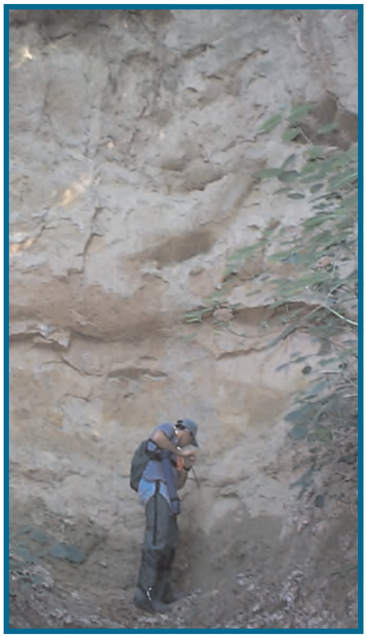
In cooperation with the Illinois Department of Natural Resources, Office of Water Resources and the U.S. Army Corps of Engineers, St. Louis District

Suspended-Sediment Yields and Stream-Channel Processes on Judy's Branch Watershed in the St. Louis Metro East Region in Illinois



Scientific Investigations Report 2006-5016

U.S. Department of the Interior
U.S. Geological Survey

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By Timothy D. Straub, Gary P. Johnson, Donald P. Roseboom, and Carlos R. Sierra

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Cover Photos:
Top Left: Bank retreat in Judy's Creek approximately 300 feet downstream of bank-rod BR123 (photo taken looking at the right bank on November 28, 2000).
Top Right: Bank retreat in Judy's Creek upstream of bank-rod BR123 and downstream of bank-rod BR124 (photo taken looking upstream on July 5, 2004).
Bottom Left: Bank retreat in Judy's Branch at bank-rod BR102 (photo taken looking upstream on March 7, 2002). Note exposed bank rod with orange flag and 3-foot long silver soil probe included for scale.
Bottom Middle: Loess bank in Judy's Branch near bank-rod BR199 (photo taken looking at left bank on May 16, 2001)
Bottom Right: This tree in Schoenberger Creek (bluff watershed in the region) originally was located on the top of bank; however, a rotational bank failure caused the tree to grow at an angle. Subsequent bank retreat left the tree in its current location and orientation in the stream channel (photo taken looking upstream on July 2, 2001).

Contents

Figures

Tables

Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Weight and Mass	
ton per day (ton/d)	0.9072	metric ton per day
ton per day (ton/d)	0.9072	megagram per day (Mg/d)
ton per mile per year (ton/mi-yr)	0.5637	megagram per year per kilometer
ton per year (ton/yr)	0.9072	megagram per year (Mg/yr)
ton per year (ton/yr)	0.9072	metric ton per year
	Pressure	
pound per square foot (lb/ft^2)	0.04788	kilopascal (kPa)
	Density	
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter (kg/m^3)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD29).

Suspended-Sediment Yields and Stream-Channel Processes on Judy's Branch Watershed in the St. Louis Metro East Region in Illinois

By Timothy D. Straub, Gary P. Johnson, Donald P. Roseboom, and Carlos R. Sierra

Abstract

Judy's Branch watershed, a small basin (8.64 square miles (mi^2)) in the St. Louis Metro East region in Illinois, was selected as a pilot site to determine suspended-sediment yields and stream-channel processes in the bluffs and American Bottoms (expansive low-lying valley floor in the region). Suspended-sediment and stream-channel data collected and analyzed for Judy's Branch watershed are presented in this report to establish a baseline of data for water-resource managers to evaluate future stream rehabilitation and management alternatives. The sediment yield analysis determines the amount of sediment being delivered from the watershed and two subwatersheds: an urban tributary and an undeveloped headwater (primarily agricultural). The analysis of the subwatersheds is used to compare the effects of urbanization on sediment yield to the river. The stream-channel contribution to sediment yield was determined by evaluation of the stream-channel processes operating on the streambed and banks of Judy's Branch watershed. Bank stability was related to hydrologic events, bank stratigraphy, and channel geometry through model development and simulation.

The average suspended-sediment yield from two upland subwatersheds (drainage areas of 0.23 and 0.40 mi^2) was 1,163 tons per square mile per year (tons/mi^2-year) between July 2000 and June 2004. The suspended-sediment yield at the Route 157 station was 2,523 tons/mi^2-year, near the outlet of Judy's Branch watershed (drainage area = 8.33 mi^2). This is approximately 1,360 tons/mi^2-year greater than the average at the upland stations for the same time period. This result is unexpected in that, generally, the suspended-sediment yield decreases as the watershed area increases because of sediment stored in the channel and flood plain. The difference indicates a possible increase in yield from a source, such as bank retreat, and supports the concept that land-use changes increase streamflows that may in turn result in higher rates of bank retreat. Utilizing both bank-rod data and resurveyed cross-section data, it was determined that approximately half of the suspended-sediment yield at Route 157 during July 2000-June 2004 came from bank retreat.

Given that bank retreat can be a substantial portion of the sediment yield, understanding bank stability processes is important. Bank stability can be assessed mathematically by computing the factor of safety, which is defined by the ratio of the shear strength (resisting force) along the failure surface and the shear stress (driving gravitational force). Once the factor of safety falls below one, the bank theoretically becomes unstable. Bank-stability conditions were related to hydrologic events, bank type, and channel geometry through model development and simulation. The most common type of bank in the watershed consists of cohesive alluvial soil deposits overlying a stiff glacial till. A stability chart for different bank types was developed using a bank-stability analysis. Banks steeper than 70 degrees and higher than from 10 to 11.5 feet (depending on bank type) become at risk for mass failure in the watershed under conditions that promote saturation of the bank and a sudden drop in the river level.

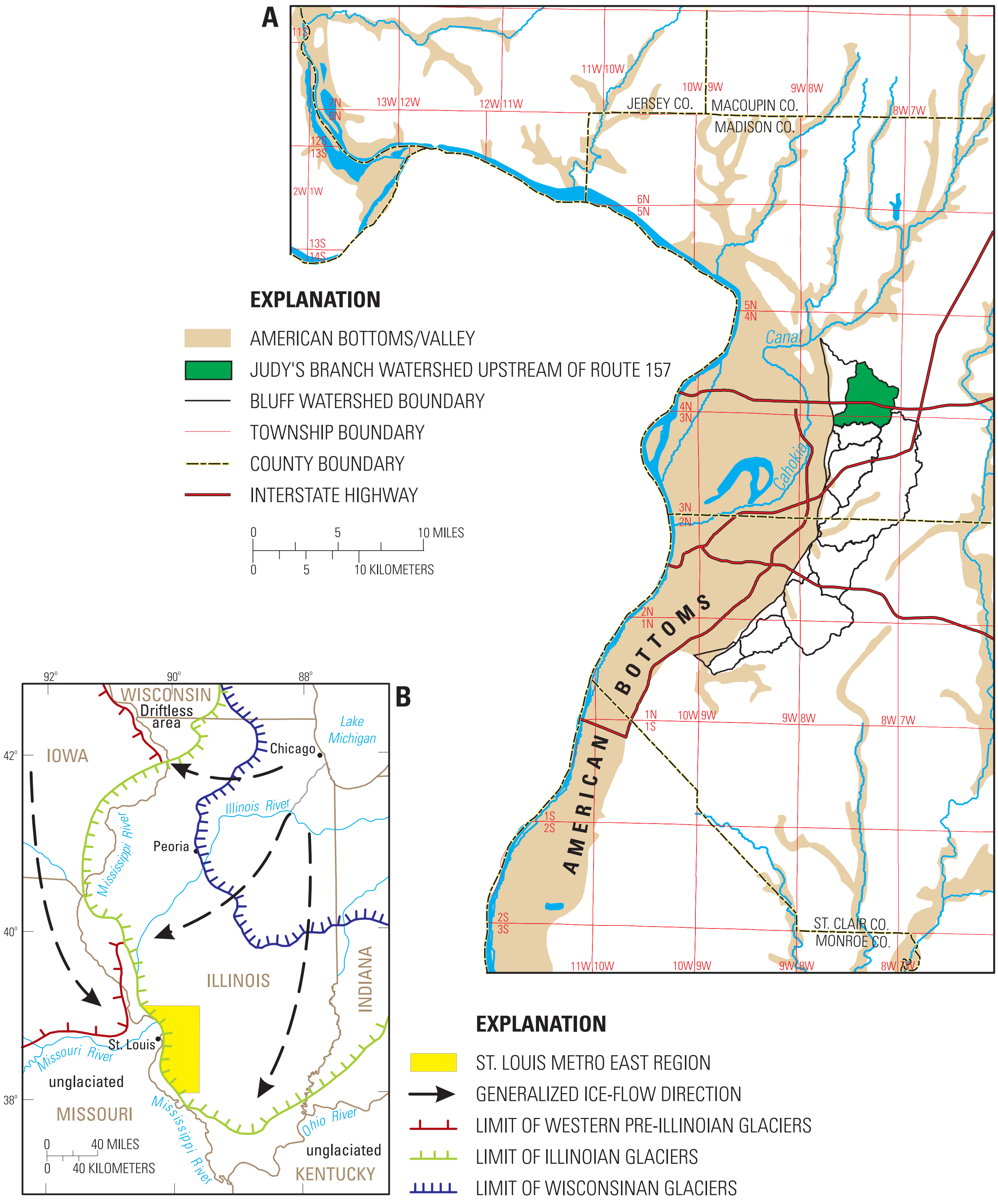

Figure 1. Location of A) Judy's Branch watershed and the St. Louis Metro East region in Illinois and B) the maximum extent of major glaciations (modified from Grimley, 2000).

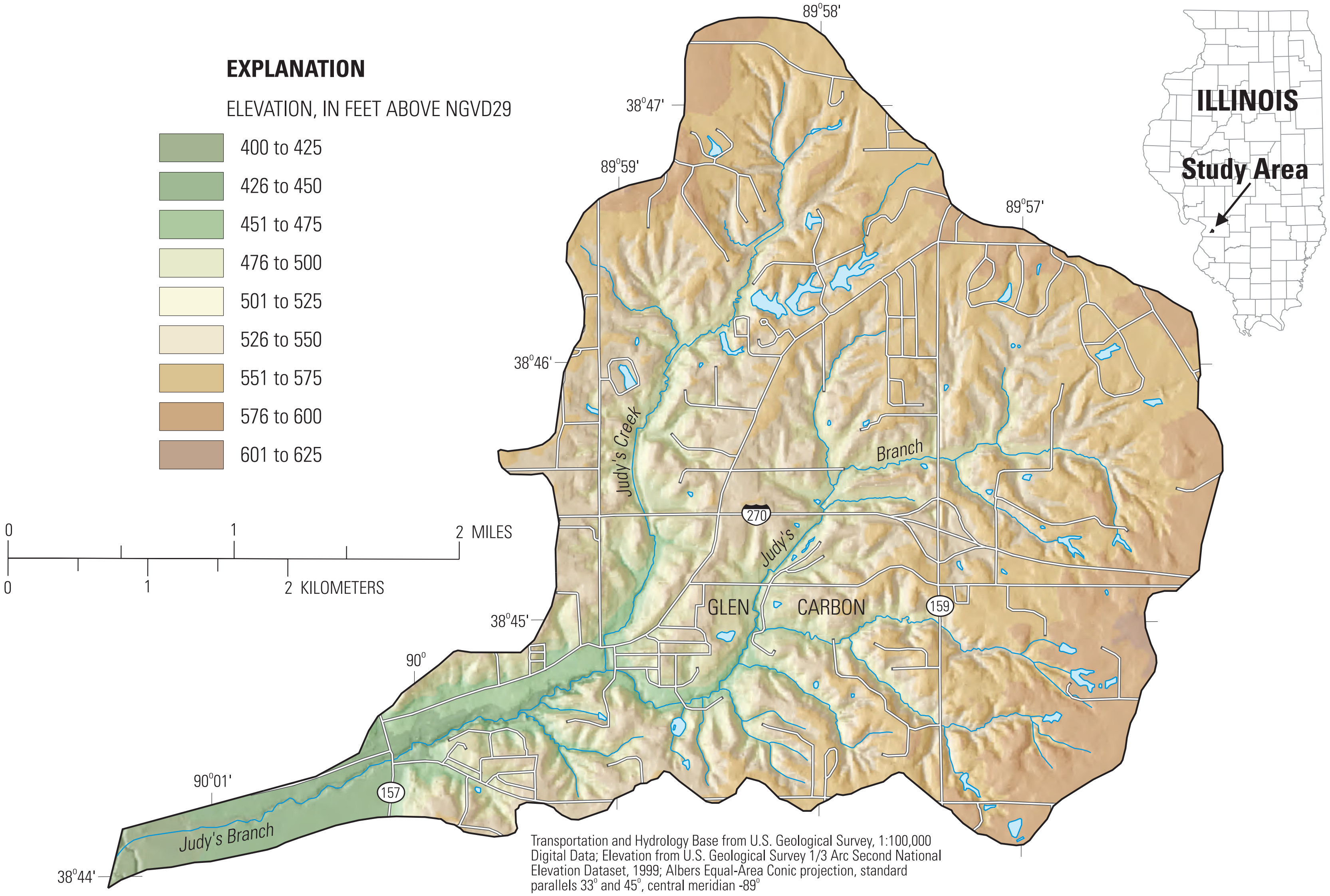

Figure 2. Judy's Branch watershed in the St. Louis Metro East region in Illinois.

Introduction

Judy's Branch[1] watershed, a small basin (8.64 mi^2) in the St. Louis Metro East region in Illinois, is affected by land-use changes in the bluffs draining to the American Bottoms (expansive low-lying valley floor in the region) (figs. 1 and 2). In the 1800s, much of the forest and prairie in the watershed, which includes the upland bluffs, was converted to agricultural land. Since the 1940's, urbanization in the uplands has caused increased streamflows to the river that can result in higher erosion rates. Erosion of the upland bluffs has resulted in the loss of private land, and deposition of sediment in the American Bottoms has resulted in increased flooding. The U.S. Army Corps of Engineers, St. Louis District (USACOE-STL) East St. Louis and Vicinity Ecosystem Restoration and Flood-Control Project has a goal to reduce sediment yield to the American Bottoms by 70 percent (U.S. Army Corps of Engineers, 2003a). In 2000, the U.S. Geological Survey, Illinois Water Science Center (USGS-IWSC); the Illinois Department of Natural Resources, Office of Water Resources (IDNR-OWR), and USACOE-STL began a cooperative investigation to analyze suspended-sediment yields and stream channel processes in Judy's Branch watershed. This information will be helpful to water-resource managers in analysis of river rehabilitation and watershed-management alternatives like those proposed in Watson and Eom (2003) to help control erosion in the upland bluffs. Methods and analyses of this study can potentially be applied to similar watersheds in the Midwest with bluffs and an extensive valley floor. Judy's Branch is similar to other bluff watersheds in the Mississippi and Illinois River watersheds and the data and analysis may be of benefit to regional and national studies by furthering the knowledge of hydrologic and sediment process in these type of watersheds. Minimal hydrologic and sediment data have been collected on small-scale watersheds such as Judy's Branch. The information from this study will help advance understanding of regional and temporal variations of suspended-sediment yield and stream-channel processes.

Purpose and Scope

Sediment and stream-channel data collected and analyzed for Judy's Branch watershed in the St. Louis Metro East region in Illinois are presented in this report to document a baseline of suspended-sediment yields and stream-channel processes that can be used by water-resource managers to evaluate future stream rehabilitation and management alternatives. The sediment-yield analysis determines the amount of sediment delivered from the watershed and two subwatersheds: an urban tributary and undeveloped headwater (primarily agricultural). The analysis of the subwatersheds is used to compare the effects of urbanization on sediment yield. The stream-channel contribution to sediment yield was determined by evaluation of the stream-channel processes operating on the streambed and banks of Judy's Branch watershed. Bank-stability conditions were related to hydrologic events, bank type, and channel geometry through model development and simulation. Precipitation, streamflow, and suspended-sediment data were analyzed on a yearly basis, with a year defined as July 1 through June 30.

[1] Spelled Judys Branch on some maps.

Description of the Study Area

The study area consists of two distinct topographic areas: a bluff region and the American Bottoms (figs. 1 and 2). The bluffs consist of hills shaped by streams incised into loess, alluvium, and stiff glacial till. The American Bottoms forms part of the Mississippi River flood plain, which contains many canals, lakes, and swamps with low relief. Judy's Branch flows into Cahokia Canal.

Geology

Knowledge of Quaternary geology and the depositional sequences underlying Judy's Branch watershed is crucial to understanding the interaction among sediment and stream-channel processes. Sediments in the St. Louis Metro East region were deposited primarily during the pre-Illinoian, Illinoian, and Wisconsinan glacial stages of the Pleistocene Epoch; and the Holocene Epoch, which are characterized by alluvial processes. The margins of glaciation and their location with respect to the St. Louis Metro East region are shown in figure 1. Further information on the geology and soil deposits is included in the following: the "Stream-Channel Processes" section of this report, Grimley (2000), Grimley and others (2001), and Willman and others (1975).

Dominant bank types for Judy's Branch watershed are as follows: 1) banks composed of alluvial soil deposits overlying stiff glacial soils (glacial till) with the presence or the absence of sand-and-gravel layers between the two deposits, with and without vegetative cover and trees; 2) banks composed of normally consolidated mixed colluvial and alluvial soils in which a glacial till soil horizon is buried; and 3) high loess cliffs (bluffs) and other bank types, such as shale and siltstone outcrops, and banks composed of fill material from past coal mining and urban development. Fill deposits from coal mines generally consist of silty sand-and-gravel with fragments of brick, wood, and other debris.

