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PLATTE RIVER QUALITATIVE GEOMORPHOLOGICAL ASSESSMENT—SAUNDERS AND SARPY COUNTIES, NEBRASKA

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Administrative Report

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ABBREVIATIONS AND ACRONYMS

a	Multiplier associated with a power equation that represents the intercept when plotted on a logarithmic grid
ABE	Average bed elevation
ABE_{resid}	Residuals of the average bed elevation and locally weighted scatterplot-smoothing line for discharge
$ALCL_{ABE}$	Ambient lower confidence level of the average bed elevation
$ALCL_{TE}$	Ambient lower confidence level of the thalweg elevation
b	Exponent associated with a power equation that represents the slope of the equation when plotted on a logarithmic grid
C&SD	Conservation and Survey Division
d	Measured disturbance
DOQ	Digital orthophoto quadrangles
dpi	Dots per inch
e	Scale offset constant associated with a power equation
EROS	Earth Resources Observation System
GH	Water-surface elevation referred to some arbitrary gage datum; gage height is often used interchangeably with the more general term “stage,” although gage height is more appropriately used for reading on a gage
GIS	Geographic Information System
LOWESS	LOcally WEighted Scatterplot Smoothing
MWSE	Water-surface elevation for median discharge
NAPP	National Aerial Photography Program
NHAP	National High Altitude Aerial Photography Program
NNRC	Nebraska Natural Resources Commission
P	Wetted perimeter
PMR–NRD	Papio–Missouri River Natural Resources District
r	Recovery time
RMS	Root mean squares
S	Stream slope
SCC	Suspended-sediment concentration
SFD	Streamflow discharge
SSD	Suspended-sediment discharge
TE	Thalweg elevation
TE_{resid}	Residuals of the thalweg elevation and locally weighted scatterplot-smoothing line for discharge
tiff	Tagged-image-file format
UNL	University of Nebraska–Lincoln
USACE	U.S. Army Corps of Engineers
USDA-FSA	U.S. Department of Agriculture’s Farm Service Agency
WSE	Water-surface elevation

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
Length		
inch (in)	2.54	centimeter (cm)
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
Area		
acre	4,047	square meter
acre	0.4047	hectare
Flow rate		
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Water year: The 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends. Therefore, the 2000 water year ends on September 30, 2000.

Platte River Qualitative Geomorphological Assessment—Saunders and Sarpy Counties, Nebraska

By Philip J. Soenksen, David L. Rus, Mary J. Turner, *and* Benjamin J. Dietsch

Abstract

As part of a study to determine the possible impacts of proposed levees on sandbars, the U.S. Geological Survey performed a qualitative geomorphological assessment along a reach of the Platte and Elkhorn Rivers upstream and downstream from U.S. Highway 6. Three Federally designated endangered species use the river and sandbars as habitat for nesting and foraging. A literature search showed that a minimum amount of scouring of the sandbars is required to keep them mobile and free of permanent vegetation and thus maintain the open habitat.

Aerial photographs for 1973, 1990, 1994, and 1997 were obtained and analyzed to determine the number, area, and shoreline length of three types of emerged sandbars, as well as of vegetated islands. There is no apparent relation between the number or area of sandbars and river stage or streamflow discharge; there were also no definite trends with time.

Long-term gradational trends at two U.S.Geological Survey stream-gaging sites on the Platte River indicated an aggrading trend at the Ashland site (U.S. Highway 6) and a degrading trend at the Louisville site (11 miles downstream). The effects of high-water discharge events on the stream channel also were evaluated at the two stream-gaging sites. This revealed a consistent downward response (scour) followed by recovery at the bridges, but no consistent response either upward or downward for the channels downstream of the bridges.

Suspended sediment data for the stream-gaging site at Louisville were analyzed for water years 1972 to 1999 and results were tested for trends using the Kendall's tau procedure. The test indicated no trends in the sediment-discharge rating curves. However, statistically significant upward trends were found in the annual values both for average annual streamflow discharge and for sediment yield.

INTRODUCTION

As part of a proposed project to improve flood protection along a reach of the Platte and Elkhorn Rivers in eastern Nebraska, the Omaha District of the U.S. Army Corps of Engineers (USACE) is studying the possible impacts that upgrading and raising existing levees might have on channel morphology, and on emerged and submerged sandbars. Three Federally designated endangered species—the pallid sturgeon (*Scaphirhynchus albus*), the piping plover (*Charadrius melodus*), and the least tern (*Sterna antillarum*)—

and two State-designated endangered or threatened species—the sturgeon chub (endangered) and the bald eagle (threatened)—use the river and sandbars as habitat for nesting and foraging. There is concern that the increased constriction of flow by the proposed levees might have detrimental effects on the areas used by these species. As part of the study, the U.S. Geological Survey (USGS) has performed a qualitative geomorphological assessment along a reach of the Platte and Elkhorn Rivers.

Purpose and Scope

As specified by the USACE, four tasks were included in the assessment—a literature search and analyses of: aerial photography, streamflow data, and sediment data. The purpose of this report is to document the methods used to accomplish these tasks and to present the results that were obtained from the literature search and the various analyses. The literature search included applicable general alluvial process theory, and case studies and assessments of similar projects. The photographic analysis covered the study reach as discussed next and included data from 1973 to 1997. The streamflow and sediment analyses incorporated data from two stream-gaging stations—the Platte River near Ashland (streamflow data at U.S. Highway 6, herein referred to as the Ashland site), and the Platte River at Louisville (streamflow and sediment data about 11 miles downstream, herein referred to as the Louisville site). The streamflow analyses included data from 1928 to 1999. The sediment analysis included data from 1971 to 1999.

Study Reach

The original study reach extended 7.3 miles upstream from the U.S. Highway 6 crossing of the Platte River and included the lower 2.3 miles of the Elkhorn River, which enters the Platte River from the left[1] (fig. Intr_1). This matched the extent of the Western Sarpy (County) levee, which runs along the left banks of the Platte and Elkhorn Rivers. The existing Clear Creek levee is in Saunders County along the right bank of the Platte River and extends from about 2.4 to 12 miles upstream from the U.S. Highway 6 bridge. To overlap the channel reach represented in the streamflow analysis for the Ashland site (which reflects channel changes downstream of U.S. Highway 6) with that for the aerial photography analysis, the study reach was shifted about 2 miles downstream, such that the reach began just upstream from the mouth of the Elkhorn River and ended near the mouth of Salt Creek (John Remus II, USACE, oral commun., 2000). Because of a problem with one of the sets of aerial photographs, as explained later, the study reach was again adjusted and shortened to end at the Saunders/Cass County line (figure Intr_1).

[1] Left and right are referenced to facing downstream.

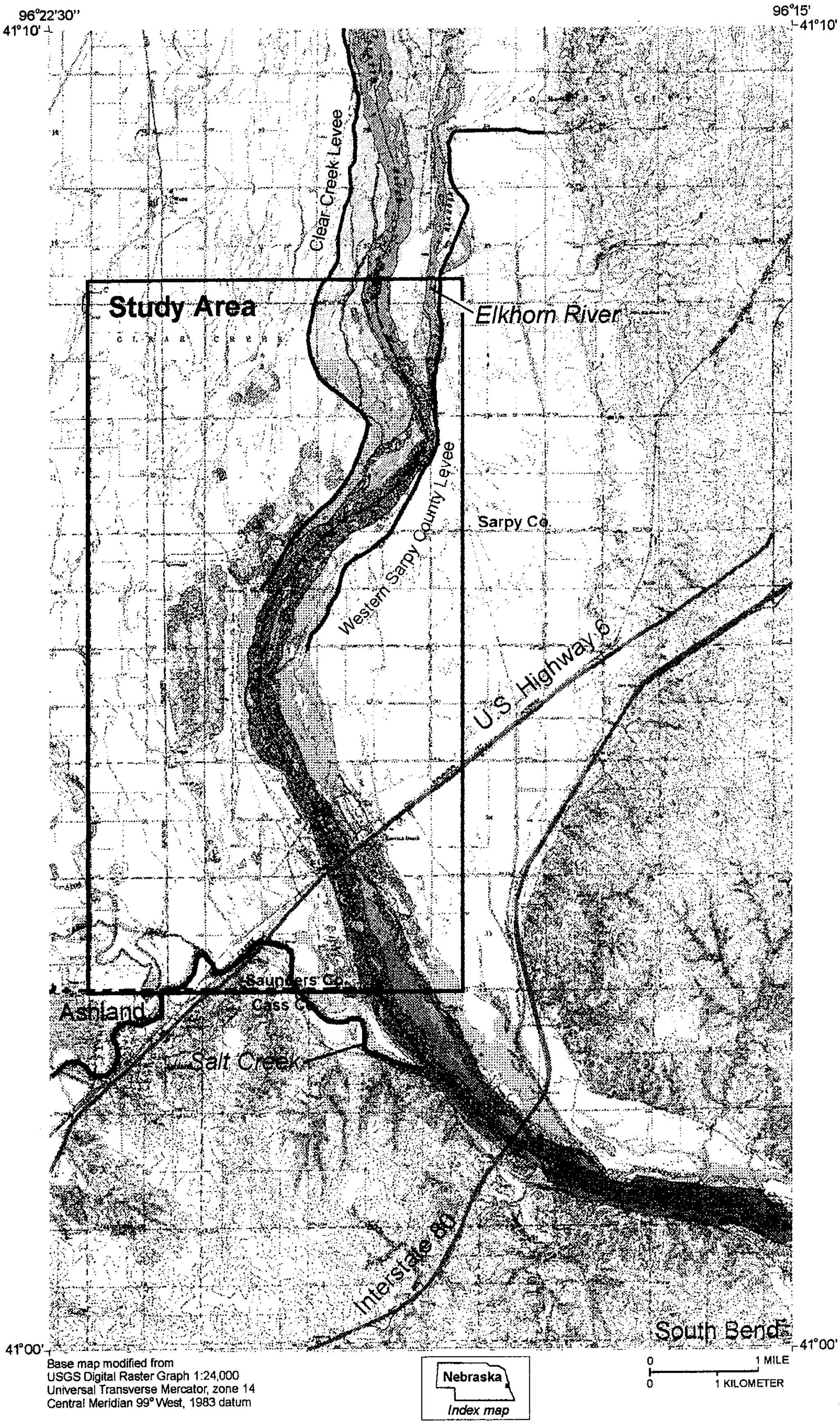


Figure Intr_1. Study reach of Platte River along Saunders and Sarpy Counties, Nebraska.

