catchments (Souchere et al., 1998). Several small swales along the field edges develop ephemeral gullies that cut across furrows and have the potential to significantly increase sediment entrainment and delivery to the ditches (Thorne and Zevenbergen, 1990). The watershed is

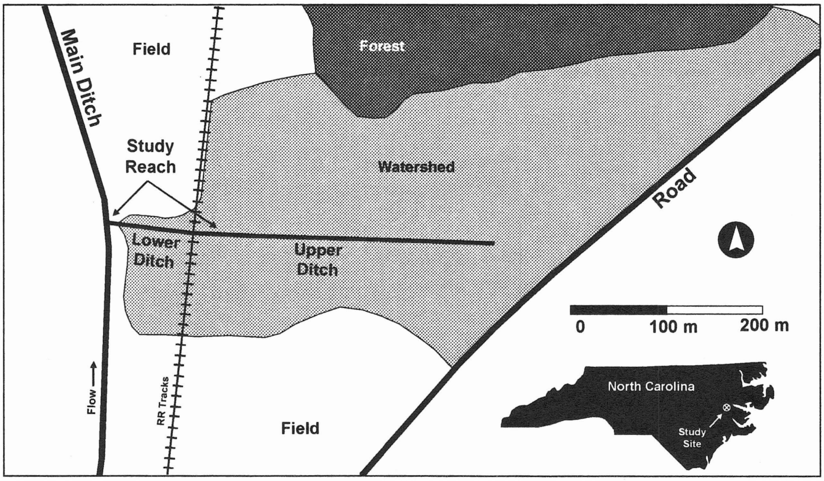

Figure 1. Study site location

truncated to the east by a county road (Fig. 1) and railroad tracks divide the upper and lower basin, further modifying the drainage pattern by forcing all upper basin surface runoff into the channel before passing under the railroad tracks via a 1 m diameter cement culvert. The railroad tracks also mark an abrupt decrease in channel gradient (from 0.04 to 0.009) and a downstream increase in the width (2 m) of the channel bottom (Fig. 2). The channel is re-excavated every 2-3 years and the alluvial sediments removed from the channel are spread on the adjacent field edges using heavy equipment.

Research Design

This study focused on the effects of channel excavation along the lower 40 m segment of the ditch downstream from where it emerges from under the railroad tracks (Fig. 2) to its outflow through a culvert leading to the larger, north-south flowing ditch. The decrease in channel gradient and channel widening below the railroad culvert leads to the deposition and storage of sediments transported from upstream. In March of 1999 a single cross-sectional profile was surveyed near the confluence with the main ditch shortly after the channel had been re-excavated (Fig. 3). In April and November of 1999 and March of 2000 sixteen cross-sectional profiles were surveyed every 2 m along the length of the lower ditch. A local datum was established for all the surveys using the elevation of the nearby railroad track. The depth of stored bed sediments was also measured at each cross-section by probing down through the softer channel-bed sediments until reaching the contact with poorly-sorted, coarser sediments. Particle-size analysis of these sediments confirm that this boundary marks the maximum depth of excavation by heavy equipment. Grab samples were collected from sediments in the channel bed, colluvium (at the base the channel banks), upper basin channel reach, and the sediment underlying the stored alluvial sediments. Finally, the bed sediments were trenched once at the upper end of the study reach and once at the lower end of the study reach and the sedimentary units measured and described. The purpose of the trenching was to measure and describe the depth and lateral extent of the sedimentary units.

Results

The study reach exhibited a positive net change in alluvial storage over the one year period between March 1999 and March 2000 (Fig. 3). Overall, 23.45 m^3 of sediment was stored along the lower ditch between re-excavation (shortly before the first survey) and the last survey in March 2000. Most of this deposition occurred before the first survey in March 1999 because the re-excavation of the ditch had lowered the

