RESEARCH SECTION

doi:10.2489/jswc.65.1.1

Historical channel movement and sediment accretion along the South Fork of the Iowa River

B. Yan, M.D. Tomer, and D.E. James

Abstract: River valleys have been influenced by sediment derived from agricultural erosion and channel straightening intended to hasten flood routing. Post-settlement alluvium (PSA) has been little documented in tile-drained areas of the upper Midwest, where agricultural settlement began around 1850, and few soils are highly erodible. This study investigated channel movement and PSA accumulation along the South Fork of the Iowa River. Channels of the South Fork and tributary Tipton Creek were digitized using rectified aerial photographs taken in 1939 and 2002. Soil cores were collected along valley-crossing transects to determine PSA extent and thickness. Within 80 m (262 ft) of the South Fork, PSA averaged 0.78 m (30.7 in) thick and 85% frequency of occurrence. Beyond 80 m, PSA decreased below 50%. Within 43 m (141 ft) of Tipton Creek, PSA averaging 0.58 m thick occurred with 75% frequency. An estimated 9.2×10^6 Mg (10.2×10^6 tn) of PSA is stored along these valleys, representing 156.6 Mg ha^{-1} (69.8 tn ac^{-1}) of soil eroded from uplands since settlement. The volume of PSA is equivalent to 11 mm (0.44 in) runoff from the watershed. The valley's flood-storage capacity has been reduced by 5.1×10^6 m^3 (4,123 ac ft), considering pore space of the PSA. Modern flooding events are accordingly exacerbated by accretion of agricultural sediment, compared to presettlement river conditions. Channels were straightened in response to local flood events, which reduced stream length by 10% and hastened routing to the Iowa River. Design of river restoration projects should take account of fluvial processes and how these processes are responding to historical sedimentation and channel straightening.

Key words: channel straightening—floodplain—historical sediment—Iowa River—post-settlement alluvium—stream meandering

Sediment loads in rivers and streams are recognized as an important issue for management of water resources across the United States and the world. Sediment dynamics in rivers are impacted not only by land management but also by natural geomorphic processes of river development (Hupp et al. 2009). The natural meander patterns of stream channels are the result of the dissipation of energy of flowing water, and recognizable patterns of transport and deposition of sediment occur in river valleys as a result (Walling and He 1998). In North America, processes of sediment transport and deposition within river valleys have been significantly altered following European settlement, and indeed throughout human history wherever land clearing for agricultural or forest harvesting has been widespread (Montgomery 2007). The long-term consequences of these human-induced impacts on river systems in the United States are increasingly being recognized (Trimble 1999; Walter and Merrits 2008).

In much of North America, increased erosion following agricultural settlement (i.e., prior to the advent of modern conservation practices) resulted in sediment loads greater than could be conveyed by streams. The result was sediment aggradation (buildup) of the channel and flood plain. Impacts of sediment accretion in valleys included exacerbation of flooding, which was addressed by stream channelization to hasten conveyance of floodwaters downstream. Many tributaries to the Mississippi River were channelized by 1930; these efforts then moved upstream into smaller tributaries and continued into the 1960s and 1970s (Simon and Rinaldi 2006). As the streams were channelized and/or naturally returned to their original bed elevation, stream bank heights were increased so that greater water depth and discharge became required before the stream could spread onto the floodplain. The increase in bank heights and bankfull discharge, in turn, increased bank erosion and is responsible for a significant portion of modern sediment loads in streams (Wilson et al. 2008). Along many streams, this caused channel spreading and, over decades, the re-establishment of a new "meander belt" (Knox 2006). The resistance of bed materials to stream incision is one of the major factors that determine how this process manifests itself along each stream course. Knox (2006), Leece (1997) and Trimble (1999) provide thorough discussions of these processes and how local (upstream) and distal (downstream) conditions have affected the response of fluvial processes to sedimentation in southwest Wisconsin. Effects of post-settlement alluvium (PSA) on river valleys and river morphology have been broadly documented in the United States in Virginia (Ambers et al. 2006), North Carolina (Leigh and Webb 2006), Georgia (Jackson et al. 2005), and California (James 1999), and internationally in Australia (Rustomji and Pietsch 2007), Britain (Owens et al. 1999), and China (Saito et al. 2001), among other studies.

The objective of this study was to determine the extent of PSA accumulation and channelization within the South Fork of the Iowa River watershed. The results will show the extent to which the river corridor of even a low-gradient agricultural watershed, dominated by subsurface drainage and with a relatively short settlement history (approximately 160 years), has been influenced by accretion of sediment from historical erosion and channel straightening. The PSA can force wider local flooding, and channel straightening hastens routing of floodwater downstream to the Iowa River, compared to presettlement conditions. The results should help parameterize hydraulic