The Clear Creek levee was originally built in 1908 and has been added onto in length and height by the local people over the years. It provides open-water flood protection to a recurrence interval of about 30 to 50 years. The Western Sarpy levee was originally built in 1918 and provides open-water flood protection to a recurrence interval of about 10 to 30 years. Both levees were overtopped in 1993, and the Western Sarpy levee was overtopped again in 1997 with breaks from that event still existing (John Remus II, USACE, oral commun., 2000). The March 1993 flood, caused by the release of an ice jam, had an estimated discharge of 130,000 cubic feet per second (ft^3/s) with much of the flow bypassing the U.S. Highway 6 bridge. The July 1993 flood had a discharge of 114,000 ft^3/s. The February 1997 flood had an estimated discharge of 38,000 ft^3/s; ice jams were involved again. According to Soenksen and others (1999), the 100-year recurrence interval flood for Platte River near Ashland is 135,000 ft^3/s and the 10-year flood is 79,900 ft^3/s.

LITERATURE SEARCH

A literature search was conducted with the goal of gathering information on levee impacts including applicable general alluvial process theory, and case studies and assessments of similar projects. More specifically, it focused on the impacts that levees have on the size and distribution of sandbars, the impacts that levees have on stage trends, and the significance of the location of the levees relative to the river banks.

Methods

Several documents, of which the authors were already aware, were gathered from individual collections or obtained from the USGS office library in Lincoln, Nebraska. A search of GeoRef[2] was done using key words including: braided rivers, sedimentation, bar formation, ice jams, and levee impacts. Several reports and papers were brought to the authors' attention by interested parties during the course of the study; these were obtained and reviewed. In addition, the USACE provided the authors with several documents. Based on the results of the GeoRef search and an examination of the references listed in the documents the authors already had, more documents were retrieved from the University of Nebraska–Lincoln and USGS regional libraries or directly from the appropriate agencies. The amount of literature available as well as that collected is extensive. However, no case studies or analytical assessments of similar projects were found—none relating directly to the effects of levees on sandbars. A summary of the applicable literature is given next. References for the literature discussed are included in the list of selected references at the end of this report. References for the

[2] Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

literature examined but not specifically discussed are contained in appendix A. The review of that literature was limited by the time span of this project and cannot be considered comprehensive.

Results

The work of **Leopold and Wolman (1957)** appears to be fundamental and is often cited by others in discussions of river channel patterns and bedforms. The paper incorporates data from flume runs and for actual rivers. They present many conclusions, only a few of which will be discussed here.

- "Braiding does not necessarily indicate an excess of total load." —page 39
- "Channel width appears to be primarily a function of near-bankfull discharge, in conjunction with the inherent resistance of bed and bank scour. ... achievement of a relatively stable width at high flow is a primary adjustment to which the further interadjustments between depth, velocity, slope, and roughness tend to accommodate."—page 39

Constriction of high flows by levees close to existing banks would seem to impose a new condition that could result in nonequilibrium of the system. Based on the previous discussion, this could result in a readjustment by widening of the channel. The duration of the confined flow is probably a key factor to be considered.

- "Roughness in streams carrying fine material ... is also a function of the dunes or other characteristics of the bed configuration. ... if roughness also is variable, depending on the transitory configuration of the bed, then a number of combinations of velocity, depth, and slope will satisfy equilibrium."—page 39

This would imply that bedforms could very well change in response to nonequilibrium conditions as might happen with confining of flows by levees.

Based on a report by **Crowley (1981)**, a certain amount of scouring of emerged sandbars is needed to keep them unvegetated; otherwise, they can become stabilized and develop into islands. This island development results in eventual narrowing of the channel and increases overbank flooding. Scouring occurs only during high flows when sandbars are submerged by at least 20 centimeters (cm) of flow.

- "The channels of the Platte River in Nebraska are characterized by large spatially periodic deformations of the channel bed ... here termed macroforms ...and are emergent at all but the highest flow stages. Macroforms are quasi-stable features ... that move at relatively slow rates through the channel during high flows." —page 1
- "Analysis of land-grant maps and aerial photographs taken by the writer show that relatively minor channel changes have occurred along the Platte River downstream

of Grand Island, Nebraska since 1865; therefore, there has been little change in the flow regime. ... before the encroachment of vegetation on the channels, there is no historical evidence to indicate that overbank flows occurred regularly. ... Overbank flows ... appear to be recent phenomenon caused by bank stabilization and increased channel roughness from vegetation." —page 4

- "Macroforms are active only at the highest flows. ... Macroforms do not move downstream at any detectable rate until they are covered with approximately 20 cm of water. Sediment is eroded from the stoss side of the macroforms and ... avalanches down the slipface ..."—page 16
- "These data indicate that migration rate increases downstream ... because discharge increases downstream, particularly downstream from the junction with the Loup River. However, a definite trend cannot be established because of insufficient data. These migration rates are average rates; some years, the macroforms probably do not migrate at all." —page 19
- "Channel narrowing is chiefly the result of vegetation encroachment on macroforms in the river. The vegetation anchors the sediment ... and prevents the macroform from moving downstream at high flow. Once anchored, the macroform is transferred slowly into an island." —page 20
- "Vegetation has the opportunity to be established on the macroforms upstream from Grand Island, because annual peak flows no longer are capable of clearing vegetal growth from macroforms each year. Downstream from Grand Island, peak flows inundate macroforms often enough to maintain the original width of the river."—page 24
- "From simple geometrical considerations of macroform shape (fig. 13), an equation can be developed to predict the depth and duration of flow required to erode the stoss side of macroforms to a sufficient depth to remove new vegetal growth."—page 32

The general character of the types of sandbars occurring on the lower Platte River is given by **Smith (1971).**

- "... the Platte River in eastern Nebraska carries a dominantly sand bed load, and braiding is primarily affected by dissection of transverse bars. ... In braided streams composed of well-sorted sandy sediments, however, bars are more typically transverse with wide, flat-topped tabular bodies and sinuous to lobate depositional fronts which characterize the braided reaches of the lower Platte." —page 3407
- "Transverse bars are the most characteristic and important bed forms in the lower Platte River." —page 3410
- "Bars at high flows are often uniformly lobe-shaped and sometimes assume a quasi-repetitive character ... As discharges decrease, however, they tend to

coalesce and distort into a randomly distributed variety of large and small solitary forms."—page 3411

Culbertson and Scott (1970) documented the development and movement of transverse bars in the Rio Grande conveyance channel near Bernardo, New Mexico. The channel has a maximum capacity of 2,000 ft^3/s.

- "Suspended sediment concentration at the gaging station was relatively constant, varying from about 3,000 to 5,000 milligrams per liter. An experiment was carried out to determine how the large dune bed forms would change as a result of periodically increasing the discharge at the headgates. A number of transverse bars were produced, apparently caused by the periodic increase in discharge. ... Discharge was then increased from about 900 to 1,000 cfs [cubic feet per second]. ... No discernible change in the bed configuration was noted. ... The discharge was increased to 1,100 cfs on May 25 and to 1,200 cfs on May 26. No discernible change in the bed configuration or water-surface slope was observed during this period. On May 27, a large transverse bar had formed ... the bar ... continued to move as a discrete form until May 30. ... The average length of the bar ... was about 350 feet, and it covered the entire width of the channel. The average rate of travel ... was about 350 feet per day. ... Other bars also were observed in the channel farther downstream ... These bars moved as periodic forms, but the length and number of bars within a series changed from day to day, indicating that the bars coalesced and broke up again as they moved down the channel."—page B238
- "Samples of bed material show that the median diameter on the bar was 0.18 mm [millimeters] and that the median diameter in the dune bed reaches was 0.24 mm."—page B241

Miall (1977) discussed, among other things, the necessity of high flows in the formation of sandbars in braided streams.

- "Linguoid and transverse bars are most typical of sandy braided rivers." —page 14
- "... the bars themselves are large-scale bedforms generated during flood stages (Collinson, 1970, p. 41). N.D. Smith (1971, p. 3411) suggested that they form by the coalescence of dune fields, and this would appear to be confirmed by the observation of Culbertson and Scott (1970). They observed that bars were generated only at a discharge [total discharge in the channel] in excess of 28 m^3/sec. [cubic meters per second], whereas the bar modification processes documented by N.D. Smith (1971a, fig. 8) occurred when discharges over the bar [bar mouth discharge, not the total discharge of the river] was less than 4 m^3/sec."—page 15
- "Point bars tend to be thought of as typical of meandering streams, but they also occur in braided environments ... This group of bar structures is of a larger order of magnitude ...They tend to form in braided rivers by the coalescence of smaller bedforms, such as dunes and linguoid bars ..."—page 16

Randle and Woodward (1991) suggest that the reduction in sediment supply is primarily responsible for the narrowing of the Platte River in the Overton area and that an increase in the effective discharge will not cause it to widen. This would seem to conflict with conclusions of Leopold and Wolman (1957).

