Jacobson, R.B. and Coleman, D.J., 1986. Stratigraphy and recent evolution of Maryland Piedmont Flood Plains. *American Journal of Science* 286:617-637.

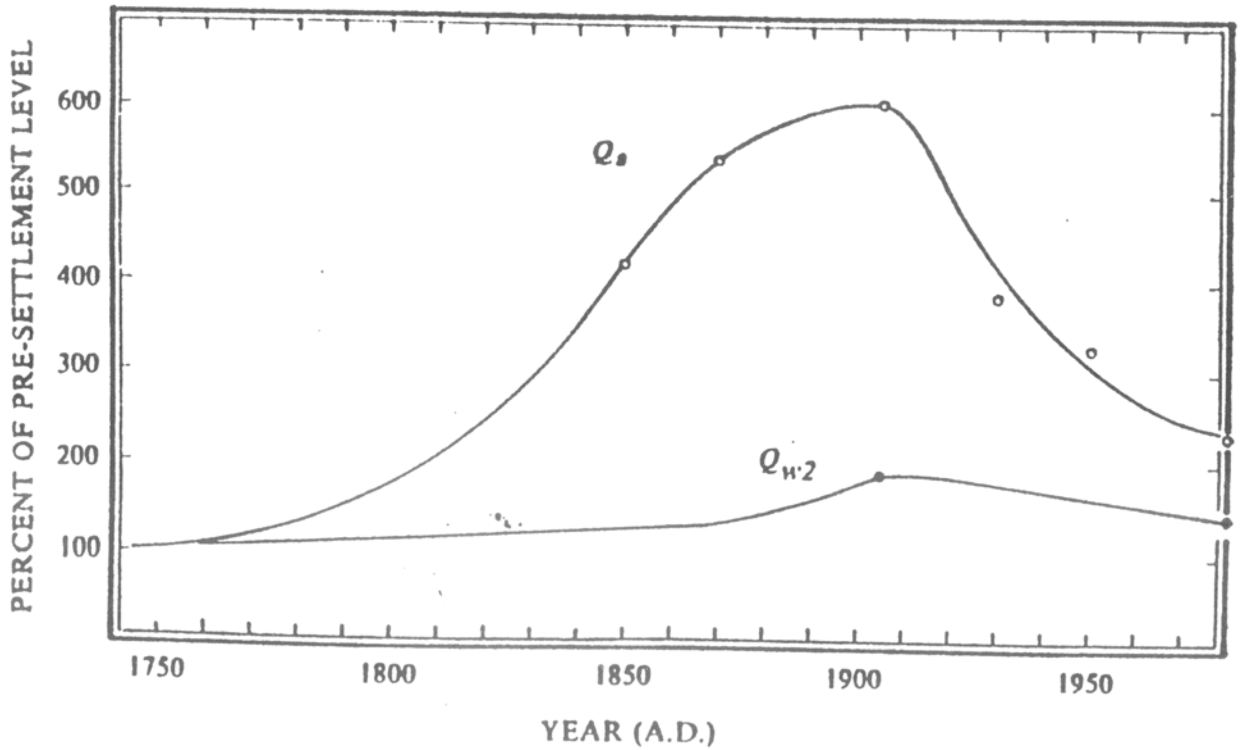


Fig. 6. Flood discharge and sediment supply. Estimated relative changes in sediment delivered to streams, $Q_s$, and discharge of 2 yr recurrence flows, $Q_{w2}$. See text for calculations.

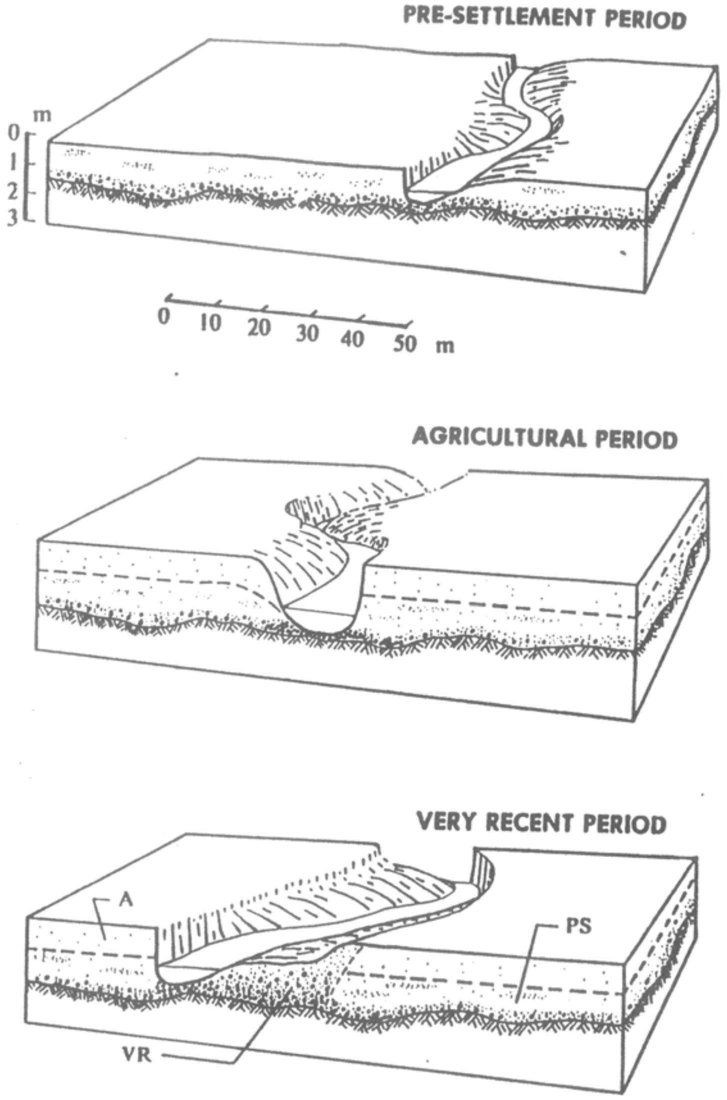


**Fig. 7.** Flood plain development model. Schematic representation of three-stage d velopment of Maryland Piedmont flood plains. Pre-settlement period (PS): undisturb stream in natural regime. Agricultural period (A): excessive upland erosion and flo plain sedimentation. Very Recent period (VR): reduced sediment load, reworking flood plain sediment and redeposition of coarsest sediment as new, lower flood pla level.