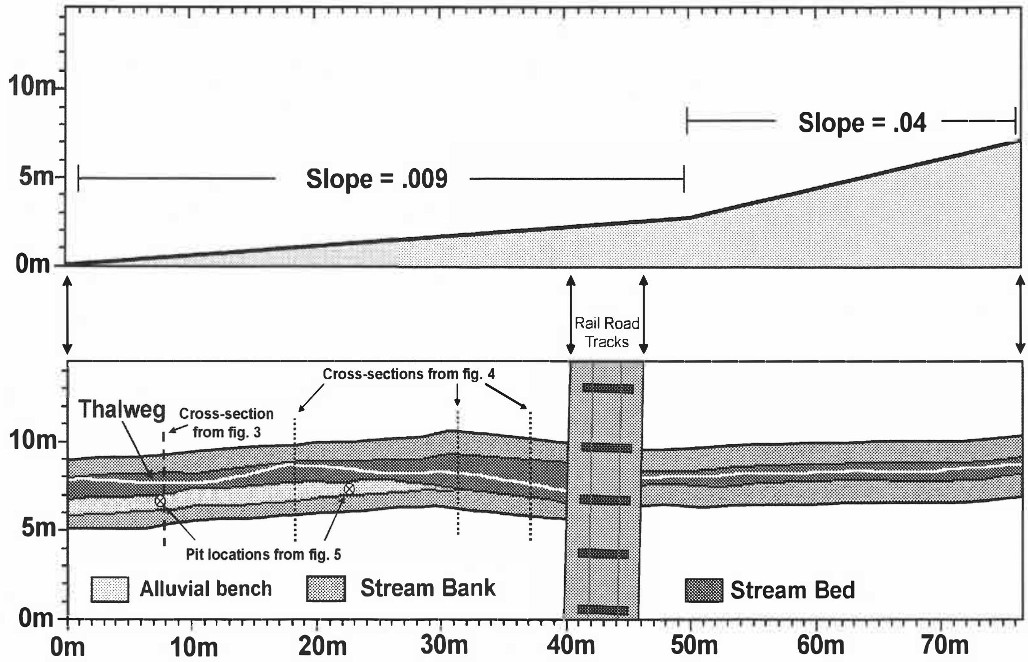

Figure 2. Enlarged view of the study reach, labeled on figure 1. The figure shows a linear profile (5x exaggeration) and a map view of study reach. The locations of cross-section and pits shown in figures 3-5 are shown.

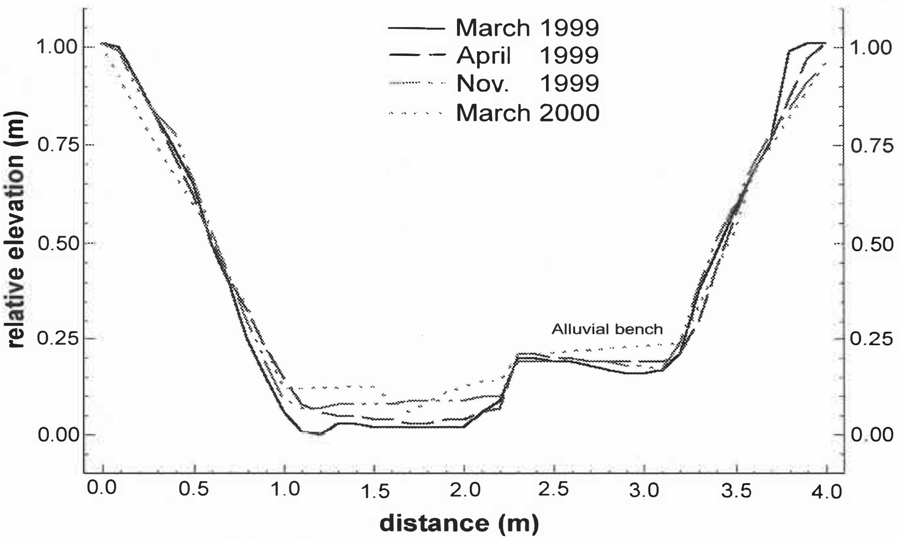

Figure 3. Profiles measured four times over a one year period for a cross-section at the lower end of the study reach, 8m upstream from a culvert pipe. The location is shown on figure 2.