- "...channel narrowing of the Platte River can be described primarily by changes in water discharge and sediment load even when the effects of vegetation, streambank protection, or bridges are ignored." —page 14–17
- "Comparison of the width-discharge curves for the 1938 and 1983 conditions shows that the channel has primarily remained narrow due to a reduction in the bed material load supplied to the Platte River. The reduction in bed material load has also resulted in coarsening the bed with concurrent narrowing. ... Because of the reduction in the supply of sediments from 1938 to 1983, an increase in the effective discharge will not result in a substantial change in the channel width. However, a decrease in the effective discharge would cause further narrowing of the channel under 1983 conditions." —page 14–24

A study by the **U.S. Army Corps of Engineers (1990)** of the Platte River (Platte River cumulative impacts analysis, report no. 5) shows that flow-distribution changes, channel-width reduction, and woody-vegetation encroachment have decreased habitat within the basin. Reach 3 from Duncan to the Missouri River confluence (including the area of the proposed project) was considered the least impacted of the three study reaches, which span the whole river basin. The report states that bank stabilization structures encroaching riverward less than 5 percent of the active channel width have resulted in negligible impacts. If bank stabilization structures, that are in the channel and would necessarily constrict flow most of the time, are not detrimental (if their size is limited), then it would seem that levees that are outside the channel and restrict flow for a small part of the time probably would not be detrimental.

Karlinger and others (1983) present three methods for estimating discharges necessary to maintain channel widths on the Platte River. The first method involves the use of an empirical equation to estimate effective discharge and the second method derives from basic geometry of the bedforms and is based on the work of Crowley (1981), previously discussed. Regime equations that relate channel slope, center depth of channel, width of channel, water discharge, total bed-material load, and a measure of the bed-material particle size are used in the third method.

Based on an analysis of aerial photographs of the lower Platte River for the period 1949 to 1988, **Rodekohr and Engelbrecht (1988)** note that "since the stability of barren islands increases as one proceeds downstream from the Wann quadrangle, the source of the sediment may be attributed to the Elkhorn River." —page 13. The Wann quadrangle includes the area immediately upstream of the study reach.

AERIAL PHOTOGRAPHY ANALYSIS

Four sets of large-scale aerial photographs of the study reach were obtained for the years 1973, 1990, 1994, and 1997. Using a geographic information system (GIS), the photographs were analyzed to determine the number, area, and shoreline length of three types of emerged sandbars in the study reach, as well as of islands. Emerged sandbars were defined as having no permanent (woody) vegetation, whereas islands were defined as having permanent (woody) vegetation. There appears to be no relation between the number or area of sandbars and river stage (gage height) or streamflow discharge; there were also no definitive trends with time.

Data

Several types and sources of aerial photography for the study reach were available, including, but not limited to:

- **USACE**—The U.S. Army Corps of Engineers, Omaha District, had one set of color photographs that were taken in 1995.
- **EROS Data Center**—The Earth Resources Observation System (EROS) Data Center had various types of aerial photography available including those from the National High Altitude Aerial Photography Program (NHAP), which was started in 1980, to consolidate the many federal programs for aerial photography. The scale of photographs was 1:20,000. The National Aerial Photography Program (NAPP) replaced NHAP in 1987 when the flying height was changed to 40,000 feet, which changed the scale to 1:40,000. The U.S. Geological Survey's National Mapping Division administers the program, and photographs are updated every 5 years.
- **NNRC**—The Nebraska Natural Resources Commission (NNRC, now part of the Nebraska Department of Natural Resources) had digital orthophoto quadrangles (DOQs) available at a scale of 1:12,000.
- **UNL–C&SD**—The Conservation and Survey Division (C&SD) of the University of Nebraska—Lincoln (UNL) had a library of aerial photographs at various scales, which includes a historical collection.
- **USDA–FSA**—The aerial photography field office of the U.S. Department of Agriculture's Farm Service Agency (USDA–FSA) had NHAP/NAPP photographs and other photographs back to 1978.
- **City of Omaha**—The city had black and white aerial photographs of the greater Omaha area that were taken on a 2- to 3-year schedule from 1973 to 1997. The photographs were at a scale of 1:6,000.

Photographs from the USACE and the City of Omaha could be obtained in a matter of days, which was considerably shorter than the time required from the other sources. Additionally, the City of Omaha's photographs were at the largest scale, which provided the best resolution. Because of the larger scale and the faster delivery time, the photographs were obtained from the City of Omaha. The Papio-Missouri River Natural Resources District (PMR–NRD) served as intermediary and they were able to obtain the photographs quickly and at minimal cost.

Methods

The photographs from the years 1973, 1990, 1994 and 1997 were selected to cover the time span of interest (from earliest available photographs, and covering 20 years or more) and to have similar river stage during the time each of the photographs were taken. The dates of the photographs and the corresponding mean daily discharge and stage associated with those days are given in table AP_1. The photographs were on paper medium, approximately 34 inches square. The photographs were checked visually for quality and consistency. The revised river reach to be analyzed was to begin just above the Elkhorn River confluence and end just below the Salt Creek confluence. This reach spanned a four-photograph grid, with two main photographs spanning the reach from just upstream of the mouth of the Elkhorn River to the Saunders-Cass County boundary, and the other two photographs spanning the short reach remaining. However, a date discrepancy was found on the photographs of this short reach in the December 21, 1994, set. The full foliage on the trees indicated that they had obviously been taken during the summer, and therefore did not match up with the other photographs of the set. For this reason, the final reach studied was changed to coincide with the area of the two main photographs.

Table AP_1. Dates of aerial photographs analyzed and the corresponding streamflow discharges and stages for Platte River near Ashland, Nebraska

Date photographed	Corresponding mean daily discharge (cubic feet per second)	Corresponding mean daily stage (feet)
11/29/73	9,875	16.4
3/19/90	6,580	15.7
12/21/94	7,400	16.11
[1] 5/5/97 & 5/9/97	[1] 7,510 & 10,700	[1] 16.0 & 16.6

[1] Photograph set for 1997 was taken on two separate days, and respective discharges and stages are shown for each date.

Scanning Photographs and Rectifying Images

Personnel at the NNRC scanned the photographs on a drum scanner at 500 dots per inch (dpi). The images were saved in tagged-image-file format (tiff) and transferred onto

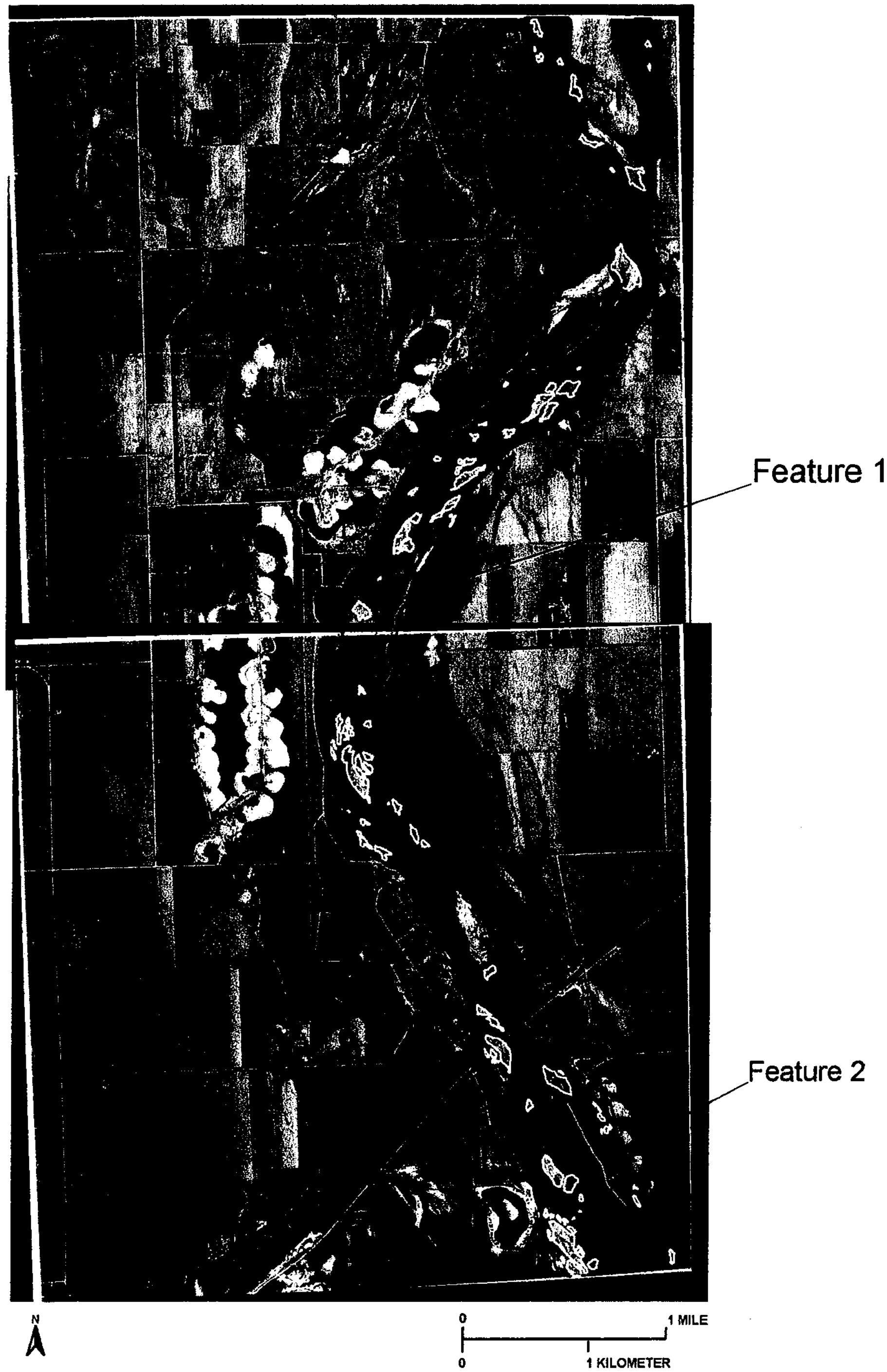
CD-ROMs; each file was approximately 320 megabytes. Because of this large file size, the files were re-sampled to 25 percent of the original scanned size using a bicubic algorithm in Adobe PhotoShop.