Jacobson, R.B. and Coleman, D.J., 1986. Stratigraphy and recent evolution of Maryland Piedmont Flood Plains. *American Journal of Science* 286:617-637.

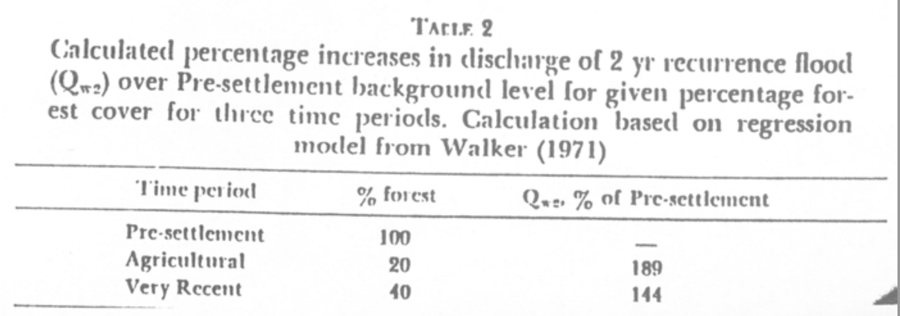
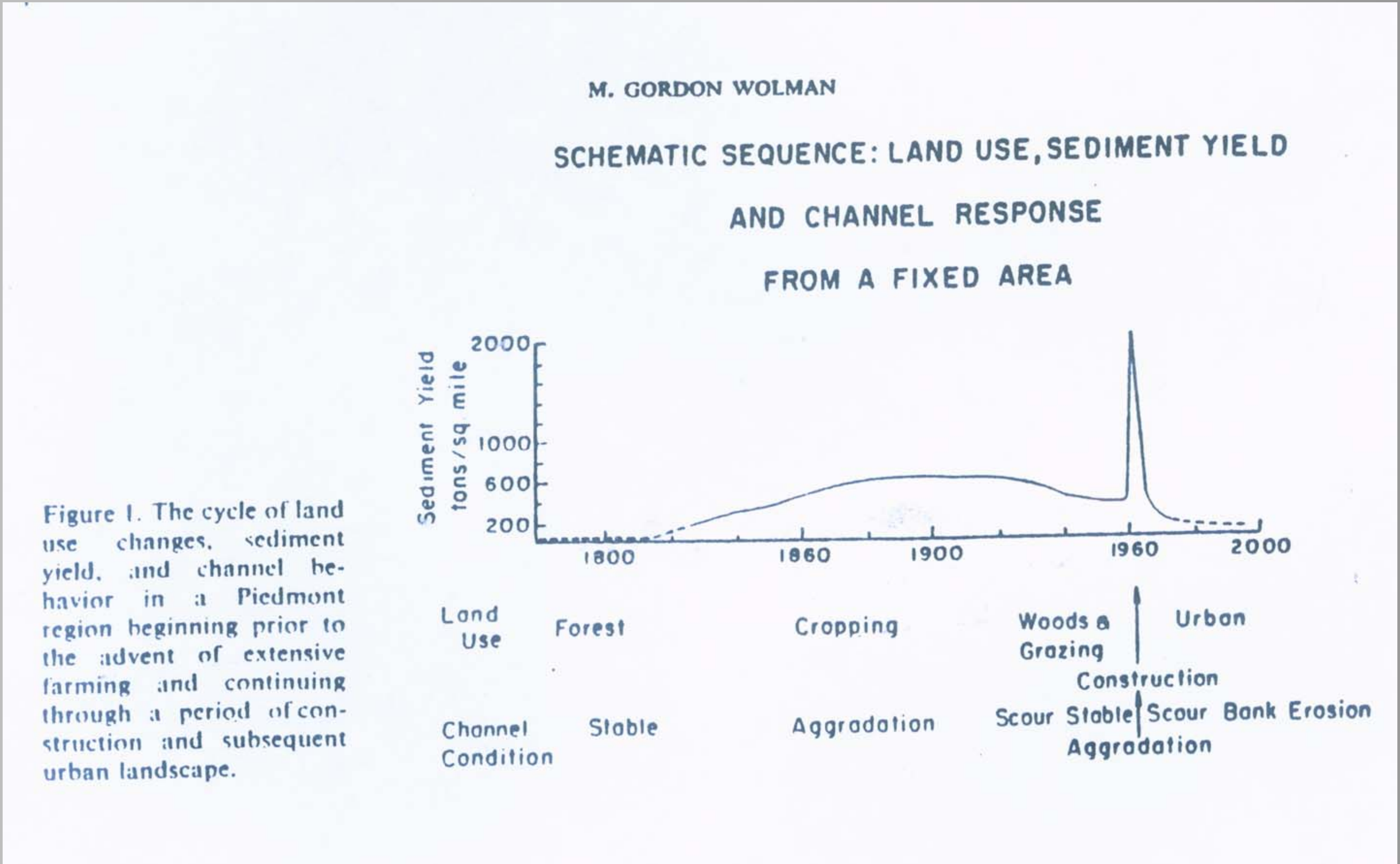


TABLE 2

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)

| Time period | % forest | $Q_{w2}$, % of Pre-settlement |
|---|---|---|
| Pre-settlement | 100 | — |
| Agricultural | 20 | 189 |
| Very Recent | 40 | 144 |

