# THE IMPACT OF AGRICULTURAL SETTLEMENT ON CANADIAN SANDY CREEK, OKLAHOMA

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**Canadian Sandy Creek, a small stream basin in central Oklahoma, was studied in order to evaluate its response to an altered hydrologic regime produced by land use changes associated with agricultural settlement. Peak discharge for moderate storm events is now nearly three times that of the presettlement period (*ca*. 1871). Stream channel capacity has increased markedly to accommodate the increased runoff. Moreover, large volumes of sediment have been deposited on the floodplain during times of overbank flow, creating alluvial deposits up to 16 feet thick.**

## INTRODUCTION

Stream system morphology is adjusted to the prevailing hydrologic conditions. The cross-sectional area of the channel is adjusted to the flow regime of the stream system (1, 2), i.e., the magnitude and frequency characteristics of surface runoff. Further, channel cross-section shape is a function of the nature of the sediment load (3). A change in these factors will bring about disequilibrium in the stream system if a threshold of stability is exceeded (4). The resulting disequilibrium produces morphologic changes in the stream system as a new equilibrium state is attained. Changes in the prevailing hydrologic regime that are of sufficient magnitude to create stream system instability can be attributed to either land use changes due to human activity or climatic change. This paper demonstrates the impact of land use change on stream system character in the Canadian Sandy Creek basin of southcentral Oklahoma. Reasons for the selection of this basin include the following:

(1) Changes which have occurred in the study basin are representative of those occurring throughout the central plains;
(2) its small drainage area (7.5 square miles) makes possible the use of runoff modeling techniques for the evaluation of hydrologic changes;
(3) smaller streams typically exhibit a greater response to an altered hydrologic regime than larger ones;
(4) it empties directly into the South Canadian River, making it a high-energy tributary, i.e., the steep channel gradient and valley slopes maximize the effects of a change in the hydrologic regime;
(5) since it was once Indian land, two (rather than one) early land surveys exist from which to extract data regarding the conditions of the watershed during the early historical period.

## METHODS

In order to assess the magnitude of the change in the hydrologic regime of the basin, land-use maps were assembled for three different times: 1871, 1899, and 1979. Vegetation and land-use patterns were reconstructed for 1871 and 1899 utilizing federal land surveys. Such reconstruction is possible because the notes made by the surveyors indicate by size and genus certain trees along survey lines, as well as the limits and composition of woodland areas which interrupted the prairie. The 1871 survey apparently represents pristine conditions, since the surveyors indicated no cultural activity in the basin except for a wagon road along the uplands (Fig. 1). By the time of the 1899 survey, however, appreciable agricultural activity had occurred as suggested by the several fields and road network (Fig. 2). Present-day land use was mapped using data gathered from recent aerial photographs and field surveys (Fig. 3).

The contrast between the land use of the late 1800s and the present agricultural land use impresses one with the magnitude of change, a change which certainly affected the hydrologic regime of the basin. Peak stream flows were calculated for each of the three times. A method for the determination of peak discharge from small rural basins has been developed by Chow (5). The peak discharge associated with a predetermined rainfall frequency is derived using data on soil type, vegetation cover, climate, basin area, and channel length and gradient. Soil type and vegetation cover form a composite variable used to determine runoff characteristics of the basin. This variable is weighted based on soil types and land uses. A climatic factor computed from rainfall data considers the effect of variability in the spatial distribution of rainfall. Lag time is determined from basin area, channel length, and channel gradient. The equation used is: $Q = A X Y Z$ where Q = discharge in cubic feet per second; A = drainage area in acres; X = the runoff factor, Y = the climatic factor; and Z = the hydrograph modification factor.

The impact of the increased runoff on channel dimensions was analyzed. The presettlement channel capacities were significantly smaller than those of today due to the change in the discharge magnitude-frequency relationships. The notes from the 1899 federal land survey include the width of streams where they intersected section lines. The present-day widths were measured at the same section-line crossings in order to detect any trends in width change. Both bankfull and low-flow water widths were measured because it is uncertain as to which the federal surveyor measured. The low-flow width was likely measured since the surveys were done in the fall, a time of low flow. Unlike the present-day measurements, however, little difference probably existed then between bankfull and low-flow width because the surveyors' notes imply near-vertical channel banks. Modern bankfull, modern low-flow, and 1899 stream widths are represented in Figure 4.

