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4 Historical changes in channel network extent and channel planform in an
5 intensively managed landscape:
6 natural versus human-induced effects
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1 Abstract

2 Humans have become major geomorphological agents, effecting substantial change in the
3 characteristics of Earth's physical landscapes. The agricultural Midwest of the United States is a
4 region marked by pronounced human influence at the landscape scale. Humans undoubtedly
5 have strongly influenced critical zone processes, including fluvial processes, in intensively
6 managed agricultural landscapes, yet the exact nature of human alteration of these processes is
7 unknown. This study documents historical changes in the extent of the stream channel network
8 and in channel planform within the upper Sangamon River basin - an intensively managed
9 agricultural watershed in Illinois. Results indicate that the channel network in the 1820s was
10 nearly three times less extensive than the modern channel network. Most change in drainage
11 density has occurred in headwater portions of the basin where numerous drainage ditches have
12 been added to the network to drain flat uplands. No detectable change in channel position is
13 evident between 1940 and 2012 along about 60% of the total length of the Sangamon River and
14 its major tributaries. Nearly 30% of the total length exhibits change related to meander dynamics
15 (cutoffs and lateral migration), whereas about 8% has changed as a result of channelization.
16 Channelized sections typically remain straight for decades following human modification,
17 supporting the notion that humans produce long-lasting catastrophic change in channel planform
18 in this region. The findings confirm that humans are effective agents of morphological change in
19 fluvial systems in this intensively managed watershed. Documenting human-induced versus
20 natural changes in fluvial systems is important for evaluating how other critical zone processes in
21 intensively managed landscapes have been affected by these changes. Human-induced changes
22 in channel extent and planform most likely have altered this landscape from one dominated by
23 biogeochemical transformations and storage of water and sediment prior to agricultural
24 development into one now characterized by enhanced fluxes of water, sediment, and nutrients.

Keywords: human-impact; rivers; geomorphology; channel change

1. Introduction

The influence of human activity on landscape forms and processes has become a major focus of contemporary geomorphological research. Over 50% of the Earth's land area (exclusive of ice-covered land masses) has been directly modified by human action (Hooke et al., 2012). In this era of marked human effects on the Earth system, which has led to debate about whether a case can be made for a new geological epoch – the Anthropocene (Zalasiewicz et al., 2011; Brown et al., 2013; Lewin and Macklin, 2014;) – the movement of sediment by humans appears to equal that of the most effective erosional process (fluvial action) as well as of tectonic processes, such as mountain building (Hooke, 1994, 1999). Moreover, since the Industrial Revolution, the rate at which humans move earth material has increased exponentially (Hooke, 2000).

As part of this global-scale change in the Earth environment, geomorphological effects of humans on rivers have been pervasive (Gregory, 2006). These effects can be classified as indirect, i.e., those related to changes in climate and land use (Goudie, 2006; James and Lecce, 2013), and direct, i.e., those that involve direct modification of rivers through channelization or the construction of dams (Brookes, 1988; Csiki and Rhoads, 2010). The topic of human impacts on river systems has been a major focus of research by William Graf over the course of his career (Graf, 1977, 1979, 1999; 2001, 2006) and he has contributed substantively to the understanding of both types of effects on rivers. He has also highlighted the relevance of human-impact research for informed public policy.

Perhaps no environment has been more affected by human activity at the landscape scale than the fertile agricultural region of the midwestern United States. The sweeping

1 transformation of this landscape from forest and prairie to agriculture has fundamentally altered
2 sediment and water fluxes. A major focus of previous research in the Midwest has been on
3 regions of relatively high relief, such as the unglaciated Driftless Region, where the advent of
4 agriculture induced landscape-scale changes in hillslope sediment fluxes (Trimble, 1983, 2013),
5 resulting in dramatic floodplain sedimentation and changes in stream channel characteristics
6 along valley bottoms (Knox, 1972, 1987, 2006; Magilligan, 1992). Less is known about the
7 impacts of human activity on stream systems in low-relief landscapes produced by deposition of
8 glacial material and loess at the end of the Pleistocene Epoch. Initial research has indicated that
9 the need for land drainage to farm perennially wet soils can lead to fundamental changes in
10 channel networks and river dynamics (Rhoads and Herricks, 1996; Urban and Rhoads, 2003). In
11 such low-relief environments, channelization of streams is widespread, particularly in the
12 headwaters, where as much as 100% of the total length of streams has been channelized in some
13 watersheds (Mattingly et al., 1993). Whereas channelization of high-gradient streams tends to
14 induce erosional responses through incision and widening (Brookes, 1988; Simon, 1989; Simon
15 and Rinaldi, 2006), straightening and widening of low-gradient headwater channels to form
16 drainage ditches often invokes a depositional response characterized by the formation of
17 vegetated benches within the bottom of the ditch (Landwehr and Rhoads, 2003). Although
18 preliminary insight into the geomorphological impacts of humans on stream systems in low-
19 relief landscapes of the agricultural Midwest has begun to emerge (Urban and Rhoads, 2003;
20 Guneralp and Rhoads, 2009), general understanding of the spatial extent of human impact and
21 the magnitude of this impact relative to the effects of natural processes is still incomplete.
22 Moreover, human-induced changes in fluvial systems have important implications for near-
23 surface biogeochemical processes that characterize what has become referred to as the critical

1 zone - the portion of the Earth system that extends from the top of the tree canopy to the shallow
2 subsurface (National Research Council (NRC), 2001; Richter and Mobley, 2009). Such changes
3 can alter pathways of water and sediment movement; the proximity of hillslopes to channels; the
4 rate at which water moves into the channel system; and the mobilization, transport, and storage
5 of sediment within the channel-floodplain system, all of which are important factors influencing
6 biogeochemical activity at the landscape scale.

7 The purpose of this paper is to examine historical changes in river channels within a
8 small agricultural watershed in east-central Illinois that is part of a new Critical Zone
9 Observatory funded by the National Science Foundation focusing on intensively managed
10 landscapes (IML-CZO). The major research questions addressed in this study are: (i) how has
11 the spatial extent of the channel network changed at the watershed scale during transformation of
12 the landscape from pre-settlement conditions to agriculture and (ii) how has channel planform of
13 the main stem and major tributaries changed over the past several decades and what factors
14 (human versus natural) have contributed to this planform change? The results of the study
15 provide a foundation for future work in the IML-CZO that will examine water, sediment, and
16 biogeochemical fluxes within the intensively managed landscape of the midwestern United
17 States. The central hypothesis for the IML-CZO is that, through human modification, the critical
18 zone of IMLs has passed a tipping point and has gradually shifted from being a *transformer* of
19 material flux with high nutrient, water, and sediment storage to being a *transporter* of material
20 flux with low nutrient, water, and sediment storage. Evaluation of this hypothesis requires
21 placing contemporary fluxes within the context of human-induced historical changes in the
22 stream channel network to determine how intensive management of the landscape has influenced
23 the spatial distribution, magnitudes, and trajectories of various fluxes.

2. Study area

The study area for this research is the upper Sangamon River basin (USRB) in east-central Illinois (Fig.1). The 2400-km² USRB drains a low-relief landscape produced mainly by deposition of end moraines, ground moraine, and glacial outwash during the Wisconsin Episode glaciation (13,500-25,000 YBP) of the Pleistocene Epoch (Illinois Department of Natural Resources, 1999a). The thickness of glacial deposits ranges from 30 to 120 m. These deposits are covered by about 0.5 to 1.5 m of loess, which provides the parent material for upland soils within the watershed (Fehrenbacher et al., 1986). Local relief generally is < 30 m and most hillslopes have gradients below 2% (Illinois Department of Natural Resources, 1999b).

