STRATIGRAPHY AND RECENT EVOLUTION OF MARYLAND PIEDMONT FLOOD PLAINS

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ABSTRACT. Flood plains in nine reaches of seven small Maryland Piedmont streams (drainage areas 10.6-215.0 km²) show three distinct stratigraphic units deposited during three periods of differing hydrology and sediment supply. Prior to European settlement about 1730, flood plains were formed with relatively thin, fine, overbank sediments deposited on top of thin laterally-accreted sand and gravel. As settlement progressed and agricultural use of Piedmont uplands grew, more sediment was supplied to streams, and upland water yields were augmented from increased runoff. Greatly increased sediment supply and moderately increased discharges produced thick, fine overbank sediment deposits and thin lateral accretion sands in the period 1730 to approx 1930. Farm abandonment and introduction of soil conservation techniques slightly decreased water yield and substantially decreased sediment yield to streams in the post-1930 era. Stratigraphic evidence shows that streams accommodated these changes by altering the flood plain formation process to one of lateral accretion of sand and gravel while removing a larger volume of fine sediments from flood plain storage. Evidence for progressive channel deepening is retained in the stratigraphic record and channel widening can be inferred.

INTRODUCTION

The stratigraphy and sedimentology of Maryland Piedmont flood plains (fig. 1) show three very distinct units reflecting three different sets of fluvial conditions. The history of land use in the area allows rough quantitative estimates of the changes in upland hydrology and sediment supply responsible for the observed stratigraphy. These estimates show how processes of flood plain formation and sediment flux in and out of flood plain storage have been controlled by the relative magnitudes of water discharge and sediment supply. The stratigraphic record of stream response to changes in upland land use provides a basis for predicting future sensitivity to similar changes in hydrology and sediment supply.

Human disruptions of drainage basin sediment supply and hydrology have been discussed in many recent papers including those by Costa (1975), Knox (1977), Trimble (1974, 1983), Trimble and Lund (1982), Overstreet and others (1968), and Wolman (1967). These studies document the profound effects that land use can have on erosion, transport, and storage of sediment. Flood plain strata contain a record that can be used to assess stream response to land-use changes in the drainage basin. Simple models can be used to show the direction and estimate the magnitude of changes in hydrology and sediment supply. Land use changes may also mimic

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Fig. 1. Location map. Study site locations are indicated with solid circles; the watershed boundaries are drawn from gage locations.
natural events such as prolonged drought, climatic change, or fires, which would produce a transient condition of increased or decreased sediment supply, peak discharges, and (or) flood frequency. Thus, studies of how land use changes influence the fluvial system may have more general applicability.

ACKNOWLEDGMENTS

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LAND USE ON THE MARYLAND PIEDMONT

Prior to the first significant settlement around 1730, the Maryland Piedmont was heavily forested (Porter, 1975). Thick soils on deeply weathered crystalline rocks and a carpet of absorbent forest litter probably combined to reduce overland flow to negligible amounts during all but the most intense storms. The work of Cleaves, Godfrey, and Bricker (1970) suggests that, prior to European settlement, most of the denudation of the Piedmont was by geochemical dissolution and transport. The amount of sediment supplied to streams from physical erosion of Piedmont soils must have been relatively small and highly dependent on the magnitude and frequency of natural events such as windfall, forest fires, and drought. Maxwell (1910) maintained that it was also common for Native Americans to set forest fires on the Virginia Piedmont to clear land for agriculture and to provide more diverse game habitat; presumably, this occurred in Maryland as well. However, human land disturbance before European settlement was probably not extensive and is treated here as part of the natural condition.

When European settlement of the Piedmont began around 1730, tobacco was the staple crop of the colonies and was planted on the thick acid soils of the Piedmont uplands (Craven, 1925, p. 32-71). When several years of tobacco crops had sapped the nutrients stored in the thin A horizons of the former forest soils, crops of secondary importance were planted, chiefly wheat and corn. Poor land use practices and farming techniques resulted in erosion and loss of productivity. The first 100 yrs of settlement on the Piedmont yielded a shifting mosaic of progressively disappearing virgin forest, eroding cleared land, and abandoned fields supporting second growth forest. During this period only the best land was kept in cultivation. Hence, sediment supplied from the Piedmont probably increased only moderately above natural background levels.

Records of Piedmont land use are available beginning in the mid-1800's with the start of the agricultural census. Census records for four Maryland Piedmont counties and one Pennsylvania Piedmont county
(fig. 2) depict a rapid increase in cropland (U.S. Census Office Repts., 1840-1978). This increase is attributed to new farming techniques introduced during the agricultural revival of the mid 1800's, urban market growth, use of chemical and natural fertilizers, use of mechanical farm equipment, and development of railroad transportation routes (Craven, 1925, p. 128-131, 134-143).