Alluvial Soil Deposits over Glacial Till

Alluvial soil deposits over stiff glacial till (fig. 3) may include sand-and-gravel layers between the alluvium and the glacial till. Vegetative cover, including trees, may be present. The alluvial soil deposits consist of normally consolidated, medium-to-soft clayey silt. Alluvial soils at Judy's Branch watershed generally contain approximately 30-percent clay and the rest silt, with trace amounts of sand (fig. 4) (methods for determining grain-size distributions are discussed

Figure 3. Typical bank type with cohesive alluvium, a thin alluvial sand lens, and glacial till at Judy's Branch watershed, in the St. Louis Metro East region in Illinois.

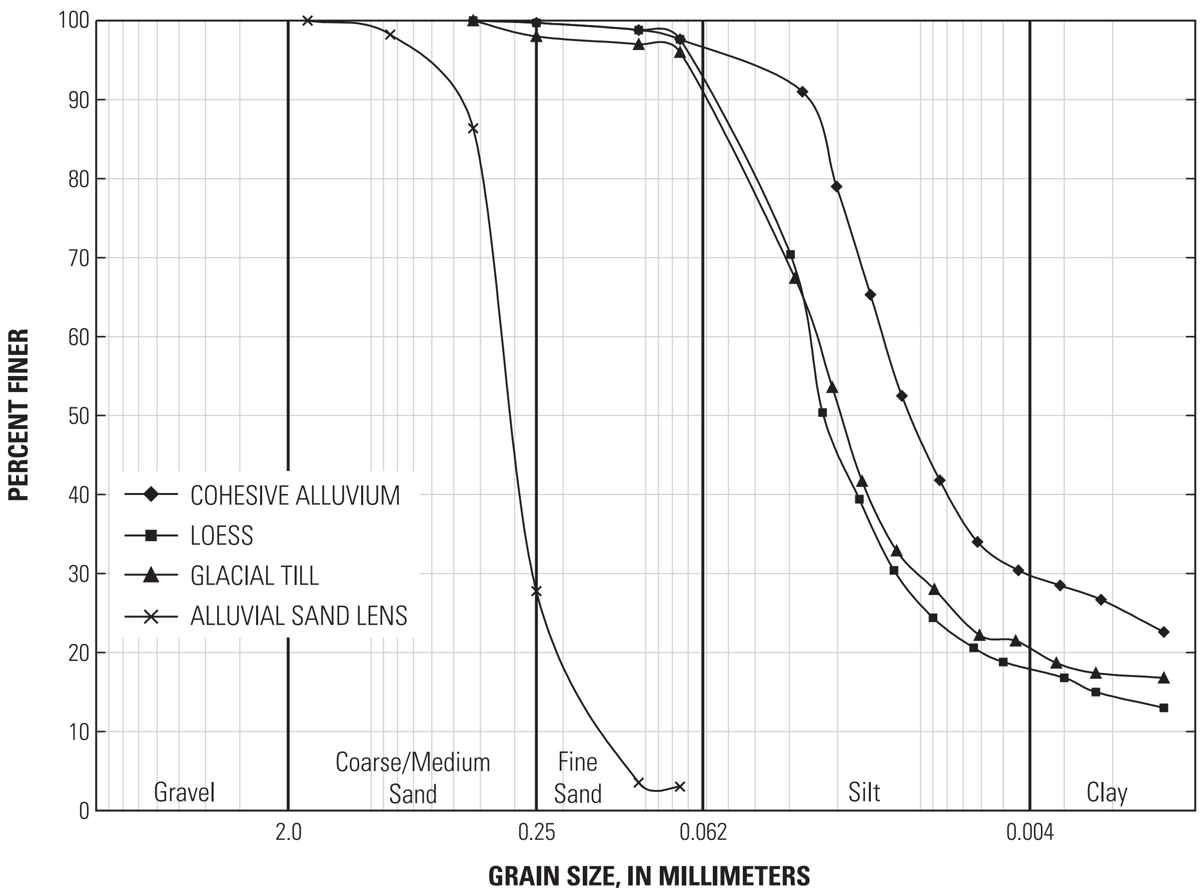

Figure 4. Grain-size distribution for different representative soils found in Judy's Branch watershed, in the St. Louis Metro East region in Illinois.

in the "Stream-Channel Processes" section of this report). Although the grain-size distributions for most of the samples collected are consistent with these percentages, some samples had substantially greater sand content. Sand-and-gravel layers within the alluvial soil deposits commonly occur at the interface between the clayey-silt alluvial deposits and the glacial till. Sand layers also are present within the alluvial stratigraphy and likely were deposited as bars.

Glacial till consistently crops out at the base of the banks and is sometimes found at mid-bank height. The glacial till strength probably varies with the amount of time exposed to water. Weathered till has soft-to-medium consistencies, whereas the intact till has stiff-to-hard consistencies. Glacial till has low clay content (20 percent), and most of the till consists of silt. The glacial till is similar to the loess (wind-blown silt) in terms of grain-size distribution (fig. 4). In some areas, the glacial till contains sand, gravel, and cobbles, but the subsample shown in figure 4 does not include particle sizes greater than 2 mm. Although the coarse material in the till constitutes a small proportion of the particle-size distribution, this material can be vital in distinguishing one deposit from another (Drew Phillips, Illinois State Geological Survey, written commun. 2002).

Colluvial Deposits

Colluvial deposits are generally loose soil material that accumulates at the base of a hill. The material is moved to the base of the hill by gravity in the form of bank failure or is washed downslope by rain. These deposits are of softer consistencies than the cohesive alluvial deposits. These deposits are usually clayey silt mixed with some sand and organic matter.

Loess Cliffs

Although loess deposits constitute most of the surficial materials of the Judy's Branch watershed and the upland bluffs of the St. Louis Metro East region, seldom do these deposits control bank stability and erosion of the streambanks. Loess cliffs generally are formed at appreciable distances away from streams.

Loess has a high strength when dry but low strength when wet. The decrease in strength results primarily because of the dissolution of the calcium carbonate that holds silt particles together. Also, the dry loess mass has a high magnitude of suction forces holding the silt together because of capillary effect (Terzaghi and others, 1996).

Climate

The study area has a temperate, humid, continental climate. Long-term daily climatic data are available for the National Oceanic and Atmospheric Administration (NOAA) station at Edwardsville, Ill, approximately 1.5 mi north of the study area. The average annual precipitation is 40.21 in. from calendar year 1971 through 2000. The average annual precipitation is 45.90 in. from July 2000 through June 2004 (table 1).

Streamflow

Knowing the properties of streamflow is important when quantifying sediment yields and stream-channel processes. Automated streamflow-gaging equipment and suspended-sediment samplers were installed at three stations in the watershed in June 2000 (table 2 and fig. 5). Measurements of discharge are made with current meters and acoustical flowmeters based on methods adapted by the USGS-IWSC. These methods and streamflow-computation methods are described in Rantz and others (1982), and Cutshaw and others (2004).

The mean daily streamflows for the study period (July 1, 2000, through June 30, 2004) and individual years are presented in table 3. The daily mean streamflow is the average of all the instantaneous flows (collected at 5-minute intervals for each station). These daily mean streamflows are then averaged over the time period of interest to obtain the mean daily streamflow. The mean daily streamflow for a given time period is useful in comparing

Table 1. Precipitation values at the National Oceanic and Atmospheric Administration (NOAA) station at Edwardsville, Illinois, July 2000 through June 2004.

Precipitation at Edwardsville, Illinois (inches)				
Average Annual July 2000-June 2004	Total July 2000-June 2001	Total July 2001-June 2002	Total July 2002-June 2003	Total July 2003-June 2004
45.90	45.19	57.23	34.16	47.03

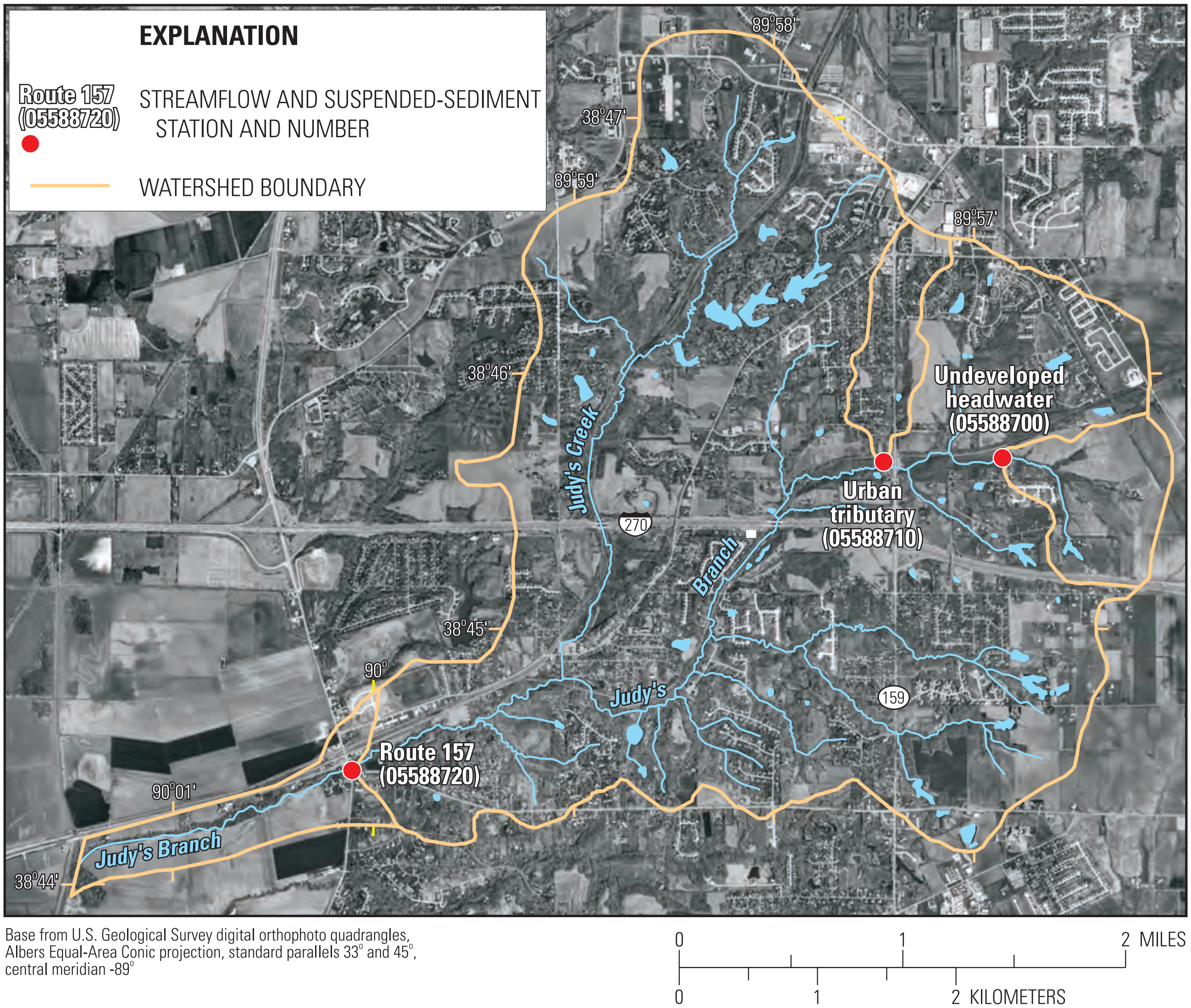

Figure 5. Location of streamflow and suspended-sediment stations in Judy's Branch watershed, in the St. Louis Metro East region in Illinois, and stream network used for analysis of bank-rod data.

Table 2. Streamflow and suspended-sediment stations used in the study and corresponding drainage areas, Judy's Branch watershed, in the St. Louis Metro East region in Illinois.

[mi², square miles]

Station (fig. 5)	Station Number	Drainage Area (mi²)
Urban tributary	05588710	0.23
Undeveloped headwater	05588700	.40
Route 157	05588720	8.33

Table 3. Mean daily flow for July 2000 through June 2004 and individual years at suspended-sediment stations in Judy's Branch watershed, in the St. Louis Metro East region in Illinois.

[ft^3/s, cubic feet per second]

	Mean Daily Flows (ft^3/s)				
Station (fig. 5)	**July 2000-June 2004**	**July 2000-June 2001**	**July 2001-June 2002**	**July 2002-June 2003**	**July 2003-June 2004**
Urban tributary	0.31	0.29	0.40	0.24	0.33
Undeveloped headwater	.40	.32	.59	.23	.48
Route 157	7.67	6.45	11.14	4.56	8.52

Table 4. Peak instantaneous streamflow for July 2000 through June 2004 and individual years for the Route 157 station, in Judy's Branch watershed, in the St. Louis Metro East region in Illinois.

[ft^3/s, cubic feet per second]

Time Period	Date	Time	Peak Streamflow (ft^3/s)
July 2000–June 2004	08-24-2001	2:25	2,540
July 2000–June 2001	07-18-2000	21:35	1,500
July 2001–June 2002	08-24-2001	3:00	2,540
July 2002–June 2003	06-26-2003	2:25	654
July 2003–June 2004	05-27-2004	20:10	1,700

Table 5. Peak instantaneous streamflow for July 2000 through June 2004 and individual years for the undeveloped headwater station, in Judy's Branch watershed, in the St. Louis Metro East region in Illinois.

[ft^3/s, cubic feet per second]

Time Period	Date	Time	Peak Streamflow (ft^3/s)
July 2000–June 2004	06-11-2002	15:45	155
July 2000–June 2001	07-18-2000	20:05	99
July 2001–June 2002	06-11-2002	15:45	155
July 2002–June 2003	06-10-2003	17:40	48
July 2003–June 2004	05-27-2004	18:20	107

Table 6. Peak instantaneous streamflow for July 2000 through June 2004 and individual years for the urban tributary station, in Judy's Branch watershed, in the St. Louis Metro East region in Illinois.

[ft^3/s, cubic feet per second]

Time Period	Date	Time	Peak Streamflow (ft^3/s)
July 2000–June 2004	06-11-2002	16:10	107
July 2000–June 2001	07-18-2000	20:30	58
July 2001–June 2002	06-11-2002	16:10	107
July 2002–June 2003	06-26-2003	:50	32
July 2003–June 2004	05-27-2004	19:35	52

the relative magnitudes of flow among other time periods of the same length. This comparison is important when determining the flows available for transporting sediment and affecting stream-channel processes.

The lowest mean daily flow during the study period occurred between July 2002 and June 2003. The highest mean daily flow during the study period occurred between July 2001 and June 2002 (table 3).

The peak-instantaneous streamflow for the study period and individual years are presented for each of the three stations in tables 4-6. The peak instantaneous streamflow when compared to the mean daily flow for a given time period can give an indication of the flashiness of the stream in the watershed. The term flashiness reflects the frequency and rapidity of changes in streamflow, especially during storm events (Baker and others, 2004). In other words, flashiness can indicate how the peak for a storm event compares to the average flow. The greater the discrepancy between the two values, the greater the flashiness of the stream. Also, as with the mean daily flows for a given time period, the peak streamflow is important when determining the flows available for transporting sediment and affecting stream-channel processes. The variation in peak streamflow and mean daily flow values is similar (tables 3-6).

Suspended-Sediment Yields

Suspended-sediment data are useful in quantifying the sediment yield from Judy's Branch watershed. The following sections describe suspended-sediment data collection and analysis.

Data Collection

At continuous-record sediment stations (table 2 and fig. 5), suspended-sediment concentrations were determined from samples collected with depth-integrating, isokinetic samplers at single-vertical locations, and/or with automatic water samplers collecting samples from a fixed point. Periodic cross sections are obtained at various verticals with depth-integrating, isokinetic samplers to compare to and adjust the single-vertical samples and/or the fixed point samples to compute the mean suspended-sediment concentration at the cross section.

Because of the small drainage areas of the data-collection sites, the hydrograph for storm events are relatively short duration (hours), and, therefore, logistically difficult to sample by USGS-IWSC personnel or local observers. Stage-weighted event, suspended-sediment samples were collected by electronically connecting the automatic suspended-sediment collector to the streamflow station. When possible, USGS-IWSC personnel collected depth-integrated samples using isokinetic samplers to compare and adjust the fixed-point samples to compute the mean suspended-sediment concentration at the cross section. All suspended-sediment samples were collected following protocols outlined in Edwards and Glysson (1999).

Analysis and Results

Methods used in the computation of sediment records are described in Guy (1970) and Porterfield (1972). During periods of rapidly changing flow, samples are collected more frequently (generally, multiple times on the rising and falling limbs of the storm hydrograph) (fig. 6). Certain streamflow conditions cause the shear stress to be higher on the rising limb than on the falling limb of the hydrograph, causing larger sediment transport on the rising limb than on the falling limb at a given flow depth (Julien, 2002). This pattern can be seen in Judy's Branch watershed at Route 157 (fig. 6). Also, as noted in the "Stream-Channel Processes" section, mass failures can occur on the falling limbs in flashy streams. The slump material may stay near the bank and then be transported downstream on the next rising limb of a storm, causing increased sedi-

Table 7. Streamflow and suspended-sediment concentrations for a storm event on July 19, 2001, at Route 157 on Judy's Branch watershed, in the St. Louis Metro East region in Illinois.

