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Meander Growth in Artificially Straightened Streams

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Abstract. Two rivers near Ames, Iowa, which were artificially straightened in 1900, are developing a meandering pattern. Meander amplitudes and wavelengths and channel widths were measured on aerial photographs taken in 1939, 1953, 1958 and 1966. Linear regressions between meander parameters and time, distance downstream from a bend, channel width-depth ratio, bank materials and discharge indicate that the rate of meander development decreases with distance from a bend in the channel, that meander amplitude increased more rapidly with time than does meander wavelength, that meander amplitude increases most rapidly in channels with low width-depth ratios and meander wavelength increases most rapidly in channels with high width-depth ratios. Bank materials and discharge did not provide close correlations. Very wide channels cut into sands did not develop meanders because excess energy was expended in moving bedload. Channels which did meander approximated in most cases the behavior predicted by the laboratory channels of Friedkin.

Geologic data and engineering experience indicates that given the right conditions, a stream will tend to meander. Some naturally meandering streams in Iowa which were straightened to improve flood control and tile drainage, are returning to a meandering condition. Sections of the Skunk River and Squaw Creek near Ames, Iowa, were straightened about 1900. In 1952, Hussey and Zimmerman reported in this journal that the meander pattern was developing. The purpose of this paper is to compare these streams, considered as natural models, with the laboratory models of Friedkin (1945) and Tiffany and Nelson (1939) to determine what factors affect the development of meanders.

Figure 1, a 1967 aerial photograph of the Skunk River and of Squaw Creek, shows the developing meander pattern as well as three previous meander belts. Figure 2, a composite plan showing the meander pattern of the straightened streams, was traced from 1939, 1953 and 1965 photographs.

Records in the Story County Court House indicate that in the late 19th century, drainage ditches were dug in the reaches labeled A, B (1886), C (1893) and D - H (1894). According to the records, these ditches were dug 20 feet wide at the top and sloped to a depth of 3½ feet. No record was found of how or when the main flow of the Skunk River was diverted into the drainage ditches. However, a 1905 petition and a 1910 engineer's report indicate that the ditch was at this time carrying almost the entire flow of the Skunk River and that the ditch had a width of 60-85 feet and a depth of 7-10 feet which are approximately the dimensions of the lower reaches today (1968).

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Figure 1. Aerial photograph of Ames, Iowa, showing meander development on the Skunk River and Squaw Creek.

Figure 2. Development of meanders through time. The rivers were straightened in approximately 1900. Studied reaches labeled A through K.

The Ames quadrangle map, published by the U.S.G.S. in 1912, shows reach J in approximately its present position and all of the earlier channels of the Skunk River. A restraightening of section J was carried out between 1953 and 1958, but no record of this work exists. The foregoing illustrates the first difficulty of the study, i.e., determination of the exact history of the straightening. Subsequently, individuals have worked on certain sections without filing records in the county office.

RESULTS OF PREVIOUS STUDIES

The work of Friedkin (1945) and of Tiffany and Nelson (1939) in laboratory flumes indicates that meander wavelength and amplitude increases with discharge and valley slope and that meander amplitude increases with increasing angle of attack, whereas meander wavelength decreases with increasing angle of attack. Tiffany and Nelson (1939) also noted that meanders developed immediately and simultaneously throughout the channel, but that the meandering was dampened in a downstream direction away from the initial bend. The rate of meander growth and final meander size was also found to be related to the load-discharge ratio, a deficient load causing scour upstream and an increasing meander size in a downstream direction. The analysis of Bruun (1966) suggests that laboratory models should duplicate prototype behavior.

Studies of irrigation canals (Blench, 1966) and natural streams (Leopold and Maddock, 1953; Schumm, 1960; Schumm, 1963; Leopold and Wolman, 1957) show that channels having noncohesive bed materials which move at some stage of flow, will adjust their widths, depths, slopes and meander sizes to values which depend on effective discharge, sediment load, bank erodibility and artificial controls. Any disturbance of the regime of a stream must be followed by a trend back to the equilibrium state (Blench, 1966). Expressing the concept of entropy in terms of the probability of various states, Leopold and Langbien (1962) suggested that a quasi-equilibrium is approached rather rapidly.