Agricultural land use peaked between 1900 and 1910 in these five counties with an average of 67 percent of the land in crops. A precipitous decline in cropland acreage from 1930 to 1935 resulted from the general economic decay of the 1930's and the inability of Maryland farms to compete with expanding midwestern agriculture. During this period abandoned farmland grew up into wood lots and scrub. Presently only the best land in rural areas is maintained in row crops, and most of this land is farmed using improved soil conservation techniques. Suburbs are now growing at the expense of both cropland and woodland.

FLOOD PLAIN STRATIGRAPHY

The history of land use in the Maryland Piedmont suggests that hydrology and sediment supply of Piedmont watersheds must have varied substantially over the last 250 yrs. Evidence for stream response to these alterations was sought in the stratigraphic and sedimentologic record of flood plain sediments at nine sites on seven Piedmont streams. Data for these sites are summarized in table 1, and their locations are shown in

Fig. 2. Agricultural land use change. Amount of total area devoted to crops, by county, since the start of the National Agricultural Census. Data from U.S. Bureau of the Census, 1850 to present.
figure 1. The reaches chosen represent a range of drainage areas from 10.6 km\(^2\) (4.1 mi\(^2\)) to 215.0 km\(^2\) (82.9 mi\(^2\)). All the sites are upstream from and close to gaging stations, and valleys at the sites are wide enough to ensure that valley-wall bedrock control is minimal.

For each 100 to 400 m reach, large-scale topographic maps were constructed, all cutbank sediment exposures were thoroughly examined, and at least three cross-valley stratigraphic sections were constructed from coring transects. A 3-m long, 2.5-cm-diam soil corer and a 5-m long, 4-cm-diam auger were used for coring. These tools were unable to pierce gravel, cobbles, or bedrock, but these materials were identified with high confidence by extrapolation from cutbank exposures and resonance of the materials when struck. Sediment color, particle size, degree of soil formation, mottling, concretions, human artifacts, and amount of particulate organic matter were described in the field. Several sediment samples from each site were returned to the laboratory for analyses of organic matter, bulk density, and pollen content. Sampling for laboratory analyses did not include all sites but was designed to illustrate representative sections.

Three lithofacies are recognized in the field: coarse lateral accretion deposits, finer overbank deposits, and valley margin colluvial deposits. Lithofacies were distinguished primarily by comparing grain size and primary sedimentary structures of the flood plain strata with those of sediments recently deposited under known flow conditions. Lithofacies and their stratigraphic relations are shown in columnar section in figure 3, and four representative flood plain cross sections are shown in figure 4.

Lateral accretion deposits may be divided into two subfacies, a channel bed subfacies and a point bar subfacies. These two units are transitional but are separable by grain size differences, sedimentary structures, and degree of homogeneity. Point bar sediments are generally finer than channel bed sediments and contain a wider range of sediment sizes, ranging from clay to gravel. In general, grain size decreases away from the channel and from upstream to downstream along the point bar. In sections perpendicular to the channel these deposits form sigmoidal beds.
which are inset against, and drape over, pre-existing point bar deposits. Within the sigmoidal beds, point bar deposits have structures ranging from thin, flat laminae to ripple drift cross laminae and dune scale trough and tabular cross bedding. In contrast, channel bed sediments range from coarse sand to cobbles and are sorted according to pools and riffles. Pools in present day channels often contain muddy sediments; however, these fine sediments are probably eroded during channel migration and are not incorporated into flood plain strata. Channel bed deposits are composed of planar sand beds and massive to planar gravel beds.

Vertical accretion deposits are divided into backswamp, organic backswamp, and levee subfacies. Backswamp deposits are laminated to massive
silt loams and clays with common, thin, A soil horizons buried by successive layers of fine sediment. Backswamp deposits grade into organic backswamp deposits which occur as 0.05- to 0.5-m-thick tabular to lenticular, massive or laminated silts and clays characterized mainly by very dark black color and high organic matter content. Abundant particulate organic debris gives this sediment a spongy consistency. Organic backswamp subfacies are distinguished from buried A soil horizons by their abrupt lower boundaries, lack of soil structure, and the abundance of detrital organic particles. Levee subfacies are silt loams to medium sands which are massive when disturbed by roots and fauna but can show ripple scale cross laminae and planar, horizontal laminae. Levee deposits thin away from present channel margins toward a transition into backswamp deposits. Discontinuous overbank sands are occasionally interbedded with backswamp deposits and may form long bars parallel to the valley slope. These sand units probably represent major flood events (Costa, 1974, p. 302).

Silty colluvial deposits at valley margins were identified mainly by their location at the base of valley sideslopes and by their grain size characteristics. Surface colluvial units are generally thin with internal sedimentary structure commonly disturbed by plowing or soil formation.