[ft^3/s, cubic feet per second; mg/L, milligrams per liter]

Time	Streamflow (ft^3/s)	Concentration (mg/L)	Sample Method
7:37	6.6	226	Estimated Sample
8:17	93	2,120	Estimated Sample
8:46	267	3,330	Estimated Sample
9:11	503	5,800	Automatic Sample
9:27	583	13,200	Depth-Integrated Sample
9:48	574	6,680	Automatic Sample
10:33	371	1,640	Automatic Sample
11:17	382	1,800	Automatic Sample
11:31	480	7,530	Automatic Sample
11:42	578	9,990	Depth-Integrated Sample
12:03	731	16,200	Automatic Sample
13:50	389	4,500	Estimated Sample
17:46	119	872	Estimated Sample
22:34	39	450	Estimated Sample

ment concentrations on the rising limb as compared to the falling limb. Also, during low-flow periods, sediment can be deposited in the river channel and then again be transported during the rising limb of the next storm. Lastly, the higher of the two flood peaks has higher resulting sediment concentration (fig. 6 and table 7). In general, the higher the flood peak, the higher the peak sediment concentration at a given location.

The computed sediment discharges for days of rapidly changing flow or concentration were computed by the subdivided-day method (time-discharge weighted average) (Guy, 1970 and Porterfield, 1972). Therefore, for those days when the published sediment discharge value differs from the value computed as streamflow (ft^3/s) times mean suspended-sediment concentration (mg/L) times 0.0027 (conversion factor to tons/day), the sediment discharge for that day was computed by the subdivided-day method. For periods when no samples were collected, daily discharges of suspended sediment were estimated on the basis of streamflow, suspended-sediment concentrations observed immediately before and after the periods, and suspended-sediment concentrations for other periods of similar streamflow. The sediment load for a given day was calculated by the product of the sediment discharge and 1 day. The daily suspended-sediment loads from July 1 through June 30 of the following year were then summed and divided by the number of days in a year and by the drainage area of the watershed to obtain the suspended-sediment yield (table 8).

The suspended-sediment yield from the undeveloped headwater and urban tributary were 1,204 and 1,122 tons per square mile ($tons/mi^2$-year) (table 8) for the study period. Suspended-sediment yields from a fully developed urban watershed are expected to be less than that of an undeveloped watershed given less source of sediment supply in an urban environment (Wolman, 1967) (assuming the stream channel is not of an appreciable size or substantially eroding). Note that for the first 3 years of the study, the urban tributary had a higher suspended-sediment yield than the undeveloped headwater. The suspended-sediment yield from the

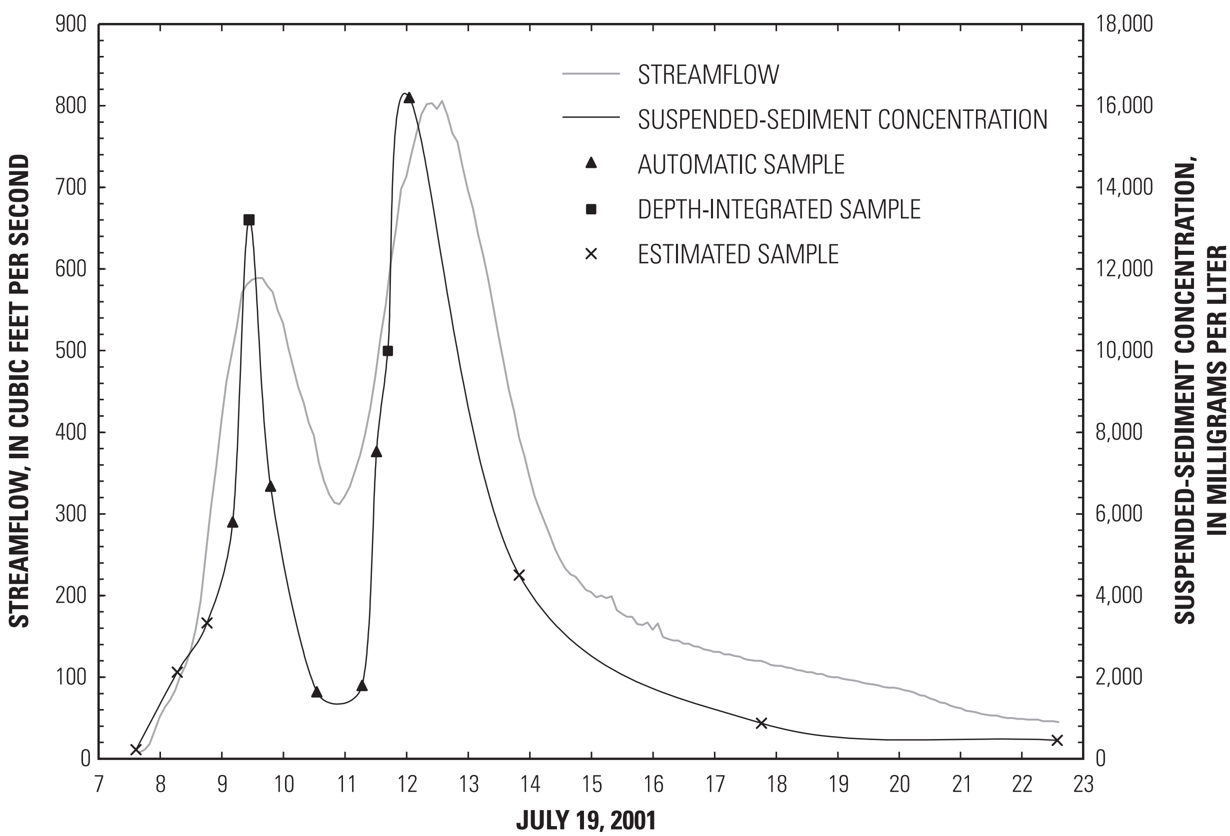

Figure 6. Streamflow and suspended-sediment concentrations for a storm event on July 19, 2001, at Route 157 on Judy's Branch watershed, in the St. Louis Metro East region in Illinois

urban tributary may have been less if it were not for demolition and reconstruction of a substantial number of buildings in the watershed that increased the amount of exposed soil surface available for erosion. Building demolition and reconstruction was essentially complete before the fourth year (July 2003 through June 2004) of data collection.

The suspended-sediment yield at the Route 157 station (2,523 tons/mi^2-year) is approximately 1,360 tons/mi^2-year larger than the average of the urban tributary and undeveloped headwater suspended-sediment yields. This result is unexpected in that, generally, the suspended-sediment yield decreases as the watershed area increases because of sediment being stored in the channel and flood plain. In general, the sediment-delivery ratio decreases primarily with the size of drainage area (Julien, 2002). The sediment-delivery ratio is defined as the ratio of sediment yield and gross erosion on a watershed. The gross erosion amounts to the sum of the upland and channel erosion in a watershed (Julien, 2002). The increase in suspended-sediment yield seen in Judy's Branch watershed indicates a possible increase in yield from a source, such as bank retreat, and supports the concept of the land-use changes causing increased streamflows that may result in higher rates of bank retreat. Stream-channel processes like bank retreat will be presented in the "Stream-Channel Processes" section and then compared to the suspended-sediment yields.

Stream-Channel Processes

Understanding the stream-channel processes operating on the streambed and banks of Judy's Branch watershed can help determine the stream-channel contribution to sediment yield. In this study, bank retreat, streambed incision (lowering of the streambed elevation), and channel deposition (material filling any portion of the channel) were considered.

Given that bank retreat can be a substantial portion of the sediment yield in a watershed, understanding bank-stability processes that lead to bank failure by mass wasting (collapse of all or part of the bank in mass) is important. Bank stability can be simulated by computing the ratio of the shear strength (resisting force) along a failure surface and the shear stress (driving gravitational force). Bank-stability conditions were related to hydrologic events, bank type, and channel geometry through model development and simulation.

Data Collection

To determine the sediment yield from bank retreat in Judy's Branch watershed, bank rods were installed at 28 locations (fig. 7 and table 9). Steel rods driven horizontally into the river banks are measured from the end of the rod to the bank regularly and after large storm events (near or greater than the bankfull flow). Also, IDNR-OWR personnel have surveyed the majority of the stream channel and surrounding flood plain at approximately 300- to 500-ft intervals. Twenty-seven of the cross sections are used in this study, including 16 that have been surveyed twice and, therefore, are referred to as resurveyed cross sections (figs. 7 and 8, and tables 9 and 10).

The grain-size distribution data for the streambed samples are presented in appendix A. The streambed samples were not analyzed for this study, but may be useful for studies concerning sediment-transport modeling and stream rehabilitation such as Watson and Eom (2003).

Bank-stability data were collected by way of field visits, exploratory soil borings, in-situ tests, laboratory tests, and visual classification of samples obtained from both the borings and directly from the banks. A Geoprobe model 5400 was used to obtain continuous soil borings at six locations (fig. 9) with depths ranging from 20 to 24 ft below ground surface (appendixes B and C). Bank samples were taken at various locations from the different bank types (appendix C).

Analysis and Results

Bank retreat is composed of two components: bank erosion by hydraulic shear and bank failure by mass wasting. Bank erosion is the detachment, entrainment, and removal of bank material as individual grains or aggregates by fluvial and sub-aerial processes (Thorne and others, 1997). Bank failure is the collapse of all or part of the bank in mass, in response to bank instability processes (Thorne and others, 1997). In this study, stream-channel processes are considered as a combination of bank retreat, streambed incision (lowering of the streambed elevation), and channel deposition (material filling any portion of the channel).

The maximum bank and streambed movement for the time period were determined at each resurveyed cross section (table 10). Also, at all 27 cross sections, the bank height and angle were determined (table 9). Photos of bank retreat through time for BR104_204 (see fig. 7 for location) are shown in figure 10. The initial bank geometry (June 2, 2000)

Table 8. Sediment yield for July 2000 through June 2004 and individual years for each station, in Judy's Branch watershed, in the St. Louis Metro East region in Illinois.

[tons/mi^2-year, tons per square mile per year]

Station (fig. 5)	Station Number	Sediment Yield (tons/mi^2-year) 07/2000–06/2004	07/2000–06/2001	07/2001–06/2002	07/2002–06/2003	07/2003–06/2004
Urban tributary	05588710	1,122	1,202	1,526	521	1,239
Undeveloped headwater	05588700	1,204	996	1,519	443	1,860
Route 157	05588720	2,523	1,709	4,872	637	2,875

Table 9. Cross-section information near bank rods in Judy's Branch watershed, in the St. Louis Metro East region in Illinois. Cross-section and bank-rod locations are shown in figure 7.

[ft, feet; deg, degrees; ---, no data]

Cross Section	Cross-Section Map Number	Nearest Bank Rod Map Number	Distance from Cross Section, (ft)	Bank Rod Installed on	Right Bank Height (ft)	Right Bank Base (ft)	Right Bank Angle (deg)	Left Bank Height (ft)	Left Bank Base (ft)	Left Bank Angle (deg)	First Survey Date	Second Survey Date
7+41.74 (4) Ditch	xs1	---	---	---	19.9	41.0	25.8	10.5	21.9	25.7	10/1997	04/04/2002
7+41.74 (4)	xs2	---	---	---	9.5	11.7	38.9	8.8	9.3	43.5	10/1997	04/04/2002
188+43.73 (36)	xs3	BR101	116 upstream	Left Bank	13.3	25.7	27.3	12.1	26.4	24.6	10/1997	06/10/2002
182+94.9	xs4	BR102	235 upstream	Left Bank	10.9	11.3	43.9	11.7	10.7	47.7	10/1997	04/04/2002
149+75.01(30)	xs5	BR103_203	185 downstream	Left Bank	12.4	17.5	35.3	12.9	3.1	76.5	10/1997	06/10/2002
2+76.48 (41)	xs6	BR104_204	278 downstream	Right Bank	12.9	15.9	38.9	10.7	49.1	12.3	01/1999	04/04/2002
2+76.48 (41)*	xs6*	BR105_205	42 downstream	Right Bank	12.9	15.9	38.9	10.7	49.1	12.3	01/1999	04/04/2002
14+56.18 (46)	xs7	BR199	160 downstream	Right Bank	14.1	13.2	47.1	10.4	19.2	28.5	01/1999	04/04/2002
28+30.53 (53)	xs8	BR106	50 downstream	Right Bank	14.5	13.0	48.1	9.4	48.0	11.0	01/1999	04/04/2002
32+27.09 (54)	xs9	BR106	465 downstream	Right Bank	14.1	23.8	30.6	11.7	18.0	33.0	01/1999	04/04/2002
32+27.09 (54) (219)	xs10	BR106	714 downstream	Right Bank	4.0	7.9	26.6	7.4	7.9	43.0	01/1999	04/04/2002
---	---	BR107_108	---	---	---	---	---	---	---	---	---	---
44+56.34 (60)	xs11	BR109	9 downstream	Right Bank	6.7	10.1	33.6	5.6	6.5	40.6	01/1999	04/04/2002
48+35.80 (62)	xs12	BR110	110 downstream	Right Bank	17.0	20.2	40.2	9.2	28.0	18.1	01/1999	04/04/2002
67+32.55 (72)	xs13	BR111_211	71 downstream	Right Bank	7.3	9.6	37.2	8.9	31.3	15.9	01/1999	04/04/2002
92+80.74 (86)	xs14	BR125	20 downstream	Left Bank	6.8	8.0	40.5	6.9	4.7	55.7	01/1999	04/04/2002
110+90.47 (94)	xs15	BR112	102 downstream	Left Bank	13.1	26.8	26.0	12.5	17.5	35.6	01/1999	04/04/2002
119+59.70 (99)	xs16	BR113	126 downstream	Right Bank	7.9	17.9	23.7	10.7	8.0	53.3	01/1999	04/04/2002
17+46.12 A (6600)	xs17	BR114	181 downstream	Left Bank	4.8	2.3	64.4	5.7	9.7	30.4	08/2000	---
35+40.44 A (15100)	xs18	BR115	12 downstream	Left Bank	5.5	14.1	21.4	6.9	6.3	47.4	08/2000	---
35+40.44 A (15101)	xs19	BR116	35 downstream	Left Bank	5.0	5.8	40.7	6.8	6.8	45.0	08/2000	---
47+26.94 A (158)	xs20	BR117_217	23 upstream	Left Bank	7.3	12.3	30.6	13.5	13.5	45.1	08/2000	---
66+00.18 A (17903)	xs21	BR118	123 upstream	Left Bank	2.9	2.0	55.3	5.3	7.8	34.1	08/2000	---
66+00.18 A (17903)	xs21	BR126	143 downstream	Right Bank	2.9	2.0	55.3	5.3	7.8	34.1	08/2000	---
14+52.13 Tr114(287)	xs22	BR119	15 upstream	Right Bank	5.4	3.1	60.2	9.2	14.3	32.7	02/1999	---
14+52.13 Tr114(77)	xs23	BR120	7 upstream	Right Bank	9.0	6.3	54.9	7.1	19.9	19.6	02/1999	---
24+01.22 Tr (118)	xs24	BR121	5 downstream	Left Bank	5.6	3.8	56.0	7.5	19.9	20.6	02/1999	---
28+49.44 Tr (120)	xs25	BR122	46 downstream	Left Bank	5.4	4.6	49.7	9.9	16.3	31.2	02/1999	---
30+14.24 Tr (211)	xs26	BR123	5 upstream	Left Bank	6.1	4.7	52.5	2.6	4.8	28.0	02/2002	---
34+63.10 Tr A (212)	xs27	BR124	286 downstream	Left Bank	10.8	7.4	55.6	4.1	7.4	29.0	02/2002	---

*Cross section listed twice because it is nearest to two sets of bank rods.

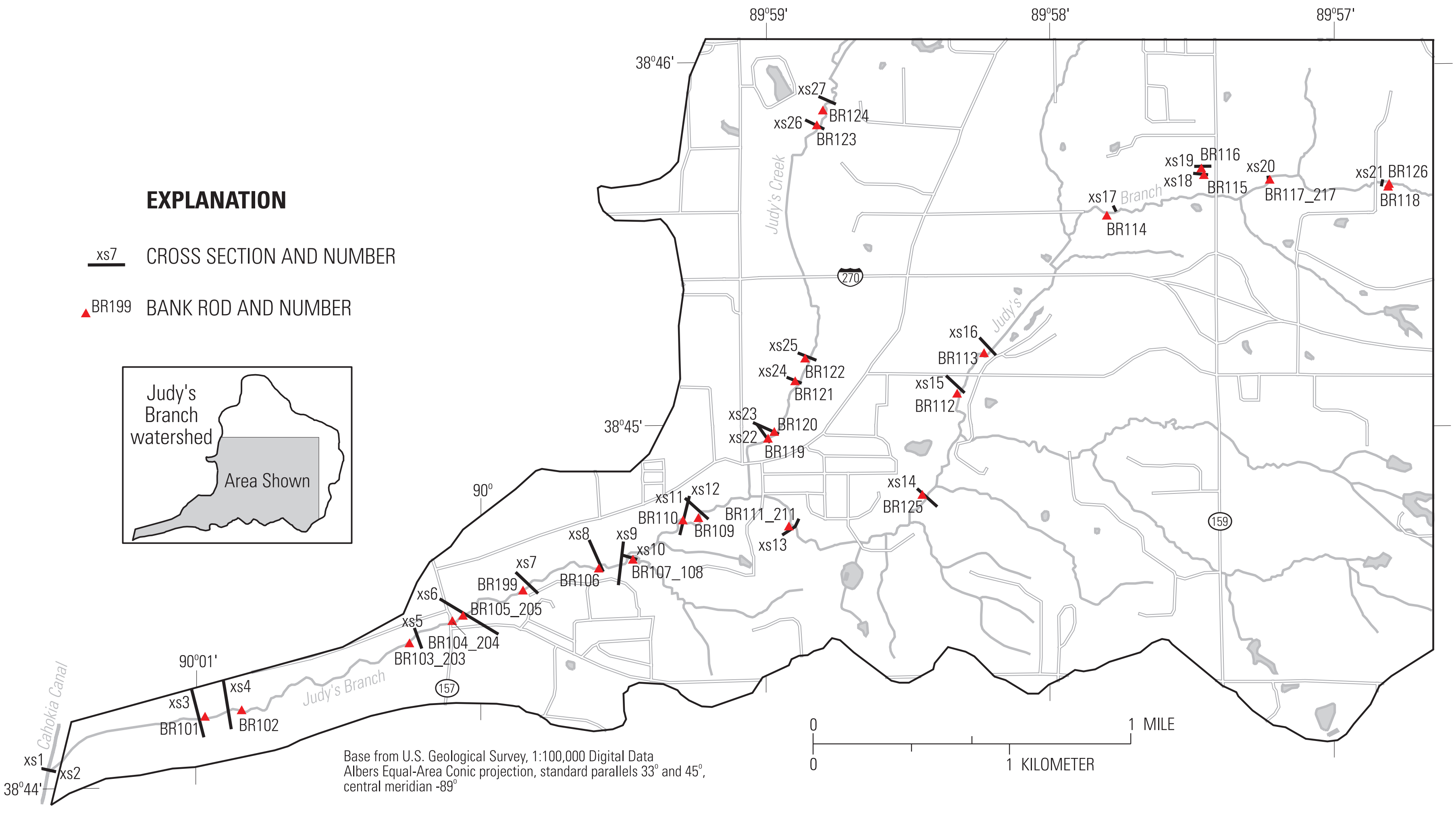

Figure 7. Location of cross sections and bank rods for Judy's Branch watershed, in the St. Louis Metro East region in Illinois.