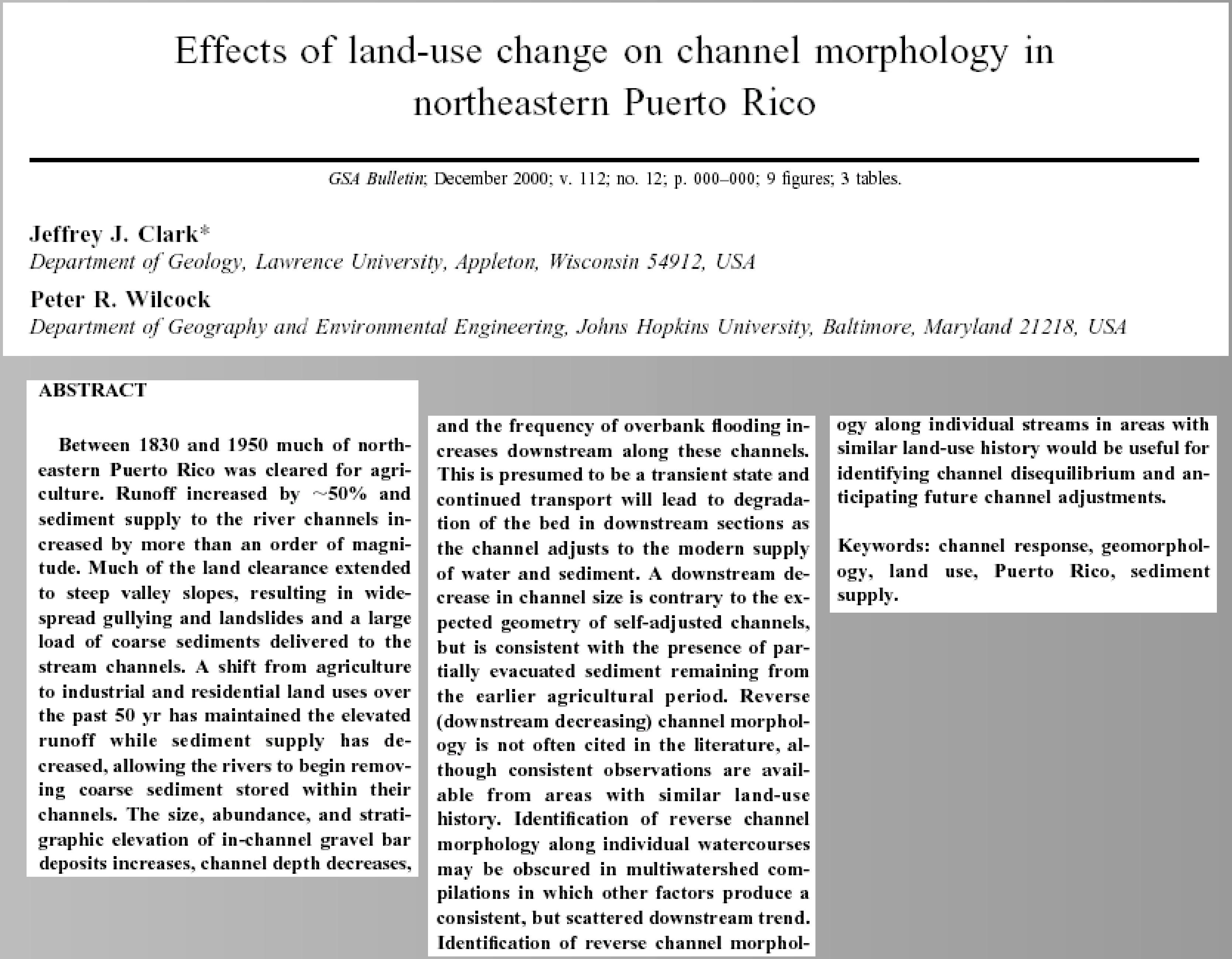
Wolman, M.G., 1967. A cycle of sedimentation and erosion in urban river channels. *Geografiska Annaler* 49(a).



M. GORDON WOLMAN

SCHEMATIC SEQUENCE: LAND USE, SEDIMENT YIELD AND CHANNEL RESPONSE FROM A FIXED AREA

Figure 1. The cycle of land use changes, sediment yield, and channel behavior in a Piedmont region beginning prior to the advent of extensive farming and continuing through a period of construction and subsequent urban landscape.



# Effects of land-use change on channel morphology in northeastern Puerto Rico

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## ABSTRACT

**Between 1830 and 1950 much of northeastern Puerto Rico was cleared for agriculture. Runoff increased by ~50% and sediment supply to the river channels increased by more than an order of magnitude. Much of the land clearance extended to steep valley slopes, resulting in widespread gullying and landslides and a large load of coarse sediments delivered to the stream channels. A shift from agriculture to industrial and residential land uses over the past 50 yr has maintained the elevated runoff while sediment supply has decreased, allowing the rivers to begin removing coarse sediment stored within their channels. The size, abundance, and stratigraphic elevation of in-channel gravel bar deposits increases, channel depth decreases, and the frequency of overbank flooding increases downstream along these channels. This is presumed to be a transient state and continued transport will lead to degradation of the bed in downstream sections as the channel adjusts to the modern supply of water and sediment. A downstream decrease in channel size is contrary to the expected geometry of self-adjusted channels, but is consistent with the presence of partially evacuated sediment remaining from the earlier agricultural period. Reverse (downstream decreasing) channel morphology is not often cited in the literature, although consistent observations are available from areas with similar land-use history. Identification of reverse channel morphology along individual watercourses may be obscured in multiwatershed compilations in which other factors produce a consistent, but scattered downstream trend. Identification of reverse channel morphology along individual streams in areas with similar land-use history would be useful for identifying channel disequilibrium and anticipating future channel adjustments.**