Fig. 4. Flood plain stratigraphy. Simplified cross valley stratigraphic sections showing sediments of Pre-settlement, Agricultural, and Very Recent ages. Pre-settlement and Agricultural age sediment is clay to silt loam texture, and Very Recent age sediment is predominately sand to gravel. Coarse channel gravels underlie all sediments.
Thickened Ap (plow) soil horizons at the surface attest to deposition during farming. Subsurface gravel and gravelly diamicton units are also occasionally found dipping downslope toward the stream and interbedded with flood plain deposits.

Most vertical cutbank exposures show a striking layered stratigraphic sequence with iron oxide cemented gravel at the base, overlain by the following units from bottom to top: a light-gray clay loam, a black to dark-gray buried A soil horizon, and a laminated, brown silt loam. In some places along stream channels, cutbank sections are composed entirely of the brown silt-loam unit overlying a thin, coarse sand to gravel unit. Point bars of predominantly coarse sand to gravel are inset laterally against both these sequences. This arrangement of units is the basis for a three-fold division of chronostratigraphic units, which we informally name Pre-settlement (light-gray clay loam over cemented gravel), Agricultural (brown silt loam), and Very Recent (sand to gravel point bars).

The two older deposits are separated by the buried soil, identified as such by its color (Munsell system, 10YR2/0, black to 10YR4/2, very dark brown), granular soil structure, abrupt upper contact, and diffuse lower boundary. In some instances, the buried A horizon is underlain by a cambic B horizon which has developed weak to medium, subangular blocky structure.

The buried soil separates backswamp facies deposits of Pre-settlement and Agricultural ages. Pre-settlement backswamp deposits are gray to light-gray to yellow (2.5Y4/0 to 2.5Y7/0 to 2.5Y8/4) and have many distinct. 0.5 mm to 2.0 cm mottles and concretions (2.5Y2/0, black, and 2.5YR5/8, red). This unit is massive, dense, stiff, and sticky.

In contrast, Agricultural age backswamp deposits are a more uniform yellowish brown to brown color (10YR5/4,5/6 to 7/5YR5/4,4/4). The Agricultural backswamp unit is very friable and somewhat sandier than the Pre-settlement unit. Black organic backswamp deposits occur most frequently near the base of the Agricultural unit.

The maximum age of Pre-settlement deposits is unknown. No organic material suitable for radiocarbon dating was found in unambiguous stratigraphic context. The lack of an argillic B horizon in the buried soil suggests that the residence time of the Pre-settlement flood plain was relatively short. A comparison with regional soil formation chronologies (Jacobson, unpub. data) suggests that the Pre-settlement flood plain was formed during the mid- to late Holocene.

The minimum age of the Pre-settlement deposits and the beginning of sedimentation of the Agricultural deposits are datable from a knowledge of local land use history. Artifacts of European settlement, such as bottles, cans, textiles, brick fragments, and hewn timbers, are only found stratigraphically overlying the buried soil. Pollen was extracted from samples above and below the buried soil at the South Branch Patapsco River and Western Run sites and was analyzed for oak:ragweed (Quercus sp.:Ambrosia sp.) ratios. Brush and others (1982) argue that initial settlement and clearing of limited areas of the Piedmont around 1730 resulted
in moderate increases in the _Ambrosia_ contribution to the pollen rain. Our samples showed ratios of oak:ragweed averaged 0.27 above the soil and 2.70 below the soil, respectively. These observations indicate that the brown silt loam (Agricultural age) sediments began to be deposited after settlement of the Piedmont, about 1730.

Early railways of the Baltimore and Ohio and Western Maryland systems ran adjacent to three of the study reaches. Railroad traffic on the systems began around 1840 to 1850. Since there are no natural coal sources in these basins, the lowest stratigraphic occurrence of coal at these sites marks the 1840 to 1850 period. Coal occurs only stratigraphically above the buried soil but does not always occur at the contact. For example, at the South Branch Patapsco site, the lowest occurrence of coal is 75 cm above the buried soil, in a section with nearly 4 m of Agricultural age overbank sediments. This observation is consistent with the arguments of Brush and others (1982, p. 206-210) that large-scale land disturbance and increased sediment supply did not occur until the mid 1800's during the agricultural revival of that period. Thus, the bulk of the Agricultural age sediment was probably not deposited before about 1850.

Thick, coarse point bar deposits inset against the older units comprise the Very Recent chronostratigraphic unit. The date of the end of Agricultural age deposition and beginning of Very Recent deposition is determined from land use history and limited tree ring dates from trees growing on the surface of the Very Recent deposits. As noted above (fig. 2), the percentage of land in crops peaks at the turn of the century and then undergoes a precipitous decline after 1930. The post-1930 era was also the period during which soil conservation measures were introduced (Meade, 1982, p. 240).