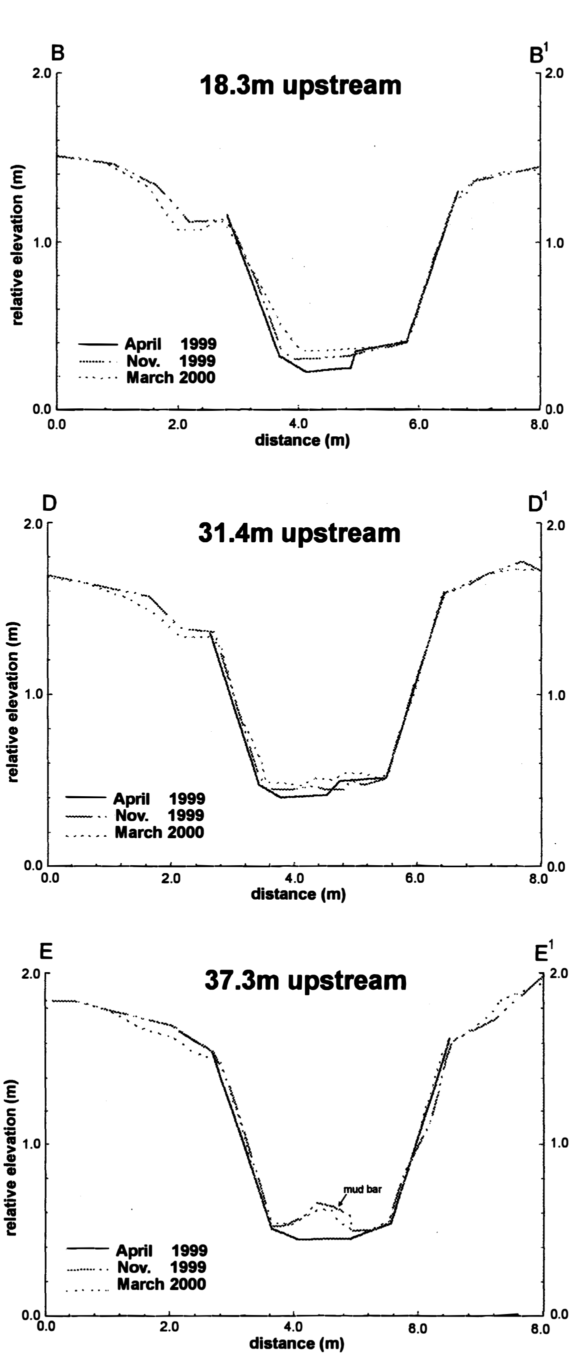

Figure 4. Selected cross-sections illustrating the influence of vegetation on bed morphology, particularly up channel, over a one year period. Locations are shown on figure 2.

level of the bed below the outflow culvert by about 25 cm. Whether this "over-trenching" was inadvertent or purposeful is unknown, but it created a large sediment sink that filled in rapidly until the channel bed was graded to the elevation of the outflow culvert. Nevertheless, the surveys identified significant sediment storage with the channel bottom aggrading by about 8 cm between March 1999 and November 1999, and by 4 cm between November 1999 and the last survey in March 2000.

The cross-sectional profiles also indicate the development of a small alluvial bench along the channel bed (Figs. 3 and 4). The height of the bench increased down-channel, indicating that it was produced by thalweg downcutting at low flow conditions. The bench alluvium was likely deposited as excess bed sediment during the first several high discharge events and the thalweg subsequently incised through this alluvium in an effort to reach equilibrium relative to base level, in this case the outflow culvert that discharges into the main ditch. Because sediment transport rates at low flows were not large enough to move significant quantities of sandy bedload, this downcutting was slow and an equilibrium profile was probably never fully formed before the next storm event. The difference between the slow rate of downcutting during low flow, and the higher frequency of large discharge events in the spring months that are capable of transporting large quantities of sand for deposition in the heavily vegetated channel bottom led to a net aggradation of the channel bed.