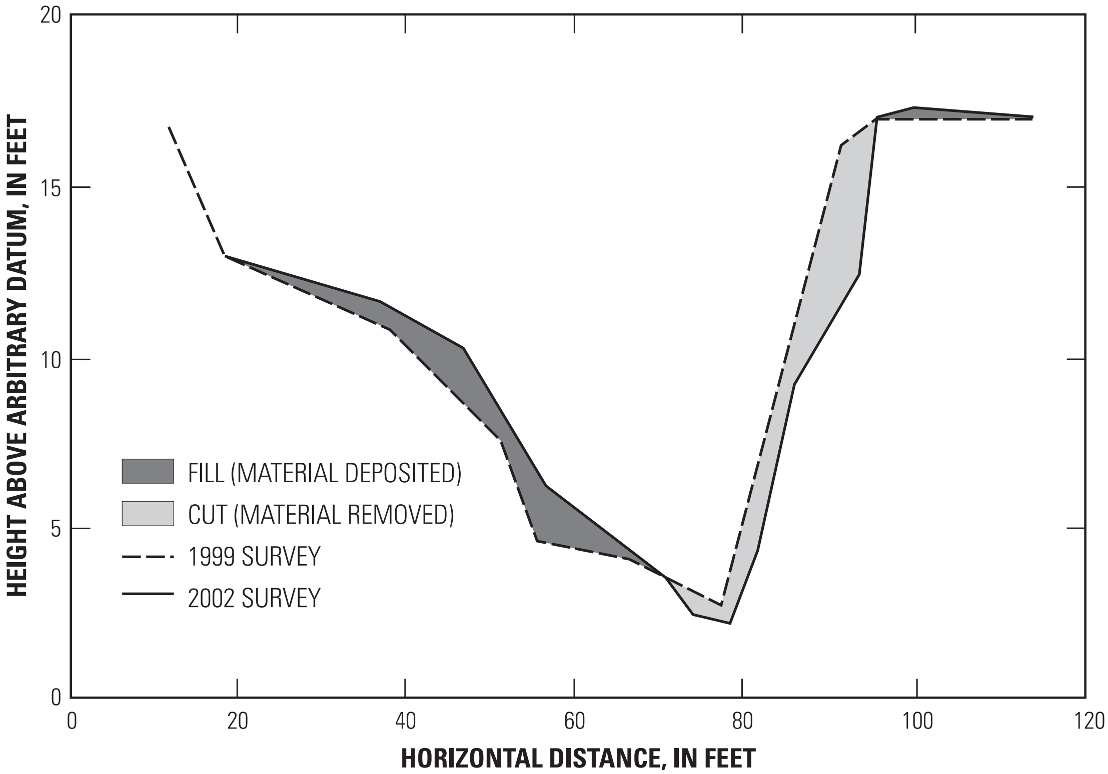

Figure 8. Example of survey data including cut and fill indicators at xs8 (fig. 7, and tables 9 and 10) in Judy's Branch watershed, in the St. Louis Metro East region in Illinois. Vertical scale is exaggerated four times that of the horizontal scale.

Table 10. Stream-channel changes at resurveyed cross sections in Judy's Branch watershed, in the St. Louis Metro East region in Illinois. Cross-section locations are shown in figure 7.

[Negative values for bank retreat and fill minus cut indicate material removed; positive values for bank retreat and fill minus cut indicate materials deposited; Max., maximum; ft², square feet; ft, feet; Elev., elevation; ---, not applicable].

Cross Section	Cross-Section Map Number	Cut (ft²)	Fill (ft²)	Fill minus Cut (ft²)	Streambed Max. Elev. Change (ft)	Maximum Right Bank Retreat (ft)	Maximum Left Bank Retreat (ft)	Reach Characteristic	Comment
7+41.74 (4) Ditch	xs1	0.0	143.8	143.8	1.1	3.3	10.1	Straight	
7+41.74 (4)	xs2	31.6	19.4	-12.2	.0	-5.1	2.3	Straight	
188+43.73 (36)	xs3	321.4	28.5	-293.0	-1.1	4.1	-24.4	Straight	Debris Jam
182+94.9	xs4	23.6	14.2	-9.4	-.7	1.3	-1.3	Straight	
149+75.01(30)	xs5	15.9	3.3	-12.6	-.3	-1.3	.9	Straight	
2+76.48 (41)	xs6	42.7	47.0	4.3	-.2	-2.9	7.1	Meandering	
2+76.48 (41)	xs6	42.7	47.0	4.3	-.2	-2.9	7.1	Meandering	
14+56.18 (46)	xs7	40.9	41.7	.8	1.3	-2.5	2.9	Meandering	
28+30.53 (53)	xs8	53.4	41.5	-12.0	-.7	-6.9	6.8	Meandering	
32+27.09 (54)	xs9	42.0	51.2	9.2	-.6	-1.4	-3.2	Straight	
32+27.09 (54) (219)	xs10	42.9	31.4	-11.6	-.3	4.1	-2.4	Meandering	
44+56.34 (60)	xs11	.2	5.5	5.3	-.3	-1.2	-3.4	Straight	
48+35.80 (62)	xs12	91.4	13.4	-78.0	-.1	-3.3	-6.3	Meandering	Old Mass Failure Eroding on Left
67+32.55 (72)	xs13	20.0	25.2	5.2	.0	-2.6	2.6	Straight	
92+80.74 (86)	xs14	25.5	26.9	1.4	.0	5.5	-1.3	Meandering	
110+90.47 (94)	xs15	13.5	5.1	-8.4	-.1	-1.0	-1.1	Straight	
119+59.70 (99)	xs16	89.8	2.4	-87.4	-1.0	-3.5	-7.5	Straight	Root Wad
Total	---	897.5	547.5	-350.3	---	---	---	---	---

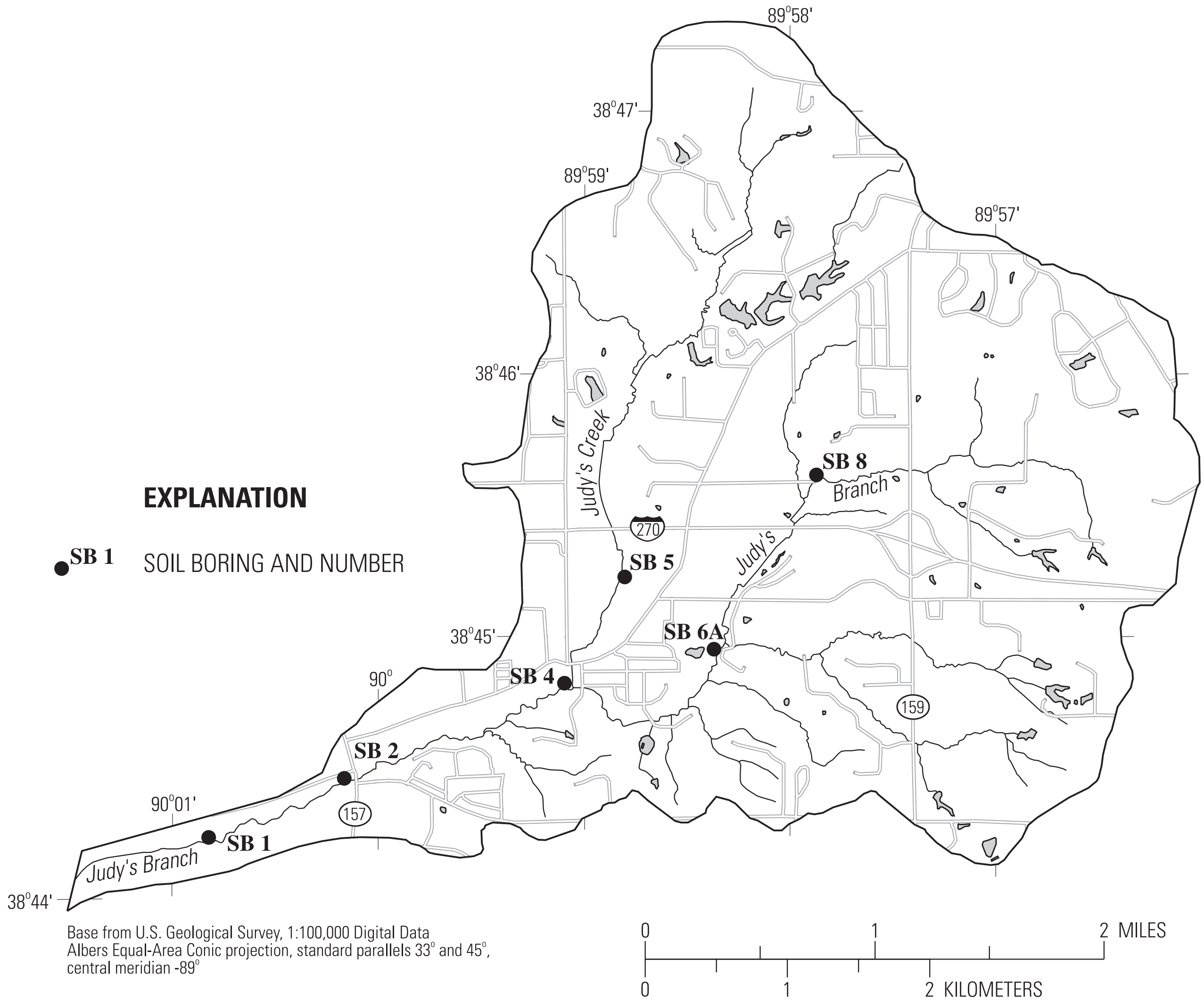

Figure 9. Location of soil borings in Judy's Branch watershed, in the St. Louis Metro East region in Illinois.

is steeper than 70 degrees and higher than from 10 to 11.5 ft. These values are the criteria for the banks to become unstable as noted in the "Model Simulation" section. Although, for example, the cross section (xs6) nearest BR104_204 (fig. 7 and table 9) indicate that the bank angles are 47.7 and 38.9 degrees. The geometry of xs6 is nearly 280 ft upstream of BR104_204 and is not representative of the banks at the bank rod. Of the 27 cross sections nearest the bank rods, only one has a bank angle greater than 70 degrees (table 9).

High maximum bank retreat on the left bank is indicated on cross-sections xs3, xs12, and xs16 (table 10). These changes result from either tree jams or apparent erosion of a previous bank failure. Also, high maximum bank retreat on the right bank is evident in cross-section xs8 (fig. 8), but an equal amount of deposition on the left bank may indicate that the retreat results from lateral migration and hydraulic shear as opposed to bank instability. Many of the resurveyed cross sections have similar properties. The maximum streambed elevation changes range from –1.1 ft (material removed) to 1.3 ft (material deposited). These changes do not represent substantial movement (usually characterized by multiple feet of movement), but monitoring of streambed-elevation changes is critical in determining bank stability.

Bank Rod

The bank-retreat values from the bank-rod locations (fig. 11 and table 11) were annualized by dividing by the years of data collected. After a detailed stream reconnaissance, the annual bank-retreat value at each bank-rod location was assigned to a representative stream reach (fig. 12). Note that

June 2, 2000–note tree in upper right-hand corner of photo.

August 3, 2000–close up of bank retreat that occurred below the tree.

August 29, 2001–bank retreat causes the tree to start to lean.

June 21, 2002–close up of bank retreat and tree beginning to slide down the bank.

February 20, 2003–bank retreat with with additional sliding.

April 12, 2004–bank retreat at base of bank.

Figure 10. Bank retreat through time for BR104_204 in Judy's Branch, in the St. Louis Metro East region in Illinois. View looking downstream towards the Route 157 bridge that can be seen in the background. Photo on June 2, 2000, was taken by U.S. Geological Survey volunteer Dave Straub.

physical variation is present that cannot be represented with this methodology, but more detailed bank-rod monitoring was beyond the scope of the study. To obtain the annual volume of sediment contributing from the reach, the annual bank-retreat value is multiplied by the reach length and the average bank height at approximately the 1.5-year flow event. This annual volume is converted to sediment load by multiplying it by an approximate unit-weight of soil (115 lbs/ft^3, reference discussion and data for soil borings in the "Bank Stability" section and appendix B, respectively) and then converted to tons (units used in the annual suspended-sediment load calculations). The annual sediment load is then divided by the stream miles to obtain sediment yield per linear increment (table 12).

Sediment yield calculated using bank-rod data equals 1,354 tons/mi-year (table 12) for the stream reach analyzed upstream of Route 157 (8.33 mi of stream–blue, green, orange, and red highlighted lines in figure 12). The bank-rod data were adjusted to the full stream network upstream of Route 157 (20.2 mi of stream – dark black stream line in figure 12), after the values were adjusted using the resurveyed data (discussed in the "Bank-Retreat Sediment Yield" section).

Cross Section

At each of the 17 resurveyed cross sections (table 10), the cut (material removed) and fill (material deposited) were determined (fig. 8 and table 10). This area was annualized by dividing by the number of years between the survey dates (fig. 13 and table 11). Note that xs1 is in Cahokia Canal, which is outside of Judy's Branch watershed. Results at Cahokia Canal are not used to determine bank-retreat sediment yield in this study, but indicate that fill may be coming from sediments in other bluff watersheds like Judy's Branch watershed.

Table 11. Bank-retreat data from bank rods in Judy's Branch watershed, in the St. Louis Metro East region in Illinois. Bank-rod locations are shown in figure 7.

		Bank Retreat as of July 05, 2004 (feet)	
Bank Rod	Installation Date	Total	Annual
BR101	June 1, 2000	2.07	0.51
BR102	June 1, 2000	12.12	2.97
BR103_203	June 1, 2000	.41	.10
BR104_204	June 1, 2000	8.40	2.06
BR105_205	June 1, 2000	2.30	.56
BR106	June 1, 2000	8.22	2.01
BR107	June 1, 2000	4.37	1.07
BR108	June 1, 2000	4.77	1.17
BR109	June 1, 2000	.67	.16
BR110	June 1, 2000	1.28	.31
BR111_211	June 1, 2000	2.12	.52
BR112	June 1, 2000	.92	.23
BR113	June 1, 2000	5.82	1.43
BR114_214	June 1, 2000	1.81	.44
BR115	June 1, 2000	1.45	.36
BR116	June 1, 2000	1.75	.43
BR117_217	June 1, 2000	2.35	.57
BR118	June 1, 2000	2.32	.57
BR119	June 1, 2000	3.47	.85
BR120	June 1, 2000	.77	.19
BR121	June 1, 2000	.52	.13
BR122	June 1, 2000	.97	.24
BR123	June 1, 2000	2.27	.56
BR124	June 1, 2000	9.54	2.34
BR125	November 21, 2000	3.75	1.03
BR199	November 21, 2000	9.15	2.52
BR126	March 7, 2002	1.25	.54

The annual area of cut or fill then was assigned to a representative reach (fig. 14). Note that physical variation is present that cannot be represented with this methodology, but more detailed cross-section resurveying was beyond the scope of the study. The annual area was converted to sediment load by multiplying it by the length of the reach and an average unit-weight of soil (115 lbs/ft^3) and then converted to tons (units used in the annual suspended-sediment load and bank-retreat calculations). The annual sediment load is then divided by the stream miles to obtain sediment yield per linear increment (table 12). Sediment yield calculated using cross-section data equals 652 tons/mi-year (table 12) for the stream reach analyzed upstream of Route 157 (4.45 mi of stream–red, orange, and green highlighted lines in figure 14).

Bank-Retreat Sediment Yield

Suspended-sediment yield at Route 157 was 2,523 tons/mi^2-year (fig. 15 and table 8). It is assumed that 1,163 tons/mi^2-year of the suspended-sediment yield (average of the urban tributary and undeveloped headwater) comes from smaller watersheds within Judy's Branch watershed with negligible stream channels (in other words, the sediment sources are overland and gully). This assumption leaves a minimum of 1,360 tons/mi^2-year that must come from others sources in the watershed such as bank retreat.

Bank-retreat sediment yield, estimated with bank-rod data, was 1,354 tons/mi-year for 8.33 mi of stream-channel length (assuming none of the sediment is stored in the channel). There are 20.2 mi of stream-channel length, upstream of Route 157.