Around 1820, prior to European settlement of the region, vegetation in the USRB consisted of about 90% prairie and 10% forest (Illinois Department of Natural Resources, 1999c). Most forest cover was restricted to bottomlands along the Sangamon River and to the downstream portions of tributaries. Today, about 90% of the land is used for row-crop agriculture, with the main crops being corn and soybeans. Wetlands probably covered as much as 40 to 50% of the total land area in the basin prior to settlement, whereas today the percent of total land in wetlands is < 2% (Illinois Department of Natural Resources, 1999c). Conversion of the land to agriculture involved the construction of deep drainage ditches and the installation of tile drains beneath flat, perennially wet areas. This drainage boom occurred largely in the late 1800s, following passage of the Illinois Drainage and Levee Act in 1879 (Rhoads and Herricks, 1996).

The stream network in the USRB includes the Sangamon River and numerous tributaries (Fig.1). Headwater sections of tributaries and the main river consist mainly of drainage ditches, whereas downstream sections are unchannelized and flanked by forested floodplains. Gradients

1 on the main river range from 0.00084 in the headwaters to 0.0002 near Lake Decatur (Demissie
2 and Keefer, 1996).

3 The upper Sangamon River drains into Lake Decatur, an 11-km² artificial reservoir
4 constructed in the early 1920s to supply water for the city of Decatur, Illinois, and its corn
5 refining industry. Over the past 90 years, erosion throughout the USRB has resulted in about
6 200,000 tons of sediment being delivered annually to Lake Decatur, about 23% of which is
7 trapped by the reservoir. As of the 1980s the lake had lost about one-third of its original capacity
8 because of sedimentation (Fitzpatrick et al., 1987). Dredging of the lake, which is ongoing at
9 present and expected to continue until 2019, is required to offset the loss of capacity caused by
10 sedimentation (Petty, 2014). Lake Decatur also is plagued by water quality problems related to
11 nonpoint source pollution from agricultural runoff in the USRB. In particular, the lake has had
12 exceptionally high nitrate-N loads; the Illinois Environmental Protection Agency issued eight
13 warnings between 1979 and 1992 for noncompliance with drinking water standards for nitrate-N
14 (10 mg/l maximum concentration level) (Demissie and Keefer, 1996). Between 1967 and 2008
15 the average annual maximum concentration of nitrate-N in Lake Decatur was 10.6 mg/l (Keefer
16 et al., 2010). Because nitrate-N cannot be removed through standard water purification
17 processes, the city of Decatur was forced in 2002 to construct a special ion-exchange facility to
18 comply with drinking water standards for nitrate-N.

19 The USRB is one of three watersheds included in the new Critical Zone Observatory
20 focusing on intensively managed landscapes. The other two sites in the IML-CZO are the 270-
21 km² Clear Creek watershed in Iowa and the 44,000-km² Minnesota River basin in Minnesota.
22 These three watersheds are all situated within regions of the Midwest influenced by Pleistocene
23 glaciation yet differ in size, the history of glaciation, and the amount of relief within the

watersheds. Thus, collectively these sites represent a range of environmental conditions found throughout the glaciated Midwest and provide an opportunity to advance understanding of the critical zone in this important region.

3. Data and methods

Data for the analysis of channel change consist of maps of the stream network in the USRB produced from General Land Office (GLO) surveys conducted in the early 1800s, historical aerial photographs from 1940-1941, and contemporary 2012 aerial orthophotographs. These three sources of information have been shown to be useful for reconstructing changes in the characteristics of stream channels (Trimble and Cooke, 1991). Surveyors for the General Land Office typically recorded the locations of streams that crossed section lines in their survey notes and included streams on plat maps produced from these notes. Survey notes often include information on stream widths, which indicate that at least in some cases surveyors documented streams < 1 m in width. The early plat maps, which have a scale of 1:31,680, provide valuable information on the extent of the stream network prior to European settlement and alteration of the landscape by farming. The maps are not adequate for determining changes in channel position related to lateral movement or human displacement because the exact location of channels was only recorded at section lines and the course of the stream depicted on plat maps between the section lines was interpreted by the surveyor.

3.1. Change in the spatial extent of the channel network

Digital, georeferenced versions of the GLO plat maps, in the form of shape files for ArcGIS, were used to determine the extent of the drainage network in the USRB recorded by land surveyors. These digital maps, produced by the Prairie Research Institute at the University

1 of Illinois, were generated from digital versions of the original paper maps available through the
2 Illinois State Archives (<http://landplats.ilsos.net/>). Two sets of plat maps exist for all portions of
3 the USRB. Original maps were hand-drawn by the surveyors within a few months following the
4 surveys. The vast majority of these surveys occurred in the early 1820s. Original maps for 25 of
5 the 28 townships in the USRB with streams have dates between 1821 and 1824, two maps have
6 dates of 1832, and one map has a date of 1849. Revised versions of these maps were produced
7 by the Inspector General of the GLO in the 1850s (1 in 1850, 2 in 1853, and the remainder in
8 1857). The latter, although revised, are still based on the original field notes. Stream traces in
9 the digital, georeferenced files correspond to the extent of the stream network depicted on
10 revised versions of the plat maps.

11 Digital orthoimagery with a ground resolution of 1 m/pixel acquired in the summer 2012
12 through the National Agricultural Imagery Program (NAIP) of the U.S. Department of
13 Agriculture (USDA) was the main source of information used to determine the extent of the
14 stream channel network in the USRB. The NAIP imagery is available online at the USDA-
15 NRCS (National Resource Conservation Service) Geospatial Data Gateway. The mapping of
16 stream channels was guided by georeferenced digital line graph files of streams at a scale of
17 1:24,000 available from the U.S. Geological Survey through the National Hydrography Dataset
18 (NHD). Streams depicted in the NHD were overlain onto the aerial imagery, and segments were
19 added or subtracted based on interpretation of channels on the imagery. Only well-defined
20 channels, either natural or artificial, were included in the mapping of network extent. The high
21 resolution of the NAIP imagery allowed channels as small as 1-2 m wide to be identified.
22 Features such as farmed swales or grassed waterways were not included.

Although published standards for the NHD indicate that streams included as features in this digital data set begin at the upper limit of ‘where the feature first becomes evident as a channel’ (USGS, 2009, p. 103), the comparative analysis between the aerial imagery and the NHD indicated that the latter was not a reliable source for identifying stream channels. The NHD is derived from blue lines on 1:24,000 topographic maps and the criteria used to identify streams in the topographic mapping process are not specific (Thompson, 1981). The same concern arises in using blue lines on historical topographic maps to define changes in the extent of the channel network. Visual comparisons between channels evident on aerial imagery and blue-line depictions of streams either in the NHD or on historical topographic maps show that many streams included in the mapping products are not channels (Fig. 2). The stream network for the USRB based either on historical topographic maps or the NHD is far more extensive than the channel network defined through inspection and interpretation of aerial imagery (Fig. 2). Thus, the blue line networks in the NHD and on historical topographic maps overestimate the number of well-defined channels on the landscape. This comparison between fluvial information derived directly from aerial photographs and that available from topographic mapping illustrates limitations of the topographic-mapping data for defining the extent of *channel* networks in midwestern watersheds.