A distinction can be made between stored bed sediments derived from sources in the upper and lower basin (Fig. 5). Darker, organic-rich soils of the Bibb complex (Karnowski et al., 1974) were supplied by slumping and gullying of the channel banks in the lower basin downstream from the railroad tracks. The sediments supplied by the upper basin are eroded from lighter colored, sandier soils of the Wagram and Aycock series (Karnowski et al., 1974). The sediment profile in the channel bed in the lower end of the study reach (Fig. 5) reflects these two sediment sources, showing distinct units of darker soils that alternate with thicker, lighter colored units. These darker units were not visible in the sediment profile at the upper end of the reach. The upper basin area is considerably larger than the lower basin and this is manifested by the comparatively large volume of upper basin alluvium in the profile. Several large slumps involving over 4 m of bank length were observed along the bank of the channel in the upper basin (above the railroad tracks) and certainly contributed lighter colored sediments for transport into the lower reach. Moreover, the channel profiles in the lower ditch all show evidence of smaller-scale bank slumping (Figs. 3 and 4).

Further evidence for the provenance of sediments can be found in the results of grain size analyses. A ternary plot of sediment sizes (Fig. 6) shows three distinct populations: the underlying coarse sediments, the sandy bed sediments, and the finer field and colluvium/alluvium sediments. The dark colored colluvium/alluvium was collected at the base of the channel bank in the lower ditch. The stored bed sediments are sandy and are missing the finer fractions present in the soils found up-basin (Wagram and Aycock series). The fines, although not abundant in these sandy soils, are probably carried away as suspended load, leaving the sand to be transported episodically as bedload.

Discussion

Although the data presented in this paper are limited, they provide some interesting insights that should be considered as speculative in nature. We suggest that the initial consequences of channel excavation are twofold. First, the erosion of sediment in the upper basin was probably enhanced by several factors: the removal of vegetation along the ditch, increasing the gradient of the ditch, oversteepening of the banks of the ditch, and the cultivation of fields that exposes soil for erosion during winter months. The concurrent cultivation of fields and ditching would lead to a sudden increase in sediment production and delivery to the study reach in the lower basin. Rather than generating higher sediment yields as might be expected under the assumption of a constant alluvium storage rate (Boardman et al., 1990), the increase in sediment production was countered by a second effect of re-channeling: the over-deepening and wid-

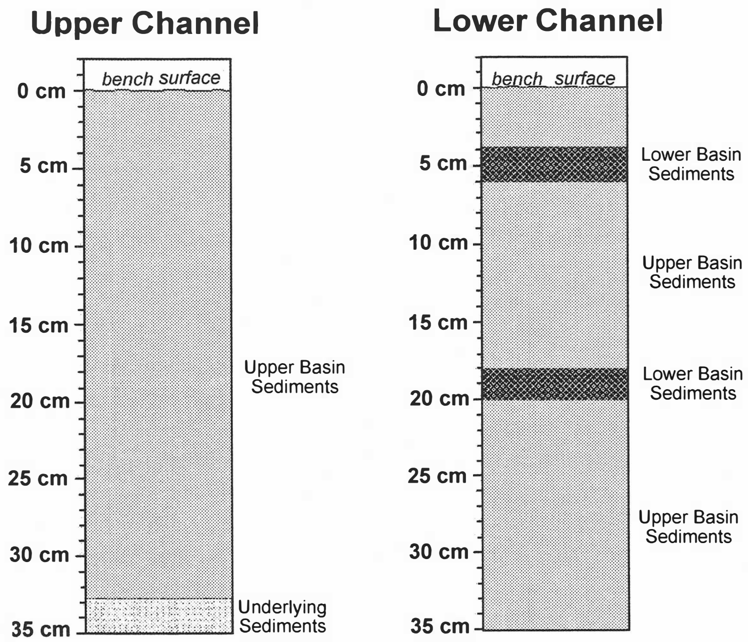

Figure 5. Channel sediment profiles from pits dug in the ditch bed. Locations are given on figure 2.