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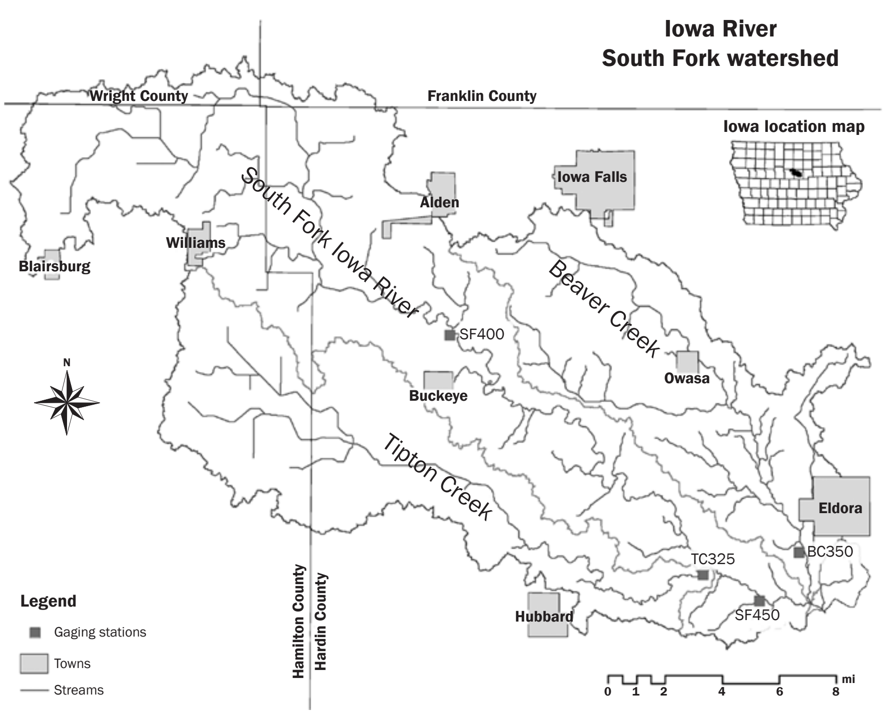
Figure 1
General map of the South Fork of the Iowa River.



models to determine how such changes can exacerbate routing of tributary flood waters to the Iowa River, which caused more than 750 million dollars of damage downstream in Iowa City in 2008. Also, in this Conservation Effects Assessment Project (CEAP) watershed (Richardson et al. 2008), this research is expected to show how stream banks, rather than agricultural erosion, have become the major source of suspended sediment (Wilson et al. 2008).

Materials and Methods

Background on Study Watershed. The Iowa River's South Fork (SF) watershed (figure 1) lies in north-central Iowa, and covers about 78,000 ha (193,000 ac), including the tributaries of Tipton (TC) and Beaver (BC) Creeks. It lies on the eastern edge of the Des Moines Lobe (Prior 1991), with young terrain developed in glacial till deposited about 10,000 years ago. Natural stream incision and development of alluvial valleys is limited to the lower (southeastern) third of the watershed due to the youth of the glacial terrain and limited time (approximately 10,000 years) available for stream-network development. The upper parts of the watershed are occupied by till plains dominated by internally drained "prairie potholes," which originally were wetlands. European-American settlement began around the 1850s. Settlers converted the prairie, wetland, and oak-savanna vegetated landscape (Weaver 1968) into cropland and pasture. This extensive land-use transformation decreased water detention in wetlands and plant water use, increasing stream discharge. Tomer et al. (2008a, 2008b) described the land use and water quality of the South Fork watershed, and showed that subsurface drainage water dominates the hydrology. Simon and Klimetz (2008) estimated that 50% of SF stream banks were actively eroding, with SF sediment yields averaging nearly 70 Mg y^{-1} km^{-2} (nearly 200 tn yr^{-1} mi^{-2}), about 2.4 times the average found for gauged streams in the western cornbelt ecoregion, which covers much of Iowa, southern Minnesota, and western Nebraska. Also, using a Be:Pb (Beryllium: lead) radionuclide ratio technique, Wilson et al. (2008) estimated that 80% of the sediment load discharged from TC during a September 2006 runoff event originated from stream banks. These results point out the need to evaluate post settlement changes along the river corridor as potential causes of bank and channel conditions in this benchmark watershed of the Conservation Effects Assessment Project (Richardson et al. 2008).