3.2. *Changes in channel planform*

Changes in channel planform over more than seven decades were determined primarily from historical aerial photographs of the USRB obtained in 1940-1941 (scale 1:20,000) and the 2012 NAIP orthoimagery. The historical aerial photographs were downloaded from the Illinois State Geological Survey (ISGS) Geospatial Data Clearinghouse. Images for Champaign, Piatt, Ford, and McLean counties were acquired in summer 1940, whereas those for DeWitt and

1 Macon counties, in the downstream part of the USRB, were acquired in fall 1941. These aerial
2 photographs were georeferenced to the 2012 USDA orthoimagery of the area. In most cases
3 between 8 and 10 ground control points were used to rectify each aerial photo, but in a few cases
4 the lack of well-defined control points resulted in only 5-6 points being used in this process. In
5 all but three cases a first-order polynomial affine transformation was used to rectify the photos.
6 A second-order polynomial function was used in three cases to obtain an RMSE < 10 m. The
7 average root mean square error of rectification for 117 aerial photos was 2.9 m and the maximum
8 RMSE was 8.8 m. In most cases the RMSE was < 2 m.

9 Historical USGS topographic maps for the region were obtained to use blue lines on these
10 maps to help guide interpretations of stream channel positions on the historical aerial
11 photographs, particularly where channel locations on the photographs were obscured by tree
12 cover. The maps include the following 15-min Illinois quadrangles at a scale of 1:62,500:
13 Decatur (map edition 1929, surveyed in 1929), Gibson City (map edition 1928, surveyed in
14 1924-1925), Mahomet (map edition 1907, surveyed in 1904-1905), and Monticello (map edition
15 1937, surveyed in 1936-1937). One of these maps (Mahomet) greatly predates the availability of
16 aerial photography in the USRB, whereas the other three were produced around the same time as
17 the earliest aerial photographs. These maps were georeferenced using the 2012 aerial
18 orthoimages.

19 Channel centerlines for the Sangamon River and its main tributaries were manually
20 digitized from the 1940-1941 aerial photographs and from the 2012 imagery following
21 established procedures (Gunalp and Rhoads, 2008). Where channels were partially obscured
22 by the tree canopy of riparian forest in the 2012 imagery, a set of aerial photos obtained in March
23 2011 by the USGS during leaf-off conditions was used to confirm the location of the channel.

1 This set of images is available online through the USGS Earth Explorer web portal. Only about
2 5% of the stream length was obscured in 2012. For leaf-obscured parts of the streams on the
3 1940-1941 imagery, the historical topographic maps were consulted to determine channel
4 locations. In addition, aerial photos from the early 1950s were obtained through the Earth
5 Explorer site to help guide interpretations of leaf-obscured channel positions in 1940-41. The
6 Sangamon River was digitized from its mouth at Lake Decatur to the farthest upstream extent
7 where water is conveyed in a channel. At a few locations, the Sangamon River splits into two or
8 more distinct channels that actively convey water. In these locations, each channel was
9 digitized. Tributary channels were digitized from their confluence with the Sangamon River to
10 the farthest location upstream where a conspicuous channel exists. Because the headward
11 portions of channels are ditches, the termination point of these channels is usually quite distinct.

12 Channel centerline movement was determined by first creating a buffer equal to one-half
13 the average RMS error of image rectification on each side of the centerline (Urban and Rhoads,
14 2003; Guneralp and Rhoads, 2009). Buffers for different years were then overlain onto one
15 another to evaluate change in channel positions. Only sections of the buffers that did not overlap
16 were identified as locations where channel movement had occurred. This method helps to ensure
17 that changes in channel position over time are not the result of imprecision in image rectification.
18 Channel buffers were examined for movement and classified according to the following criteria:
19 (i) no movement – the river buffers for successive images overlap with one another, (ii) natural
20 movement – the river buffers for successive images do not overlap with one another and the
21 movement of the channel involves migration of meander bends or avulsion through cutoffs , (iii)
22 channelization – the river buffers for successive images do not overlap with one another and the
23 movement of the channel is caused by artificial straightening of the channel (i.e., the channel is

not straight on an earlier photo and is straight on a later photo), and (iv) the river buffers for successive images do not overlap with one another and the river was straight in the first image and adjusted to this straightening by developing a meandering planform in the second image. Classification occurred on the basis of channel reaches, where reaches were delineated by obvious changes in channel pattern, such as the transition from a naturally meandering pattern to an artificially straightened pattern.

4. Results and discussion

4.1. Changes in the channel network

The comparison between the extent of streams shown on the GLO plat maps and the extent of channels derived from the 2012 orthoimagery indicates that major human-induced changes in the extent of the channel network have occurred in the USRB (Table 1; Fig. 3). Many new channels, particularly drainage ditches, have been added in the headwaters to provide outlets for tile drains underlying low-gradient upland hillslopes (Fig. 3). The total length of stream channels in the USRB identified on the 2012 orthophotos is almost three times greater than the total length of streams depicted on the 1820 GLO plat maps, resulting in a corresponding increase in drainage density (Table 1). In the Big Ditch and Corn Valley subbasins, total channel length and drainage density in 2012 are six and eight times greater, respectively, than in 1820. The smallest difference is in the Phillippe Creek subbasin, a fairly small tributary to the Sangamon River, where channel length and drainage density in 2012 are only 1.3 times greater than in 1820. Notably, in 1820 no channels were recorded by the GLO surveyors in four subbasins, whereas in 2012 the channel networks in these subbasins collectively account for 13% of the total channel length in the USRB.

1 The exact timing of channel-network extension in the USRB is unknown because no
2 detailed information on stream extent is available between the 1820s and early 1900s. Extension
3 of the networks probably occurred mainly between 1880 and the early 1900s, immediately
4 following passage of the Farm and Levee Drainage Act in 1879 by the Illinois General Assembly
5 (Rhoads and Herricks, 1996). This act authorized the formation of drainage districts and led to
6 what is now referred to as the drainage boom in Illinois. The authority to levy assessments on
7 property owners provided drainage districts with the financial resources required to initiate the
8 construction of large ditches that serve as outlets for tile drainage systems installed beneath farm
9 fields.

10 The historical aerial photography suggests that considerable extension of the network had
11 occurred by the early 1940s. No channels were identified by land surveyors in the 1820s in the
12 Dickerson Slough subbasin (Fig. 3). By 1940, the total length of channels in this subbasin
13 evident on aerial photography is 49.2 km ($DD = 0.62 \text{ km/km}^2$) (Figs. 2 and 3). By comparison,
14 the total length of channels identified on the 2012 imagery is 62.7 km (Figs. 2 and 3). The aerial
15 photographs indicate that by 1940 at least two-thirds of the modern (2012) channel network was
16 already in place in the Dickerson Slough watershed.

17 Although the analysis here suggests that humans have radically altered the spatial extent
18 of the channel network in the USRB, the comparison of channels derived from the GLO maps
19 and modern orthoimagery must be interpreted cautiously. The completeness of the GLO records
20 is unknown. Land surveyors were instructed to document the crossings and widths of all streams
21 crossing section lines (White, 1983), but how large a stream had to be for a surveyor to record it
22 and the degree of consistency in recording streams, for an individual surveyor and among
23 different surveyors, remains uncertain. The plat maps and surveyor notes for the USRB include

1 some streams with recorded widths < 1 m and in many cases the most headward portions of
2 streams have recorded widths < 2 m. This finding is consistent with previous work in the region
3 that indicated surveyors documented streams as small as 1 to 1.5 m wide (Rhoads and Herricks,
4 1996). These widths probably represent flow widths rather than channel widths (Knox, 1977).
5 Nevertheless, widths this small correspond to the widths of channels at the most headward
6 locations of the modern drainage network, far upstream of the headward locations of streams
7 documented in the GLO surveys. Also, surveyors probably only documented channels with
8 flowing water, and crossings of dry, yet well-defined channels may not have been noted. Some
9 small channels included in the modern drainage systems are so short that these features do not
10 cross a section line; these channels would not have been recorded by surveyors even if present in
11 the 1820s. However, many of these short channels are tributaries to extended channels that do
12 cross section lines, yet were not recorded by the surveyors. Thus, it seems highly unlikely that a
13 short tributary channel existed in 1820 but not the extended channel into which it now drains.
14 Only 3% of the channels in the drainage network do not cross section lines; thus, even if these
15 channels are eliminated from the comparison, the difference in stream lengths and drainage
16 densities between 1820 and 2012 does not change substantially.