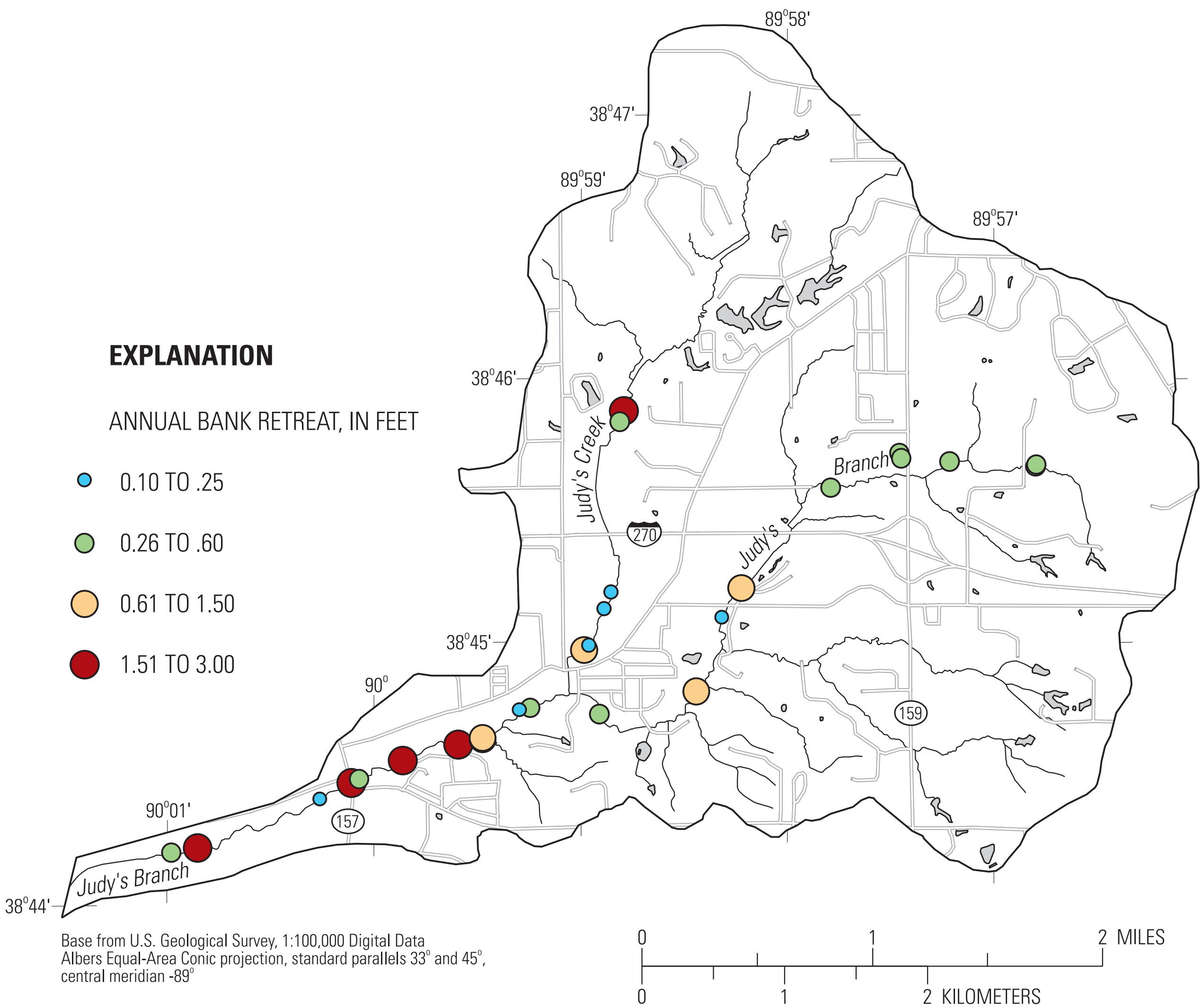

Figure 11. Annual bank-retreat values from bank rods in Judy's Branch watershed, in the St. Louis Metro East region in Illinois.

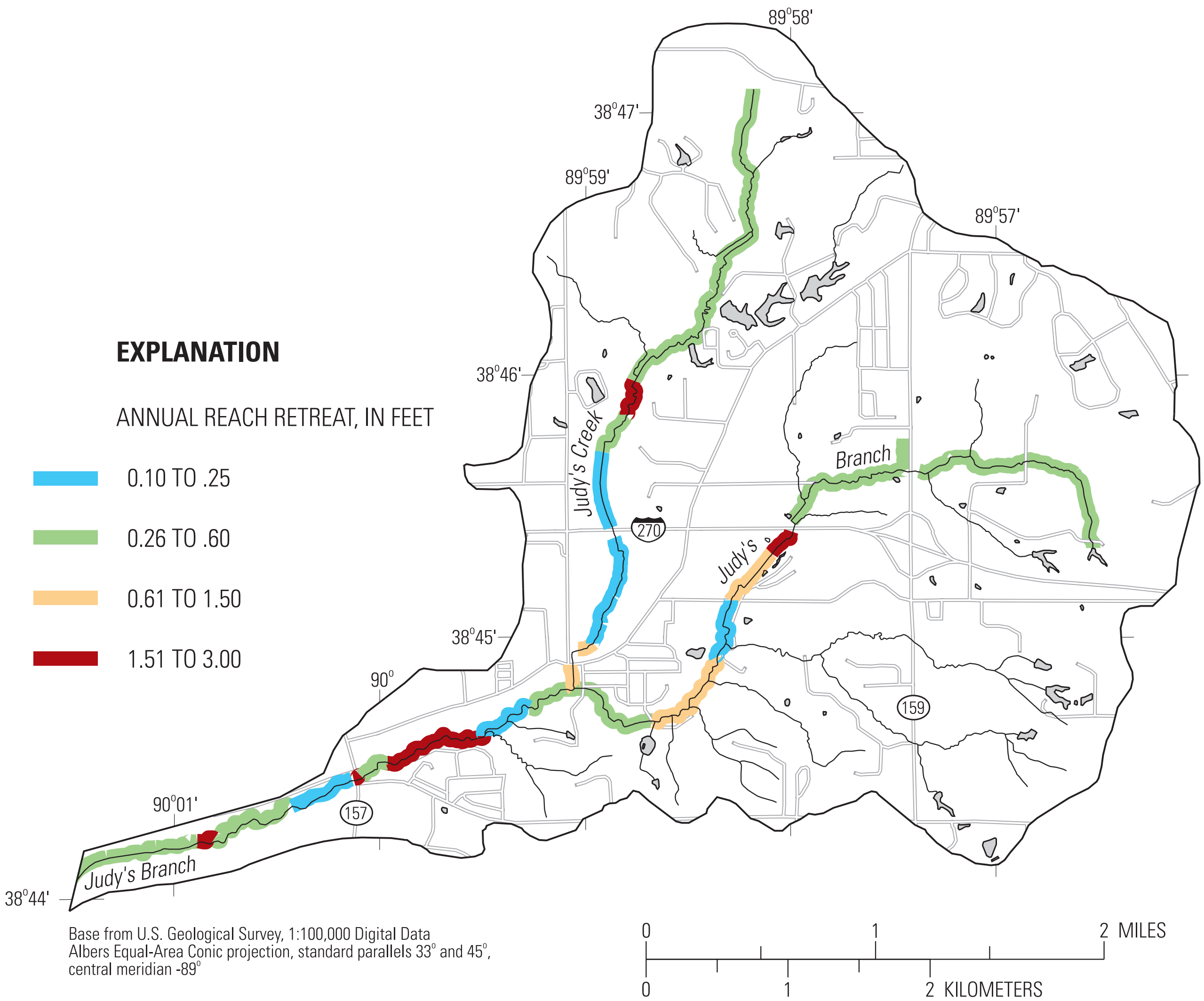

Figure 12. Annual estimated reach-retreat values from bank rods in Judy's Branch watershed, in the St. Louis Metro East region in Illinois. Gaps represent riprap reaches.

Table 12. Sediment-yield results for different types of data for Judy's Branch watershed, in the St. Louis Metro East region in Illinois.

[tons/mi-year, tons per mile per year]

Type	Sediment Yield (tons/mi-year)	Length of Stream Reach (miles)
	U.S. Geological Survey	
Bank-Retreat Rods (6/2000-7/2004)		
Bank-Rod Data to Route 157	1,354	8.33
Bank-Rod Data to mouth	1,413	8.64
	Illinois Department of Natural Resources	
Cross-section Resurvey Data (10/1997–6/2002 and 1/1999–6/2002)	652	4.45

Multiplying 1,354 tons/mi-year times 20.2 mi and then dividing by the drainage area (8.33 mi^2) results in 3,283 tons/mi^2-year. From resurveyed cross-section data (table 10), it can be roughly estimated that for every ton of material removed from the channel, 0.61 ton is stored in the channel. The exact percentages of stored sediment from bank retreat, upland, and gully erosion are not known. To obtain the lowest estimate of bank-retreat sediment yield, it is assumed that all the stored sediment is from bank retreat. Multiplying 3,283 tons/mi^2-year by 0.39 gives a sediment yield of 1,280 tons/mi^2-year from bank retreat (fig. 15).

Based on the discussion above, approximately half of the suspended-sediment yield at Route 157 during July 2000-June 2004 came from bank retreat. The percentage from bank retreat probably would slightly increase if the amounts from each source that were stored in the channel could be determined.

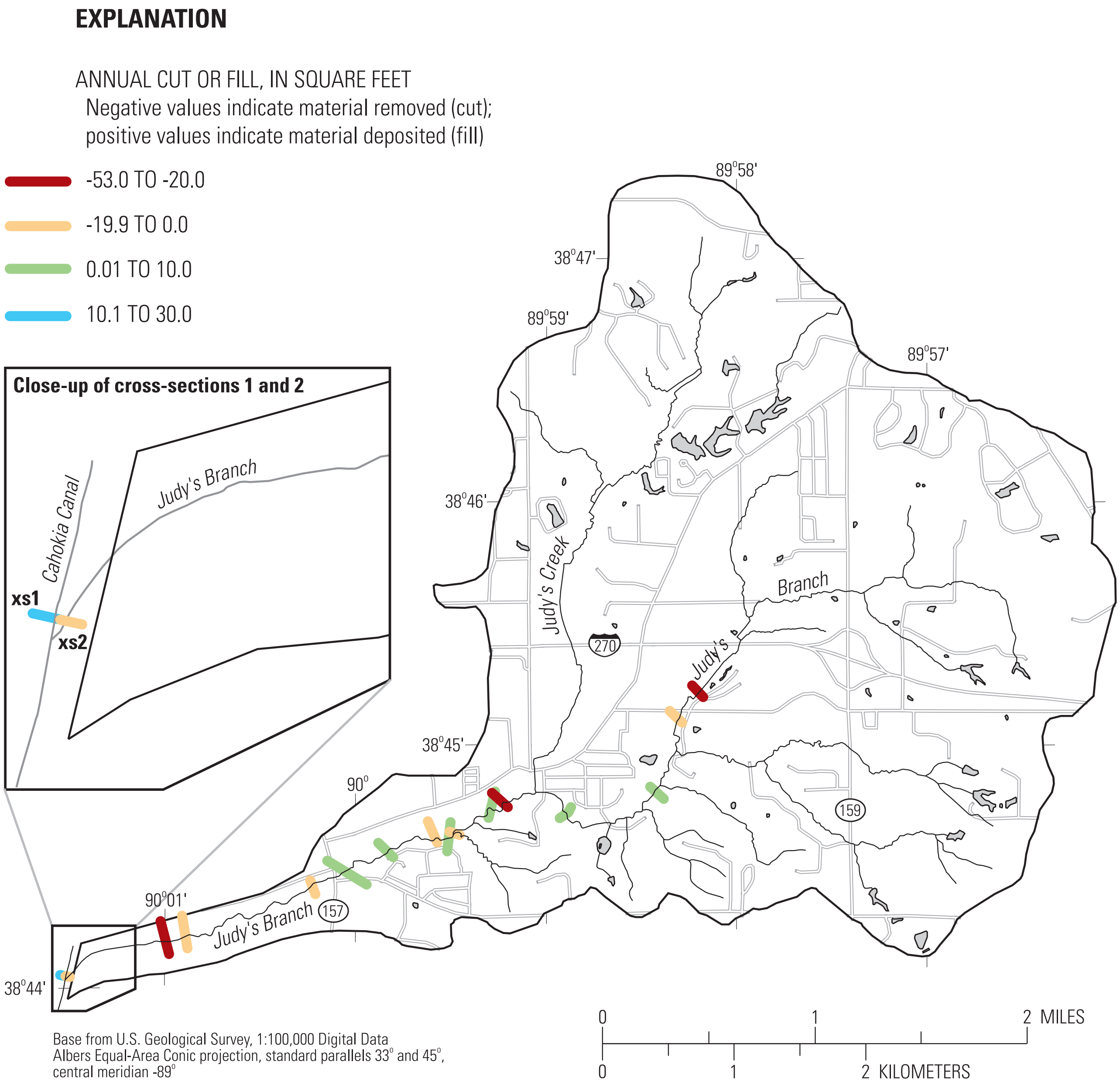

Figure 13. Annual cut or fill values from resurveyed cross sections in Judy's Branch watershed and Cahokia Canal, in the St. Louis Metro East region in Illinois.

Bank Stability

The bank-stability laboratory tests for the soil borings were performed at the Natural Resources Conservation Service (NRCS) soil mechanics laboratory in Lincoln, Nebraska. The tests consisted of routine grain-size distributions of both the coarse- and fine-grained material. Atterberg limits (plastic limit and liquid limit), torvane, unconfined compression tests, and consolidated undrained triaxial (CU) tests were done on cohesive soils. The results of the tests are presented in appendixes B and C. Results from the torvane and unconfined compression tests were not used in this study, so test methods are not discussed in this report. The CU test results are discussed in the "Model Simulation" section.

The USGS-IWSC tested samples in the laboratory collected from the banks. Tests for Atterberg limits and particle size by sieve analysis and hydrometer were completed on selected bank samples. Laboratory tests performed by both the NRCS and USGS-IWSC are made in conformance with the pertinent American Society for Testing and Materials (ASTM) (2000) procedures. Hydrometer tests and grain-size distribution tests were made in accordance with ASTM D422 and ASTM D2217 specifications, respectively. ASTM D4318 specifications were used for Atterberg limit tests (appendix C). More detailed information on all the tests can be found in Terzaghi and others (1996).

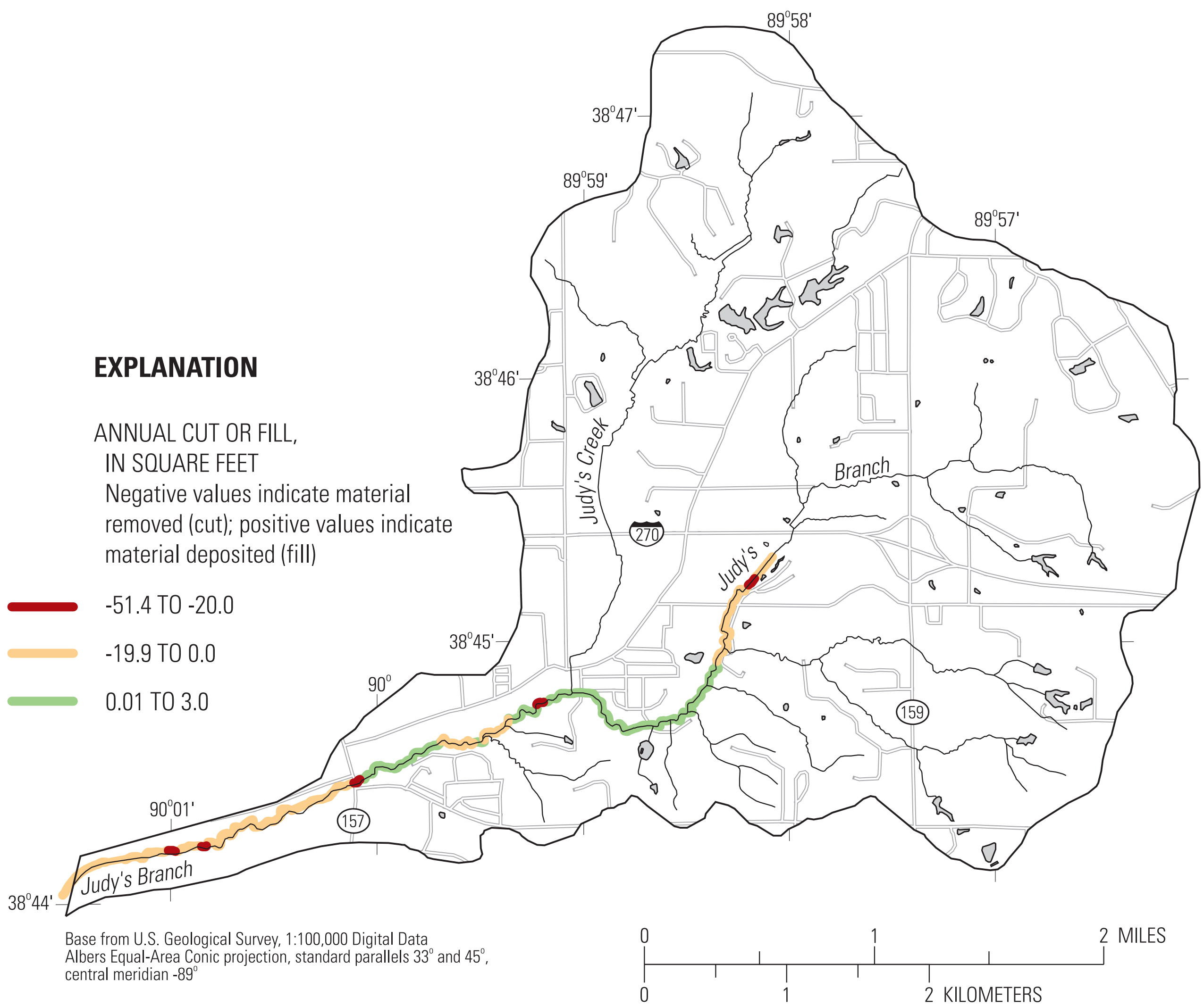

Figure 14. Annual estimated reach cut or fill values from resurveyed cross sections in Judy's Branch watershed, in the St. Louis Metro East region in Illinois.