METHODS

Aerial photographs taken in 1939, 1953, 1958 and 1966 were utilized to determine the meander development. The channel was traced off each set of photographs after enlarging to a scale of approximately one inch equals 660 feet. Most measurements were taken from the tracings, however, a check with measurements taken directly from the photographs showed no appreciable differences. The parameters measured are indicated in Figure 3. Most measurement errors are less than 10 percent; however, some measurements, particularly of meander wavelengths of low amplitude, may be in error by as much as 20 percent.

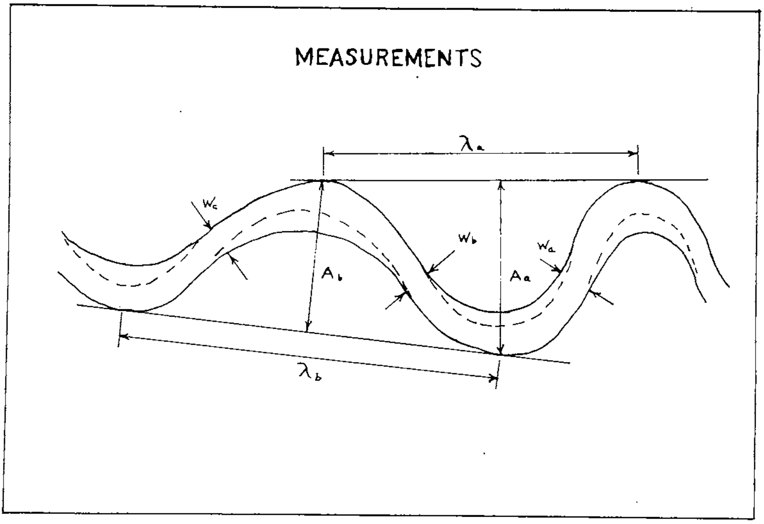

Figure 3. Definition of parameters used to describe channel geometry.

Discharge data were approximately from precipitation data using the relationship $Q_{MAF} = 0.000009856A^{.856} S^{.926} P^{3.926}$ where Q is mean annual flood, A is drainage area, S is main channel slope and P is normal precipitation (Schwob, 1966). The mean annual flood calculated from each year's precipitation was used as a parameter of the mean annual discharge. The channel bank and bed were sampled at nine localities and the weighted percent silt in the bank and bed calculated after the method of Schumm (1960).

Discussion

The variations in amplitude and wavelength of the developing meanders on the Skunk River and Squaw Creek are similar in space and time to the laboratory models of Friedkin (1945) and Tiffany and Nelson (1939). The meander amplitude in reaches A, B, C and J decreased downstream from each bend (Figure 4) in agreement with data in Tiffany and Nelson (1939). However, in reach D, amplitude was constant and in E increased. Even though a direction change appears to increase meandering as noted by Hussey and Zimmerman (1952), the value of the angle of attack does not effect the meander pattern as found by Friedkin (1945). As can be seen in Figure 4, meander amplitudes vary from one reach to another even though the angle of attack (30-35 degrees) is constant for all these reaches (A, B, C, D, E). Meander amplitude (Figure 5) and wavelength (Figure 6) both increase with time except in reaches A, B and J. The variations in reach A can be related to change in the angle of attack which occurred prior to 1953.