17 Given the characteristics of the landscape of the USRB prior to settlement by European
18 descendants, the lack of channels as depicted on the GLO maps is not implausible. Surveyors
19 within the region reported vast expanses of prairie and the vegetation recorded on the GLO plats
20 is predominantly prairie, especially in the flat uplands. Much of this prairie included wetlands,
21 reported by surveyors as wet prairie. Indeed the USRB lies within the Grand Prairie Natural
22 Division of Illinois, a region originally dominated by tall grass prairie, now converted
23 extensively to agriculture (Urban, 2005). The grasses, sedges, and forbs of the tall-grass prairie

1 had tough fibrous roots that extended into the soil to depths of 3 to 4 m. The dense, matted
2 prairie sod was highly resistant to erosion, and concentrated flows within the relatively flat
3 landscape of the USRB may not have generated sufficient erosional force to penetrate the sod
4 and carve channels. A testament to the strength of the sod was the effort required to cut into this
5 material; breaking the prairie sod required a heavy cast-iron or steel plow weighing 30 to 50 kg,
6 typically powered by six to eight oxen and sometimes as many as 14 oxen (Schrob, 1973).

7 Determining the net hydrological effect of the addition of channels to the drainage
8 network in the USRB is beyond the scope of this paper, but past work in the nearby Mackinaw
9 River basin of central Illinois suggests that the increase in drainage density has dramatically
10 altered rates of runoff and magnitudes of peak streamflows compared to conditions in the 1800s
11 (White et al., 2003). The addition of artificial channels in the USRB is similar to the extension of
12 drainage networks in suburbanizing environments, which decreases the travel time of surface
13 runoff and the lag time to peak discharge (Graf, 1977).

14 Another major factor affecting the hydrology of the USRB is the installation of tile drains
15 beneath farm fields to improve land drainage. The purpose of the drainage ditches is to serve as
16 outlets for extensive tile networks underlying farm fields. Although the extent of tile drain
17 networks is extensive, the characteristics and exact locations of tile systems are in most cases
18 unknown. Few, if any, detailed maps of tile networks are available and mapping of tiles using
19 remote sensing methods of detection has yet to be perfected (Naz and Bowling, 2008; Naz et al.,
20 2009). Modeling work suggests that as much as 80% of the total annual runoff in the upper
21 Sangamon River basin can be attributed to tile drainage (Li et al., 2010). Flow through tile
22 drainage systems appears to affect base flow more than peak flow, especially the recession
23 curves of hydrographs (Schilling and Helmers, 2008).

Undoubtedly the net effect of channel network expansion and installation of tile drainage systems, along with removal of prairie and the implementation of widespread crop-based agriculture, has been enhanced rates of subsurface and surface runoff, which in turn have resulted in increased flashiness of stream hydrographs (Basu et al., 2010). This acceleration of the hydrological flux contributes to enhanced fluxes of sediment and nutrients at the watershed scale, particularly given working of the soil and widespread application of fertilizers to farmland to enhance crop production (Lemke et al., 2011). Within headwater watersheds such as the USRB, runoff from individual storm events, especially when these events occur in conjunction with the timing of field preparation for planting and applications of fertilizer, can result in substantial export episodes that account for a large percentage of the total annual nutrient loads (Royer et al., 2006). Locally, conversion of the USRB from a presettlement landscape characterized by storage and transformation of materials to a modern agricultural landscape dominated by transport of materials has resulted in problems associated with water quality and sedimentation in Lake Decatur (Fitzpatrick et al., 1987; Keefer et al., 2010). At regional scales enhanced material fluxes associated with tile drainage and enhanced storm runoff contribute to downstream problems, such as hypoxia in the Gulf of Mexico and sedimentation along major midwestern rivers (Bhowmik and Demissie, 1989; Rabalais et al., 2002). Increased rates of runoff have also been implicated in enhanced erosion of stream channels in some areas of the Midwest (Schottler et al., 2014); however, the extent to which this effect occurs in the USRB has yet to be determined.

4.2. Changes in channel planform

Change in channel planform was examined for the main stem of the Sangamon River and for several major tributaries: Friends Creek, Goose Creek, Camp Creek, Big Ditch, Madden Creek, Wildcat Slough, and Drummer Creek. Results show that 62% of the total length of these

1 channels did not exhibit any detectable change in planform between 1940 and 2012 (Figure 4,
2 Table 2). This finding is generally consistent with results of previous work on channel planform
3 change in east-central Illinois. Nearly 90% of the total length of channels in the nearby upper
4 Embarras River basin did not exhibit detectable change in planform between 1936 and 1993
5 (Urban and Rhoads, 2003). Channels in the USRB that did not change include both those with
6 meandering planforms and those with straight channelized planforms (Figs. 5 and 6). Most
7 channels that were channelized in 1940 remained straight in 2012; < 1% of the straightened
8 channels exhibited any response to channelization, and the amount of response was on the order
9 of one channel width of change in spatial position (Table 2). Response to channelization
10 occurred only along Camp Creek and Madden Creek (Fig. 4; Table 2). Headwater portions of
11 tributaries that were already channelized in 1940 were highly stable, exhibiting little or no
12 change in planform (Fig. 5). Maintenance of these ditches every 20-30 years probably
13 contributes to planform stability. This maintenance prevents the development of bar forms in the
14 bottom of the ditch, which often lead to the formation of a meandering inset channel that can
15 potentially erode the ditch banks (Landwehr and Rhoads, 2003).

16 The entire lower part of the Sangamon River main stem, which is meandering, did not
17 exhibit any planform change over the period of record (Fig. 4). This lack of change may in part
18 reflect effects of backwater from Lake Decatur. To evaluate this possibility, backwater effects
19 for different flow levels were evaluated using the one-dimensional HEC-RAS hydraulic model
20 calibrated to lake level information available from the City of Decatur. This information was
21 used to define the downstream boundary condition for the model. Cross sections of the channel
22 and floodplain provided by the Illinois State Water Survey defined the channel and floodplain
23 geometry. The results indicate that while the backwater effect over the lower 12 km of the river

1 is pronounced at low flow, this effect is essentially eliminated for the 2-year flood (assuming a
2 median water surface elevation in the lake), which suggests that many bankfull flows along the
3 lower river are not impeded hydraulically by backwater (Fig. 7). Other factors that may
4 contribute to planform stability along this part of the river include heavy forest cover along the
5 channel banks and an abundance of woody debris within the channel; the former enhances bank
6 resistance to erosion, whereas the latter contributes to flow resistance and decreased erosional
7 energy of the flow.

8 Meander dynamics, which include lateral migration and natural avulsions, constitute the
9 largest category of planform change with nearly 30% of the total length of streams exhibiting
10 change in planform via natural fluvial processes between 1940 and 2012 (Fig.8; Table 2).