Model Development

Bank failure in response to instability, as presented in the "Bank Rod" section was observed at BR102, BR104_204, BR106, BR113, BR124, and BR199 (fig. 10 and table 11). A detailed discussion of bank failure types observed is presented in appendix D. Bank stability can be assessed mathematically by computing the factor of safety (Terzaghi and others, 1996). Factor of safety (FS) is defined by the ratio of the shear strength (resisting force) along the failure surface and the shear stress (driving gravitational force) and given as

$$FS = \frac{Shear\ Strength}{Shear\ Stress} \; .$$

Once the factor of safety falls below one, the bank theoretically becomes unstable.

The simulation of the factor of safety computations using limit equilibrium was done with the bank-stability analysis software (SLIDE 3.0, 2005). The software searches for the critical failure surface through a user-specified region (fig. 16), considering river water confinement, pore-water pressures, surcharges, and layered banks. The software contains slope-stability analysis methods that are specified by the user. The U. S. Army Corps of Engineers (1970) and the Spencer (1967) methods were chosen for this study because they satisfy force equilibrium and may be applied to any shape of failure surface. More information about bank-

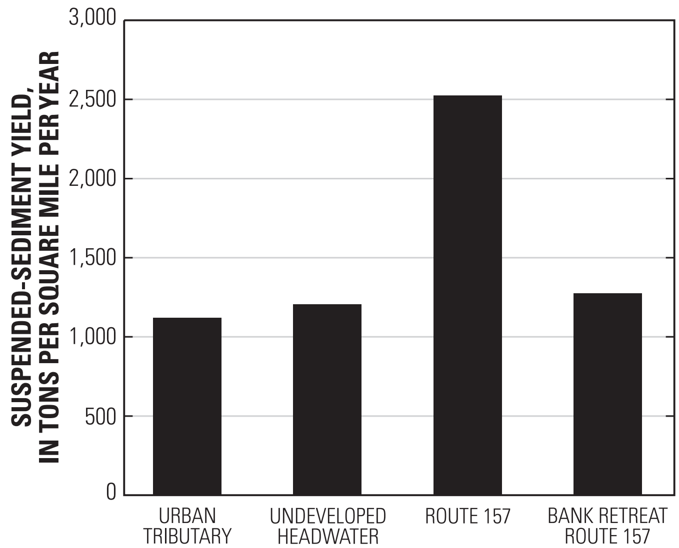

Figure 15. Average-annual suspended-sediment yield for each station (July 2000 through June 2004) and estimated average-annual suspended-sediment yield from bank retreat (June 2000 through June 2004), in Judy's Branch watershed, in the St. Louis Metro East region in Illinois.

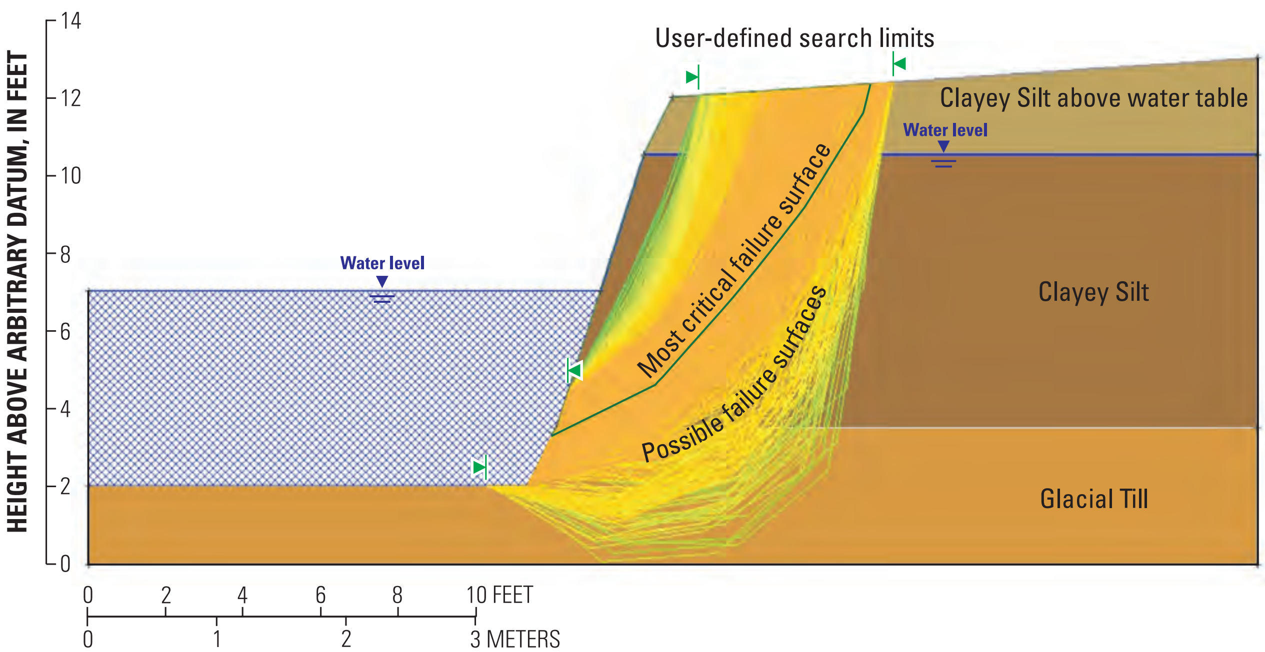

Figure 16. Conceptualized modeled streambank showing all failure surfaces attempted for one bank type in Judy's Branch watershed, in the St. Louis Metro East region in Illinois.

stability methods may be found in Duncan (1996), Nash (1987), and U.S. Army Corps of Engineers (1970 and 2003b).

The consolidated undrained (CU) with pore-water pressure measurement test was used to determine cohesive and frictional components of shear strength as outlined in Terzaghi and others (1996) and U.S. Army Corps of Engineers (2003b). Shear strength is represented by a Mohr-Coloumb failure envelope that relates shear strengths to either total or effective normal stress on the failure plane and is expressed in the case of total stresses as (U.S. Army Corps of Engineers, 2003b)

$$s = c + \sigma \tan \phi \ ,$$

where:

c = cohesion intercept,
σ = total normal stress, and
ϕ = friction angle.

The undrained or total stress approach is necessary for analysis of short-term rapid loading of soil slopes, where dissipation of pore pressures is not allowed (U.S. Army Corps of Engineers, 1970 and 2003b; Duncan, 1996). The strength parameters used for this analysis are those that occur when a large, sudden increase in load is brought on a soil mass. This action is similar to the conditions of excavated and built-up soils or slopes. The parameters to use for these cases are those obtained from an analogy with the "end of construction" condition for which the total stress approach applies.

A storm event in which the bank becomes suddenly saturated reduces the negative pore-water pressure and increases the unit weight of the soil. Reduction of negative pore-water pressure during saturation after prolonged rain events is a critical factor in determining bank stability (Simon and others, 2000). Given the above conditions, the bank is considered acted upon by a rapid loading for which the prevailing conditions and strength parameters are consistent with the "end of construction" analogy.

Laboratory results on clayey silt alluvium (ML) samples show an approximate value of cohesion intercept, $c = 180$ lb/ft^2, and an angle of internal friction, $\phi = 18^{o}$ (appendix B). The colluvial banks are mainly composed of soft-to-very soft clayey silts and were considered to have a $c = 100$ lb/ft^2 and a $\phi = 25^{o}$, back calculated from observations of failed bank geometry. The glacial till, which consists of stiff-to-very stiff overconsolidated clayey silts to silty clays, was assumed to have a $c = 275$ lb/ft^2 and a $\phi = 25^{o}$. The strength parameters for the glacial till are not as important as those parameters assigned for the bank materials above because the failure plane rarely crosses through the glacial till. The glacial till typically represents a boundary for failure planes or a base over which the sloping soil mass slides or rotates.

The cohesion incorporated by tree roots is $C_r = 205$ lb/ft^2, as determined by Simon and Collison (2001) as a typical value for sycamore trees. Root cohesion was considered for the upper 1.5 ft in this study for Judy's Branch watershed. Tree surcharge was estimated assuming that the tree is a 30-ft long post with 2 ft diameter. The load was distributed over a 4-ft diameter base.

The cohesion for the sand lens was determined to be negligible and the $\phi = 30^{o}$. These values were taken from typical strength values for loose cohesionless medium grained, poorly graded sands (Terzaghi and others, 1996).

Model Simulation

The simulated bank types were alluvium over stiff glacial till with and without a sand lens (fig. 16), alluvium over glacial till with a tree on top, and a bank consisting of colluvial deposits. Banks of 8, 10, and 13 ft in height were simulated for bank angles of 60, 70, and 80 degrees. Each of these combinations was simulated for five different stream-level heights. The glacial till was assumed to be at 1, 1.5, and 2 ft above the streambed for 8, 10, and 13 ft banks, respectively. For every type, the banks were considered to be completely saturated except for the top approximately 2 ft of the bank (fig. 16). The water levels in the river varied from bankfull height to 1.5 ft depth to match the receding portion of a storm hydrograph. The combination of a saturated bank with receding water levels represents a flashy stream, during storm events, similar to that found in the urban setting in Judy's Branch watershed.

The results of the analysis for alluvium over glacial till (10 ft high and 70-degree bank angle) during the recession limb of the storm are shown in figure 17. Factor of safety degrades with the lowering of the river level when the alluvium remains saturated.

Stability charts for all bank types and the condition where the stream level is at 1.5 ft and the streambank remains saturated are shown in figure 18. Additional model runs were completed for bank angles other than 70 degrees. In order to know the factor of safety for bank angles other than 70 degrees, a correction factor must be used. For an 80-degree bank angle, the factor of safety for the given bank height must be multiplied by 0.9. For a 60-degree bank angle, the factor of safety for the given bank height must be multiplied by 1.2.

The colluvial bank type has the lowest factor of safety. Also, this bank type becomes unstable at a bank height of approximately 9.8 ft. The alluvium over glacial till with sand-lens bank type has the second lowest factory of safety for bank heights less than 10.8 ft and the second highest for bank heights greater than 10.8 ft, and becomes unstable at a bank height of approximately 10 ft. The alluvium over glacial till with tree bank type has the greatest factor of safety for bank heights below 9.5 ft and the second highest between 9.5 and 10.8 ft, and the second lowest for bank heights greater than 10.8 ft. This bank type becomes unstable at a bank height of 10.3 ft. The alluvium over glacial till type has the greatest factor of safety for bank heights greater than 9.5 ft and the second highest between 8 and 9.5 ft. This bank type becomes unstable at bank height of 11.5 ft.

It can be interpreted from the analysis that the sand lens has a slight negative effect on the stability of the banks as compared to the alluvium over glacial till bank type. This effect results because sand lenses have little to no cohesion and mechanical strength is based only on frictional forces (Terzaghi and others, 1996). The simulation does not account for the sand lens allowing faster drainage of the bank, which can potentially increase bank stability.

Summary and Conclusions

Judy's Branch watershed, a small basin (8.64 mi^2) in the St. Louis Metro East region in Illinois, is affected by land-use changes in the bluffs draining to the American Bottoms. Judy's Branch watershed was selected as a pilot site to determine suspended-sediment yield and stream-channel processes of streams draining the bluffs. In 2000, the U.S. Geological Survey, Illinois Water Science Center;

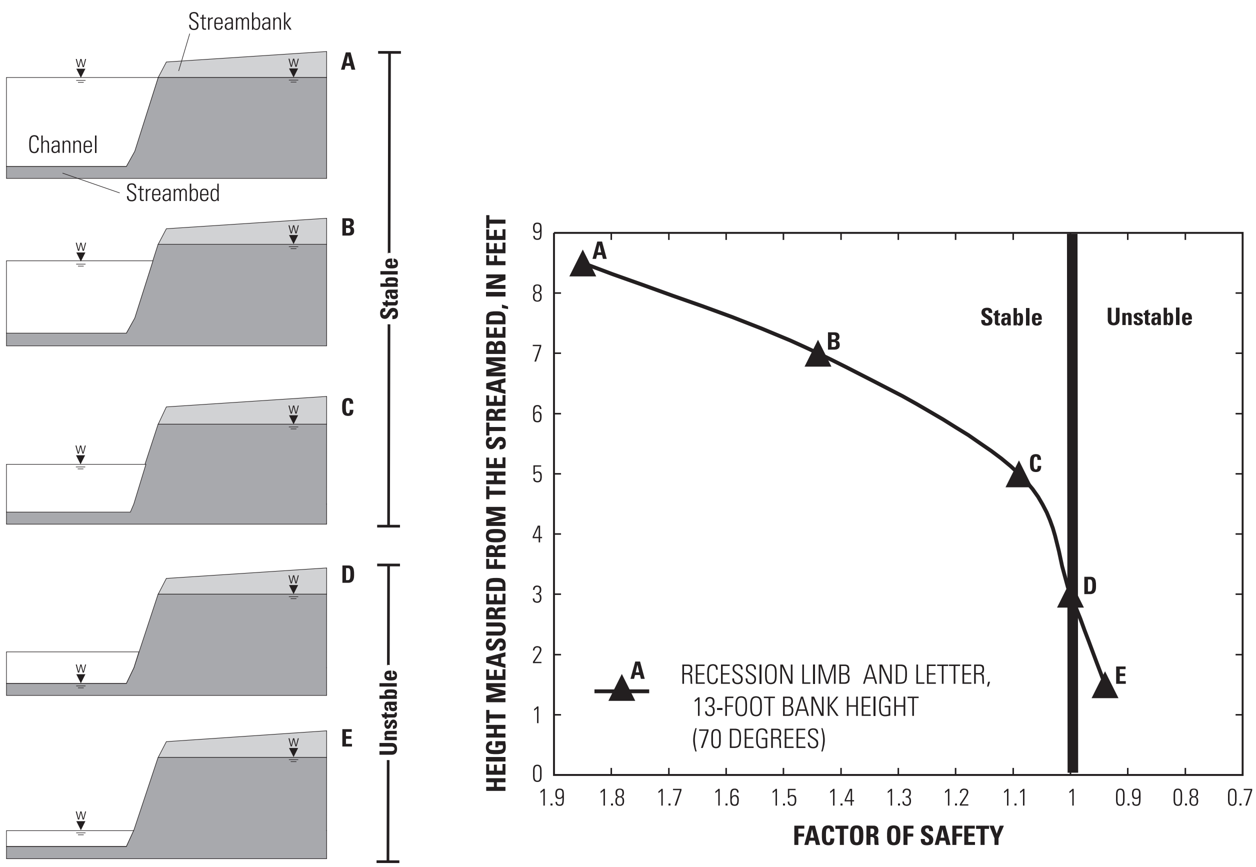

Figure 17. Factor of safety with respect to the river height as measured from the streambed on the recession limb of the hydrograph in Judy's Branch watershed, in the St. Louis Metro East region in Illinois.

the Illinois Department of Natural Resources, Office of Water Resources; and the U.S. Army Corps of Engineers, St. Louis District began a cooperative investigation to analyze suspended-sediment yields and stream channel processes in Judy's Branch watershed. This information will be helpful to water-resource managers in analysis of river rehabilitation and watershed-management alternatives to help control erosion in the upland bluffs. Methods and analyses of this study can potentially be applied to similar watersheds in the Midwest with bluffs and an extensive valley floor. Judy's Branch is similar to other bluff watersheds in the Mississippi and Illinois River watersheds and the data and analysis may be of benefit to regional and national studies by furthering the knowledge of hydrologic and sediment process in these types of watersheds. Minimal hydrologic and sediment data have been collected on small-scale watersheds such as Judy's Branch. The information from this study will help advance understanding of regional and temporal variations of suspended-sediment yield and stream-channel processes.

The sediment yield analysis determines the amount of sediment being delivered from the watershed and two subwatersheds: an urban tributary and an undeveloped headwater (primarily agricultural). The stream-channel contribution to sediment yield was determined by the analysis of stream-channel processes operating on the streambed and banks of Judy's Branch watershed. Bank-stability conditions were related to hydrologic events, bank type, and channel geometry through model development and simulation.

The average suspended-sediment yield from two upland subwatersheds (drainage areas of 0.23 and 0.40 mi^2) was 1,163 tons/mi^2-year between July 2000 and June 2004. The suspended-sediment yield at the Route 157 station was 2,523 tons/mi^2-year near the outlet of the watershed (drainage area = 8.33 mi^2). This yield is approximately 1,360 tons/mi^2-year greater than the average of the upland stations for the same time period. This result is unexpected in that, generally, the suspended-sediment yield decreases as the watershed area increases because of sediment stored in the channel and flood plain. The difference indicates a possible increase in yield from a source, such as bank retreat, and supports the concept that land-use changes increase streamflows that may result in higher rates of bank retreat.