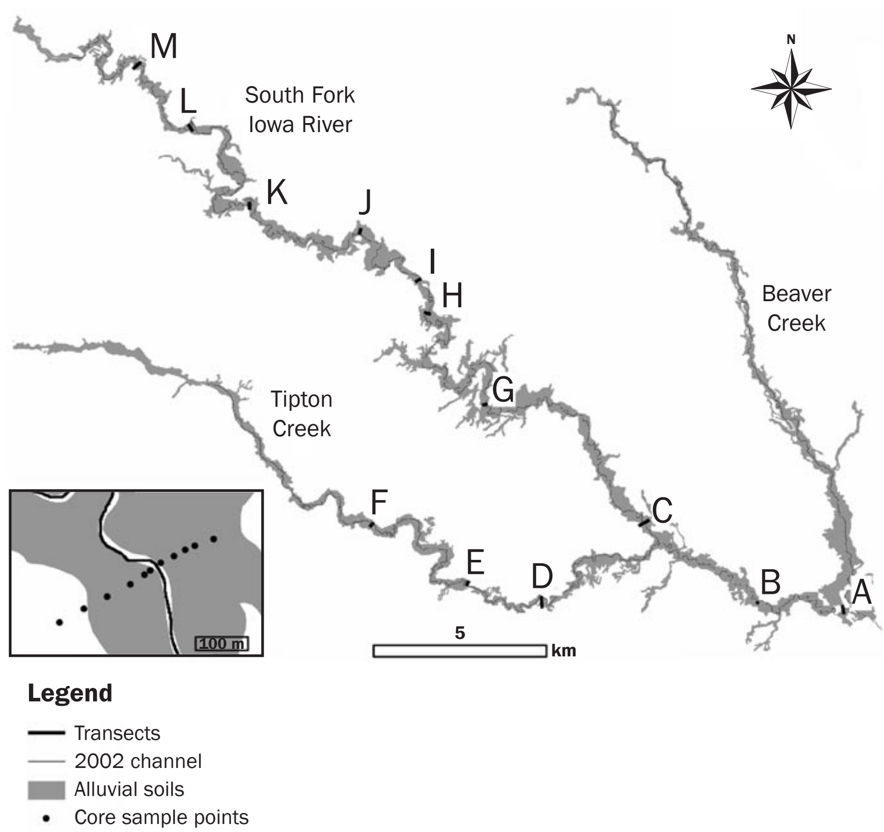
This study was focused within the alluvial valley of the SF and TC (figure 2), in the lower (southeastern) part of the watershed. Upper parts of the river network are straight ditches, which were dug through weakly channelized sloughs that originally collected seepage and occasional overland flows discharged from the complex of prairie pothole wetlands that dominated the uplands prior to settlement. The floodplains of the alluvial valleys are occupied by soils classed as poorly drained Cumulic Haplaquolls (Coland series) or somewhat poorly to moderately well-drained Cumulic Hapludolls (Turlin, Spillville, and Hanlon series) (National Cooperative Soil Survey 1986). Alluvial soils were often mapped as complex map units, and therefore, provided little information to help define extent or thickness of PSA. The study was comprised of a field study and a map analysis. The field study aimed to determine the extent and thickness of PSA, while the map analysis was aimed to document the extent of channel meandering and straightening that occurred in the watershed during recent decades (since the 1930s).

Field Study. The field study began with selection of 13 transects across the valleys of the SF and TC (figure 2). Three transects were located across TC and 10 across the SF. These locations were selected based on map-interpreted accessibility and to represent the length of the alluvial valley of these two streams. Landowners were contacted, and all but one landowner granted permission to access their properties. One transect was moved to the neighboring upstream property (about 400 m [440 yd]) due to the single denial of access. Discussions of the river and its history with several landowners assisted in locating transect positions and understanding the river's recent history. The field work was conducted during late summer 2008, after recession of the major floods that occurred in June. Transect sites were selected with the intent to cross the valley and observe sediment conditions on both sides of the channel. Ten of the 13 transects did include observations on both sides of the channel; channel proximity to one edge of the riparian valley prevented or deterred access to one side of the channel at the other three.

Soil cores were collected along each transect to a maximum depth of 2.4 m (8 ft) at sample points purposively determined in the field (Burt 2004; Schoeneberger et al. 2002). Three to six sample points were cored on

Figure 2

Map of the South Fork watershed's alluvial valleys with transect locations, denoted by letters, included in the core survey. Alluvial soil map units (shaded) reasonably delimit the valley floodplains. On the inset map (lower left), an example transect (C) is shown with the distribution of core sample points.



each side of the stream, beginning close to the stream bank edge, and then proceeding at a right angle away from the bank and taking additional cores at 20 to 30 m (66 to 100 ft) intervals or where changes in elevation occurred. Most cores were 3.8 cm (1.5 in) in diameter, were taken with a truck-mounted hydraulic sampler (figure 3), and were retained intact in clear plastic sleeves. At six transect locations, vehicular access was partly restricted, and a subset of cores was collected by hand using push-probes; these 2.5 cm (1 in) diameter hand-cored samples were collected to a maximum depth of 1.7 m (5.5 ft) and were retained in plastic bags. One transect was not vehicle accessible and was sampled entirely by hand. During sampling, the geographic coordinates of core-sample points were determined using a hand-held global positioning system receiver (accurate to within 1 m [3.3 ft]) and field notes were made of observed layering.