All images were geo-rectified to 1993 DOQs in ArcView 3.2, using a third-party extension called ImageWarp. By utilizing road intersections and identifiable landmarks, eleven or more ground control points were selected interactively for each image. Using these points, a third order polynomial transformation was applied to the images to geo-rectify them to an existing GIS projection. The scanned images were considered rectified when this transformation produced a root mean squares (RMS) error equal to or less than 1. Two of the images—the southern half of the study area for 1990 (1990-S) and the northern half of the study area for 1994 (1994-N), had to be re-rectified. After repeated attempts, the 1994-N image did not rectify with an acceptable RMS error. Instead, the lines of interest in this image were digitized directly from the paper photograph, using an Altek digitizer. The geo-rectified tiff images were saved with the associated world file in UTM zone 14, units meters, North American Datum 83. All images then were drawn in Arc/Info 7.2.1, using the ArcEdit module.

Drawn geo-rectified images were digitized "heads-up" (or on-the-screen) to define selected channel features. The identification of emerged bars and islands was accomplished from color contrasts in the aerial photographs. In some cases, color contrasts showed clear separation between water and emerged bars. Lighter colors usually indicated emerged bars without vegetation. Often shadows on the water surface were distinct indications of emerged bars and islands. Shadows also could be used to verify vegetation, especially trees. In other cases, the colorations were transitional between the color of the water and the color of emerged bars, a possible indication of submerged bars. Judgment was used to differentiate shallowly submerged and emerged features. The image quality may have contributed to subjective elements of this task. Darker areas of the photographs made determination more difficult because of reduced contrast. The digitizing process consisted of defining nine different types of lines (or arcs) based on differentiation of the channel features (table AP_2 and figs. AP_1-AP_4). Note that the black areas in figures AP_1-AP_4 represent the movement or rectification of the images from their original to their final sizes, shapes, and locations. Although there was overlap for each set of images, ImageWarp, which was used to generate the figures, did not allow the underlying rectified images to show through the original area of the overlaying images. Once digitized, the arcs associated with each year were placed into four separate GIS coverages: RIV73 (for arcs associated with 1973), RIV90 (for arcs associated with 1990), RIV94 (for arcs associated with 1994), and RIV97 (for arcs associated with 1997).

Table AP_2. Digitized arc types

Arc type number	Channel features
1	Reach cutoffs (used to define the ends of the study reach)
2	Bank–water interface
3	Bank–bank bar interface
4	Bank bar–water interface
5	Water–isolated island interface
6	Water–island (with bar) interface
7	Island (with bar)–island bar interface
8	Island bar–water interface
9	Water–isolated bar interface

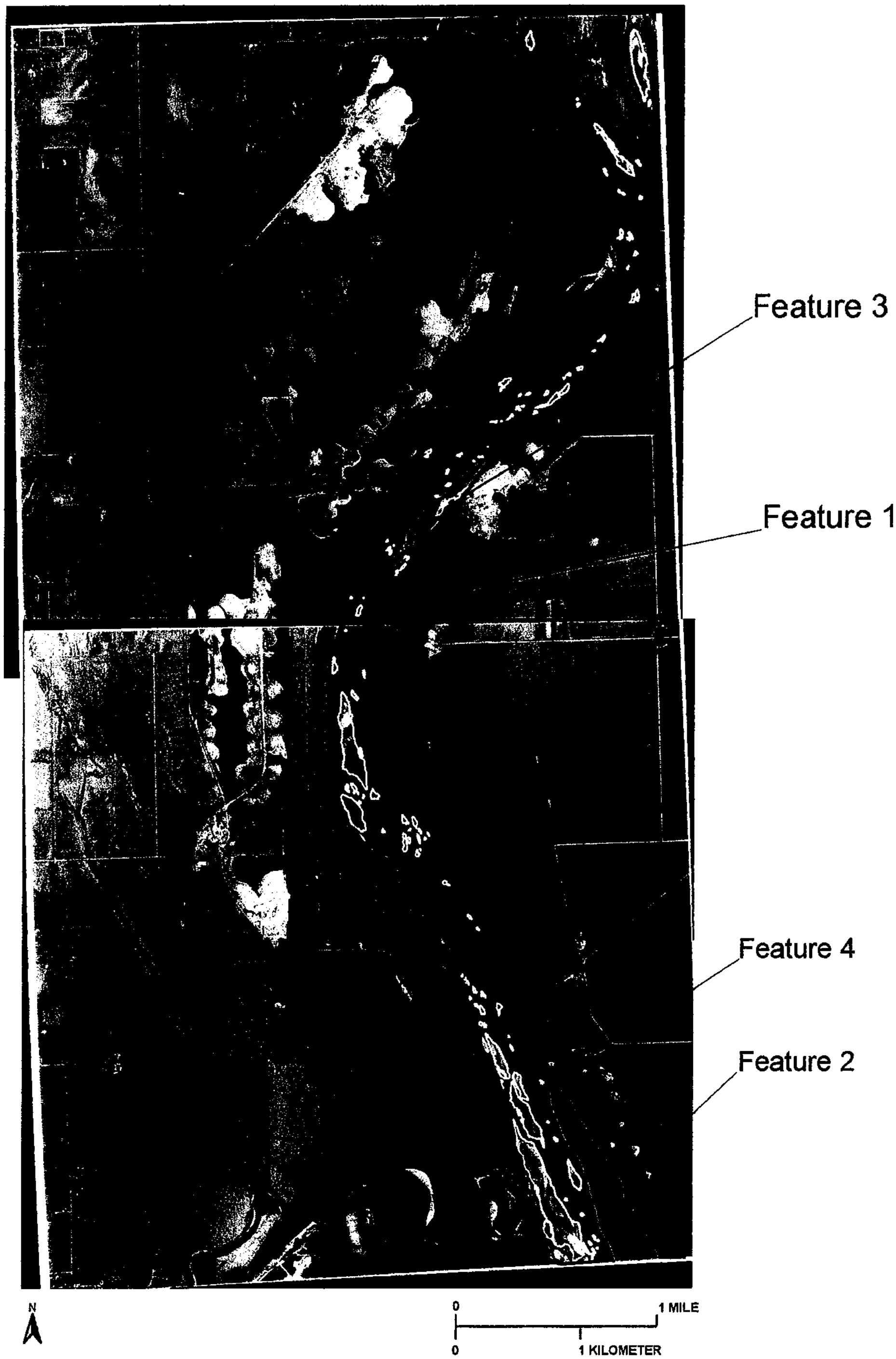


EXPLANATION

Digitized arc types

- Reach cutoffs (define ends of study reach)
- Bank--water interface
- Bank--bank bar interface
- Bank bar--water interface
- Water--isolated island interface
- Water--island (with bar) interface
- Island (with bar)--island bar interface
- Island bar--water interface
- Water--isolated bar interface