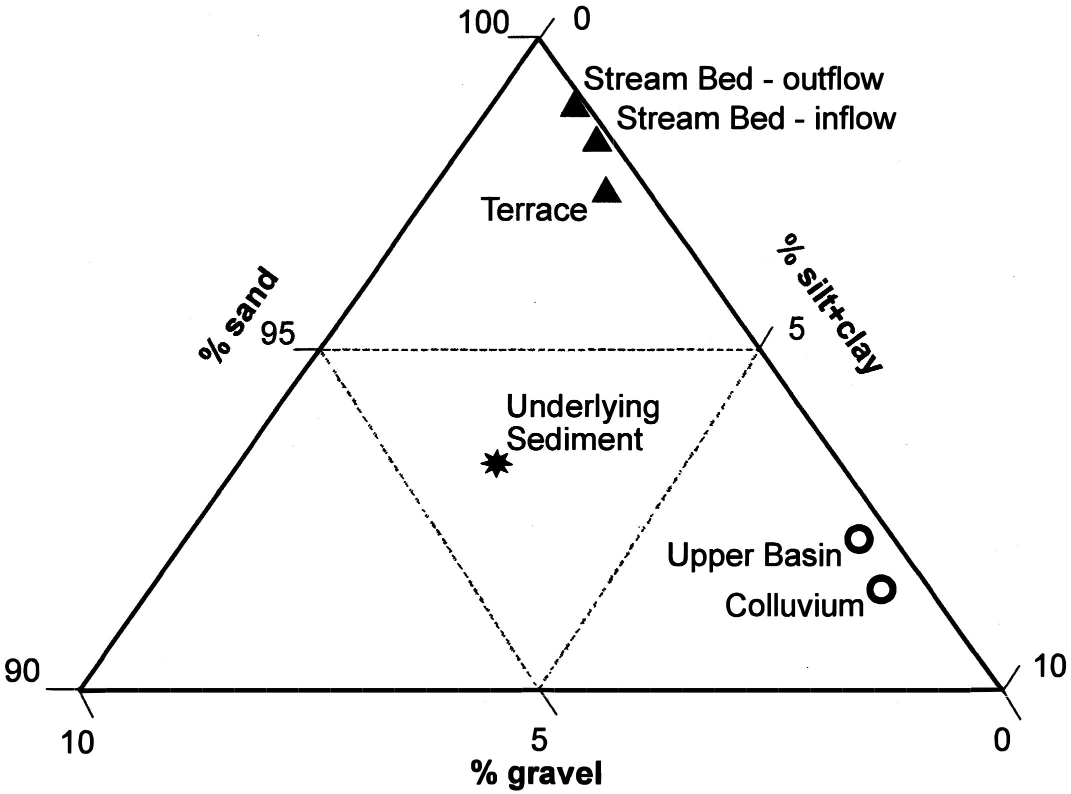

Figure 6. Ternary plot showing sediment grain size distribution.

ening of the lower basin channel. This, in combination with the low channel slope, created a sediment sink. The total effect was to quickly move large volumes of sediment from the upper basin and store it in the lower channel. It appears that the fine fraction is carried beyond the study channel leaving the sand fraction to be stored, if only temporarily, in the lower ditch.

Channel morphology appears to have been storm-controlled, with large storms resulting in high discharge events that aggraded the channel bed in the lower reach. Between storms, thalweg downcutting during low flows produced an alluvial bench that increased in height downstream. This is similar to the findings of Friedman et al. (1996) who identified stages of channel narrowing in a sandbed stream. They found that large discharge events produced an elevated bed due to the deposition of sands and small gravels. During periods of low flow the channel incised and a single thalweg developed. Over several seasons vegetation established a control over sub-areal portions of the bed, stabilizing most of the channel bottom around a well-defined, narrow channel. The Littlefield study site appears to follow a similar process of channel narrowing.