It is reasonable to associate these great changes in upland land use and farming practices with the dramatic unconformity between Agricultural and Very Recent deposits. We use 1930 as a date for the unconformity as a general approximation for the Maryland Piedmont region, although timing and lags between land-use change and sedimentation are expected to differ from basin to basin. Available information suggests that the shift from deposition of Agricultural age fine sediments to Very Recent age sandy to gravelly sediments was, in fact, highly variable in time and space. Tree ring dates of the oldest trees found on the Very Recent surfaces at the South Branch Patapsco and Little Falls sites range from 16 to 27 yrs (1964 to 1953 A.D.), suggesting that the shift is a fairly recent phenomenon at these sites. In contrast, 1938 air photos of the Western Run site show abundant light-colored sediment (presumably sand) near the channel margin suggesting that the shift to Very Recent deposition of coarse sediment had occurred at this site by 1938. Furthermore, Costa (1975) argues that the flood plain of Western Run was still rapidly aggrading at least up to 1924 based on the presence of a 1924 automobile license plate buried under 0.81 m of flood-plain sediment. These observations indicate that our use of 1930 must be viewed as a minimum date for the shift, and lags up to 20 yrs may be common.
ESTIMATES OF CHANGES IN HYDROLOGY AND SEDIMENT YIELD ACcompanyING LAND USE CHANGES

The following discussion is intended to establish the links between known land use history and observed flood plain stratigraphy by presenting order-of-magnitude estimates of sediment supply and flood discharge changes caused by land use changes. It will be shown that the three part flood plain stratigraphy can be explained by changes in sediment supply and flood discharge and the balance between these two factors. Because channel geometries during the first two hydrologic and sediment regimes are not clearly recorded in flood plain stratigraphy, estimates of sediment supply and flood discharge are also used to infer changes in channel cross-section geometry.

An important premise in this argument is that effects of land use can be isolated as the major influence on sediment supply (Qs) and flood discharge (Qw) over this time period. This requires that the effects of natural disturbances, such as forest fires, major storms, and climatic trends can be discounted for the period from Pre-settlement time to the present. The flood plain stratigraphy we observe in the Maryland Piedmont is consistent with observations at many other sites in the eastern and midwestern United States (Happ, Rittenhouse, and Dobson, 1940; Knox, 1972, 1977; Trimble, 1974; Trimble and Lund, 1982). This similarity in flood plain stratigraphy over a wide area is evidence that regional natural disturbances, such as forest fires and major storms, cannot be responsible for the observed stratigraphy and that a more widespread change must be invoked to explain it. Natural disturbances on a local and regional scale, however, would surely have a secondary influence on the larger, human changes and may also have had profound effects at specific sites. Similarly, the fact that penecontemporaneous changes in stream channel characteristics and flood plain aggradation processes have occurred over wide areas of the eastern United States suggests that these changes are not simply internal adjustments of the separate fluvial systems, because such changes would be expected to be random in time and space.

The potential importance of climate changes can be assessed from a 230-yr synthetic annual precipitation series centered on Philadelphia, Pa. (fig. 5; Landsberg and others, 1968). This climatic time series was synthesized from a number of discontinuous, historical records from different sites in the eastern United States; gaps exist where historical data were insufficient. The series shows a slight decreasing trend in precipitation from the early to late 1700's, a climb to a maximum from approx 1830 to 1880, a decreasing trend from 1910 to 1930, and a slight rise to the end of the series in 1970. The maximum and minimum annual precipitation values for the 230-yr record (117.6 cm in 1859 and 93.5 cm in 1822) are only 11 percent higher and 12 percent lower, respectively, than the mean value. Langbein and others (1949, p. 8), and Langbein and Schumm (1958, p. 1077) show that, if all other variables remain constant, variations in precipitation of this magnitude should produce similarly small variations in runoff, with a maximum of approx plus or minus 25 percent. As
Fig. 5. Synthetic rainfall record. Two hundred thirty yr synthetic rainfall record centered on Philadelphia, Pa., based on scattered, discontinuous northeastern U.S. historical records. From Landsberg, Yu, and Huang, 1968.

will be shown in the following discussion, this amount of variability in the climatic record is much less than the calculated hydrologic responses produced by land use changes. However, the 1830 to 1880 increase and the 1910 to 1930 decrease in annual precipitation are synchronous with the land use peak and abandonment, respectively. Hence, precipitation trends may have enhanced the hydrologic response to land use to some extent.

When watersheds are deforested, annual water yields increase because of reduced evapotranspiration and increased runoff (Patric and Reinhart, 1971, p. 1186-1187). In a review of experimental watershed studies, Bosch and Hewlett (1982, p. 16) conclude that total annual water yield increases approx 25 mm for every 10 percent of deciduous hardwood forest cover cleared. Much of the increased yield comes in late summer and early fall, when base flow would ordinarily be minimized by evapotranspiration. Reinhart, Eschner, and Trimble (1963) argue that, in general, spring peak flows are not noticeably affected by deforestation. However, Patric and Reinhart (1971, p. 1184) note small increases in instantaneous peak flows on some cleared watersheds. Thus, watershed experiments predict that deforestation of the Maryland Piedmont probably resulted in increased water yields and, perhaps, increased peak flows as well.