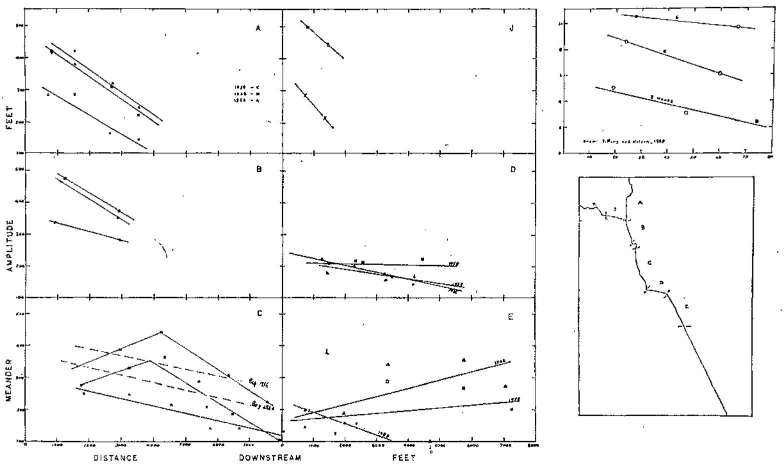

Figure 4. Relationship of meander amplitude to distance downstream from a major bend in the channel.

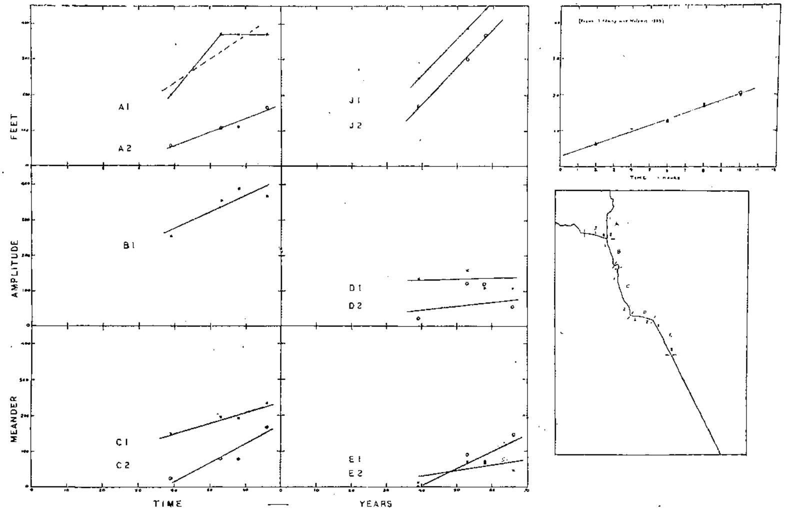

Figure 5. Change in meander amplitude with time for selected meanders within each reach.

The relationships between channel width and meander geometry of the straightened reaches were compared with those of natural channels (Figure 7). The scatter of points around the regression line for natural channels suggests that meander wavelength rapidly attains equilibrium value, but that meander amplitude does not.

The growth rate or rate of change for the various meander parameters is indicated by the slope of the regression line between amplitude

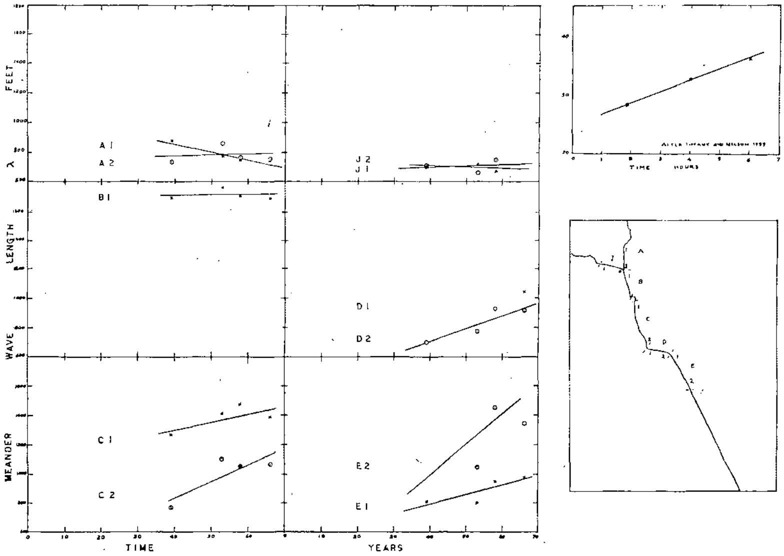

Figure 6. Change in meander wavelength with time for selected meanders within each reach.