In this study, stream-channel processes were considered a combination of bank retreat, streambed incision (lowering of the streambed elevation),

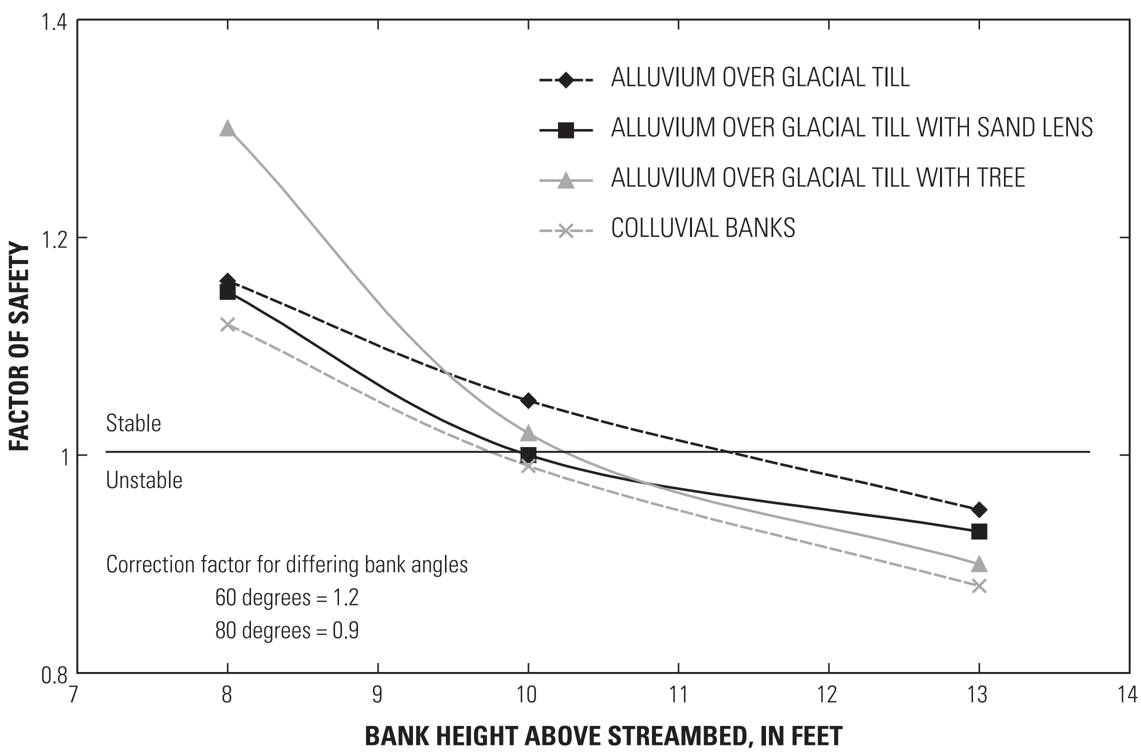

Figure 18. Factor of safety with respect to bank height for a saturated bank and 1.5 feet river level and 70 degrees bank angle for streambank types in Judy's Branch watershed, in the St. Louis Metro East region in Illinois.

and channel deposition (material filling any portion of the channel). Utilizing both bank-rod data and resurveyed cross-section data, it was determined that approximately half of the suspended-sediment yield at Route 157 during July 2000-June 2004 came from bank retreat. Bank-rod data and analysis collected in Judy's Branch watershed also indicate that bank failure in response to bank instability occurred at six sites. Also, high maximum bank-retreat values for resurveyed cross sections appeared to result from debris jams, erosion of colluvial deposits, or lateral migration of the stream channel. Data from resurveyed cross sections indicated the maximum streambed-elevation changes ranged from –1.1 ft (material removed – cut) to 1.3 ft (material deposited – fill).

Given that bank retreat can be a substantial portion of the sediment yield, understanding bank-stability processes is important. Bank stability can be assessed mathematically by computing the factor of safety. Factor of safety is defined by the ratio of the shear strength (resisting force) along the failure surface and the shear stress (driving gravitational force). Once the factor of safety falls below one, the bank theoretically becomes unstable. Different bank-stability simulations, as related to hydrologic events, and bank types and geometry were evaluated. The most common bank type is that of cohesive alluvial soil deposits overlying a very stiff glacial till. A stability chart for different bank types and geometries was developed. Banks steeper than 70 degrees and higher than from 10.0 to 11.5 ft (depending on bank type) become theoretically unstable and mass failure may occur under conditions that promote saturation of the bank and a sudden drop in the river level.

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Appendix A. Weight and coarse-sieve analysis data for bed-sediment samples collected on riffles near bank rods and soil borings in Judy's Branch watershed, in the St. Louis Metro East region in Illinois, on November 21, 2000.

[mm, millimeters; g, grams; BR, Bank Rod; SB, Soil Boring]

Sieve Number	Sieve Opening (mm)	Material Retained (g)	Cumulative Retained (g)	Cumulative Percent Retained	Percent Finer
Judy's Branch, Riffle near BR102 (fig. 7)					
3/4	19	9.5	9.5	0.9	99.1
1/2	12.5	75	84.5	7.9	92.1
3/8	9.5	48.5	133	12.4	87.6
4	4.75	279	412	38.3	61.7
12	1.7	242.5	654.5	60.9	39.1
20	.85	192	846.5	78.8	21.2
40	.425	189.5	1,036	96.4	3.6
60	.25	29	1,065	99.1	.9
140	.106	7.5	1,072.5	99.8	.2
200	.075	.5	1,073	99.9	.1
pan		1.5	1,074.5	100.0	.0
Judy's Branch, Riffle near SB2 (fig. 9)					
3/4	19	139.5	139.5	20.4	79.6
1/2	12.5	58.5	198	28.9	71.1
3/8	9.5	64.5	262.5	38.3	61.7
4	4.75	101	363.5	53.1	46.9
12	1.7	101	464.5	67.8	32.2
20	.85	48	512.5	74.8	25.2
40	.425	118	630.5	92.0	8.0
60	.25	47.5	678	99.0	1.0
140	.106	7	685	100.0	.0
200	.075	0	685	100.0	.0
pan		0	685	100.0	.0
Judy's Branch, Riffle near BR199 (fig. 7)					
3/4	19	0	0	0.0	100.0
1/2	12.5	29.5	29.5	3.8	96.2
3/8	9.5	28	57.5	7.5	92.5
4	4.75	136	193.5	25.2	74.8
12	1.7	299.5	493	64.3	35.7
20	.85	121	614	80.1	19.9
40	.425	81.5	695.5	90.7	9.3
60	.25	49	744.5	97.1	2.9
140	.106	21	765.5	99.8	.2
200	.075	.5	766	99.9	.1
pan		1	767	100.0	.0
Judy's Branch, Riffle near BR106 (fig. 7)					
3/4	19	103.5	103.5	12.4	87.6
1/2	12.5	68.5	172	20.7	79.3
3/8	9.5	62	234	28.1	71.9
4	4.75	145	379	45.6	54.4
12	1.7	212	591	71.1	28.9
20	.85	87.5	678.5	81.6	18.4
40	.425	109.5	788	94.8	5.2
60	.25	33	821	98.7	1.3
140	.106	8	829	99.7	.3
200	.075	0.5	829.5	99.8	.2
pan		2	831.5	100.0	.0

Appendix A. Weight and coarse-sieve analysis data for bed-sediment samples collected on riffles near bank rods and soil borings in Judy's Branch watershed, in the St. Louis Metro East region in Illinois, on November 21, 2000—continued.

[mm, millimeters; g, grams; BR, Bank Rod; SB, Soil Boring]

Sieve Number	Sieve Opening (mm)	Material Retained (g)	Cumulative Retained (g)	Cumulative Percent Retained	Percent Finer
Judy's Branch, Riffle near BR109 (fig. 7)					
3/4	19	36	36	7.1	92.9
1/2	12.5	51	87	17.3	82.7
3/8	9.5	65.5	152.5	30.3	69.7
4	4.75	112	264.5	52.5	47.5
12	1.7	154	418.5	83.0	17.0
20	.85	50.5	469	93.1	6.9
40	.425	22	491	97.4	2.6
60	.25	6.5	497.5	98.7	1.3
140	.106	4	501.5	99.5	.5
200	.075	.5	502	99.6	.4
pan		2	504	100.0	.0
Judy's Branch, Riffle near BR111 (fig. 7)					
3/4	19	122	122	21.7	78.3
1/2	12.5	77.5	199.5	35.5	64.5
3/8	9.5	48	247.5	44.0	56.0
4	4.75	82	329.5	58.6	41.4
12	1.7	115.5	445	79.2	20.8
20	.85	44.5	489.5	87.1	12.9
40	.425	44.5	534	95.0	5.0
60	.25	20.5	554.5	98.7	1.3
140	.106	4.5	559	99.5	.5
200	.075	.5	559.5	99.6	.4
pan		2.5	562	100.0	.0
Judy's Branch, Riffle near BR115 (fig. 7)					
3/4	19	22.5	22.5	4.3	95.7
1/2	12.5	45.5	68	13.1	86.9
3/8	9.5	46.5	114.5	22.1	77.9
4	4.75	116	230.5	44.5	55.5
12	1.7	124.5	355	68.5	31.5
20	.85	56.5	411.5	79.4	20.6
40	.425	63.5	475	91.7	8.3
60	.25	32	507	97.9	2.1
140	.106	8	515	99.4	.6
200	.075	.5	515.5	99.5	.5
pan		2.5	518	100.0	.0
Judy's Branch, Riffle near BR116 (fig. 7)					
3/4	19	0	0	0.0	100.0
1/2	12.5	7.5	7.5	2.2	97.8
3/8	9.5	14.5	22	6.4	93.6
4	4.75	50	72	21.0	79.0
12	1.7	102	174	50.7	49.3
20	.85	64	238	69.3	30.7
40	.425	60.5	298.5	86.9	13.1
60	.25	27	325.5	94.8	5.2
140	.106	6	331.5	96.5	3.5
200	.075	1.5	333	96.9	3.1
pan		10.5	343.5	100.0	.0

Appendix A. Weight and coarse-sieve analysis data for bed-sediment samples collected on riffles near bank rods and soil borings in Judy's Branch watershed, in the St. Louis Metro East region in Illinois, on November 21, 2000—continued.

[mm, millimeters; g, grams; BR, Bank Rod; SB, Soil Boring]

Sieve Number	Sieve Opening (mm)	Material Retained (g)	Cumulative Retained (g)	Cumulative Percent Retained	Percent Finer
Judy's Branch, Riffle near BR117 (fig. 7)					
3/4	19	28	28	5.4	94.6
1/2	12.5	35.5	63.5	12.3	87.7
3/8	9.5	37	100.5	19.5	80.5
4	4.75	117	217.5	42.3	57.7
12	1.7	150.5	368	71.5	28.5
20	.85	57	425	82.6	17.4
40	.425	50.5	475.5	92.4	7.6
60	.25	25	500.5	97.3	2.7
140	.106	7.5	508	98.7	1.3
200	.075	1	509	98.9	1.1
pan		5.5	514.5	100.0	.0
Judy's Branch, Riffle near BR118 (fig. 7)					
3/4	19	53.5	53.5	8.1	91.9
1/2	12.5	77	130.5	19.7	80.3
3/8	9.5	81	211.5	31.9	68.1
4	4.75	95	306.5	46.2	53.8
12	1.7	153.5	460	69.3	30.7
20	.85	68.5	528.5	79.6	20.4
40	.425	74	602.5	90.7	9.3
60	.25	30	632.5	95.3	4.7
140	.106	12.5	645	97.1	2.9
200	.075	2.5	647.5	97.5	2.5
pan		16.5	664	100.0	.0
Judy's Branch, Riffle near BR119 (fig. 7)					
3/4	19	20	20	2.4	97.6
1/2	12.5	34.5	54.5	6.5	93.5
3/8	9.5	19	73.5	8.8	91.2
4	4.75	72.5	146	17.5	82.5
12	1.7	154.5	300.5	36.0	64.0
20	.85	128	428.5	51.4	48.6
40	.425	279.5	708	84.9	15.1
60	.25	67.5	775.5	93.0	7.0
140	.106	25.5	801	96.0	4.0
200	.075	6	807	96.8	3.2
pan		27	834	100.0	.0
Judy's Branch, Riffle near BR120 (fig. 7)					
3/4	19	6.5	6.5	2.1	97.9
1/2	12.5	36	42.5	13.8	86.2
3/8	9.5	28	70.5	22.8	77.2
4	4.75	69	139.5	45.1	54.9
12	1.7	70.5	210	68.0	32.0
20	.85	20.5	230.5	74.6	25.4
40	.425	23.5	254	82.2	17.8
60	.25	32	286	92.6	7.4
140	.106	17	303	98.1	1.9
200	.075	0	303	98.1	1.9
pan		6	309	100.0	.0

Appendix A. Weight and coarse-sieve analysis data for bed-sediment samples collected on riffles near bank rods and soil borings in Judy's Branch watershed, in the St. Louis Metro East region in Illinois, on November 21, 2000—continued.

[mm, millimeters; g, grams; BR, Bank Rod; SB, Soil Boring]

Sieve Number	Sieve Opening (mm)	Material Retained (g)	Cumulative Retained (g)	Cumulative Percent Retained	Percent Finer
Judy's Branch, Riffle near BR122 (fig. 7)					
3/4	19	140	140	25.7	74.3
1/2	12.5	40.5	180.5	33.1	66.9
3/8	9.5	30	210.5	38.7	61.3
4	4.75	57	267.5	49.1	50.9
12	1.7	86	353.5	64.9	35.1
20	.85	38.5	392	72.0	28.0
40	.425	63.5	455.5	83.7	16.3
60	.25	55.5	511	93.8	6.2
140	.106	19.5	530.5	97.4	2.6
200	.075	0	530.5	97.4	2.6
pan		14	544.5	100.0	.0
Judy's Branch, Riffle near BR123-124 (fig. 7), Note: Piece of slag (94.5 g) regarded as a rock					
3/4	19	27	27	2.0	98.0
1/2	12.5	43.5	70.5	5.1	94.9
3/8	9.5	48.5	119	8.6	91.4
4	4.75	148	267	19.4	80.6
12	1.7	250.56	517.56	37.6	62.4
20	.85	114	631.56	45.9	54.1
40	.425	143.5	775.06	56.3	43.7
60	.25	565	1,340.06	97.3	2.7
140	.106	22	1,362.06	98.9	1.1
200	.075	3.5	1,365.56	99.2	.8
pan		11	1,376.56	100.0	.0

Appendix B: Soil-boring analysis for Judy's Branch watershed in the St. Louis Metro East region in Illinois

Definitions for appendix B tables

Abbreviation/Symbol	Definition
ft	feet
USC	Unified Soil Classification
UC or Qu	Unconfined Compression tests
CU	Consolidated Undrained triaxial shear tests
torvane	torvane test
SB	soil boring
USGS-IWSC	U.S. Geological Survey—Illinois Water Science Center
USDA-NRCS	U.S. Department of Agriculture—Natural Resources Conservation Service
w	water content
%	percent
LL	liquid limit
PI	plasticity index
G	specific gravity
γ_d	dry soil specific weight
lb/ft^3	pounds per cubic foot
psf	pounds per square foot
NP	non plastic
c	cohesion intercept
c'	effective cohesion intercept
ϕ	friction angle
ϕ'	effective friction angle

Soil group symbols and typical names as established in the Unified Soil Classification (USC)

Soil Group Symbol	Definition
ML	Inorganic silt and very fine sand, silty or clayey fine sand, or clayey silt with slight plasticity
CL	Inorganic clay of low to medium plasticity, gravelly clay, sandy clay, silty clay, lean clay
OL	Organic silt and organic silty clay of low plasticity
MH	Inorganic silt, micaceous or diatomaceous fine sandy
CH	Inorganic clay of high plasticity, fat clay
OH	Organic clay of medium to high plasticity
SP	Poorly graded sands
SC	Sand with plastic clayey fines
SM	Sand with non-plastic sitly fines

Table B1. Soil-boring profile and laboratory test results for SB1 collected on September 5, 2000, in Judy's Branch watershed, in the St. Louis Metro East region in Illinois.

Boring Date: 9/5/2000, USGS-WRD, Urbana						**Tested by:** USDA-NRCS, Lincoln, NE				
Depth (ft)	**Soil Description**	**USC**	**w (%)**	**LL (%)**	**PI (%)**	**G**	**γ_d, (lb/ft^3)**	**Test**	**Results**	**Comments**
0.65	Light brown silt (loess)									
2	Medium brown silt with thin sand lens and organic matter	ML	15.4	28	5	2.65				
4										
6	Same as above	ML	6	26	4					
8										
10	Same as above	ML	6	28	5	2.66				
12										
14	Same as above	CL-ML	15.4	25	5					Streambed level
16										
18	Medium gray clayey silt	CL	21.5	29	8	2.69				
20	Silty sand	SM	14	17	1					
22	Clayey silt w/ silty sand lenses (fine to medium grained)	SP-SM		NP			103			
24										End of boring

Table B2. Soil-boring profile and laboratory test results for SB2 collected on September 5, 2000, in Judy's Branch watershed, in the St. Louis Metro East region in Illinois.