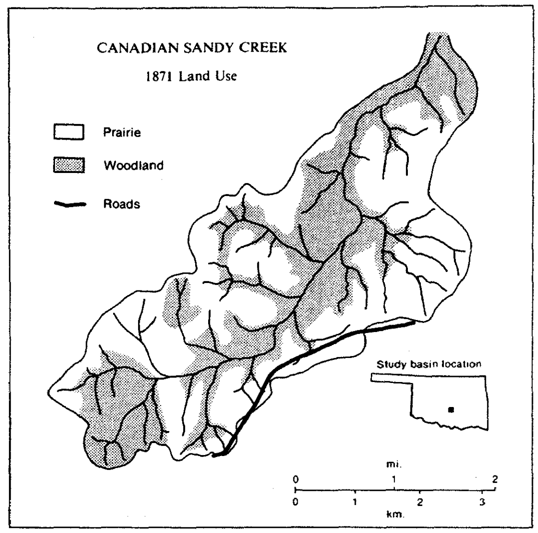


FIGURE 1. Pristine vegetation patterns as reconstructed from the original federal land survey conducted in 1871.

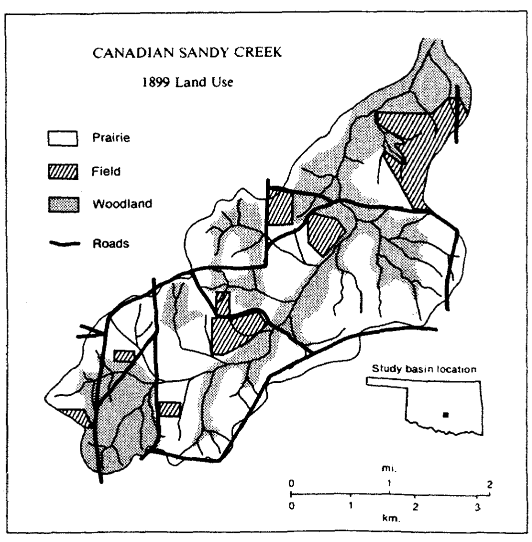


FIGURE 2. Land-use patterns as reconstructed from the U. S. Geological Survey land survey conducted in 1899.

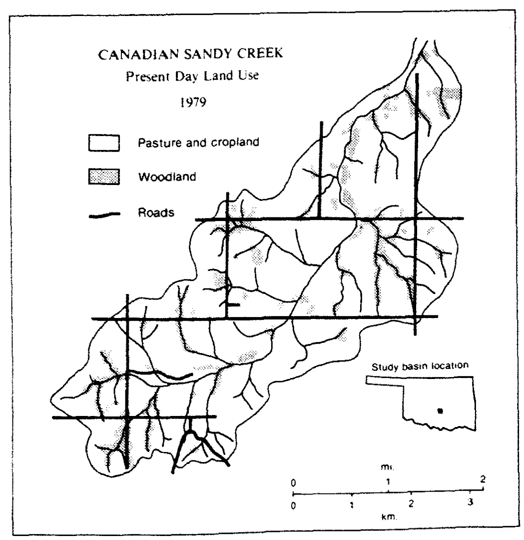


FIGURE 3. Land-use conditions for the present day as compiled from recent aerial photographs and field surveys. Owing to the intricacy of the pasture and cropland patterns, the above has been generalized from the large-scale work copy.

The accelerated erosion initiated by cultivation of the watershed tremendously increased sediment loads. Thus, the increased frequency of the overbank flow resulted in deposition of large amounts of alluvium on the formerly stable floodplain surface. The final facet of the analysis was an evaluation of the amount of post-settlement alluvium stored on the presettlement floodplain surface. Valley cross sections were surveyed at four locations along the main stream from the headwaters to the lower reaches. The thickness of post-settlement alluvium was measured at close intervals along each of the cross sections utilizing a belgium-type auger. Figure 5, an example of one of the valley cross sections, illustrates the magnitude of recent overbank deposition. Although cross sections were not established in the tributaries, a reconnaissance was made. Calculation of the sediment volume was made using the following formula:

$$V = 1/3 \left[ \frac{(E_1 + E_2)}{(W_1 + W_2)} + D_1 + D_2 \right] A$$

where V = volume of sediment, in acre feet; A = surface area of sediment between ranges, in acres; $E_1$ and $E_2$ = cross-sectional areas of sediment ranges 1 and 2, in square feet; $W_1$ and $W_2$ = width of sediment on ranges 1 and 2, in feet; and $D_1$ and $D_2$ = average depth of sediment on range 1 and 2, in feet (6).