Field observations over the year-long study period suggest that the immediate effects of re-channelization are dampened through time by the re-establishment of vegetation. Each fall the farmers mow the vegetation growing in and along the ditches. During the winter and early spring, sediment transport is unimpeded by the hydraulic roughness introduced by vegetation (Fig. 7). Dense vegetation growth during the spring and summer, however, quickly chokes these drainage ditches. This is particularly true for the small ditches where baseflow is minimal or absent, and much growth occurs directly in the bed of the channel. Only the largest of flows (e.g., Hurricane

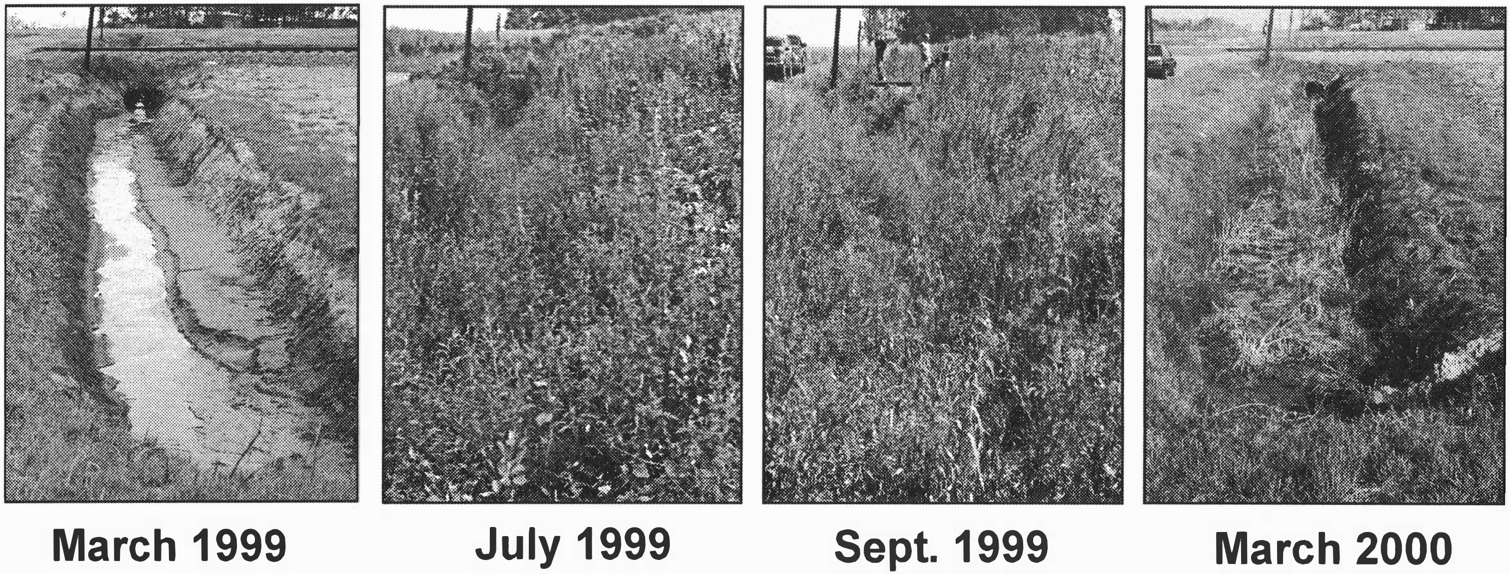

Figure 7. Photographs showing the evolution of channel vegetation over the study period. The photographs are facing to the east and show the Lower Ditch study reach up to the culvert pipe under the rail road tracks.

Floyd) are likely to disrupt the vegetation enough to allow significant amounts of sediment to be transported through these channels. Cross-sectional profiles indicate that channel morphology is influenced by vegetation that is effective in trapping sediment along the channel bed (Fig. 4). While the bed aggraded considerably in the lower channel section, vegetation trapped sediment in the upper channel section resulting in the accumulation of a large mid-channel bar. Although vegetation growth and sedimentation in the lower channel (reducing the channel gradient) favors the accumulation of sediments, the planting of crops and the stabilization of channel banks with vegetation reduces sediment production up-basin.

Assuming the rapid sedimentation of the small ditch examined in our study is generally representative of the region, the return of ditch sediments to the field would appear to be an effective mechanism for minimizing soil loss from agricultural fields. Indeed, the recycling of sediment has been suggested as a potential remedy to the coastal plains agricultural erosion problem (Phillips, 1985). However, even though a large part of the sand fraction is returned to the field, a significant portion of the fine fraction may be lost as suspended load. Thus, the net result may be to concentrate the sand fraction in sediment which is then recycled to fields.