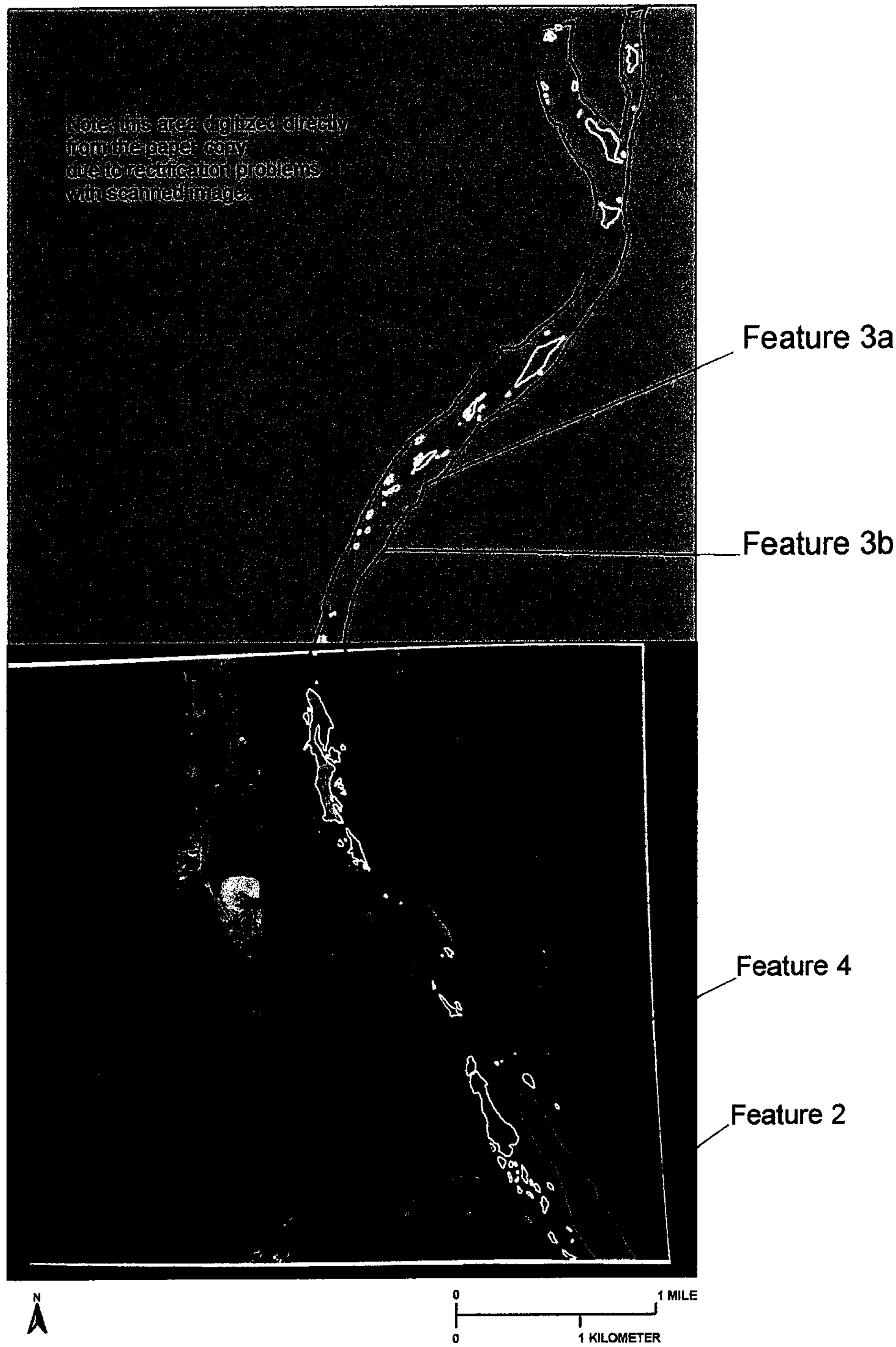
Figure AP_1. Aerial photographs and digitized channel features of the Platte River near U.S. Highway 6 for November 29, 1973.



EXPLANATION

Digitized arc types			
———	Reach cutoffs (define ends of study reach)	———	Water--isolated island interface
———	Bank--water interface	———	Water--island (with bar) interface
———	Bank--bank bar interface	———	Island (with bar)--island bar interface
———	Bank bar--water interface	———	Island bar--water interface
			Water--isolated bar interface

Figure AP_2. Aerial photographs and digitized channel features of the Platte River near U.S. Highway 6 for March 19, 1990.

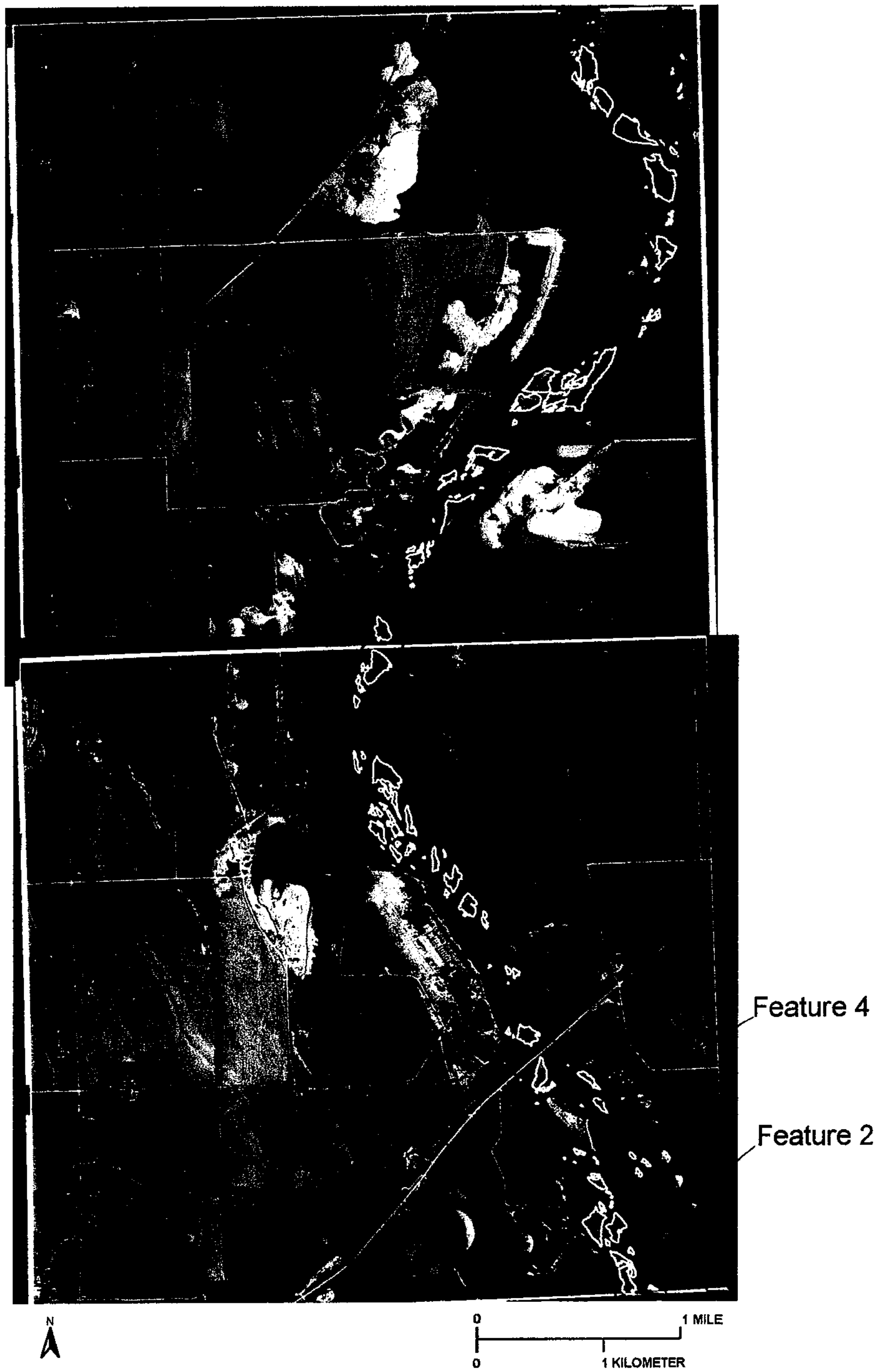


EXPLANATION

Digitized arc types

- Reach cutoffs (define ends of study reach)
- Bank--water interface
- Bank--bank bar interface
- Bank bar--water interface
- Water--isolated island interface
- Water--island (with bar) interface
- Island (with bar)--island bar interface
- Island bar--water interface
- Water--isolated bar interface

Figure AP_3. Aerial photographs and digitized channel features of the Platte River near U.S. Highway 6 for December 21, 1994.



EXPLANATION	
Digitized arc types	Water--isolated island interface
Reach cutoffs (define ends of study reach)	Water--island (with bar) interface
Bank--water interface	Island (with bar)--island bar interface
Bank--bank bar interface	Island bar--water interface
Bank bar--water interface	Water--isolated bar interface

Figure AP_4. Aerial photographs and digitized channel features of the Platte River near U.S. Highway 6 for May 5 or 9, 1997.

Assigning Attributes and Computing Feature Variables

After each GIS coverage was digitized, either from the scanned aerial photographs or from paper prints, the coverage was 'built' as a line coverage using the BUILD command in Arc/Info. The attribute field "arctype" was added to each coverage, then the arc type field values from table AP_2 were assigned to the digitized coverage. Once all the arcs were coded, the coverage was 'built' as a polygon coverage and the attribute field "polytype" was added. The values assigned to the polytype attribute for each polygon were computed based on the criteria shown in table AP_3.

Table AP_3. Digitized polygon types

Polygon type number	Polygon type	Arc types
1	Reach area	1, 2, and 3
2	Bank bar area	3 and 4
3	Isolated island area	5
4	Island area of island/bar combination	6 and 7
5	Bar area of island/bar combination	7 and 8
6	Total area of island/bar combination	6 and 8
7	Isolated bar area	9

The following command sequence was used to add the arctype and polytype attributes to each coverage:

For the arctype attribute:

build riv73 line

additem riv73.aat riv73.aat arctype 3 3 N

arcedit

(manually code arc values, save coverage)

For the polytype attribute:

build riv73 poly

additem riv73.pat riv73.pat polytype 3 3 N

arcedit

(manually code polygon values, save coverage)

When assigning the values for the arctype and polytype fields in ArcEdit, the same processing sequence was used: (1) The edit feature was set to either "arc" or "polygon", (2) a set of arcs or polygons was selected using the mouse, (3) the desired features displayed on-screen were selected by clicking, and (4) the command "calc arctype = N" (or polytype) was given, where N is a value from 1 to 9 for arcs or 1 to 7 for polygons.

Once the coverages were set up with the proper attributes, several feature variables were computed from them. These variables included the bank length, reach length, reach area, and water area of the entire area being analyzed as well as the shoreline length, area, and number of the different types of features that were identified within that area. The arcs and polygons that comprised these different variables are given in table AP_4.