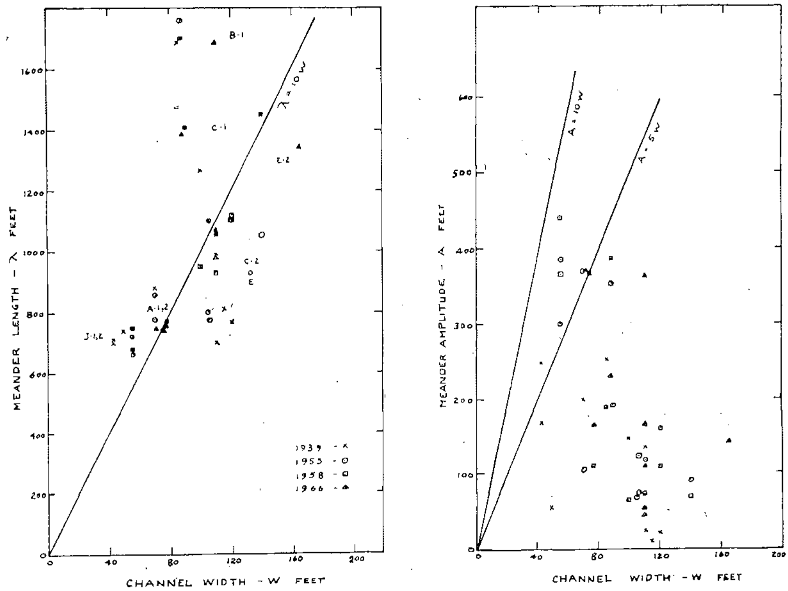

Figure 7. Relationships between channel width and meander amplitude and wavelength. Regressions indicate relationships for natural undisturbed channels.

or wavelength and time. A comparison of the growth rates for meander amplitude and wavelength with the width-depth ratio, percent silt in bank and mean annual flood (Figure 8) suggests that the width-depth ratio has the greatest influence on the rate of growth. Schumm (1963) noted that the sinuosity of natural streams varied inversely with the width-depth ratio of the channel. The direct relationship between the rate of wavelength growth and the width-depth ratio and the inverse relationship between rate of amplitude development and the width-depth ratio evident in Figure 8 are in agreement with Schumm. If wavelength increases at a greater rate than amplitude a stream will tend to straighten and have a low sinuosity. On the other hand, if amplitude increases faster than wavelength, a highly sinuous channel will develop. The general decrease in the rate of meander growth from reach A to reach H which occurs as channel width increases (Figure 9) suggests that width is a dominant control. Variations in channel width (Figure 9) may also explain the erratic behavior of the meanders in reaches C, D, E (Figure 4) and the lack of meander development in reaches F, G, H (Figure 2). This conclusion is supported by Schumm (1963) who found that narrow channels are more sinuous than wide channels.

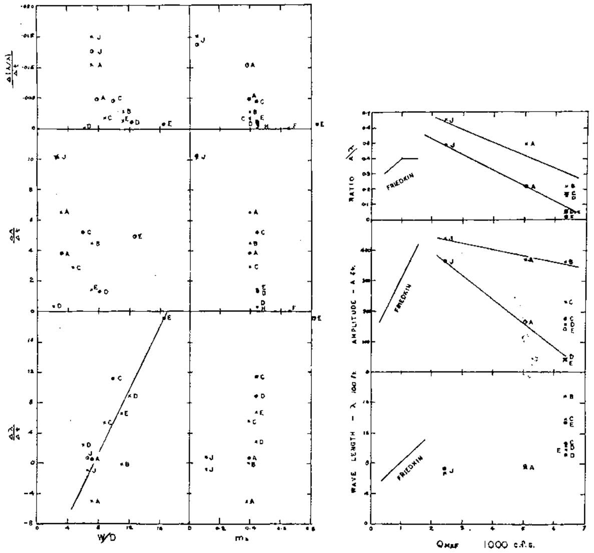

Figure 8. Relationships between growth rates and channel cross-section, bank materials and mean annual flood.