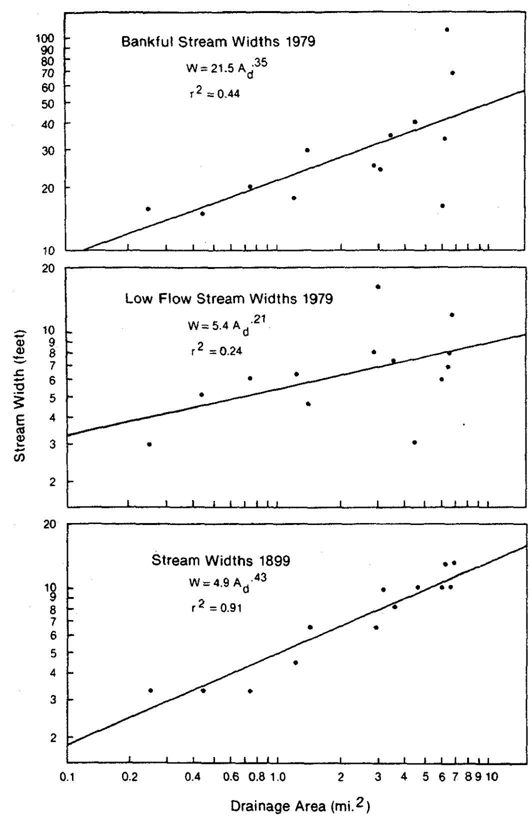


**FIGURE 4.** Modern bankfull, modern low-flow, and 1899 stream widths as a function of drainage area.

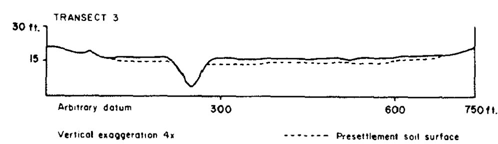


**FIGURE 5.** The land surface and presettlement soil surface survey at transect three.

## RESULTS AND DISCUSSION

### Changes in Basin Hydrology

Little or no cultural activity existed in the basin in 1871 (Fig. 1). Under these pristine conditions the erosion rates were extremely low when compared to those of the post-settlement period. Surface runoff was much less, due to well-developed soils and the luxuriant stand of prairie grasses described by the surveyors. When overbank flows occurred, suspended-sediment concentrations were far smaller than during the post-settlement period (7).

By 1899, 7% of the woodland had been cut, nearly 800 acres of prairie had been cultivated, and sixteen miles of road established (Fig. 2). At present only 5% of the watershed is forested (Fig. 3), and nearly one-half of that is pastured.

In order to assess the change in basin hydrology, the Chow method has been used to compute the peak runoff of the 2-year, 2-hour event, i.e., a storm occurring at least once in two years and lasting for two hours. Peak runoff increased from 220 cubic feet per second (cfs) in 1871, to 360 cfs in 1899, and to 610 cfs in recent years. The 2-year, 2-hour event was selected because it represents a storm of moderate intensity and relatively frequent recurrence. Knox (8), in applying the Chow method for a similar event to a 2.8-square mile basin in southwestern Wisconsin, also reports a threefold increase from the early settlement period to the present time.

**Channel Response**

In response to the increased runoff, channel capacities increased markedly throughout the small basin. Similar channel response has been documented in southwestern Wisconsin (8, 9, 10). The surveyors' stream-width observations provide quantitative channel data to compare with the present situation. Records of stream widths for the entire basin were only available from the 1899 survey. Early settlement (1899) stream widths were slightly less than modern lowflow width in the headwaters. Modern bankfull widths are far greater than the 1899 counterparts. The few existing width measurements from the 1871 survey indicate that in the 30-year interval between 1871 and 1899 stream width increased two to threefold. This implies that the level of cultural activity represented by the 1899 survey had already had a significant impact on the stream channel capacity. The estimated 60% increase in the peak runoff from 1871 to 1899 corroborates the rapid increase in channel capacity.