Table AP_4. Arcs and polygons used to compute various geomorphologic variables

Feature variable	Arcs, polygons, or computation
Bank length	Arcs 2+3
Reach length	Bank length / 2
Shoreline length of:	
Bank bars	Arc 4
Isolated islands	Arc 5
Islands with bars	Arc 6
Island bars	Arc 8
Isolated bars	Arc 9
Water area	Polygon 1 - (Polygons 2+3+6+7)
Number and areas of:	
Bank bars	Polygon 2
Isolated islands	Polygon 3
Bar islands	Polygon 4
Island bars	Polygon 5
Islands plus attached bars	Polygon 6
Isolated bars	Polygon 7

Once these variables were computed, relative frequencies and proportions were computed for the features. Relative frequencies of each feature, for reach length and reach area, were computed by taking the number of occurrences of the feature and dividing by the reach length or area. The ratio of shoreline length to reach length was computed by dividing the total shoreline length of each feature by the reach length. The percentage of feature area to reach area was computed by dividing the total area of each feature by the area of the reach.

Results

The areas and resulting shoreline lengths of the various geomorphic features were computed for each set of images. These feature variables were compared to evaluate differences with time, stage, and discharge. However, no definitive correlation of the variables to time, stage, or discharge was found.

Numbers, Areas, and Shoreline Lengths of Geomorphic Features

The numbers and areas of bank bars (sandbars attached to the river bank), island bars (sandbars attached to islands), and isolated bars (sandbars completely surrounded by water) are listed by size range and by total in table AP_5. The numbers and areas of bar islands (islands with one or more attached sandbars) and isolated islands (islands with no attached sandbars) are listed by size range and by total in table AP_6. The images (figs. AP_1-AP_4) and tables show how dynamic the system is. Over time, sandbars can appear and disappear, attach to banks or islands, or can become parts of islands or banks when vegetation becomes well established. It is important to consider the figures and tables in combination. What may appear in the table to be a large loss or gain in area is often a change in classification of the area.

For example, in 1973 (fig. AP_1), there is one large isolated island (feature 1) near the intersection of the photo images and one large bar island (feature 2) downstream from U.S. Highway 6. In 1990 (fig. AP_2), both islands switched classifications, as an island bar became attached to the isolated island (feature 1) and the bank bars on the bar island (feature 2) either washed away or became part of the island as woody vegetation was established. In addition, a second large isolated island (feature 3) and a small bar island (feature 4) were formed. By 1994 (fig. AP_3), the large bar island of 1990 (feature 1) became attached to the bank and was no longer classified as an island at all, and the small bar island of 1990 (feature 4) appears to have converted to a sandbar. Meanwhile, the smaller of the two large isolated islands of 1990 (feature 3) appears to have split into two islands by 1994 (features 3A and 3B); then by 1997 (fig. AP_4), both of those have disappeared. The larger of the two isolated islands of 1990 (feature 2) remained relatively unchanged for 1994, but, by 1997 a bank bar had become attached and it was once again reclassified—this time as a bar island (as per 1973).

Over the entire period 1973 to 1997, the total sandbar area has increased (table AP_5) while the total island area has decreased (table AP_6) (primarily due to a large island attaching to the banks (feature 1) as previously discussed), but overall, the combined bar and island area remained generally stable over the period. The largest change in total feature area occurred between 1994 and 1997 when the area increased about 5 percent. For each set of images, isolated bars accounted for most of the total area of sandbars. Isolated bar area remained relatively constant until 1994 after which it increased considerably by 1997. In the same time span, bank bar area decreased and island bar area increased.

Table AP_5. Numbers and areas of bank, island, and isolated sandbars by size range and total as determined from aerial photographs for November 29, 1973, March 19, 1990, December 21, 1994, and May 5 or 9, 1997

[Area values computed from original unrounded data and then rounded to the nearest ten; total values, therefore, may not match the sum of the values shown for the individual size ranges]

Size range	Number				Area (square meters)			
(square meters)	1973	1990	1994	1997	1973	1990	1994	1997
	Bank bars (attached to stream banks)							
>0–500	1	0	1	1	360	0	80	40
>500–1,000	1	0	4	0	940	0	3,120	0
>1000–2,000	0	0	1	2	0	0	1,030	2,450
>2000–4,000	1	2	0	0	3,160	6,240	0	0
>4,000	3	4	8	6	153,740	76,040	241,950	137,720
Total	**6**	**6**	**14**	**9**	**158,200**	**82,280**	**255,460**	**140,210**
	Island bars (attached to islands)							
>0–500	0	0	0	0	0	0	0	0
>500–1,000	0	1	0	0	0	550	0	0
>1000–2,000	1	0	0	0	1,200	0	0	0
>2000–4,000	0	1	0	0	0	2,550	0	0
>4,000	1	0	0	1	57,980	0	0	66,290
Total	**2**	**2**	**0**	**1**	**59,180**	**3,100**	**0**	**66,290**
	Isolated bars (completely surrounded by water)							
>0–500	17	69	29	68	4,100	17,850	7,680	13,840
>500–1,000	15	30	20	27	10,220	21,680	14,070	18,730
>1000–2,000	20	14	20	18	29,740	21,060	27,710	24,610
>2000–4,000	13	10	8	13	37,620	29,700	23,260	37,020
>4,000	31	12	15	32	370,240	410,930	384,350	575,680
Total	**96**	**135**	**92**	**158**	**451,930**	**501,210**	**474,860**	**669,870**
	All bars							
>0–500	18	69	30	69	4,460	17,850	7,830	13,880
>500–1,000	16	31	24	27	11,170	22,230	17,190	18,730
>1000–2,000	21	14	21	20	30,950	21,060	31,330	27,060
>2000–4,000	14	13	8	13	40,780	38,490	23,260	37,020
>4,000	35	16	23	39	581,960	486,970	641,420	779,680
Total	**104**	**143**	**106**	**168**	**669,310**	**586,590**	**721,030**	**876,370**

Table AP_6. Numbers and areas of bar islands and isolated islands by size range and total as determined from aerial photographs for November 29, 1973, March 19, 1990, December 21, 1994, and May 5 or 9, 1997

[Area values computed from original unrounded data and then rounded to the nearest ten; total values, therefore, may not match the sum of the values shown for the individual size ranges]

Size range	Number				Area (square meters)			
(square meters)	1973	1990	1994	1997	1973	1990	1994	1997
Bar islands (areas do not include that of the attached bars)								
>0–500	0	0	0	0	0	0	0	0
>500–1,000	0	0	0	0	0	0	0	0
>1000–2,000	0	0	0	0	0	0	0	0
>2000–4,000	0	0	0	0	0	0	0	0
>4,000	1	2	0	1	385,060	137,430	0	330,460
Total	**1**	**2**	**0**	**1**	**385,060**	**137,430**	**0**	**330,460**
Isolated islands (no attached bars)								
>0–500	0	0	0	0	0	0	0	0
>500–1,000	0	0	0	0	0	0	0	0
>1000–2,000	0	0	0	0	0	0	0	0
>2000–4,000	0	0	0	0	0	0	0	0
>4,000	1	2	3	0	143,220	444,060	428,180	0
Total	**1**	**2**	**3**	**0**	**143,220**	**444,060**	**428,180**	**0**
All islands								
>0–500	0	0	0	0	0	0	0	0
>500–1,000	0	0	0	0	0	0	0	0
>1000–2,000	0	0	0	0	0	0	0	0
>2000–4,000	0	0	0	0	0	0	0	0
>4,000	2	4	2	1	528,280	581,490	428,180	330,460
Total	**2**	**4**	**2**	**1**	**528,280**	**581,490**	**428,180**	**330,460**

The water-feature interfaces, or shoreline lengths, were computed for each feature type, and are shown in table AP_7. As with data for the numbers and areas of sandbars and islands, the data for the shoreline lengths can change significantly—not only because of their dynamic nature, but also as a result of a change in classification from one type of feature to another. The total shoreline lengths for both sandbars and islands increased over the period 1973 to 1997, especially since 1994. Just as for area, isolated bars accounted for most of the total shoreline lengths of sandbars.

Table AP_7. Shoreline lengths for each feature
[Length values computed from original unrounded data and then rounded to the nearest ten; total values, therefore, may not match the sum of the values shown for the individual categories]

	Shoreline length (meters)			
	1973	**1990**	**1994**	**1997**
Bank bars	1,830	1,680	3,150	2,340
Island bars	1,180	150	0	1,460
Isolated bars	28,730	30,300	23,840	39,880
All bar types	**31,740**	**32,130**	**26,990**	**43,670**
Bar islands	2,850	3,360	0	2,930
Isolated islands	3,140	6,500	6,640	0
All islands	**5,990**	**9,860**	**6,640**	**2,930**
All features	**37,740**	**42,000**	**33,630**	**46,600**

The total reach length and area were computed for each year (table AP_8). Although there are fluctuations in the data for the various years, both reach length and area have decreased, overall, during the period 1973 to 1997.

Table AP_8. Total reach length and area for each year
[Values computed from original unrounded data and then rounded to the nearest ten]

	Reach Dimensions			
	1973	**1990**	**1994**	**1997**
Length (meters)	13,550	13,230	13,480	13,250
Area (square meters)	5,328,230	5,454,680	5,008,950	5,104,980

Relative Comparisons of Geomorphic Features

Number, area, and shoreline length data for the various feature types and of the river reach were used to compute relative frequencies and densities, and ratios and percentages of those features. The relative frequency (table AP_9) and density (table AP_10) of combined sandbars and island features for each year are reported. Both have fluctuated but show overall increases during the period 1973 to 1997.