Boring Date: 9/5/2000, USGS-WRD, Urbana						**Tested by:** USDA-NRCS, Lincoln, NE				
Depth (ft)	**Soil Description**	**USC**	**w (%)**	**LL (%)**	**PI (%)**	**G**	**γ_d, (lb/ft^3)**	**Test**	**Results**	**Comments**
2	Light brown silt (loess)	ML	22.2	29	4	2.64				
4										
	Medium to brown clayey silt with thin	CL-ML	25.7	25	4					
6	silty sand lenses and									
	some organic matter	ML	24.8	28	4	2.67				
8										
	Same as above	ML	21.3	24	3					
10		CL-ML	14.7	24	5		99			
		ML	18.2	NP			105	torvane	c=1,300 psf	
12										Streambed level
	Same as above with more sand	ML	20.7	22	3	2.66	105			
14	Gray clayey silt with gray sandy silt	CL-ML		27	6	2.65	94	UC	c=1,238 psf	
	and trace organic carbon							torvane	c=1,250 psf	
16	Silty fine to medium fine sand	SC-SM	18.6	22	4	2.67				
	with silty clay									
18										
	Medium gray silty clay with	ML	39.4	32	8					
20	fine sand and trace organic matter	CL	26.5	34	15					End of boring
	(stiff overconsolidated)									
22										

Table B3. Soil-boring profile and laboratory test results for SB4 collected on September 5, 2000, in Judy's Branch watershed, in the St. Louis Metro East region in Illinois.

Boring Date: 9/5/2000, USGS-WRD, Urbana						**Tested by:** USDA-NRCS, Lincoln, NE				
Depth (ft)	**Soil Description**	**USC**	**w (%)**	**LL (%)**	**PI (%)**	**G**	**γ_d, (lb/ft^3)**	**Test**	**Results**	**Comments**
	Cinder, topsoil, brick, gray silt									
2	cobbles and gravels, mixed									
	with clay and silt (fill)									
4		ML	22.7	42	15	2.12				
6	Medium brown gray silt	CL-ML	17.9	23	4	2.66				
8	Same as above with slight clay	ML	17.4	27	3	2.54				
		CL-ML	24.6	27	5	2.65				
10	Gravel cobble and sand lens									
	Clayey silt with fine sand	CL	18.4	24	8					
12	and organic matter	CL-ML	19.4	26	7					
	Same as above without organic									
14		CL-ML	25.0	26	5	2.65				Streambed level
16										
	Same as above	ML	28.9	27	4	2.65	90	UC	c=893 psf	
18								torvane	c=750 psf	
20	Silty clay (glacial till)									
22		CL-ML	28.2	26	6					
24	Same as above									
		SC-SM	18.3	17	4		105			
26										
	Very stiff to hard silty clay	CL	21	35	15	2.76				
28	(possibly weathered rock)									Refusal

Table B4. Soil-boring profile and laboratory test results for SB5 collected on September 5, 2000, in Judy's Branch watershed, in the St. Louis Metro East region in Illinois.

Boring Date: 9/5/2000, USGS-WRD, Urbana						**Tested by:** USDA-NRCS, Lincoln, NE				
Depth (ft)	**Soil Description**	**USC**	**w (%)**	**LL (%)**	**PI (%)**	**G**	**γ_d, (lb/ft^3)**	**Test**	**Results**	**Comments**
	Medium brown fine silt (loess)									
2	with fine rootlets	ML	21.6	27	3	2.67				
	Same as above but lighter brown									
4	color and some organic matter									
6	Brownish gray silt with orange	ML	19.8	22	2	2.66				
	(oxidized) fine-to-medium	ML	22.6	24	2	2.65				
8	grained sand lenses	ML		25	3			torvane	c=500 psf	Streambed level
	Gray silty sand	SM	22.5	19	1		103			
10	Silt with thin laminae of fine							torvane(top/bottom)	c=625/750 psf	
	sandy silt	ML	20.2	21	1	2.66	107	CU (remolded)	c=198 psf	End of boring
12									Φ=17.6^o	
									Φ'=37.5^o	
									c'=0 psf	

Table B5. Soil-boring profile and laboratory test results for SB6A collected on September 6, 2000, in Judy's Branch watershed, in the St. Louis Metro East region in Illinois.

Boring Date: 9/6/2000, USGS-WRD, Urbana						**Tested by:** USDA-NRCS, Lincoln, NE				
Depth (ft)	**Soil Description**	**USC**	**w (%)**	**LL (%)**	**PI (%)**	**G**	**γ_d, (lb/ft^3)**	**Test**	**Results**	**Comments**
2	Top soil, organic clayey silt	ML	27.2	34	10					
4	Silty clay with rock fragments	CL	26.4	33	10	2.70				
6		ML	29.4	29	4					
8	Medium gray clayey silt	ML	25.6	32	7					
								torvane	c=1,000 psf	
10								CU	c=182 psf	
	Same as above	ML	24.3	29	5	2.72	100		Φ=15.8°	
12									Φ'=27.8°	
		ML	25.2	29	5	2.7			c'=0 psf	
14	Very stiff to hard silty clay	CL-ML	26.5	28	7	2.69	97	UC	c=1,145 psf	
	(glacial till)							torvane	c=1,375 psf	
16										
18	Saturated gray clayey silt	CL-ML	26.4	25	5	2.67				Streambed level
20										End of boring

Table B6. Soil-boring profile and laboratory test results for SB8 collected on September 5, 2000, in Judy's Branch watershed, in the St. Louis Metro East region in Illinois.

Boring Date: 9/5/2000, USGS-WRD, Urbana						**Tested by:** USDA-NRCS, Lincoln, NE				
Depth (ft)	**Soil Description**	**USC**	**w (%)**	**LL (%)**	**PI (%)**	**G**	**γ_d, (lb/ft^3)**	**Test**	**Results**	**Comments**
2	Light brown silt with organic rootlets	ML	9.1	26	3	2.63				
	and oxidized orange silts									
4										
6	Medium dark gray clayey silt	CL	28	30	8	2.63				
	to silty clay									
8	Same as above with higher clay content									
10	Medium gray clayey silt	CL-ML	27.4	26	7					
	with fine-grained thin sand lens									
12								UC	c=936 psf	
	Medium dark gray silty clay	CL-ML	21.7	24	6	2.67	103	torvane	c=1,000 psf	Streambed level
14	with organic material	CL	31	37	15			torvane	c=750 psf	
		CL-ML	27.4	26	7	2.67				
16										
		CL	25.3	26	8					
18	Tan brown clayey silty with									
	lenses of silty sand and cobbles	SM	20.9	18	2	2.66				
20	(glacial till)									End of boring

Table B7. Grain-size distribution for various depths of each soil boring in Judy's Branch watershed, in the St. Louis Metro East region in Illinois. Collected by the USGS-IWSC on September 5-6, 2000. Testing completed by the USDA-NRCS, Lincoln, Nebraska.

Soil Boring and Depth (ft)	Grain-Size Distribution in Percent Finer														
	Particle Size Diameter (mm)														
	25.40	19.05	12.70	9.525	4.760	2.000	0.840	0.420	0.250	0.105	0.074	0.050	0.020	0.005	0.002
SB1															
2.0	100	100	100	100	100	100	100	100	100	100	100	93	35	15	12
6.0	100	100	100	100	100	100	100	100	100	100	100	94	37	16	12
10.0	100	100	100	100	100	100	100	100	100	100	100	93	36	14	9
14.5	100	100	100	100	100	100	100	100	100	100	83	75	30	16	14
17.0	100	100	100	100	100	100	100	100	100	100	89	81	36	19	16
19.0	100	100	100	100	100	100	100	98	78	38	37	37	21	15	14
22.0	100	100	100	100	100	100	99	87	40	9	8	8	2	1	1
SB2															
2.0	100	100	100	100	100	100	100	100	100	100	94	86	32	15	10
5.0	100	100	100	100	100	100	100	100	100	100	96	86	32	15	12
7.0	100	100	100	100	100	100	100	100	100	100	100	97	41	16	14
9.5A	100	100	100	100	100	100	100	100	100	100	80	74	27	12	9
9.5B	100	100	100	100	100	100	100	100	100	100	89	81	28	14	14
11.5	100	100	100	100	100	100	99	96	87	67	66	61	22	9	9
13.0	100	100	100	100	100	100	99	93	78	58	57	53	21	10	7
14.0	100	100	100	100	100	100	100	100	100	100	83	80	36	16	13
17.5	100	100	100	100	100	100	94	74	58	49	48	46	20	10	8
19.0	100	100	100	100	100	100	100	100	100	100	78	73	33	19	13
19.5	100	100	100	100	100	100	100	100	100	100	100	95	62	48	35
SB4															
4.0	100	100	100	100	100	100	98	91	77	60	58	55	39	27	26
6.5	100	100	100	100	100	100	100	100	100	100	86	75	30	12	12
8.5	100	97	95	94	90	88	83	77	71	60	58	54	31	14	12
10.0	100	100	100	100	100	100	100	100	100	100	98	87	33	15	15
11.5	100	100	100	100	100	100	100	100	100	100	81	75	33	16	14
12.5	100	100	100	98	95	92	87	82	77	70	69	64	30	14	8
15.0	100	100	100	100	100	100	100	100	100	100	96	89	39	16	9
18.5	100	100	100	100	100	100	100	100	100	100	80	72	31	14	10
22.0	100	100	100	100	100	100	100	100	100	100	96	89	41	16	15
25.0	100	100	100	100	100	100	99	96	75	42	41	39	19	11	11
27.0	100	100	100	100	100	100	100	100	100	100	93	86	52	30	26
SB5															
2.0	100	100	100	100	100	100	100	100	100	100	96	84	35	15	15
6.0	100	100	100	100	100	100	100	100	100	100	78	71	24	12	12
7.0	100	100	100	100	100	100	100	100	100	100	83	73	27	14	14
9.0A	100	100	100	98	93	80	80	70	54	42	42	41	16	9	9
9.0B	100	100	100	100	100	100	100	100	100	100	89	81	27	12	12
11.0	100	100	100	100	100	100	99	95	86	68	63	54	22	10	10
SB6A															
1.5	100	100	100	100	100	100	100	100	100	100	100	96	45	22	20
4.0	100	100	100	100	100	100	100	100	100	100	98	96	48	23	22
6.5	100	100	100	100	100	100	100	100	100	100	100	96	41	16	16
8.0	100	100	100	100	100	100	100	100	100	100	100	96	41	20	20
11.0	100	100	100	100	100	100	100	100	100	100	100	94	38	15	14
13.0	100	100	100	100	100	100	100	100	100	100	100	95	41	17	17
14.0	100	100	100	100	100	100	100	100	100	100	100	100	43	15	12
18.5	100	100	100	100	100	100	100	100	100	100	100	91	35	16	15
SB8															
2.0	100	100	100	100	100	100	100	100	100	100	99	90	33	15	14
6.0	100	100	100	100	100	100	100	100	100	100	100	94	47	22	17
10.0	100	100	100	100	100	100	100	100	100	100	98	90	37	15	14
13.0	100	100	100	100	100	100	100	100	100	100	82	75	29	13	13
14.0	100	100	100	100	100	100	100	100	100	100	100	100	56	28	21
15.5	100	100	100	100	100	100	100	100	100	100	96	71	33	15	14
17.0	100	100	100	100	100	100	100	100	100	100	90	81	32	15	13
19.0	100	100	100	100	100	100	97	77	53	53	49	42	20	10	9

Appendix C: Atterberg Limits for Judy's Branch watershed in the St. Louis Metro East region in Illinois

Atterberg limits commonly are used to classify soils and provide information on the behavior of fine-grained soils including liquid limit (LL), plastic limit (PL), and plasticity index (PI) as defined in Terzaghi and others (1996). The LL is the moisture content at which the soil loses its consistency and behaves like a viscous fluid. The PL is the moisture content at which the soil may plastically deform without crumbling. The PI is a measure of how much water a soil can absorb before behaving as a fluid. The PI is obtained by subtracting the PL from the LL; thus, the PI defines the range of moisture contents where the soil exhibits plastic behavior. The PI and the LL often are correlated to cohesive strength. The soil is more compressible and has a lower saturated strength at higher values of the PI. Soil plasticity is a function of clay content and mineralogy. Higher PIs and LLs result from higher clay contents. Silt and clay soils with high PIs typically have greater proportions of clay minerals with thin, platy-shaped particles. The nomenclature for soil groups as established in the Unified Soil Classification (USC) (Casagrande, 1948) is explained in table C1. Soils in the region consistently can be classified as low to slight plasticity clayey silt, sandy clay, or silty clay (fig. C1).

Table C1. Soil group symbols and typical names for cohesive soils as established in the Unified Soil Classification (Casagrande, 1948) for soils found in the St. Louis Metro East region in Illinois.

Soil Group Symbol	Definition
ML	Inorganic silt and very fine sand, silty or clayey fine sand, or clayey silt with slight plasticity
CL	Inorganic clay of low to medium plasticity, gravelly clay, sandy clay, silty clay, lean clay
OL	Organic silt and organic silty clay of low plasticity
MH	Inorganic silt, micaceous or diatomaceous fine sandy
CH	Inorganic clay of high plasticity, fat clay
OH	Organic clay of medium to high plasticity

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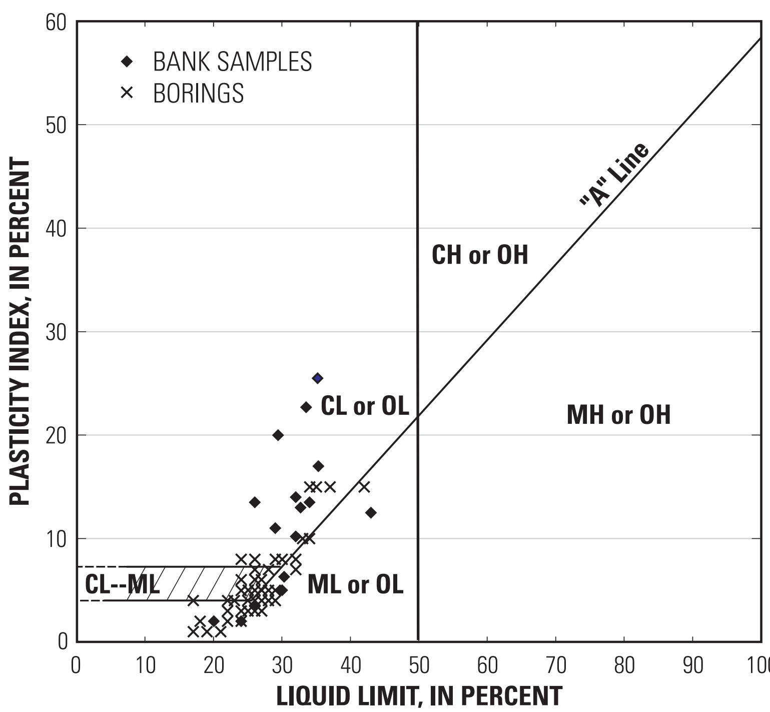

Figure C1. Plasticity chart developed from samples collected from banks and borings throughout Judy's Branch watershed, in the St. Louis Metro East region in Illinois. Refer to table C1 for definition of soil classes. Samples plotting above the "A" Line are predominantly clay and those below are predominantly silt.

Appendix D: Bank-failure types for Judy's Branch watershed in the St. Louis Metro East region in Illinois

Bank failures observed during this study were categorized as planar or rotational by their mode of failure as indicated by the shape of the failure surface (Thorne and others, 1997, and Thorne, 1998). Both failure types are observed in Judy's Branch watershed and the St. Louis Metro East region in Illinois. Pop-out failures are also discussed here. The relation of type of failure and soil material as noted in the following text was concluded from field observations of banks in the Judy's Branch watershed.

Planar failures generally occur in non-cohesive to slightly cohesive soils with slight plasticity. Planar failures sometimes are observed to begin with the development of a tension crack at the top of the bank. Size of failure wedge heights are on the order of 75 to 90 percent of the bank height, and their lateral dimension along the stream ranged from 5 to 10 ft. The depth of the failure wedge ranges from 3 to 8 ft from the failed bank surface. When a planar failure occurs, material from the top of the banks becomes redeposited at the toe, temporarily buttressing the bank. With time, the wedge may crumble and become easily detached and washed away by the river flow. The mode of failure was generally observed on silty alluvial deposits.

Two types of rotational failures were classified in the St. Louis Metro East region: deep and shallow. Deep rotational failures are common in soft deposits with high plasticity indexes (MH or CH). High plasticity deposits are not common in the St. Louis Metro East region and, therefore, deep rotational failures were not considered in this study.

Shallow rotational failures occur in low to medium plasticity soils and their orientation and extent depends on the presence of weak planes, discontinuities, zones of high infiltration rates, tree surcharge, and other factors. Shallow rotational failure is a process in which the shear stress increases because of prolonged wetting, loss of negative pore-water pressures and the shear strength becomes degraded by progressive displacement, and remolding of the soil particles along the shearing plane and the plane becomes polished. Once sufficient displacement has occurred on an unstable bank, the shear strength available on the plane will be the residual shear strength (the shear strength between the polished failure planes). Displacements and distortion of the whole mass also will open new paths for easy infiltration of water through the failure surface; thus, allowing rapid saturation and decrease in shear strength because of an increase in positive pore water pressure. Once the shear stress overcomes the weakened shear strength, it dislocates and displaces until it reaches a new state of equilibrium. The residual strength for low plasticity medium to soft soils, as the ones found during this study, is for practical purposes the same as the remolded or fully softened shear strength (Stark and Eid, 1997, and Terzaghi and others, 1996).

Shallow rotational failures are common on Judy's Branch watershed and other streams in the St. Louis Metro East region. The contact of alluvium over glacial till, when present, is a weak zone where failure surfaces result. In some cases, it was observed that the failure plane had penetrated slightly into the till; this penetration was more common if the glacial till was highly weathered.

Lastly, fill deposits in the area commonly were unstable. Generally, fill deposits are observed to fail as planar failures and soil falls (occur when a stream undercuts the toe of a bank and the soil above falls into the river (Thorne and others, 1997 and Thorne, 1998)). These observations are supported in that these fill deposits are loose and are non-cohesive. When material from planar failure or soil falls accumulates at the bottom of the bank covering a sand lens, the seepage through the sand lens may cause the soil to pop out or become detached from the bank face.

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