11 Channels in the USRB appear to be more dynamic than those in the nearby upper Embarras basin
12 where only 3% of the total length of streams displayed detectable change in planform caused by
13 meander dynamics over a comparable 57-year interval (Urban and Rhoads, 2003). Meander
14 dynamics are most spatially extensive in the lower reaches of Friends, Camp, Goose, and
15 Madden creeks; in the middle reaches of the Sangamon River between the confluences of Camp
16 Creek and Big Ditch; and in the headwaters of the Sangamon River upstream of the confluence
17 with Drummer Creek (Figs. 4 and 8). In general, these locations also exhibit the largest
18 magnitudes of change associated with meander dynamics (Table 2; Fig. 8). The greatest change
19 in channel location, nearly 30 channel widths, corresponded to a cutoff event on a meander bend
20 along Friends Creek (Fig. 9).

21 The spatial distribution of channel change caused by meander dynamics seems to be
22 related in part to topographic characteristics imprinted on the landscape by glacial activity during
23 the Pleistocene Epoch. The upper Sangamon River lies within a valley carved by glacial

meltwater emanating from the margin of the Lake Michigan Lobe of the Laurentide Ice Sheet during the Wisconsin glacial episode (Fig. 10). This valley is bounded by bluffs 15-20 m high and tributaries have incised into the surrounding upland surfaces to maintain base level with the Sangamon River (Fig. 10). Analysis of longitudinal profiles of the Sangamon River and its tributaries reveals that the locations of high rates of natural planform change generally accord either with linear or convex sections of these profiles. Downstream sections of Goose Creek, Camp Creek, Madden Creek, and Friends Creek exhibit convex profiles as these tributaries descend into the main valley of the Sangamon River, whereas Madden Creek has a fairly linear profile (Fig. 11). These profile shapes result either in increases (convex) or constant (linear) channel slopes (S) in the downstream direction. Given that discharge (Q) is proportional to drainage area and that stream power per unit length of channel (Ω) is:

$$\Omega = \gamma QS \quad (1)$$

where γ = specific weight of water, downstream increases in drainage area combined with a constant or increasing slope will produce downstream increases in Ω . Such increases will enhance erosional energy and may account for the relatively high rates and magnitudes of planform change along the lower portions of tributaries. Note that Drummer Creek, which exhibits low rates of meander dynamics, has a strongly concave-upward longitudinal profile (Fig. 11). The situation in the USBR resembles that documented in the Minnesota River basin, where the longitudinal profiles of tributaries entering the incised valley of the main river are marked by pronounced convexities, or knickpoints (Gran et al., 2009, 2013). In the Minnesota River tributaries, high rates of lateral migration of meanders below the knickpoints leads to erosion of tributary valley walls, which contributes large amounts of sediment to the tributaries and main

stem. Further work is needed to determine whether erosion along downstream portions of tributaries represents a substantial source of sediment in the USRB.

Characteristics of the longitudinal profile may also account for relatively high rates of lateral migration in the main valley of the Sangamon River, where a slight convexity, or knickpoint, in the longitudinal profile is evident at an upstream distance of about 80,000 m (Fig. 11). Upstream of the knickpoint (80,000-100,000 m) the average channel gradient is 0.00024, whereas downstream of this knickpoint (40,000-80,000 m), channel gradients increase to 0.00034, resulting in high rates of channel migration between the mouths of Camp Creek and Big Ditch (Fig. 8). The high rates of channel migration above the mouth of Drummer Creek on the Sangamon River (102,000 m upstream) correspond to the headwaters of the river system where gradients increase dramatically (Fig. 9). Sections of the Sangamon River in the headwaters also are flanked by pasture, rather than dense forest, promoting erosion of channel banks and meander migration (Fig. 12).

Channelization accounts for about 8% of planform change in the USRB over the 72-year period (Table 2). The most prominent areas of channelization between 1940 and 2012 are on Madden Creek, the downstream portion of Big Ditch, and sections of the Sangamon River main stem upstream of the mouth of Drummer Creek (Fig. 4). The largest change caused by channelization is along the upper Sangamon River and has resulted in relocation of the channel 30 widths away from its previous location (Fig. 9). Although the spatial extent of channel movement associated with channelization is much less than that associated with meander dynamics, the magnitude of channel displacement produced by channelization is comparable to the magnitude of displacement caused by meander dynamics (Figs. 8 and 13). In many cases, channelization involves straightening the course of the channel through a series of meander

bends. Most channelized sections of the main channel and tributaries show little or no evidence of recovery to human modification. Despite pronounced meander migration along some headwater sections of the Sangamon River that have not been channelized (Figs. 4 and 8), straightened sections along this portion of the river have remained straight. Similarly, channelization along Madden Creek and Big Ditch has not led to remeandering even though the longitudinal profile for Madden Creek is relatively linear and the profile for Big Ditch has a pronounced convexity – conditions that have led to high rates of meander migration along other tributaries (Fig. 14). This result is similar to findings for the nearby upper Embarras River basin, where recovery of channels to human modification is also limited and supports the contention that channelization represents a catastrophic geomorphic event in streams draining low-relief landscapes in the glaciated Midwest (Urban and Rhoads, 2003). Effects of channelization are catastrophic in the sense that this human action greatly changes the form of streams, yet natural fluvial processes apparently lack the capacity to induce recovery to these changes.

5. Conclusion

This study has shown how agricultural development at the landscape scale in the upper Sangamon River basin, a typical watershed in the portion of Illinois affected by Wisconsinan glaciation, has strongly influenced the spatial extent of the channel network and change in the planform of stream channels. Comparison of stream channel extent depicted on General Land Office Survey plat maps from the 1820s with the extent on 2012 aerial photographs indicates that the total length of channels and the drainage density in the watershed have increased nearly threefold over this 190-year period. The greatest change in network extent has been in flat, poorly drained uplands, where numerous agricultural drainage ditches have been added to the

1 network to provide outlets for tile drainage systems underlying farm fields. Thus, humans are
2 the dominant agent of network expansion. Since 1940 over 60 % of the total length of the main
3 stem of the upper Sangamon River and five of its major tributaries has not exhibited detectable
4 change in channel position, even though many of these channels, especially those in the
5 headwaters, were already channelized in 1940. Thus, channels in this low-relief environment are
6 not highly dynamic, even when modified artificially by humans – a finding consistent with
7 previous work on channel change in the the region (Urban and Rhoads, 2003). In contrast to
8 previous work, the major cause of channel planform change in the upper Sangamon River basin
9 over the 74 years is meander dynamics (migration and cutoffs), not straightening or relocation
10 associated with channelization. Locations of change in channel planform associated with
11 meander dynamics appear to be concentrated where convexities, or knickpoints, occur in
12 longitudinal profiles of tributaries and the main stem of the Sangamon River. Relatively high-
13 gradient sections of the main river in the headwaters, where the floodplain is in pasture and tree
14 cover is limited, are also foci of enhanced lateral migration. Where channelization has occurred,
15 either prior to 1940 or since 1940, recovery to this human impact is limited; responses to
16 channelization are evident on < 1% of the total stream length in the basin. Thus, channelization
17 essentially has a catastrophic, long-lasting impact on channel planform. This response of low-
18 gradient streams in east-central Illinois to channelization differs from that documented in streams
19 with moderate or high gradients, where direct modification, particularly channel straightening,
20 leads either to incision and widening (Simon, 1989) or to rapid recovery of channel sinuosity
21 (Lewin, 1976).