Soil Characterization. In the laboratory, cores were opened, described, photographed, and subsampled (figure 3). The major purpose of examining the cores was to determine depth distributions of three major depositional units: glacial outwash, Holocene sediments, and PSA. These units were distinguished based on initial reconnaissance and published literature (Bettis 1990; Bettis and Hoyer 1986; Quade 1992). Glacial outwash was generally poorly sorted sands and gravels. These materials limit stream incision and have not been penetrated by the modern stream. Following glacial melt, the outwash gravels were buried by Holocene deposits—generally fine-textured materials, typically black or gray with common redoximorphic soil features (Schoeneberger et al. 2002). The uppermost deposit, PSA, was dominantly lighter colored than underlying soils and was loam textured. The aforementioned textures were determined by feel and appearance. Bettis (1990) developed a nomenclature for post-glacial surficial deposits in western Iowa and denoted PSA as the Camp Creek Formation. Once described, the cores were sampled for bulk density (Grossman and Reinsch 2002) according to soil layer by removing a 5 cm (2 in) length of core where sample integrity allowed the core to be cut with good volume control. This was not possible for the noncohesive glacial outwash deposits; average bulk densities of Holocene and PSA materials were calculated. Bulk density of the PSA was later used to convert volume of PSA to mass.

Geographic Analyses. The observed thickness of PSA was plotted against the distance from the sample point to the stream bank. For two transects, this distance was measured to the bank of the original stream rather than the channel's current location, which had clearly been dug to straighten the stream, because most PSA was observed closer to the original stream location along these transects. A thickness of zero was assigned where no PSA was observed. As expected, the data were widely scattered, and a distance-ordinated averaging approach was applied as follows. After grouping transects along each stream (SF and TC), observed PSA depth was sorted according to distance from the stream, and average PSA rate-of-occurrence (frequency) and depth were calculated for each measured value of distance-to-stream. This ordination segregated all locations that were closer from those that were further from the stream at each measured distance. Results allowed plotting of the cumulative averages of PSA thickness and frequency, sorted according to distance from stream, both ascending and descending (i.e., moving towards and away from the stream). These distributions were interpreted to make estimates of accumulated PSA volume along the stream length, by determining the distance-from-stream beyond which frequency of PSA occurrence decreased to 0.5. This distance gave an assumed average width of PSA, and the average thickness within that distance-from-bank provided the depth dimension. Stream length was simplified to 160 m (525 ft) segments (using the simplify command in ARC-GIS) (Environmental Systems Research Institute 2002) to remove fine-scale meanders and provide the third (length) dimension to calculate volume. The volumes (for TC and SF) mere multiplied by mean bulk density to obtain an estimate of mass. Transect averages of PSA thickness were also plotted according to position along the stream to identify any longitudinal trends in average PSA thickness (i.e., trends moving up or down stream).

Figure 3

(a) Core sample collection. (b) A stream bank with light-colored PSA. (c) Photographs of soil core from four transects; the arrows show depth of contact between post-settlement alluvium (PSA) and underlying Holocene deposits.

The second part of the study was a map analysis to evaluate changes in the stream course during recent decades. This part of the study included Beaver Creek (BC) as well as the SF and TC channels. Historical aerial photographs, taken in 1939 and in 2002, were downloaded from the Iowa Geographical Map server (Iowa State University 2009). The stream channels were digitized from both sets of photographic imagery at a nominal scale of 1:5000. The sinuosity, i.e., channel length (L_c) divided by straight-line distance (L_s) and fractal dimension of each stream was calculated using Hawth's Tools (Beyer 2009). Fractal dimension (D) was calculated as

$$D = \log(n)/[\log(n)+\log(L_s/L_c)], \quad (1)$$

in which n is the number of segments that comprise the digitized channel length.