The poor correlation between mean annual flood and meander amplitude and wavelength (Figure 8) may indicate that either this parameter is not meaningful or that other factors are exerting a greater influence. The trends apparent in Figure 9 are opposite to those found in either natural or laboratory channels.

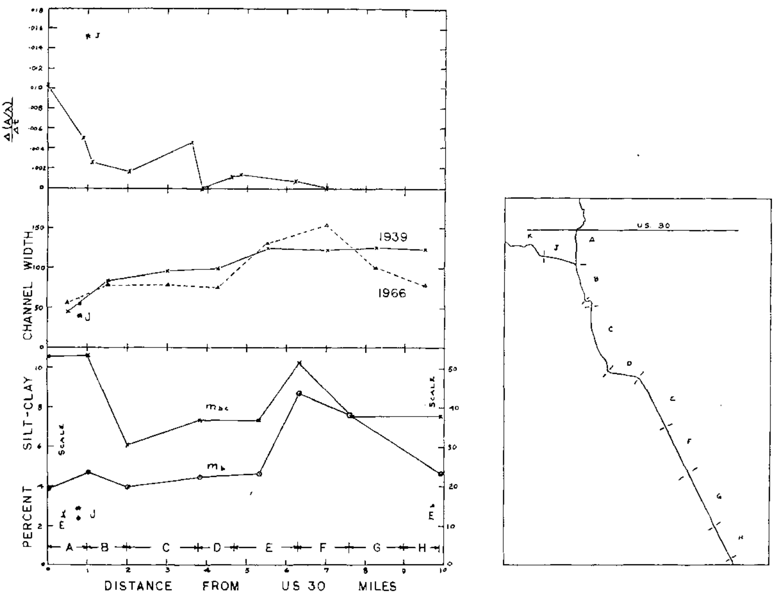

Figure 9. Change in growth rates, channel width and bank materials with distance downstream.

The lack of correlation between percent silt in the channel banks (M_b) and either meander wavelength or amplitude (Figure 8) is in line with Schumm's (1963) conclusion that while sinuous channels must have silty banks, the presence of silty banks does not guarantee meandering. Schumm (1963), however, concluded that as the weighted percent silt (M_{bc}) in the channel increases the sinuosity increases. The fairly constant M_{bc} in the study area (Figure 9) suggests that some other factor is influencing meander development. An interesting note is that the straightened reaches plot close to natural channels on Schumm's (1960) W/D-M diagram. This proximity suggests that the cross-sectional channel geometry is in equilibrium with the bank material.

The factor which appears to be having the greatest influence on meander development is, as suggested by the correlations in Figures 8 and 9, the width-depth ratio of the channel. Since the channel depth is nearly constant (9-12 feet), channel width is the important element. However, increasing width appears to inhibit meandering rather than increase it as the relationship $\lambda = kw^a$ (Leopold, Wolman and Miller, 1964) suggests. Schumm (1963) and Brunn (1966) suggest that in wide, sandy channels excess energy is utilized by moving the bed load whereas in narrow silty channels excess energy must be utilized through "meander friction." The present channel of the Skunk River is entrenched 2 to 3 feet lower than the original channel into Pleistocene outwash. Therefore as the channel width increases in a downstream direction more sand becomes available as bed load and any excess energy may be expended moving this sand rather than in meandering as in the upstream reaches.

CONCLUSIONS

This study indicates that meander development as represented by an increase in amplitude is most rapid in channels with a low width-depth ratio and least in channels with a high width-depth ratio where meander wavelength increases more rapidly with time. Channels with a low width-depth ratio approximate the laboratory studies most closely even though in the laboratory studies, channel width was not an important factor (Friedkin, 1945). It is difficult to predict if the present channel will approach its original meander pattern. It is evident that the present channel is approaching a quasi-equilibrium which suggests that meanders will not develop in reaches F, G, and H. The implications of this conclusion is that straightened channels should be dug to twice their pre-straightened width to inhibit future meandering.

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