Table AP_9. Relative frequency of combined bar and island features

Relative frequency of combined bars and islands (number per kilometer)			
1973	**1990**	**1994**	**1997**
7.8	11.1	8.0	12.7

Table AP_10. Relative density of combined bar and island features

Relative density of combined bars and islands (number per hectare)			
1973	**1990**	**1994**	**1997**
0.20	0.27	0.22	0.33

The ratio of shoreline to reach length for each feature type is given in table AP_11. The percentage of feature area to reach area is given for each feature type in table AP_12. The shoreline ratios for all bars and isolated bars increased overall during 1973 to 1997, especially since 1994, while the shoreline ratios of all islands decreased overall, especially since 1990. The percentage of bar area in the reach increased overall during 1973 to 1997 and for each image set since 1990. The opposite was true for islands as the percentage of area in the reach decreased for the same time periods. The percentage of water area in the reach remained relatively constant during the period.

Table AP_11. Ratio of shoreline length to reach length for each feature type

	Shoreline length per reach length (dimensionless)			
	1973	**1990**	**1994**	**1997**
Bank bars	0.14	0.13	0.23	0.18
Island bars	0.09	0.01	0.00	0.11
Isolated bars	2.12	2.29	1.77	3.01
All bars	**2.34**	**2.43**	**2.00**	**3.30**
Bar islands	0.23	0.25	0.00	0.22
Isolated islands	0.21	0.49	0.49	0.00
All islands	**0.44**	**0.74**	**0.49**	**0.22**

Table AP_12. Percentage of sandbars and islands relative to reach area

	Feature area per unit reach area (square meters per square meter), in percent			
	1973	**1990**	**1994**	**1997**
Bank bars	2.97	1.51	4.91	2.75
Island bars	1.11	0.06	0.00	1.30
Isolated bars	8.48	9.19	9.48	13.12
All bars	**12.56**	**10.76**	**14.39**	**17.17**
Bar islands (excluding the bars)	7.23	2.52	0.00	6.47
Isolated islands	2.69	8.14	8.55	0.00
All islands	**9.92**	**10.66**	**8.55**	**6.47**
Water	**77.52**	**78.59**	**77.06**	**76.36**

The areas and shoreline lengths computed from aerial photography were expected to correlate to river stage (gage height, or elevation of water surface) and discharge at the time the photographs were taken. This hypothesis assumed greater exposure of sandbars when river stage decreased. However, there was no strong correlation between emerged sandbar characteristics and river stage (fig. AP_5A) or discharge (fig. AP_5B). Total shoreline length of open sandbars also did not demonstrate a strong correlation with river stage (fig. AP_5C) or discharge (fig. AP_5D). These results suggest that factors beyond river stage or discharge influence the area and shoreline length of sandbars in the channel.

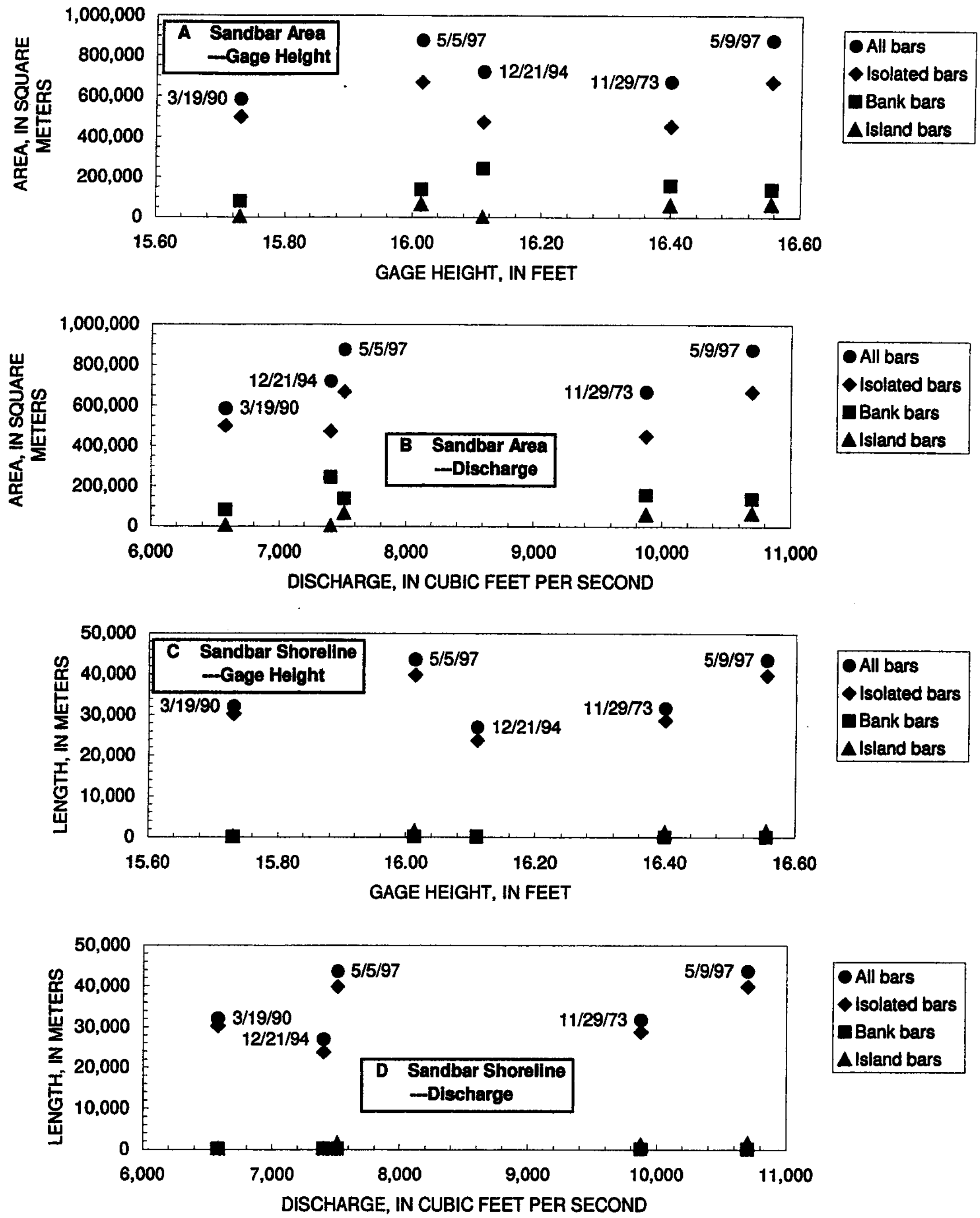


Figure AP_5. Comparisons of emerged sandbars and streamflow for Platte River near U.S. Highway 6 by (A) sandbar area and gage height; (B) sandbar area and discharge; (C) sandbar shoreline and gage height, and (D) sandbar shoreline and discharge.

In addition to comparing sandbar characteristics with river stage and discharge, a comparison with time was made to evaluate temporal changes (fig. AP_6). Ideally, sandbar areas and shoreline lengths should be computed at identical stages, but the limited availability of photographic sets prevented this. Initially, it was thought that adjustments to a common stage or discharge could be made to the measured feature variables, but no relations were found on which to base such adjustments. Figure AP_6 should be examined realizing that the measured feature variables for each set of photographs were measured at different stages. Based on these comparisons, no long-term trends in the total area (fig. AP_6A) or in the shoreline lengths (fig. AP_6B) of sandbars was evident.