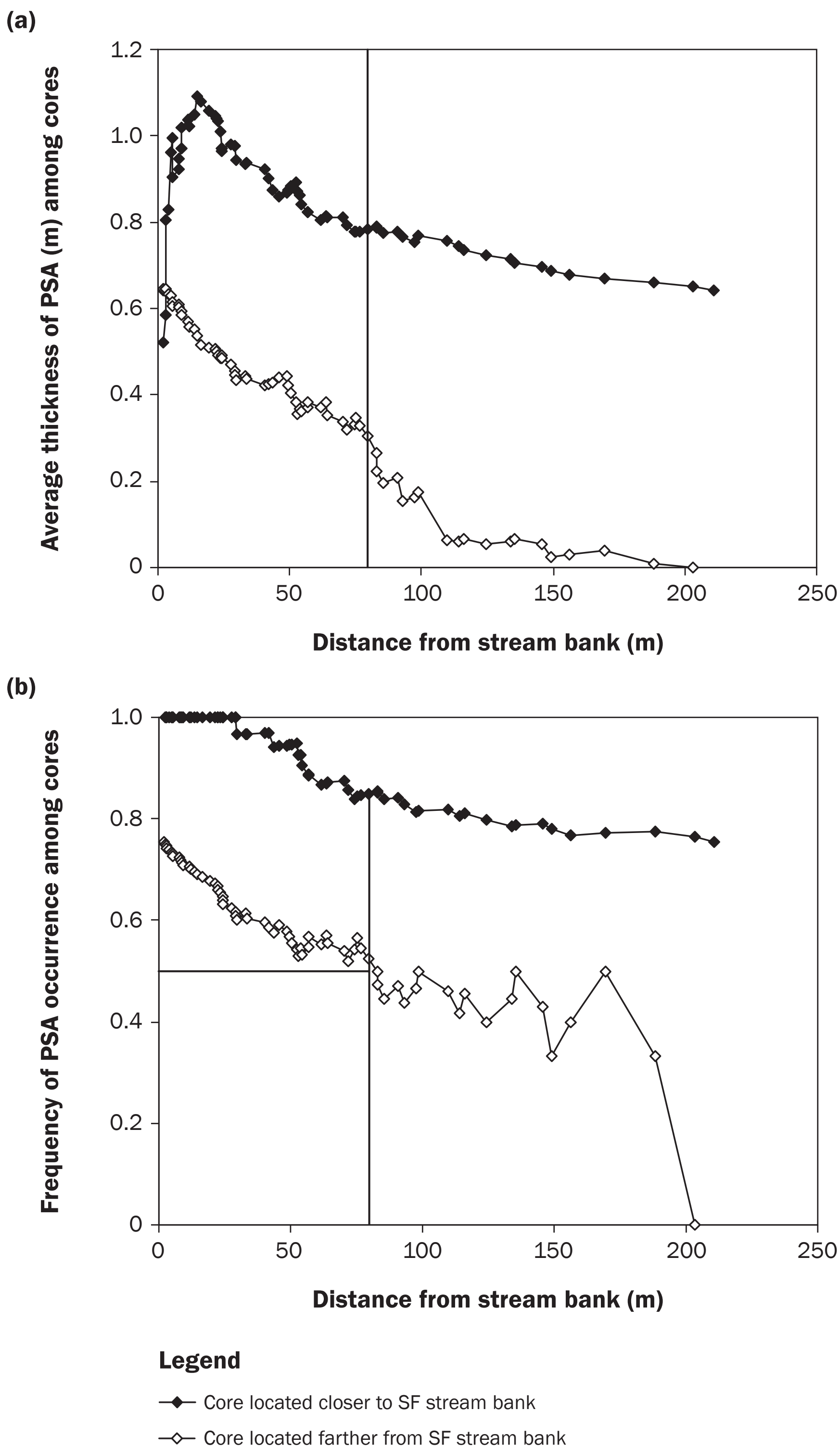
The digitized stream courses for 1939 and 2002 were also compared by overlay. A vector-to-polygon feature conversion was used to delineate those areas across which the stream had moved, either by meandering or channel straightening, since 1939. This feature conversion created 1,101 polygons, which varied in size from 11 to 53,065 m^2 (0.003 to 13.1 ac). The polygons were then classified as being created by natural stream meandering, channel straightening, or undetermined. This was essentially a manual interpretation of the aerial imagery from 1939 and 2002, conducted together by the two senior authors. Occasionally, photographic imagery taken in 1950 and 1994 (Iowa State University 2009) helped make this interpretation. Polygons were classified as meander-created, where the stream had clearly shifted position but maintained its sinuosity between 1939 and 2002, or due to channel straightening, where stream sinuosity was obviously decreased. A class of undetermined (other) was assigned where stream position in one photo (usually the 1939 image) was not clear (often due to tree cover), and small or narrow polygons may have resulted from uncertainty in digitizing the channel and/or photograph rectification. Virtually all polygons less than 200 m^2 (0.05 ac) in size were assigned the undetermined class. Polygons were often selected in groups along stream reaches where a history of straightening or meandering was apparent and classified accordingly. The number and total areas of polygons resulting from stream meandering and straightening along the three streams were used to illustrate and interpret observed changes in stream course, sinuosity and fractal dimension. Changes in stream length were used to estimate change in mean channel slope and how that would alter flow velocities between 1939 and 2002.

Results and Discussion

Field study of Post-Settlement Alluvium. A soil core survey of thirteen river-valley transects (figure 2) resulted in a total of 94 points being core sampled (7.2 average per transect). The variety of glacial materials described included not only outwash sands and gravels but apparent periglacial lakebeds comprised of varved, very fine sands at one site located below a kame and tills encountered at several core-sample points located near the margin of the alluvial valley. Holocene materials included thick (>1 m [>3.3 ft]) black, fine-textured topsoil (shown below PSA in several cores in figure 3), silty clay lakebed materials, and in two instances, thin (20 to 30 cm [8 to 12 in]) surficial loess caps on southern valley margins. At two transect locations, spoils spread after channelizing the stream were at the surface and were identified by hap-

Figure 4

Plots showing (a) average thickness and (b) frequency of post-settlement alluvium (PSA) found within and beyond varying distances from the stream channel. Data are shown for the South Fork (SF) River only. The vertical line at 80 m indicates that at distances greater than 80 m from the stream bank, the frequency of occurrence of PSA decreased to less than 50%. Soil cores collected within 80 m of the stream bank had PSA with a frequency of 0.85 and an average PSA thickness of 0.78 m.



hazard mixing of colors; PSA was noted as absent at these core points. The thickest PSA was identified near the historical channel in these locations. Deposits of PSA (figure 3b and 3c) were typically loams and sandy loams and were lighter in color than underlying materials. Occasionally, PSA was best diagnosed based on the presence of medium sand grains (about 0.5 mm [0.02 in] diameter); the coarsest Holocene deposits had only small amounts of fine sand (about 0.1 mm [0.004 in] diameter). Within five transects, light-colored sands deposited during the recent June 2008 floods were identified, up to 10 cm (4 in) thick. Within stream meander point bars, PSA was often loamy sand or sandy loam textured but was easily distinguished from outwash due to the absence of coarse sands and gravels. Complex interlayering of fine and coarse textures affecting PSA interpretation was rare (two cored locations). Uncertainties in PSA thickness were handled by assigning the shallowest value deemed reasonable.