22 The results of this study provide a crucial context for addressing questions about how
23 humans have fundamentally altered critical zone processes within the intensively managed

landscape of the upper Sangamon River basin. By increasing the density of the channel network, by channelizing streams, by removing native plant cover, and by installing tile drains beneath farm fields, fluxes of water, nutrients, and sediment have undoubtedly increased within this basin. What was once prior to major human intervention a watershed characterized by high rates of biogeochemical activity and storage of water and sediment has, most likely, become a watershed characterized by high rates of transport and limited amounts of storage and biogeochemical activity. Further work is needed to gain a full understanding of human-induced change in critical zone processes in intensively managed landscapes and to use understandings gained from such inquiry to guide effective public policy and decision making aimed at long-term sustainability of the critical zone in these important landscapes.

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References

- Basu, N.B., Rao, P.S.C., Winzeler, H.E., Kumar, S., Owens, P., Merwade, V., 2010. Parsimonious modeling of hydrologic responses in engineered watersheds: Structural heterogeneity versus functional homogeneity. *Water Resources Research*, 46, doi: 10.1029/2009wr007803.
- Bhowmik, N.G., Demissie, M., 1989. Sedimentation in the Illinois River Valley and Backwater Lakes. *J. Hydrol.*, 105(1-2), 187-195.
- Brookes, A., 1988. *Channelized Rivers: Perspectives for Environmental Management* Wiley Chichester.
- Brown, A.G., Tooth, S., Chiverrell, R.C., Rose, J., Thomas, D.S.G., Wainwright, J., Bullard, J.E., Thorndycraft, V.R., Aalto, R., Downs, P., 2013. The Anthropocene: is there a geomorphological case? *Earth Surf. Process. Landf.*, 38(4), 431-434.
- Csiki, S., Rhoads, B.L., 2010. Hydraulic and geomorphological effects of run-of-river dams. *Progress in Physical Geography*, 34(6), 755-780.
- Demissie, M., Keefer, L., 1996. *Watershed monitoring and land use evaluation for the Lake Decatur watershed*, Illinois State Water Survey Miscellaneous Publication 169, Champaign, IL.
- Fehrenbacher, J.B., Janson, L.J., Olsen, K.R., 1986. Loess thickness and its effect on soils in Illinois, Bulletin 782, University of Illinois in cooperation with the U.S. Department of Agriculture, Champaign, IL.
- Fitzpatrick, W.P., Bogner, W.C., Bhowmik, N.C., 1987. *Sedimentation and hydrologic processes in Lake Decatur*, Illinois State Water Survey, Report of Investigation 107, Champaign, IL.
- Goudie, A.S., 2006. Global warming and fluvial geomorphology. *Geomorphology*, 79(3-4), 384-394.
- Graf, W.L., 1977. Network characteristics in suburbanizing streams. *Water Resources Research*, 13(2), 459-463.
- Graf, W.L., 1979. Mining and channel response. *Annals of the Association of American Geographers*, 69(2), 262-275.
- Graf, W.L., 1999. Dam nation: A geographic census of American dams and their large-scale hydrologic impacts. *Water Resources Research*, 35(4), 1305-1311.
- Graf, W.L., 2001. Damage control: Restoring the physical integrity of America's rivers. *Annals of the Association of American Geographers*, 91(1), 1-27.

- 1 Graf, W.L., 2006. Downstream hydrologic and geomorphic effects of large dams on American
2 rivers. *Geomorphology*, 79(3-4), 336-360.
- 3
- 4 Gran, K.B., Belmont, P., Day, S.S., Jennings, C., Johnson, A., Perg, L., Wilcock, P.R., 2009.
5 Geomorphic evolution of the Le Sueur River, Minnesota, USA, and implications for
6 current sediment loading. In: L.A. James, S.L. Rathburn, G.R. Whittecar (Eds.),
7 Management and Restoration of Fluvial Systems with Broad Historical Changes and
8 Human Impacts. Geological Society of America Special Papers, pp. 119-130.
- 9
- 10 Gran, K.B., Finnegan, N., Johnson, A.L., Belmont, P., Wittkop, C., Rittenour, T., 2013.
11 Landscape evolution, valley excavation, and terrace development following abrupt
12 postglacial base-level fall. *Geological Society of America Bulletin*, 125(11-12), 1851-
13 1864.
- 14
- 15 Gregory, K.J., 2006. The human role in changing river channels. *Geomorphology*, 79(3-4), 172-
16 191.
- 17
- 18 Guneralp, I., Rhoads, B.L., 2008. Continuous characterization of the planform geometry and
19 curvature of meandering rivers. *Geogr. Anal.*, 40(1), 1-25.
- 20
- 21 Guneralp, I., Rhoads, B.L., 2009. Planform change and stream power in the Kishwaukee River
22 watershed, Illinois: Geomorphic assessment for environmental management. In: L.A.
23 James, S.L. Rathburn, G.R. Whittecar (Eds.), Management and Restoration of Fluvial
24 Systems with Broad Historical Changes and Human Impacts. Geological Society of
25 America Special Papers. Geological Soc Amer Inc, Boulder, pp. 109-118.
- 26
- 27 Hooke, R.L., 1994. On the efficacy of humans as geomorphic agents. *GSA Today*, 4(9), 217,
28 224-225.
- 29
- 30 Hooke, R.L., 1999. Spatial distribution of human geomorphic activity in the United States:
31 Comparison with rivers. *Earth Surf. Process. Landf.*, 24(8), 687-692.
- 32
- 33 Hooke, R.L., 2000. On the history of humans as geomorphic agents. *Geology*, 28(9), 843-846.
- 34
- 35 Hooke, R.L., Martin-Duque, J.F., Pedraza, J., 2012. Land transformation by humans: a review.
36 *GSA Today*, 22(12), 4-10.
- 37
- 38 Illinois Department of Natural Resources, 1999a. Upper Sangamon River Area Assessment,
39 Volume 1: Geology, Champaign, IL
- 40
- 41 Illinois Department of Natural Resources, 1999b. Upper Sangamon River Area Assessement,
42 Volume 2: Water Resources Champaign, IL
- 43
- 44 Illinois Department of Natural Resources, 1999c. Upper Sangamon River Assessment, Volume 3,
45 Living Resources. , Champaign, IL

- 1 James, L.A., Lecce, S., 2013. Impacts of land use and land-cover change on river systems. In: E.
2 Wohl (Ed.), *Fluvial Geomorphology. Treatise on Geomorphology*. Elsevier Amsterdam
3 pp. 768-793.
4
- 5 Keefer, L., Bauer, E., Markus, M., 2010. Hydrologic and nutrient monitoring of the Lake
6 Decatur watershed: Final report 1993-2008. Contract Report 2010-07. Prepared for the
7 City of Decatur. Illinois State Water Survey, University of Illinois, Champaign, IL.
8
- 9 Knox, J.C., 1972. Valley alluviation in southwestern Wisconsin. *Annals of the Association of*
10 *American Geographers*, 62(3), 401-410.
11
- 12 Knox, J.C., 1977. Human impacts on Wisconsin stream channels. *Annals of the Association of*
13 *American Geographers*, 67, 323-342.
14
- 15 Knox, J.C., 1987. Historical valley floor sedimentation in the upper Mississippi valley. *Annals of*
16 *the Association of American Geographers*, 77(2), 224-244.
17
- 18 Knox, J.C., 2006. Floodplain sedimentation in the Upper Mississippi Valley: Natural versus
19 human accelerated. *Geomorphology*, 79(3-4), 286-310.
20
- 21 Landwehr, K., Rhoads, B.L., 2003. Depositional response of a headwater stream to
22 channelization, east central Illinois, USA. *River Research and Applications*, 19(1), 77-
23 100.
24
- 25 Lemke, A.M., Kirkham, K.G., Lindenbaum, T.T., Herbert, M.E., Tear, T.H., Perry, W.L.,
26 Herkert, J.R., 2011. Evaluating Agricultural Best Management Practices in Tile-Drained
27 Subwatersheds of the Mackinaw River, Illinois. *Journal of Environmental Quality*, 40(4),
28 1215-1228.
29
- 30 Lewin, J. 1976. Initiation of bedforms and meanders in coarse grained sediment. *Bulletin of the*
31 *Geological Society of America*, 87, 281-285.
32
- 33 Lewin, J., Macklin, M.G., 2014. Marking time in Geomorphology: should we try to formalise an
34 Anthropocene definition? *Earth Surf. Process. Landf.*, 39(1), 133-137.
35
- 36 Li, H., Sivapalan, M., Tian, F., Liu, D., 2010. Water and nutrient balances in a large tile-drained
37 agricultural catchment: a distributed modeling study. *Hydrology and Earth System*
38 *Sciences*, 14(11), 2259-2275.
39
- 40 Magilligan, F.J., 1992. Sedimentology of a fine-grained aggrading floodplain. *Geomorphology*,
41 4(6), 393-408.
42
- 43 Mattingly, R.L., Herricks, E.E., Johnston, D.M., 1993. Channelization and levee construction in
44 Illinois – a review and implications for management. *Environ. Manage.*, 17(6), 781-795.
45