For this discussion, hydrologic responses of the watersheds above the study reaches are estimated by Walker's (1971) regression model which relates peak discharge of a two-year recurrence interval flood ($Q_{w2}$), to drainage area (A), basin slope (S), percentage of forest cover (F), and geological factors (primarily rock type) (G):

\[ Q_{w2} = 54.2A^{0.947}S^{0.331}F^{0.394}G^{0.809} \quad \text{S.E.} = 31.7\% \]
Calculated percentage increases in discharge of 2 yr recurrence flood ($Q_{w2}$) over Pre-settlement background level for given percentage forest cover for three time periods. Calculation based on regression model from Walker (1971)

<table>
<thead>
<tr>
<th>Time period</th>
<th>% forest</th>
<th>$Q_{w2}$ % of Pre-settlement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-settlement</td>
<td>100</td>
<td>—</td>
</tr>
<tr>
<td>Agricultural</td>
<td>20</td>
<td>189</td>
</tr>
<tr>
<td>Very Recent</td>
<td>40</td>
<td>144</td>
</tr>
</tbody>
</table>

Assuming all factors remain constant except forest cover, we have calculated flood discharges with a two-year recurrence for the three periods, pre-1730, 1850 to 1930, and post 1930, corresponding to Pre-settlement, Agricultural, and Very Recent periods. For these periods we have assumed 100, 20, and 40 percent forest cover, respectively, estimated from current land use data and historical accounts (Craven, 1925). The model predicts that $Q_{w2}$ during the Agricultural peak was 189 percent of the Pre-settlement value, and under Very Recent conditions $Q_{w2}$ is 144 percent of the Pre-settlement discharge. These values are tabulated in table 2 and impervious area in the post-1980 suburbanization era; however, because the study reaches are all in rural basins, these effects are probably small.

Knox (1985) calculated similar hydrologic changes in the driftless area of Wisconsin. In that area 1.5 yr recurrence interval floods in the period 1900 to 1920 were 135 to 145 percent of pre-settlement floods of the same recurrence frequency (Knox, 1985, p. 294, p. 297).

Fig. 6. Flood discharge and sediment supply. Estimated relative changes in sediment delivered to streams, $Q_s$, and discharge of 2 yr recurrence flows, $Q_{w2}$. See text for calculations.
Deforestation and agricultural land use increase soil erosion in two ways. First, the soil is disturbed and exposed to direct impact of raindrops (Evans, 1980, p. 110). Second, infiltration capacity is reduced through the formation of soil crusts and destabilization of soil aggregates (Thornes, 1980, p. 176-178), allowing more water to run off at the surface where it can entrain soil particles. Empirical evidence for these effects has been obtained from the numerous plot experiments used to develop and calibrate the Universal Soil Loss Equation (U.S.L.E.), an empirical equation relating soil erosion rate to soil, vegetative cover, management, rainfall intensity, and slope factors (see Mitchell and Bubenzer, 1980, p. 17-55).

Changes in soil erosion in upland areas are assessed in this discussion using the U.S.L.E. cover factor (C). If all other factors remain constant, the change in predicted annual soil erosion will be proportional to the change in the C factor. Change in land cover from forest to plowed land results in an increase in C on the order of 900 percent (Roose, 1977). With all other factors remaining constant, this change in the cover factor, weighted by the mean cropland percentage for the five Piedmont counties, produces a rough estimate of relative amounts of soil erosion for periods of the land use history:

\[ A_{rel}^\% = C_{rel} \times 9, \]

where \( A_{rel}^\% \) is soil erosion relative to Pre-settlement conditions and \( C_{rel} \) is percentage of land under plowed cultivation. In this calculation, pasture, hay fields, and orchards are lumped with forested land; this simplification will tend to underestimate soil erosion, since pastures and hay fields will probably produce slightly more sediment than forested land. Values of estimated relative soil erosion for different time periods are tabulated in table 3 and graphed as \( Q_s \) in figure 6.

The soil erosion calculation estimates that peak Agricultural period soil erosion was approx 600 percent of Pre-settlement levels; Very Recent period soil erosion is estimated at 200 percent of the Pre-settlement value; and for the 1900 peak to post 1980 period this calculation estimates a decrease to 39 percent of the peak value. The post 1980 value probably overestimates soil erosion to the extent that erosion control practices are ignored but may underestimate soil erosion associated with urbanization and construction.