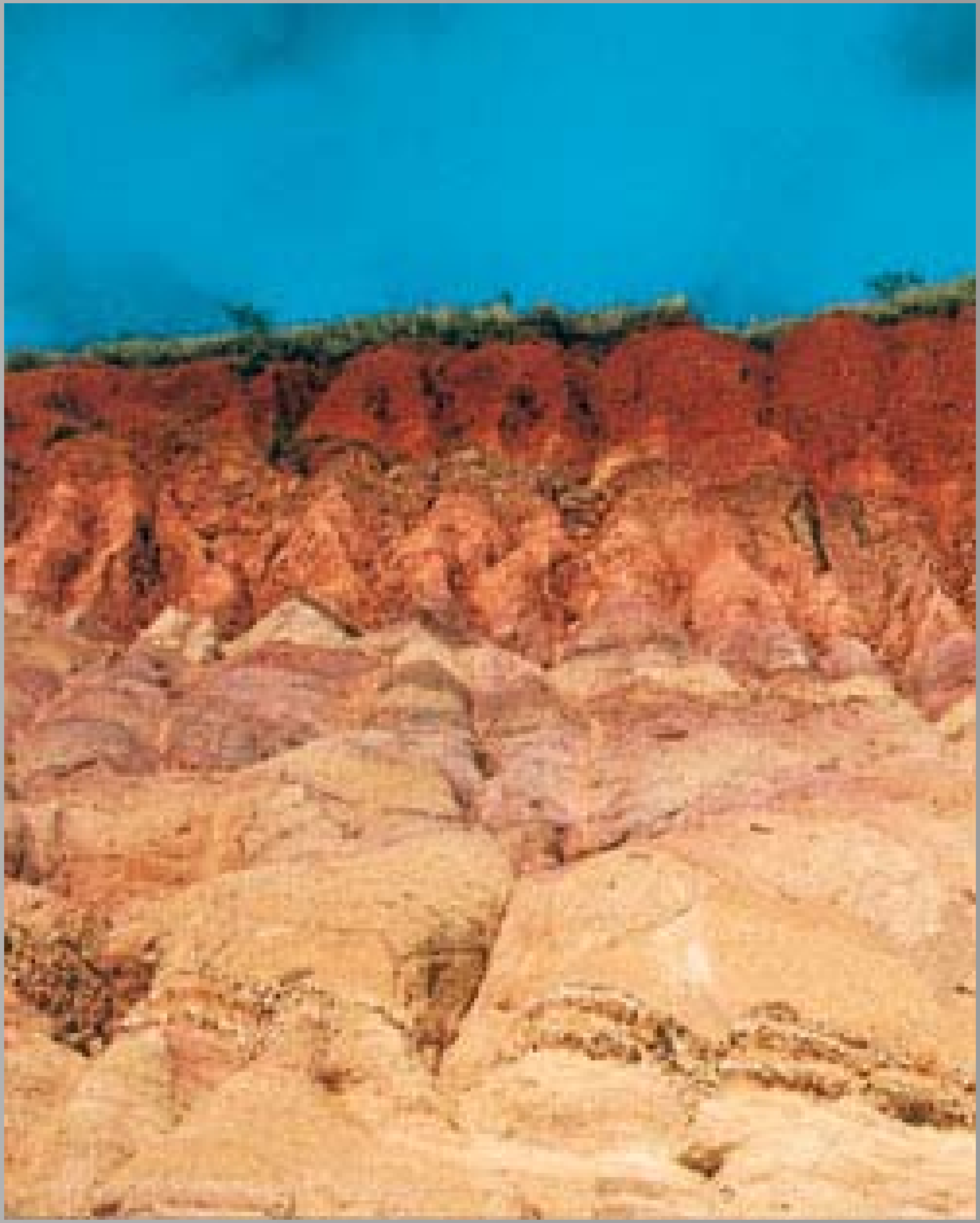
**Keywords: channel response, geomorphology, land use, Puerto Rico, sediment supply.**

NE Puerto Rico:

Very steep hillslides, cleared for subsistence agriculture.

Intense precipitation during hurricanes

Exceptionally high sediment yields, including a large fraction of coarse sediment from debris flows and gullying