From these cores, a total of 83 bulk density samples were collected, 42 of which were denoted as PSA. The average bulk density of the PSA was 1.38 g cm^{-3} (sd = 0.12 g cm^{-3}), and the average bulk density of the Holocene deposits was 1.45 g cm^{-3} (sd = 0.15 g cm^{-3}). A *t*-test showed the Holocene deposits to be denser than PSA at $p = 0.10$ but not at $p = 0.05$.

Amount and Distribution of Post-Settlement Alluvium. Distances from core-sample points to the stream bank varied between 1.5 and 267 m (5 and 876 ft). Post-settlement alluvium was observed in 67 of 94 cores, and varied in thickness from 2.5 to 173 cm (1 to 68 in). Where absent (27 of 94 cores), PSA thickness was recorded as zero and was included in subsequent calculations. To estimate the volume of PSA along the river course, average depth and frequency of occurrence of PSA was calculated and plotted with increasing/decreasing distance to the stream bank of both streams (results for SF are shown in figure 4). Results showed how PSA thickness and frequency decreased moving away from the stream banks and increased moving toward them. To obtain a conservative estimate of volume and mass of PSA along the channels of TC and SF, the average distance-from-bank was identified, beyond which PSA frequency decreased to less than 50% and within which PSA was dominantly present. In the SF, PSA was present in half the cores collected more than 80 m (262 ft) from the bank, and averaged 0.27 m (10.6 in) thick, including zero values for absence of PSA. Within 80 m of the stream bank, PSA occurred with 85% frequency and averaged 0.78 m (30.7 in) thick (figure 4). This result, within 80 m of the bank, was chosen to characterize the width and thickness of PSA deposited along the SF. In TC, there were fewer cores collected, but results were corollary given TC's smaller drainage area. The PSA occurred 75% of the time within 43 m (141 ft) of TC with an average depth of 0.58 m (22.8 in), but was only found with 46% frequency more than 43 m from the stream bank with an average thickness of 0.30 m (11.8 in). The PSA thickness decreased most rapidly away from the stream bank beyond 43 m. There was no significant trend in PSA thickness along the length of the SF, and site averages of PSA depth within 80 m of the SF varied between 0.6 and 1.1 m (23.6 and 43.3 in). Jackson et al. (2005) also found no longitudinal trend in PSA in their study on the southeast US Piedmont.

These PSA distance-from-bank and thickness values were used to conservatively estimate total volume and mass of PSA stored near the river channel. The length of channel was determined after simplifying the stream vector into 160 m (525 ft) segments. This provided geometric consistency by removing fine scale meanders. The resulting simplified channel lengths were 21.7 km (13.5 mi) for TC and 45.0 km (27.9 mi) for SF. The product of these channel lengths, times the widths and thicknesses of PSA (i.e., 80 m on both sides of the channel, times 0.78 m (30.7 in) thickness for the SF, and 43 m (141 ft) on both sides of TC times 0.58 m thickness) gives total PSA volumes of 5.61×10^6 m^3 (7.33×10^6 yd^3) for the SF and 1.08×10^6 m^3 (1.41×106 yd^3) for TC. Multiplying these volumes times the average bulk density (1.38 Mg m^{-3} [86 lb ft^{-3}]) gives a total mass of 7.74×10^6 Mg (8.52×10^6 tn) PSA stored within 80 m (262 ft) of the lower (meandering portion of) SF channel, and 1.49×10^6 Mg (1.64×10^6 tn) PSA stored within 43 m (141 ft) of the lower TC channel.

Combining the two channels and dividing by watershed area for TC and SF above the confluence with BC (59,000 ha [145,700 ac]), the PSA represents 156.6 Mg ha^{-1} (69.8 tn ac^{-1}) of soil eroded from the watershed's uplands since modern European settlement that remains stored near these two channels. The PSA's total volume represents a loss of floodplain water storage capacity that equals 11.3 mm (0.44 in) of runoff from the entire watershed. Allowing that half the PSA's pore space could be available to fill with floodwater, this number would decrease by 24%. Again allowing that half of the pore space is available to be filled by floodwater, a presettlement flood event that would have remained within the area and depth currently occupied by PSA would today create an additional estimated 5.09×10^6 m^3 (4,123 ac ft) of floodwater.

Table 1

Channel lengths, sinuosities, and fractal dimensions of South Fork Iowa River and major tributaries in 1939 and 2002. These data are for the lower (meandering) part of the streams where they occupy an alluvial valley.