Conclusion

The results of this study show that significant amounts of sediment can accumulate in drainage ditches during a relatively short period of time. Insofar as the construction of small ditches and the clearing of vegetation from these ditches is the consequence of human agency, the movement and storage of sediment in the coastal plain environment is highly modified from a "natural" condition. Previous studies have argued that soil erosion is significant, but that the fate of the eroded sediments is unclear (Phillips et al., 1993; Slattery et al., 1998). We maintain that, at least in some situations, the eroded sediment is not transported very far from its source. It is either deposited on the same field from which it was eroded (Phillips et al., 1999), or is deposited nearby in drainage ditches which must be re-excavated frequently. Indeed, this would seem to be confirmed by the relative lack of sedimentation on the Tar River floodplain during the 1999 flood which resulted from Hurricane Floyd (Lecce et al., in press).

Further study is needed to assess the recycling of sediments excavated from the ditches. Although the source area for the sediments involves a significant portion of the basin, the ditch sediments are returned only to the field edges so that soil erosion remains a significant problem on most of the field. This may lead to spatial variations in soil quality with the field edges becoming increasingly sandy as the alluvium is repeatedly spread on the field edges. Additional study is also required to quantify the loss of fines as suspended load and the rate with which sandy sediments are transported as bedload. An event-scale study of bed load and suspended load transport rates could further illuminate the processes by which eroded soil is moved and stored in drainage ditches in eastern North Carolina.

Acknowlegment

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References

Boardman, J., Dearing, J. A., and **Foster, I. D. L.** (1990). Soil erosion studies; some assessments, In Boardman, J.; Foster, I. D. L.; and Dearing, J. A. (Editors) *Soil Erosion on Agricultural Land*, (John Wiley & Sons Ltd.: New York).

Friedman, J. M., Osterkamp, W. R. and **Lewis, W. M. Jr.** (1996). The role of vegetation and bed-level fluctuations in the process of channel narrowing *Geomorphology* 14: 341-351.

Karnowski, E. H., Newman, J. B., Dunn, J. and **Meadows, J. A.** (1974). Soil survey of Pitt County, North Carolina. U.S. Department of Agriculture, 73 p.

Lecce, S. A., Pease, P. P., Gares, P. A., and **Rigsby, C. A.** In press. Sedimentation in the Tar River floodplain associated with Hurricane Floyd, in *Hurricane Floyd and its Aftermath*, Coastal Carolina Press.

Phillips, J. D. (1985). *Soil conservation, sediment control and the fluvial sediment budget: analysis and policy implications for the Tar River*, Pamlico-Tar River Foundation Resource Paper No. 4

Phillips, J. D., Wyrick, M. J., Robins, J. G., and **Flynn, M.** (1993). Accelerated erosion on the North Carolina Coastal Plain, *Physical Geography*, 14:114-130.

Phillips, J. D., Slattery, M. C., and **Gares, P. A.** (1999). Truncation and accretion of soil profiles on coastal plain croplands: implications for sediment redistribution, *Geomorphology*, 28:119-140.

Slattery, M. C., Gares, P. A., and **Phillips, J. D.** (1998). Quantifying soil erosion and sediment delivery on North Carolina Coastal Plain croplands, *Conservation Voices*, 1:20-25

Souchere, V., King, D., Daroussin, J., Papy, F., and **Capillon, A.** (1998). Effects of tillage on runoff directions: consequences on runoff contributing area within agricultural catchments, *Journal of Hydrology*, 206:256-267.

Thorne, C. R. and **Zevenbergen, L. W.** (1990). Prediction of ephemeral gully erosion on cropland in the south-eastern United States, In Boardman, J.; Foster, I. D. L.; and Dearing, J. A. (Editors) *Soil Erosion on Agricultural Land*, (John Wiley & Sons Ltd.: New York).