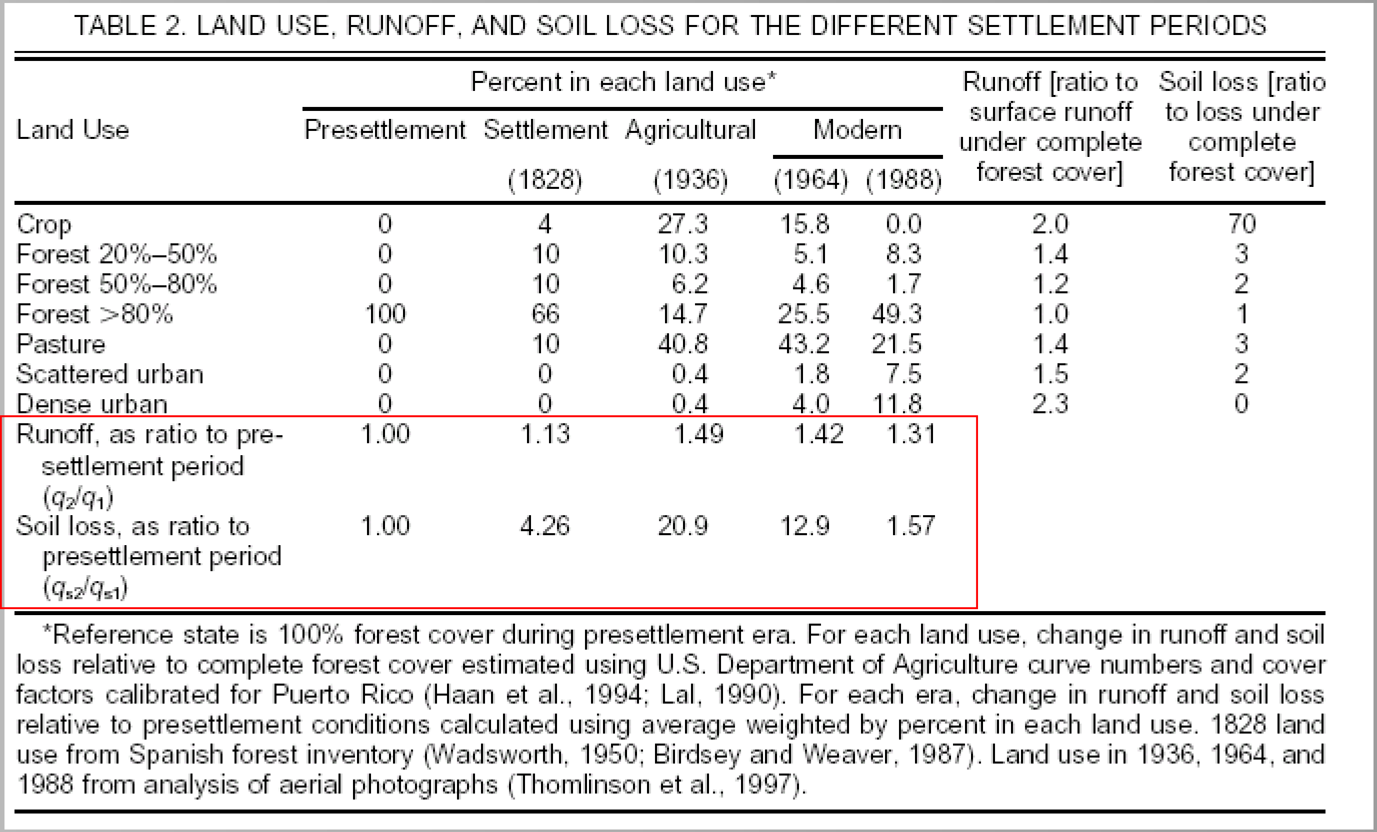


TABLE 2. LAND USE, RUNOFF, AND SOIL LOSS FOR THE DIFFERENT SETTLEMENT PERIODS

| Land Use | Percent in each land use* | | | | | Runoff [ratio to surface runoff under complete forest cover] | Soil loss [ratio to loss under complete forest cover] |
|---|---|---|---|---|---|---|---|
| | Presettlement | Settlement | Agricultural | Modern | | | |
| | | (1828) | (1936) | (1964) | (1988) | | |
| Crop | 0 | 4 | 27.3 | 15.8 | 0.0 | 2.0 | 70 |
| Forest 20%–50% | 0 | 10 | 10.3 | 5.1 | 8.3 | 1.4 | 3 |
| Forest 50%–80% | 0 | 10 | 6.2 | 4.6 | 1.7 | 1.2 | 2 |
| Forest >80% | 100 | 66 | 14.7 | 25.5 | 49.3 | 1.0 | 1 |
| Pasture | 0 | 10 | 40.8 | 43.2 | 21.5 | 1.4 | 3 |
| Scattered urban | 0 | 0 | 0.4 | 1.8 | 7.5 | 1.5 | 2 |
| Dense urban | 0 | 0 | 0.4 | 4.0 | 11.8 | 2.3 | 0 |
| Runoff, as ratio to presettlement period ($q_2/q_1$) | 1.00 | 1.13 | 1.49 | 1.42 | 1.31 | | |
| Soil loss, as ratio to presettlement period ($q_{s2}/q_{s1}$) | 1.00 | 4.26 | 20.9 | 12.9 | 1.57 | | |

*Reference state is 100% forest cover during presettlement era. For each land use, change in runoff and soil loss relative to complete forest cover estimated using U.S. Department of Agriculture curve numbers and cover factors calibrated for Puerto Rico (Haan et al., 1994; Lal, 1990). For each era, change in runoff and soil loss relative to presettlement conditions calculated using average weighted by percent in each land use. 1828 land use from Spanish forest inventory (Wadsworth, 1950; Birdsey and Weaver, 1987). Land use in 1936, 1964, and 1988 from analysis of aerial photographs (Thomlinson et al., 1997).