- 1 National Research Council (NRC), 2001. Basic Research Opportunities in Earth Science,
2 Washington, D.C.
- 3
- 4 Naz, B.S., Bowling, L.C., 2008. Automated identification of tile lines from remotely sensed data.
5 Transactions of the Asabe, 51(6), 1937-1950
- 6
- 7 Naz, B.S., Ale, S., Bowling, L.C., 2009. Detecting subsurface drainage systems and estimating
8 drain spacing in intensively managed agricultural landscapes. Agricultural Water
9 Management, 96(4), 627-637.
- 10
- 11 Petty, A., 2014. Lake Decatur dredge gets into the water, prepares to clean up, Decatur Herald
12 Review, Decatur, IL, July 19 edition.
- 13
- 14 Rabalais, N.N., Turner, R.E., Wiseman, W.J., 2002. Gulf of Mexico hypoxia, aka "The dead
15 zone". Annual Review of Ecology and Systematics, 33, 235-263.
- 16
- 17 Rhoads, B.L., Herricks, E.E., 1996. Naturalization of headwater agricultural streams in Illinois:
18 challenges and possibilities In: A. Brookes, F.D. Shields, Jr. (Eds.), River Channel
19 Restoration Wiley Chichester, pp. 331-367.
- 20
- 21 Richter, D.D., Mobley, M.L., 2009. Monitoring Earth's Critical Zone. Science, 326(5956), 1067-
22 1068.
- 23
- 24 Royer, T.V., David, M.B., Gentry, L.E., 2006. Timing of riverine export of nitrate and
25 phosphorus from agricultural watersheds in Illinois: Implications for reducing nutrient
26 loading to the Mississippi River. Environmental Science & Technology, 40(13), 4126-
27 4131.
- 28
- 29 Schilling, K.E., Helmers, M., 2008. Effects of subsurface drainage tiles on streamflow in Iowa
30 agricultural watersheds: Exploratory hydrograph analysis. Hydrol. Process., 22(23),
31 4497-4506.
- 32
- 33 Schottler, S.P., Ulrich, J., Belmont, P., Moore, R., Lauer, J.W., Engstrom, D.R., Almendinger,
34 J.E., 2014. Twentieth century agricultural drainage creates more erosive rivers. Hydrol.
35 Process., 28(4), 1951-1961.
- 36
- 37 Schrob, D.E., 1973. Sod-busting on the upper midwest frontier: 1820-1860. Agricultural History,
38 47, 47-56.
- 39
- 40 Simon, A., 1989. A model of channel response in disturbed alluvial channels. Earth Surf.
41 Process. Landf., 14(1), 11-26.
- 42
- 43 Simon, A., Rinaldi, M., 2006. Disturbance, stream incision, and channel evolution: The roles of
44 excess transport capacity and boundary materials in controlling channel response.
45 Geomorphology, 79(3-4), 361-383.
- 46

- 1 Thompson, M. 1981. Maps for America. U.S. Geological Survey, Washington, D.C.
- 2
- 3 Trimble, S.W., 1983. A sediment budget for Coon Creek Basin in the Driftless Area, Wisconsin.,
4 1853-1977. American Journal of Science, 283(5), 454-474.
- 5
- 6 Trimble, S.W., 2013. Historical Agriculture and Soil Erosion in the Upper Mississippi Valley
7 Hill Country. CRC Press, Boca Raton, FL,
- 8
- 9 Trimble, S.W., Cooke, R.U., 1991. Historical sources for geomorphological research in the
10 United States. Professional Geographer, 43(2), 212-228.
- 11
- 12 U.S. Geological Survey (USGS). 2009. National Hydrography Dataset Feature Catalog.
13 Accessed online on March 5, 2015 at <http://nhd.usgs.gov/NHDFeatureCatalog.pdf>.
- 14
- 15 Urban, M.A., 2005. An uninhabited waste: transforming the Grand Prairie in nineteenth century
16 Illinois, USA. J. Hist. Geogr., 31(4), 647-665.
- 17
- 18 Urban, M.A., Rhoads, B.L., 2003. Catastrophic human-induced change in stream-channel
19 planform and geometry in an agricultural watershed, Illinois, USA. Annals of the
20 Association of American Geographers, 93(4), 783-796.
- 21
- 22 White, A.B., Kumar, P., Saco, P.M., Rhoads, B.L., Yen, B.C., 2003. Changes in hydrologic
23 response due to stream network extension via land drainage activities. Journal of the
24 American Water Resources Association, 39(6), 1547-1560.
- 25
- 26 White, C.A., 1983. A History of the Rectangular Survey System, U.S Department of Interior,
27 Bureau of Land Management Washington, D.C.
- 28
- 29 Zalasiewicz, J., Williams, M., Haywood, A., Ellis, M., 2011. The Anthropocene: a new epoch of
30 geological time? Philos. Trans. R. Soc. A-Math. Phys. Eng. Sci., 369(1938), 835-841.

1 **Table 1 Changes in channel length and drainage density throughout the Upper Sangamon River Basin**
2 **based on 1820 GLO records and 2012 aerial imagery**