Channel depth has also increased during the period, accounting for a large amount of the increase in channel capacity. Depth increase is attributable to the increase in bank height from the deposition of post-settlement alluvium on the presettlement floodplain surface in times of overbank flow. Average thickness of the modern overbank deposits in the basin is 3.5 feet. Nearly all channels in the basin have also experienced entrenchment. Local testimony indicates that limited downcutting occurred in the early 1950s. Entrenchment occurred prior to 1950, however, as evidenced by stream-bed gravels situated as much as four feet above the present bed of the channel at several sites and by statements in the surveyors' notebooks implying one could see over the top of the streambanks when standing in the channel. It is impossible to do so at these same locations today.

Increases in channel capacity have therefore been extremely large during the post-settlement period, with increases up to seven times that of the presettlement period.

**Overbank Sedimentation**

In conjunction with the increase in runoff, sediment loads increased as a function of accelerated soil and stream channel erosion. The increase in overbank flows and sediment loads has resulted in relatively thick accumulations of alluvium on the presettlement floodplain surface. Accumulations of post-settlement overbank deposits are not uncommon and have been reported for many different locales within the eastern half of the United States (11-20). Post-settlement alluvium has several diagnostic features which attest to its youth. Mollic epipedons often have not developed in it because of frequent overbank deposition. Conversely, the stable presettlement floodplain surface typically had developed in it a soil with a dark brown or black A1 horizon. Thus, the color difference usually distinguishes the two units. Further, stratification of the recent alluvium is one of its more prominent features, whereas pedogenic processes have destroyed strata in the presettlement soil horizons. Differences in relative compaction are usually noticeable, the presettlement alluvium tending to be the more compact of the two. Post-settlement alluvium commonly contains evidence of cultural activity such as fence posts, boards, barbed wire, glass containers, and nails. Textural differences also often occur between the two units, recent alluvium being coarsest. All these characteristics are effective in differentiating the young deposits from the presettlement floodplain surface in the study basin.

A bank exposure typical of Canadian Sandy Creek is illustrated in Figure 6. Approximately 3 feet of post-settlement alluvium occur within the reach shown. Results of sediment analyses from the upper portion of the exposure are presented in Table 1. The former floodplain soil is identified by its finer texture and relatively high organic-matter content, whereas the post-settlement alluvium is generally sandier in texture and lower in organic-matter content.

The thickness of post-settlement alluvium averages 3.5 feet throughout the basin. However, a slight increase in thickness occurs in the downstream direction (Fig. 7). This slight downstream increase has been also noted in stream systems of southwestern Wisconsin (7, 8). The increase is due to the increased duration of overbank flow as the crest of the flood wave attenuates in the downstream direction. Within a short reach of the main channel, the postsettlement alluvium is 16 feet thick. This

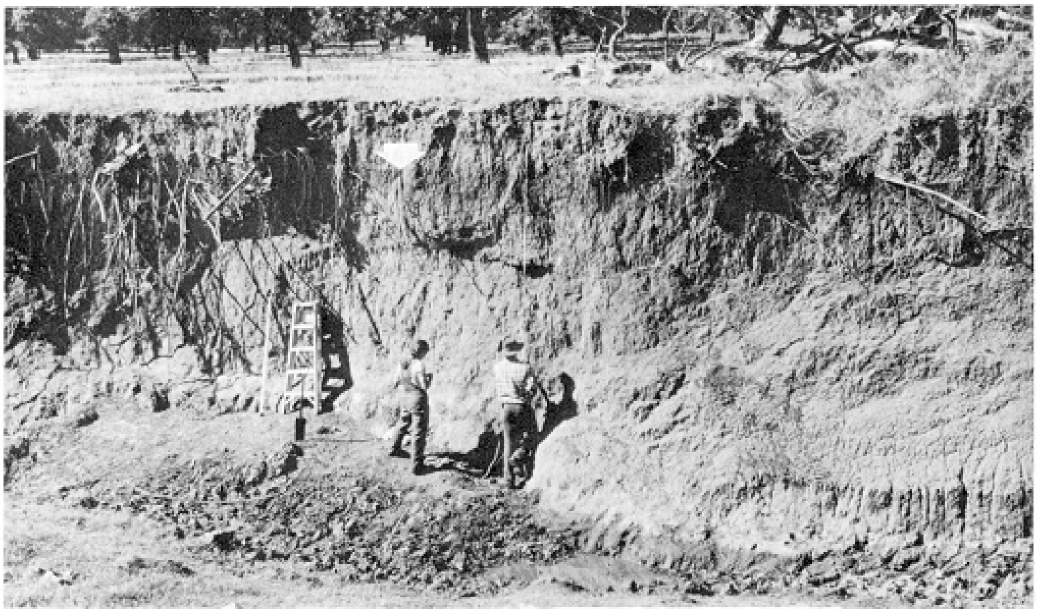

**FIGURE 6.** A representative bank exposure, which is located at transect two. The white arrow identifies the surface of the presettlement flood-plain soil, which is darker due to increased organic matter content.