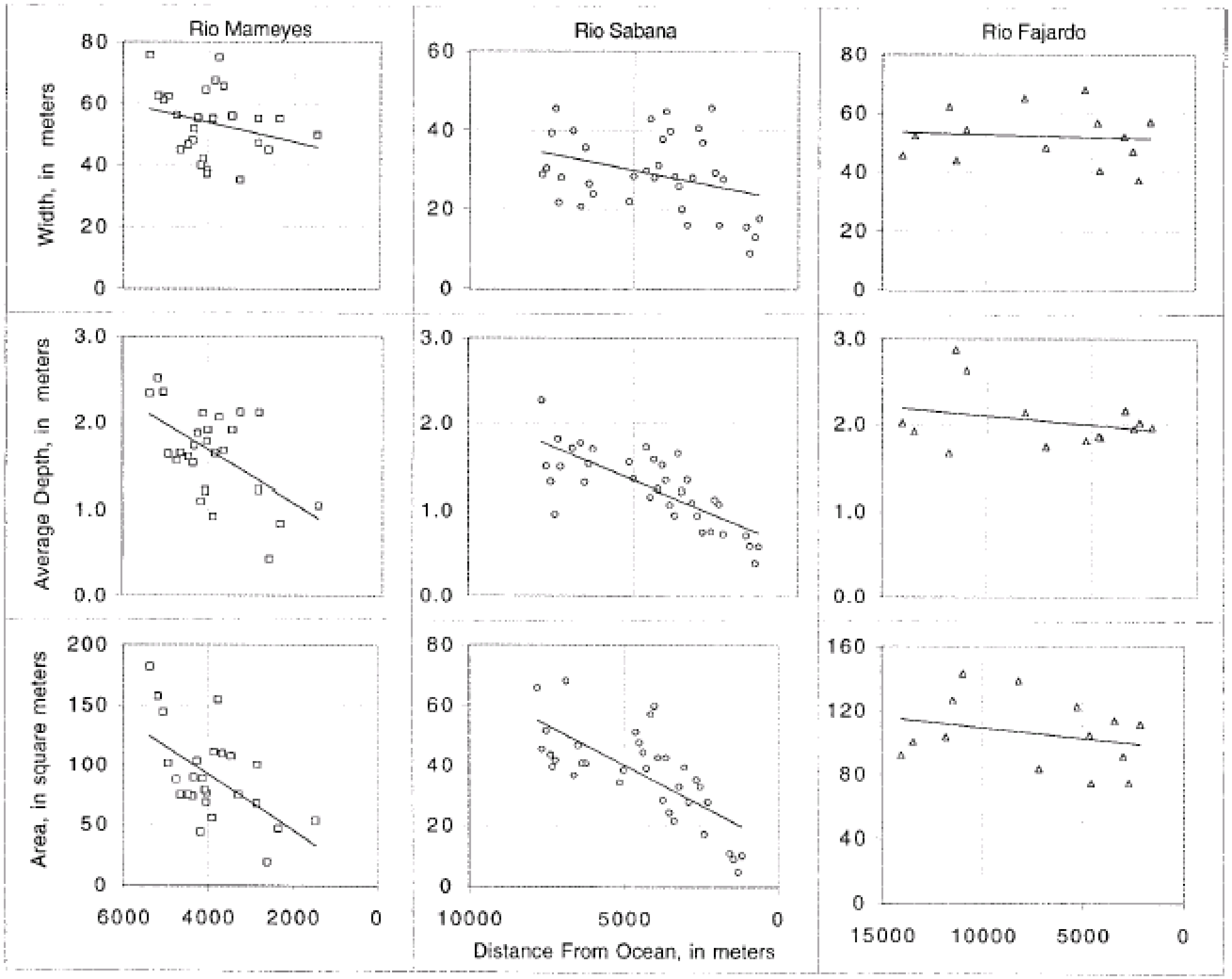


**Figure 5.** Downstream trends in channel geometry for alluvial sections of the Rio Mameyes, Rio Sabana, and Rio Fajardo. No sections were measured in estuarine portions of these streams or in a bedrock-controlled reach between stations 5100 and 6000 on the Rio Sabana. The Rio Mameyes and Rio Sabana show a distinct decrease in channel size in the downstream direction, whereas there is no significant along-stream trend in channel size for the Rio Fajardo. Note different scales used in each panel.

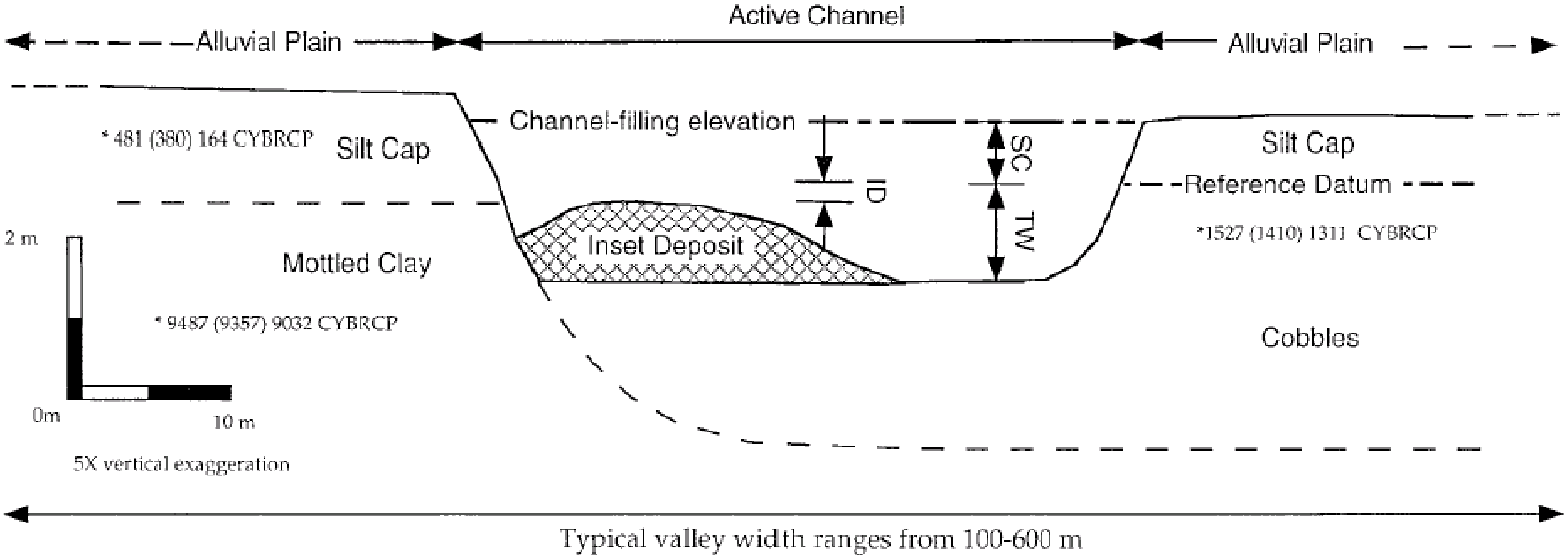


**Figure 3. Schematic cross section showing main morphologic and sedimentologic features of northeastern Puerto Rican streams. Channels typically exhibit a compound form with a gravel deposit found within the channel. A silt cap overlies a cobble layer and a mottled clay layer where present. The top of the cobble layer is used as a reference datum to measure relative elevation between the thalweg (TW), silt cap (SC), and inset deposit (ID). The estimated cross-sectional area of the inset deposit is filled with a cross-hachured pattern. Channel dimensions were determined by using the top of the silt and cobble bank to define the channel-filling elevation. Representative radiocarbon sample locations are denoted by asterisks. Calendar years before radiocarbon present (cal. B.P.) are given in parentheses and two standard deviation confidence intervals are also shown (Table 3).**