<i>Drainage basins</i>	<i>Area (km²)</i>	<i>1820 Total channel length (km)</i>	<i>2012 Total channel length (km)</i>	<i>1820 Drainage density (km/km²)</i>	<i>2012 Drainage density (km/km²)</i>
<i>Sangamon (total)</i>	<i>2059.1</i>	<i>456.4</i>	<i>1331.5</i>	<i>0.22</i>	<i>0.65</i>
<i>Sangamon (minus subbasins)</i>	<i>630.4</i>	<i>241.0</i>	<i>450.3</i>	<i>0.38</i>	<i>0.71</i>
<i>Friends Creek</i>	<i>336.7</i>	<i>61.2</i>	<i>167.5</i>	<i>0.18</i>	<i>0.50</i>
<i>Goose Creek</i>	<i>141.4</i>	<i>26.8</i>	<i>80.0</i>	<i>0.19</i>	<i>0.57</i>
<i>Camp Creek</i>	<i>140.3</i>	<i>23.1</i>	<i>68.1</i>	<i>0.16</i>	<i>0.48</i>
<i>Big Ditch</i>	<i>132.8</i>	<i>12.8</i>	<i>88.1</i>	<i>0.10</i>	<i>0.66</i>
<i>Madden Creek</i>	<i>66.2</i>	<i>25.3</i>	<i>58.5</i>	<i>0.38</i>	<i>0.88</i>
<i>Wildcat Slough</i>	<i>47.9</i>	<i>0</i>	<i>35.0</i>	<i>0.00</i>	<i>0.73</i>
<i>Drummer Creek</i>	<i>152.0</i>	<i>26.8</i>	<i>125.1</i>	<i>0.18</i>	<i>0.82</i>
<i>Wolf Run</i>	<i>33.8</i>	<i>8.9</i>	<i>25.7</i>	<i>0.26</i>	<i>0.76</i>
<i>Willow Run</i>	<i>57.8</i>	<i>12.5</i>	<i>41.2</i>	<i>0.22</i>	<i>0.71</i>
<i>Wildcat Creek</i>	<i>25.0</i>	<i>5.6</i>	<i>15.0</i>	<i>0.23</i>	<i>0.60</i>
<i>Phillippe Creek</i>	<i>11.8</i>	<i>8.9</i>	<i>12.0</i>	<i>0.75</i>	<i>1.02</i>
<i>Hillsbury Slough</i>	<i>51.8</i>	<i>0</i>	<i>44.6</i>	<i>0.00</i>	<i>0.86</i>
<i>Dickerson Slough</i>	<i>79.6</i>	<i>0</i>	<i>62.7</i>	<i>0.00</i>	<i>0.79</i>
<i>Lone Tree Creek</i>	<i>129.7</i>	<i>0</i>	<i>30.9</i>	<i>0.00</i>	<i>0.24</i>
<i>Corn Valley</i>	<i>22.0</i>	<i>3.7</i>	<i>27.0</i>	<i>0.17</i>	<i>1.22</i>

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1 **Table 2 Total channel lengths of Sangamon River and tributaries and percentage of total lengths**
2 **exhibiting no change in position (1940-2012), or change in position caused by meander migration,**
3 **channelization, and response to channelization; subcategories indicate percentages of total length**
4 **corresponding to different magnitudes of movement**

	TOTAL	Sangamon	Big Ditch	Camp	Friends	Goose	Madden	Wildcat	Drummer
Length (km)	366.3	166.7	28.3	27.2	35.4	33.0	24.3	22.3	29.1
Meander migration (% of total length)	29.5	32.0	1.3	45.2	51.9	23.8	38.2	8.1	16.0
+/- 1 Channel widths	7.1	7.9	0.0	21.7	3.8	0.0	0.0	3.5	16.0
2-4 Channel widths	15.7	14.8	1.3	23.5	43.6	7.5	29.6	4.6	0.0
4+ Channel widths	6.7	9.2	0.0	0.0	4.5	16.4	8.6	0.0	0.0
Channelization (% of total length)	7.9	3.0	31.5	2.1	0.0	0.2	39.9	15.0	5.3
+/- 1 Channel widths	1.0	0.0	0.0	2.1	0.0	0.2	10.0	3.2	0.0
2-4 Channel widths	4.0	0.0	31.5	0.0	0.0	0.0	7.7	11.5	5.3
4+ Channel widths	2.9	3.0	0.0	0.0	0.0	0.0	22.2	3.0	0.0
Response to channelization (% of total channel length)	0.7	0.3	0.0	5.1	0.0	0.0	3.3	0.0	0.0
No change (% of total channel length)	61.9	64.8	67.3	47.5	48.1	75.9	18.7	76.9	78.7

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Fig. 1. The upper Sangamon River basin.

Fig. 2. (A) Differences in the extent of the channel network within the Dickerson Slough subbasin of the URSB as interpreted from 1940 aerial photographs (1:20,000) and the extent of the stream network depicted as blue lines on a 1928 U.S. Geological Survey 1:62,500 topographic map. (B) Differences in the extent of the channel network of Dickerson Slough subbasin as interpreted from 2012 NAIP aerial orthoimagery and the extent of the stream network in the USGS 1:24,000 National Hydrography Dataset (NHD). (C) Blowup of circled area on map (A) showing channel (red) from 1940 aerial image and 1928 topo map and a "stream" (blue line) on 1928 topo map that is not a channel. (D) Blowup of circled area on map (B) showing channel (red) from 2012 aerial image and NHD and two streams (blue lines) on NHD that are not channels.

3 **Fig. 3. Differences in channel network extent in the upper Sangamon River basin based on plat maps**
 4 **produced from General Land Office surveyor's notes in the 1820s and from 2012 aerial photography**
 5 **(current network). Panels show different parts of the basin starting from the downstream end in the**
 6 **lower left and proceeding counterclockwise to the upstream end at the upper left. Labels correspond**
 7 **to subbasins.**

Fig. 4. Spatial distribution of different types of change in channel position along the Sangamon River and major tributaries between 1940 and 2012.

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4 **Fig. 5. Example of no change in planform along a straight section of Big Ditch in (A) 1940 and (B)**
5 **2012. Location of the site within the USBR shown by the circle on inset map in upper left.**

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Fig. 6. Example of no change in planform along a forested, meandering section of the Sangamon River (A) 1940 and (B) 2012. Location of the site within the USRB shown by the circle on inset map in upper left.

Fig. 7. Water surface profiles for different magnitudes of discharge along the lower portion of the upper Sangamon River as predicted using the hydraulic model HEC-RAS with and without the effect of Lake Decatur on upstream conditions. The effect of the lake on upstream conditions is simulated for a normal pool elevation of 187.3 m. At low flow ($5.7 \text{ m}^3 \text{ s}^{-1}$), backwater induced by the lake extends upstream over a distance of at least 12 km. The 2-year flood along the reach ($133 \text{ m}^3 \text{ s}^{-1}$) has the same water surface profile with and without the presence of the lake, indicating that the backwater effect of the lake at normal pool level is overcome for this event.

Fig. 8. Spatial distribution of the magnitude of channel movement associated with meander dynamics along the Sangamon River and major tributaries in the USRB, 1940-2012. Panels show different parts of the basin starting from the downstream end in the lower left and proceeding counterclockwise to the upstream end at the upper left.

Fig. 9. Largest changes in channel position in the upper Sangamon River basin between 1940 (red lines) and 2012 (base image). (A) Channelization along the upper Sangamon River (maximum change 30 channel widths); (B) meander cutoff on Friends Creek (maximum change 29 channel widths). Locations of sites within the USRB shown by circles on inset maps.

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4 **Fig. 10. Topography of the Upper Sangamon River Basin showing incision of main valley and major**
5 **tributary valleys.**

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4 Fig. 11. Longitudinal profiles of the Sangamon River and major tributaries

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3 **Fig. 12. Lateral migration of a headwater section of the upper Sangamon River between 1940 and**
4 **2012. Note the lack of forest cover within pastureland along one or both banks of the river channel.**
5 **Location of the site within the USRB shown in upper left.**

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2 **Fig. 13. Spatial distribution of the magnitude of channel movement associated with channelization**
3 **along the Sangamon River and major tributaries in the USRB, 1940-2012. Panels show different parts**
4 **of the basin starting from the downstream end in the lower left and proceeding counterclockwise to**
5 **the upstream end at the upper left.**

Fig. 14. Example of channelization (straightening) along Madden Creek between (A) 1940 and (B) 2012 and persistence of channelized state in 2012. Location of the site within the USRB shown by the circle on the inset map in the upper left.