These calculations do not measure the amount of sediment actually supplied to streams, since soil eroded from uplands may be retained in intermediate storage areas such as toeslope colluvial deposits, alluvial fans, and upstream flood plains. Sediment delivery is normally much smaller than soil eroded. Sediment delivery ratios (the proportion of eroded soil delivered to a point of interest along a stream channel) should vary with time, as land use intensity and delivery processes vary (Trimble and Lund, 1982), and with the geomorphology of the basin (Roehl, 1962). Trimble and Lund (1982, p. 17) present data that suggest delivery ratios were higher during peak land disturbance. They propose that gully development increased sediment delivery. Their data are calculated from sediment accumulation in small reservoirs with less than 5 km² drainage
areas; it is not clear if sediment delivery ratios would show comparable increases in larger drainage basins where more opportunities exist for intermediate storage. In the absence of a rigorous method for assessing changes in the sediment delivery ratio over time, we have assumed that it is constant, a conservative assumption that should lead to underestimation of relative changes in sediment delivery to streams.

Roehl (1962, p. 211) finds significant correlations between sediment delivery ratio and drainage area, total stream length, and the ratio of basin relief to total stream length. Based on drainage area alone, Roehl’s regression model predicts that sediment delivery ratios for the Maryland Piedmont study streams should decrease with increasing drainage area from about 23 percent at the smaller Jones Falls reach (drainage area = 10.6 km²) to about 8 percent at the Deer Creek reach (drainage area = 215.0 km²). Hence, flood plains of stream reaches with greater drainage areas should be less sensitive to changes in sediment supply. The relationship between drainage area and sediment supplied to the stream reaches is further complicated if Agricultural period sediments are travelling downstream as a wave and moving in and out of flood plain storage.

In view of the possible variations of sediment delivery ratio in time and among basins, we have assumed as a first approximation that sediment supplied to all stream reaches is directly proportional to the Universal Soil Loss Equation C (cover) factor. This assumption is substantiated by data presented by Meade (1982, p. 238) which show, in general for Potomac River and Susquehanna River tributaries, that measured yields from cropland are 1000 percent higher than those from forested land. This compares favorably with the 900 percent increase in the C factor used in our calculations. Calculated relative sediment supply from Pre-settlement to Very Recent time is shown in figure 6 along with relative changes in 2-yr flood discharge.

These calculations are not intended to be a rigorous analysis of the changes in hydrology and sediment supply over the time period from 1780 to the present. In view of the variability of geology and land use among the study site watersheds, more complex models are probably not justified. However, we believe that these simple calculations show correct trends

<table>
<thead>
<tr>
<th>Time period</th>
<th>% cropland</th>
<th>% of Pre-settlement soil erosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-settlement</td>
<td>0.0</td>
<td>—</td>
</tr>
<tr>
<td>1850</td>
<td>46.7</td>
<td>420</td>
</tr>
<tr>
<td>1870</td>
<td>60.0</td>
<td>537</td>
</tr>
<tr>
<td>1900</td>
<td>67.0</td>
<td>603</td>
</tr>
<tr>
<td>1930</td>
<td>43.1</td>
<td>387</td>
</tr>
<tr>
<td>1954</td>
<td>36.7</td>
<td>330</td>
</tr>
<tr>
<td>1978</td>
<td>26.0</td>
<td>234</td>
</tr>
</tbody>
</table>
and relative magnitudes of changes in the hydrology and sediment supply of the Maryland Piedmont.

Reservoir sedimentation rates are a measure of the actual rate of sediment delivery to streams, and for at least part of this century they can be used to assess the accuracy of the trends presented by the soil erosion calculations. Data available for four reservoirs on the Maryland Piedmont are given in table 4 for time periods between resurveys (Agricultural Research Service, 1973, 1977; and Chamberlin, Baec, and Winn, ms). All four reservoirs show lower sedimentation rates in the period 1940 to 1960; rates in this period are from one third to one half of those in the early part of this century. Thus, these data support both direction and magnitude of our calculated changes in sediment delivery during the twentieth century. In some of these reservoirs, sedimentation increased during the 1960's, probably reflecting rapid soil erosion and delivery associated with suburban development and construction (Wolman, 1967, p. 386).

**DISCUSSION**

Figure 6 schematically shows calculated relative sediment supply \((Q_s)\) and discharge \((Q_w)\) from pre-1730 to the present. This diagram shows the direction and relative magnitudes of changes in the two basic variables that control stream dynamics. During the change from Pre-settlement to Agricultural conditions, both flood discharges and sediment supply increased, although the increase in sediment supply was proportionally much greater. The cross sections in figure 4 show that these changes resulted in vertical accretion of overbank sediments with little deposition of coarse, point-bar, and channel facies. Where Agricultural age sediments compose the entire section, the elevation of channel sand and gravel is nearly coincident with the elevation of both Pre-settlement and present-day channel deposits. From this we conclude that either (1) channel aggradation was minimal during Agricultural conditions or (2) channels