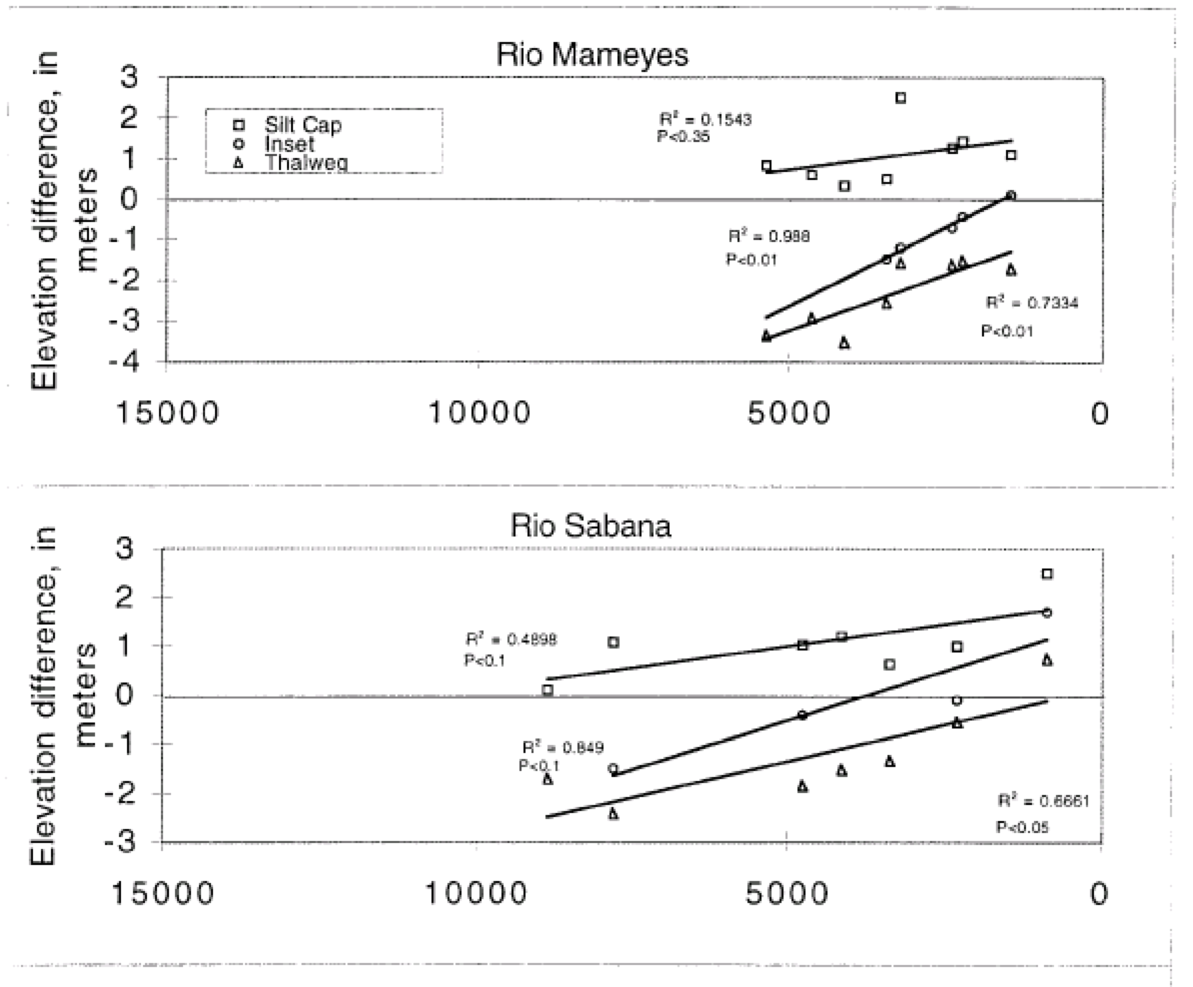


**Figure 6. Downstream trend in the top of the thalweg, silt cap, and inset deposit elevation relative to the top of the cobble layer found in the banks of alluvial sections of the Rio Mameyes, Rio Sabana, and Rio Fajardo. In all cases the top of the cobble layer is plotted at an arbitrary elevation of 0. The ordinate is the difference between the elevation of the top of the cobble layer and the tops of the other units. Only cross sections for which the cobble layer was surveyed were included. Both the top of the inset deposits and the thalweg increase in relative elevation in the downstream direction. The silt cap exhibits a weak, but statistically insignificant increase in relative elevation (thickness) as well. Note different scales used on each ordinate axis.**