extraordinary accumulation is due to a constriction of the valley walls and to the confluence of two large tributaries immediately upstream.

Measurements along the transects at the established valley cross sections and estimates from the reconnaissance of tributary valleys indicate that 714 acre feet of alluvium have been deposited in the valley bottoms since initial settlement occurred. This would indicate an average annual accumulation of approximately 7 acre feet (volume) or .035 feet (thickness). The rate of accumulation has, however, not been uniform. The adventitious growth of tree roots in the post-settlement alluvium and the examination of fence lines of various ages indicate most alluvium had accumulated by the early to middle 1940s. Little evidence exists of sedimentation since that time, except at isolated localities. Channel enlargement and overbank alluviation has progressed to such an extent that a 10-year storm event would be required to produce overbank flow in many reaches of the main channel.

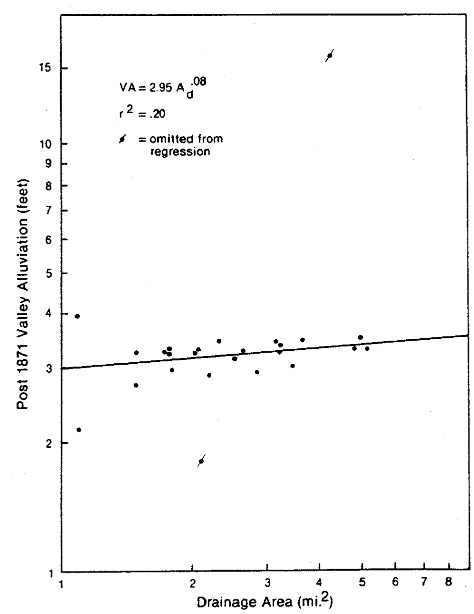


**FIGURE 7.** The relationship between the thickness of post-settlement alluvium and drainage area. Two observations were omitted from regression because they represent anomalous and very localized conditions.

Although large amounts of sediment have been stored within the watershed since settlement, much was also conveyed completely out of the basin into the South Canadian River. Although no sediment-load records are available for the study basin, investigations in a Wisconsin stream of similar physical traits has suggested that the stored volume represents about 60% of the total sediment delivered to the stream system (7), resulting in a total sediment yield of approximately 1200 acre feet for the post-settlement period.

The impact of land-use changes upon stream-system morphology has been demonstrated herein. Although significant climatic variation has been documented for the central United States during the period of study (21, 22), the role of climate in stream-system metamorphosis is difficult to evaluate because of the magnitude of human impact. However, some climatic events such as the droughts of the 1890s, 1910, 1930s, and 1950s on the Great Plains (23) undoubtedly contributed to stream-system instability and morphological change.

TABLE 1. *Sediment analyses from the postsettlement and upper presettlement alluvium of the bank exposure shown in Figure 6.*

| Sample Depth (inches) | Organic Matter (%) | Particle Size (%) Sand | Silt | Clay | Texture |
|---|---|---|---|---|---|
| | | Post-Settlement Alluvium | | | |
| 4-8 | .9 | 63 | 20 | 17 | sandy loam |
| 12-14 | .7 | 57 | 24 | 19 | sandy loam |
| 16-20 | .9 | 29 | 46 | 25 | loam |
| 24-28 | .9 | 41 | 35 | 24 | loam |
| | | Presettlement Alluvium | | | |
| 36-38* | 1.6 | 15 | 50 | 35 | silty clay loam |
| 40-44* | 1.3 | 13 | 50 | 37 | silty clay loam |
| 48-52 | .5 | 21 | 47 | 32 | clay loam |
| 60-64 | .5 | 17 | 45 | 38 | silty clay loam |

*The buried A1 horizon extends from 35-46 inches.


## ACKNOWLEDGMENTS

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