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Drainage area k(\text{m}^2)</th>
<th>Period</th>
<th>Sedimentation rate 1000 tonne/k(\text{m}^2)/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loch Raven</td>
<td>784.8</td>
<td>1914-1943</td>
<td>17.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1943-1961</td>
<td>5.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1961-1972</td>
<td>30.0</td>
</tr>
<tr>
<td>Prettyboy</td>
<td>207.2</td>
<td>1933-1943</td>
<td>20.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1943-1961</td>
<td>12.0</td>
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<tr>
<td>Atkisson</td>
<td>45.6</td>
<td>1933-1954</td>
<td>10.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1954-1965</td>
<td>5.1</td>
</tr>
<tr>
<td>Lake Roland</td>
<td>84.9</td>
<td>1861-1894</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>1894-1963</td>
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were choked with muddy sediments and were transiently aggraded so that streams flowed in mud floored channels. No stratigraphic or sedimentologic evidence was found to resolve the question of channel aggradation by fines. Similar cases of flood plain aggradation in basins affected by accelerated erosion are noted by Happ, Rittenhouse, and Dobson (1940) in Mississippi, by Trimble (1974) in the southern Piedmont, by Knox (1977) in Wisconsin, and by Costa (1975) in the Maryland Piedmont.

With the change from Agricultural to Very Recent conditions, both \( Q_w \) and \( Q_{w2} \) decreased. However, \( Q_s \) has decreased to only 30 percent of the Agricultural peak whereas \( Q_{w2} \) is still 76 percent of the Agricultural value. This proportionately greater decrease in sediment supply gives discharges with proportionately greater transport capacity. Therefore, as streams migrate across their valleys under present-day (Very Recent time) conditions, they are reworking stored flood-plain sediments, removing much of the fine grained sediment, and leaving lateral accretion deposits composed predominately of sand and gravel size sediment.

During the Very Recent period, reworking of flood plain sediments has not only created characteristic deposits, but in six out of nine study reaches a distinct new and lower flood plain surface elevation is also being created. Bankfull discharge frequencies for these new flood plain levels range from 1.23 to 3.28 yrs on the annual maximum series, whereas the recurrence intervals for discharges reaching the six higher Agricultural period surfaces range from 3.94 to 10.33 yrs (Coleman, ms). Thus, at most sites the large valley bottom area underlain by Agricultural period sediment is actually a terrace existing out of equilibrium with the present hydrologic and sediment regime.

Costa (1975, p. 1285) also notes that streams on the Maryland Piedmont with drainage areas less than 26 km\(^2\) have statistically greater recurrence intervals for bankfull flows than basins with drainage area greater than 26 km\(^2\). He uses this difference to argue that the smaller streams are presently entrenched because of a relative lack of sediment load. Knox (1977, p. 335-336) notes that the latest sediments to be deposited in a southwestern Wisconsin stream with drainage area less than 155 km\(^2\) were bedload sands and gravels. Both these studies are compatible with the results of the present study which show an increase in the proportion of sand and gravel deposited in Very Recent time compared to Agricultural time.

If small and moderate sized Piedmont basins have streams that are exporting fines and depositing coarse sediment, it might be hypothesized that the fines are accumulating on flood plains downstream. This hypothesis was tested by looking for trends in facies thickness with drainage area for the study reaches. No statistically significant relationships between thicknesses of Agricultural backswamp or Very Recent point bar facies and drainage area were obtained for our data. Perhaps this is because other variables such as bedrock lithology, geologic structure, basin physiography, and land use were not held sufficiently constant among basins and (or) over time. Alternatively, once remobilized from flood plain
storage under Very Recent conditions, fine Agricultural period sediments may be transported completely out of these small basins and into reservoirs and estuaries.

Changes in discharge and sediment supply should also have had an influence on channel morphology. According to Schumm (1977, p. 109-112) both channel width and depth vary as a function of discharge and cohesiveness of bank material if channel slope is held constant. For streams in this study, channel slopes could not vary substantially over the last few hundred years because of bedrock in channel bottoms.

Bankfull channel depth in each time interval can be estimated from the stratigraphic record by using the difference in elevation between channel gravels and the flood plain surface being formed during that time interval. In both Pre-settlement and Agricultural time intervals, flood plain elevations were established by deposition of fine grained sediment. In Very Recent time, flood plain elevations have been established by laterally prograding point bar surfaces. Measuring from the top of channel gravels to the top of backswamp silt and clay, the stratigraphic record shows an apparent increase in bankfull channel depth from the Pre-settlement to the Agricultural period (fig. 4). If fine-grained sediments were deposited on the channel bed the actual depth would have been less; as discussed above, the stratigraphy does not resolve this question. The Very Recent channel depth, as measured from the top of channel gravels to the top of the surface of point bar accumulation, is less than the maximum possible channel depth of the Agricultural period (assuming no channel aggradation by muddy sediment). Very Recent bankfull channel depths are unambiguously greater than Pre-settlement channel depths (fig. 4).