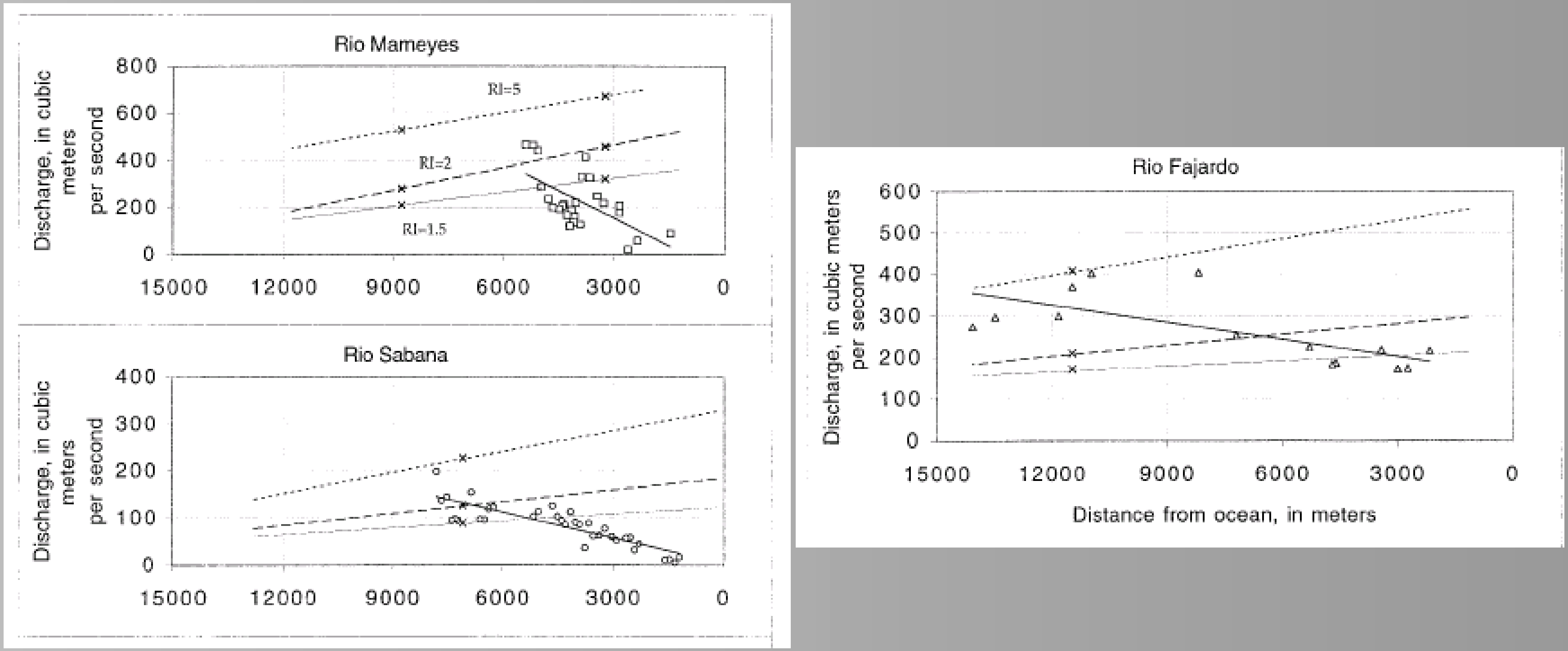


**Figure 8. Downstream trend in channel-filling discharge for alluvial sections of the Rio Mameyes, Rio Sabana, and Rio Fajardo. Locations of U.S. Geological Survey gages are denoted by x. The 1.5, 2, and 5 yr recurrence interval flows are shown as solid, long dashed, and short dashed lines, respectively. The slopes of the lines for the Rio Sabana and Rio Fajardo were determined by regional drainage area vs. discharge relationships from 9 gages in and around the study area (Table 1). The lines for the Rio Mameyes were determined using the two gages located on that river. In each case, the channel-filling discharge decreases and occurs more frequently as one moves downstream. Note different scales used on each ordinate axis.**

$$\frac{S_2}{S_1} = \frac{q_1}{q_2}\left(\frac{q_{s2}}{q_{s1}}\right)^{1/2}\left(\frac{D_2}{D_1}\right)^{3/4} \qquad (6)$$

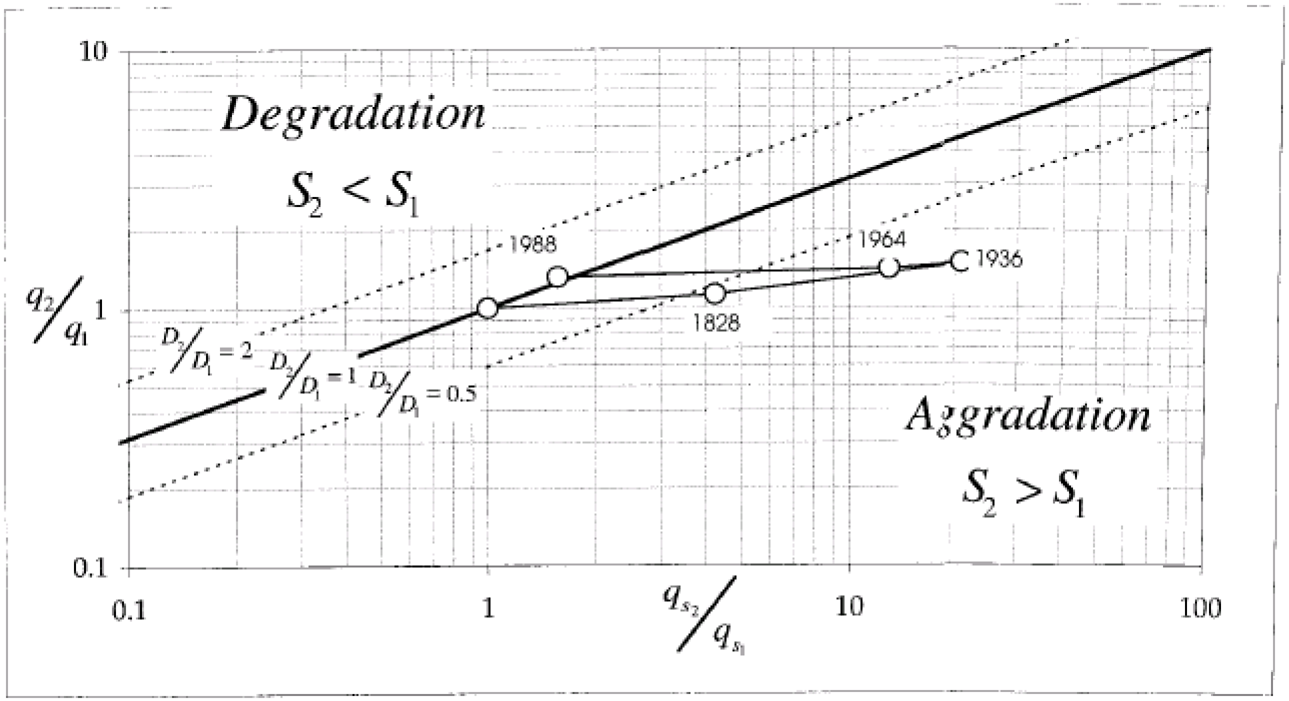


**Figure 9.** Likely channel response (scour or aggradation) to changes in water and sediment supply from $t_1$ to $t_2$. The solid line represents the solution of equation 6 for no change in the grain size of the sediment supply ($D_2/D_1 = 1$). Solutions are also shown for a factor of two change in grain size. Channels falling below or to the right of the line would tend to steepen through preferential deposition; the slope of channels above and to the left of the line would decrease through preferential scour. Approximate water and sediment supply for different periods in northeast Puerto Rico (Table 2) suggest a sequence of aggradation followed by degradation.