Year	Tipton Creek	South Fork	Beaver Creek
	Length (m)		
1939	32,935	64,868	28,168
2002	27,880	60,196	23,668
Decrease	5,055	4,672	4,500
	Sinuosity (m m^{-1})		
1939	2.44	2.34	1.76
2002	2.02	2.20	1.47
	Fractal dimension		
1939	1.135	1.118	1.070
2002	1.088	1.091	1.047

Map Analysis of Channel Movement. Between 1939 and 2002, there was a clear reduction in channel length for TC, SF, and BC (table 1). The reductions were about 15% to 16% in TC and BC tributaries and about 7% in the SF. The greater loss of stream length in the tributaries (TC and BC) is confirmed by comparing the sinuosities of the 1939 and 2002 channels (table 1). Clearly, the greatest loss of sinuosity occurred in the tributaries (TC and BC). In 1939, the sinuosities of TC and SF were similar. The BC was originally less sinuous, which may be due to BC having a steeper grade, as it traverses the outermost terminal moraine of the Des Moines lobe near the upper part of its main channel. Fractal dimension values show similar trends (table 1). A fractal dimension value of 1 represents a straight line, while a value of 1.28 represents consistency in sinuosity across a range of scales (self-similarity). All three streams moved closer to a fractal dimension of one between 1939 and 2002.

We confirmed that the loss of sinuosity was dominantly due to stream straightening by evaluating map polygons representing areas between where the stream was positioned in 1930 and in 2002 (table 2) (figure 5). Based on observation and discussion with local residents, stream straightening was common in the 1950s and continued into the 1960s. Straightened stream reaches were generally easy to interpret and could be associated with efforts to reduce stream bank cutting near bridges and roads, provide straight edges to farm fields, and to route discharge through pastures and reduce their duration of flooding. There was evidence of stream straightening upstream and/or downstream of approximately 20 bridges in the watershed. Polygon areas formed by overlay of the 1939 and 2002 stream courses (table 2) comprise about 8% of riparian valley (as defined by extent of floodplain soil map units). Along the SF, 62% of this "area of stream migration" was attributed to natural stream meandering and only 28% to stream straightening. However, in TC and BC, respectively, 47% and 64% of the migration areas were attributed to channel straightening. This explains why the decrease in sinuosity was least in the SF (table 1).

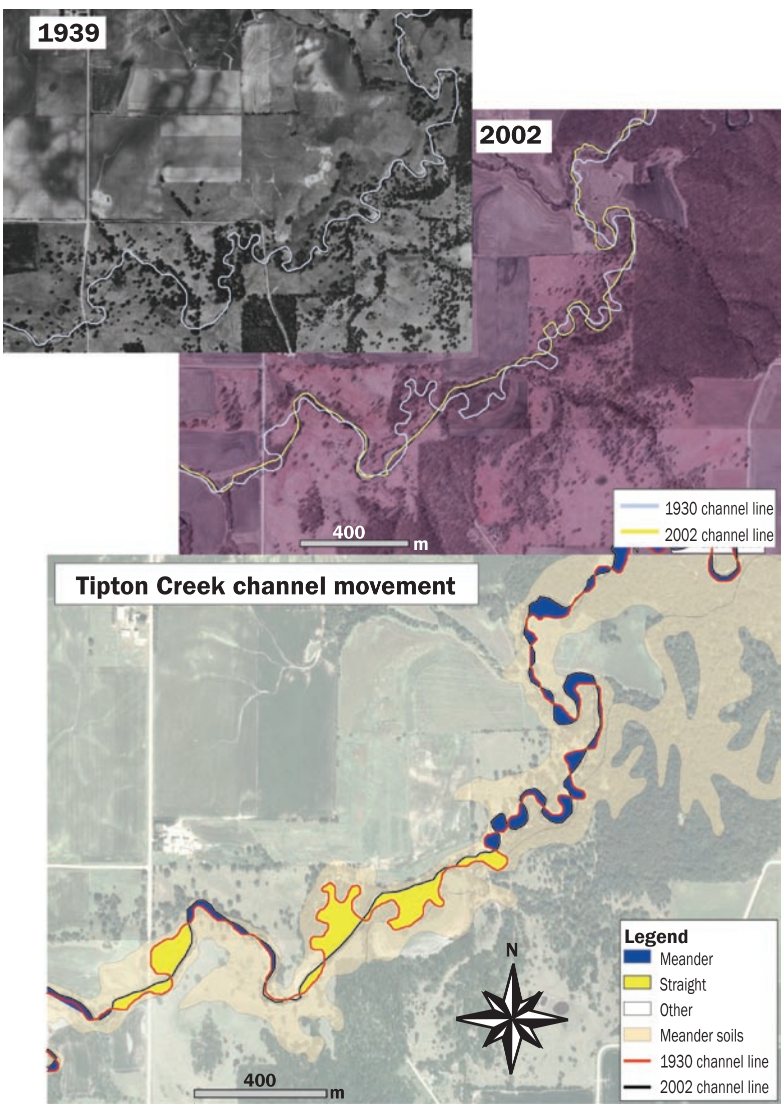
Hydrologic Implications. Due to accretion of PSA, the floodplains of SF and TC have decreased water storage capacities by 5.09×10^6 m^3 (4,123 ac ft). Water carried during today's rainfall runoff hydrographs must ascend a bank that is about 1 m (3.3 ft) higher than was originally present before spreading on to the floodplain (see average thickness of PSA within 10 m (33 ft) of stream shown in figure 4). The increased depth causes greater flow velocity and allows stream banks, particularly where cropped or close-grazed, to be undercut, increasing sediment loads. Because there is no obvious natural levy that has formed (this may be due to riparian-zone grazing and cropping), at the stage where banks are overtopped, the volume of PSA is essentially an opportunity for floodwater storage that has been removed