Evidence for pre-existing channel widths is not retained in the stratigraphic record because cross valley channel migration has destroyed the evidence. However, Schumm's model of change in channel morphology as a function of discharge and cohesion of bank sediment (1977, p. 109-112) provides a basis for arguing the direction of width changes. Schumm derived a model for channel morphology based on a study of sand-bed rivers. In this model, width varies directly with a power function of discharge and inversely with a power function of percent clay plus silt in bank material. Hence, if other variables are constant, width may increase by either an increase in formative discharge or a decrease in cohesion of bank material. Decreasing discharge or increasing cohesion tends to give narrower channel widths. If both discharge and cohesion change, but in opposite directions, width changes are predictable. However, when changes in discharge and cohesion are simultaneous and in the same direction, increase or decrease in width will be dependent on the relative magnitudes of changes in discharge and cohesion.

For the Pre-settlement to Agricultural period transition, discharges increased to 189 percent of Pre-settlement values and fine sediment supply was sufficient for flood plain aggradation. The sediment deposited as bank material was dominantly silt, not very different in texture from Pre-settlement bank material. Thus, with increased discharge and approximately
constant bank cohesion, Schumm's equation predicts that channel widths should have increased during this period. From the Agricultural period to Very Recent time, discharges have decreased slightly to 144 percent of the Pre-settlement values. Bank material is now composed of sand and gravel (less than 10 percent silt and clay) on prograding point bars and very silty, cohesive sediment of Pre-settlement and Agricultural age in eroding cut-banks (fig. 4). Both discharge and bank cohesion have decreased; however, the decrease in fine sediment is proportionally greater. This should have resulted in increased widths since the Agricultural period. Similar net bankfull channel widening on the order of 100 percent in the period 1830 to 1970 has been observed on the upper reaches of the Big Platte watershed in Wisconsin (Knox, 1977, p. 337). Thus, present day stream widths are probably the maximum of the late Holocene history of these streams. A schematic diagram of channel metamorphosis and changes in flood plain formation is presented in figure 7.

CONCLUSIONS

The alluvial stratigraphy of Maryland Piedmont flood plains reveals a threefold division of deposits corresponding to three different periods of land use. Relatively thin overbank and lateral accretion deposits accumulated in Pre-settlement time, prior to about 1730; thicker overbank and thin lateral accretion deposits accumulated in the Agricultural period, about 1730 to 1930; and thick, coarse lateral accretion deposits correspond to Very Recent time, some time after 1930. These abrupt changes in flood plain sedimentation resulted from large changes in upland sediment supply and hydrologic response. This example of stream metamorphosis illustrates that great increases in sediment supply coupled with moderate increases in flood discharges resulted in a period of rapid flood plain aggradation. The large decrease in sediment supply in Very Recent time, coupled with a slight decrease in flood discharge, changed the flood plain formation process: dominance by vertical accretion of fines was replaced by dominance by lateral accretion of sand and gravel.

Channel morphologies also changed to accommodate altered hydrologic and sediment supply regimes. The stratigraphic record shows an increase in bankfull depth from Pre-settlement time to Very Recent time. Evidence for bankfull depth changes from Pre-settlement time to the Agricultural period is ambiguous, because channels may have been temporarily aggraded by fine grained sediments that are indistinguishable from overbank sediments. Schumm's (1977) model of channel width response to discharge and particle size of bank material suggests that channels have probably widened progressively from Pre-settlement to Very Recent time.

Results of this study provide a basis for estimating the future behavior of small Maryland Piedmont streams. If sediment supply and hydrologic regime remain reasonably constant these streams will continue to rework stored flood plain sediments, resulting in the exportation of fines and retention of a smaller volume of coarser sediment as streams
Fig. 7. Flood plain development model. Schematic representation of three-stage development of Maryland Piedmont flood plains. Pre-settlement period (PS): undisturbed stream in natural regime. Agricultural period (A): excessive upland erosion and flood plain sedimentation. Very Recent period (VR): reduced sediment load, reworking of flood plain sediment and redeposition of coarsest sediment as new, lower flood plain level.
build new flood plains at lower elevations. This process will continue until cross valley stream migration has reworked the stored Agricultural period sediment, and the streams begin to rework deposits that have accumulated under present conditions. If impervious area increases through suburbanization in these watersheds and upland erosion controls are effective, more rapid flood plain reworking and flushing of fines can be expected along with increased reservoir and estuary sedimentation rates.

REFERENCES


Maxwell, H., 1910, The use and abuse of forests by the Virginia Indians: William and Mary Quart., College Hist. Mag., 1st. ser., v. 19, p. 72-100.