Table 2
Numbers and total area of stream migration polygons delineated by overlaying stream courses digitized from 1939 and 2002 aerial photography. Meander and straight classes were manually interpreted and show the proportion of stream migration due to natural meandering and stream straightening.

	Number of polygons (count)			Area of polygons (ha)		
Polygon class	SF	TC	BC	SF	TC	BC
Meander	269	159	103	72.3	22.2	13.5
Straight	73	65	101	33.0	21.8	28.9
Undetermined	190	64	76	10.7	2.7	2.7
Total	**532**	**288**	**280**	**116.0**	**46.7**	**45.1**

Notes: SF = Iowa River's South Fork. TC = Tipton Creek. BC = Beaver Creek.

Figure 5
Example of stream course overlay to determine areas of stream migration along Tipton Creek (TC). Overlay polygons were attributed to natural meandering or channel straightening (see text). Data obtained from this analysis are summarized in table 2.



from the valley. This decreased volume of water storage capacity would probably have its greatest proportional impact on hydrographs during small and intermediate flood events. While this PSA volume represents only about 8.5 hours of the peak daily discharge observed during the 2008 floods, it represents nearly 25 hours of the largest rate of discharge observed at SF450 (figure 1) during the 12 years prior to 2008. Yet, given the extent of damage that can occur during major flooding, even a small proportional increase in peak discharge due to PSA impacts on floodplain water storage could be significant. Also, a combined effect of PSA and channel straightening must be considered. The decrease in channel length (table 1) increases channel slope and decreases the water storage capacity of the channel. Assuming discharge is governed by Manning's equation, the increase in channel slope since 1939 would have led to increased discharge velocities of about 4% in the SF and about 9% in TC and BC. However, fluvial responses, particularly channel spreading, would be expected, is in evidence (Simon and Klimetz 2008), and would decrease the hydraulic radius (i.e., the area-perimeter ratio of the channel cross section) to attenuate the response in velocity. Elevation profiles of these stream beds, obtained from the US Geological Survey (USGS 2006) and checked against onsite surveys at stream gauges, can be assumed stable in the long term because since glacial retreat, the streams could not cut into coarse outwash deposits laid by a vast discharge of glacial melt-water. This research will be continued using stream routing models to evaluate how the loss of storage capacity and increase in channel slope that accompanies stream straightening would affect runoff hydrographs of varying magnitude.

Summary and Conclusions

In quantifying PSA in TC and SF, several precautionary assumptions were made to avoid over-estimating the volume and mass of historical sediment that was lost from the SF watershed's uplands and is retained in the watershed near the main stream channels. Nevertheless, this recent sediment occupies a volume of storage capacity equivalent to 11.3 mm (0.44 in) of runoff from the entire watershed and represents 156.6 Mg ha^{-1} (69.8 t ac^{-1}) of soil lost from the watershed's uplands, averaged across the entire watershed area. Obviously much of this soil loss was generated from agricultural fields nearest the watershed's alluvial valleys, but the figure remains surprising because of the generally low relief of the watershed. If little PSA is to be expected anywhere in the agricultural Midwest, it would be expected in watersheds similar to the SF that are characterized by low relief and subsurface drainage and a relatively short history of settlement. Most of the PSA sediment was certainly generated prior to modern farming practices that include conservation tillage and a range of conservation practices being used across much of the watershed (Tomer et al. 2008b). One important question concerns the implications for alterations aimed at stream management/restoration efforts that may be undertaken. Geomorphically, the stream is assessed (Simon and Klimetz 2008) to be generally aggrading and widening (Stage 5), and it is likely to be many decades before "equilibrium" conditions are reached. In the meantime, riparian vegetation management systems that encourage bank stabilization would probably be the best approach to minimize sediment movement at the least cost. These management systems could include conservation reserve buffer plantings and either cattle exclusion or short-duration grazing rotations in riparian pastures.

Acknowledgements

The authors thank Jeff Cook, Kevin Cole, and Shane Edelen for assistance with field work and processing of survey data. The research was supported by a scholarship awarded to the senior author by the Chinese Scholarship Council. The Department of Natural Resources Ecology and Management at Iowa State University hosted Dr. Yan's visit, which was facilitated through the University's Office of International Students and Scholars.

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