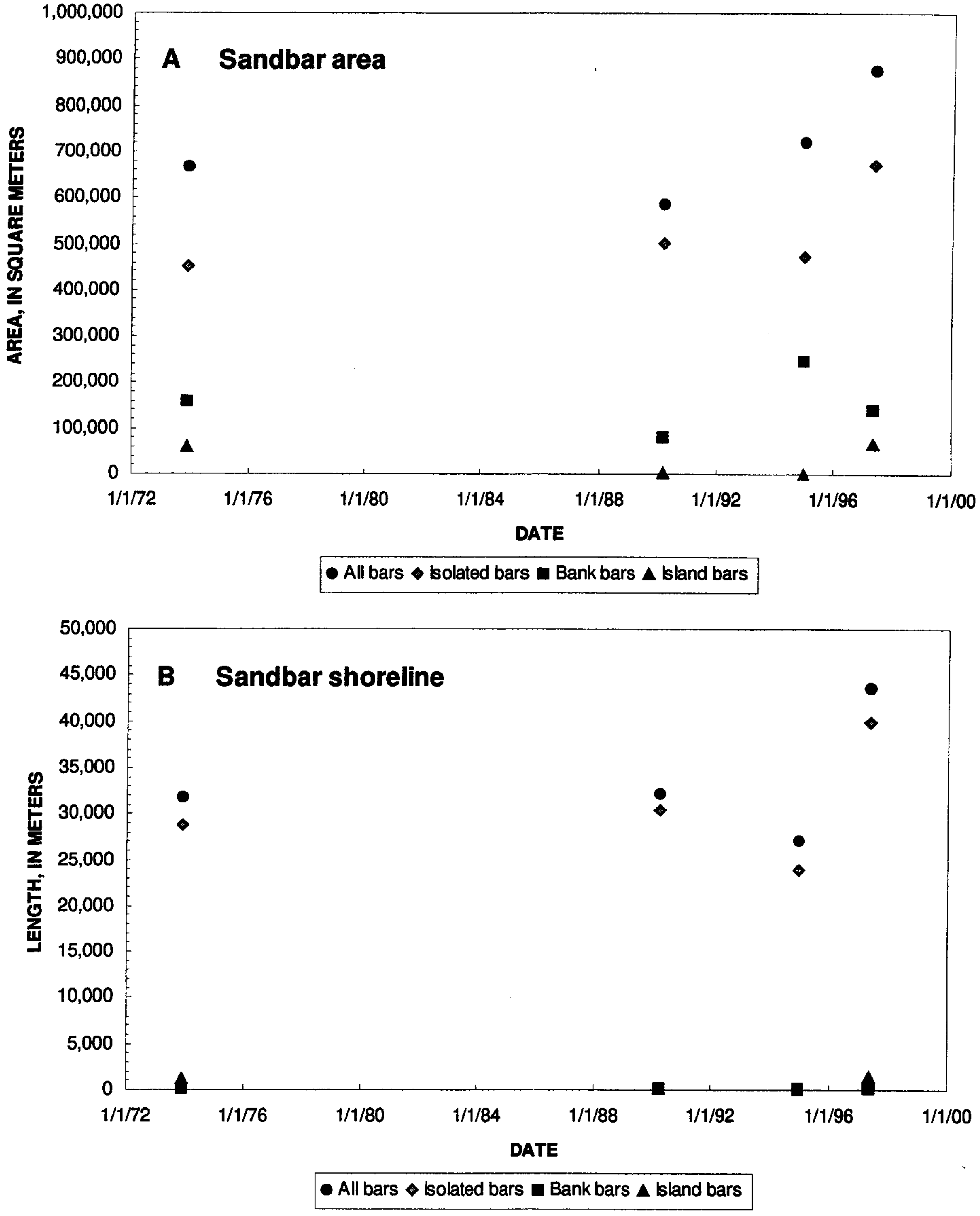


Figure AP_6. Comparisons of (A) sandbar area and (B) sandbar shoreline length and time for Platte River near U.S. Highway 6.

STREAMFLOW DISCHARGE ANALYSIS

Data

For the Platte River near Ashland (06801000), streamflow discharge (*SFD*) measurements and daily mean *SFD* data were available for August 1928 to June 1948 (at the site of former bridge, 0.5 mile upstream of the present site at datum 14.79 ft higher than present datum), and for June 1948 through May 1953 and July 1988 to September 1999 for the current site. For the Platte River at Louisville (06805500), *SFD* measurements and daily mean *SFD* data were available for May 1953 to September 1999. From December 1961 to September 1973 the gage was about 7 miles upstream of the current site at Interstate Highway 80. The data for water years 1962 to 1973 were published as Platte River near South Bend.

Methods

Stream-gaging stations offer data that can be very useful in applications other than the traditional measurement of stream level and streamflow. While these stations are in operation, discharge measurements are taken periodically that quantify the shape of the channel and the stream velocity to calculate the streamflow at the site. These measurements then are used to create stage-discharge relations (commonly called rating curves) for the channel. Individual measurements and rating curves from both the Ashland and Louisville sites were used to evaluate long-term gradational trends in the channel, using the Kendall's tau test (Kendall, 1975), as well as short-term channel responses to flood events.

Long-Term Gradational Trends

Both individual discharge measurements and the rating curves that were created from those measurements were used to test for long-term changes in the streambed. The measurements yielded values of the average bed elevation (ABE) and the thalweg elevation (TE) at several points in time, which could be analyzed for trend. Chen and others (1999) determined trends at the two sites using rating curves, which were updated here according to the same method.

Each discharge measurement consisted of a measurement of the stage, or water-surface elevation (WSE) on the day measured, and a series of transects along the entire width of the stream, which documented depth and flow velocity. These measurements provided a good representation of the width, area, and streambed morphology. Dividing the total cross-sectional area of the stream by its width yielded the average depth, which

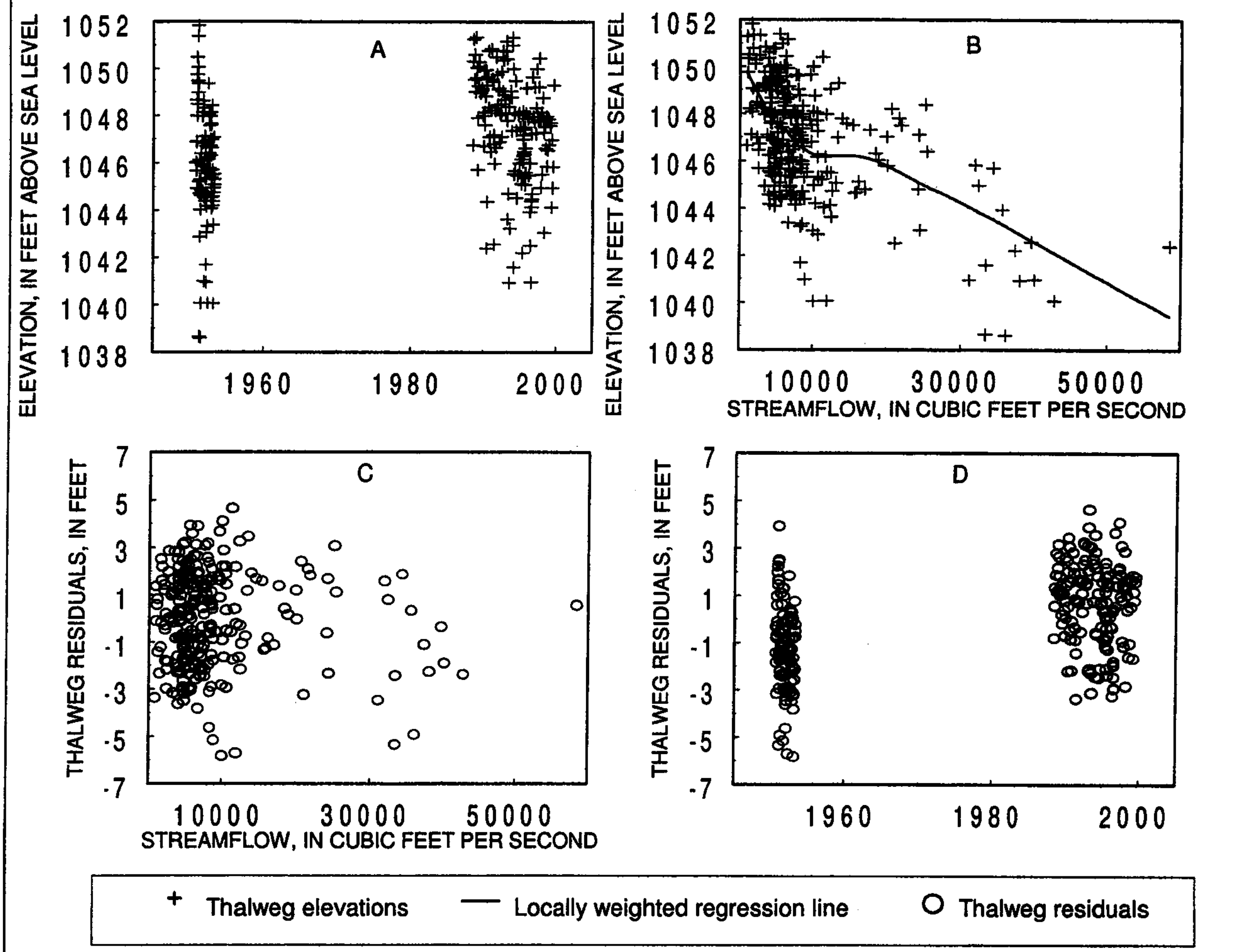


Figure SFD_1. Method for removing streamflow's effect on variability: (A) Thalweg versus time; (B) Thalweg versus streamflow, with a locally weighted, smoothing-regression line; (C) Thalweg residuals (or the deviation of each thalweg measurement from the regression line) versus streamflow; (D) Thalweg residuals versus time used for trend analysis.

Both the Ashland and the Louisville sites have gaps in the data available for analysis. In the case of the Ashland site, this gap was produced when the gage was discontinued in 1953, and then returned to operation in 1988. The Louisville site has been in continuous operation since 1953, but was 7 miles upstream from its present site between 1961 and 1973. For comparisons over the long-term, the data from this separate location was not used, which produced a 12-year gap. Trend analyses were performed across these gaps for the entire period of record at both sites, but also were performed on the recent periods (since 1988 for Ashland; since 1973 for Louisville) to isolate current trends at both sites.

Chen and others (1999) used stage-discharge relations (rating curves) to test for long-term channel gradation trends at 145 stream-gaging stations in Nebraska, including the Ashland and Louisville sites. The stage-discharge relation for a site is largely then was subtracted from the WSE to obtain the ABE. The maximum depth measured at the transect was subtracted from the WSE to obtain the TE. This provided two time-series data sets regarding the channel. Because it incorporated the streambed along the entire transect, the ABE was considered a better measure of changes in sandbar occurrence than the TE. Traditionally, though, the TE is used in evaluating bed-level changes with time (Simon, 1994). Both the ABE and the TE reflect characteristics of the channel where the measurement was made, which is usually at the bridges in the cases of the Ashland and the Louisville sites.

If the width and slope of the stream remain fairly constant, then as the streamflow increases, the shear stress on the streambed increases (Schumm and others, 1984). In a noncohesive streambed like that of the Platte River, it was expected that these flow-derived changes in shear stress would result in dynamic gradational changes to the bed through the processes of scour and fill. Therefore, to evaluate the long-term trends in the gradational patterns of the Platte River using individual measurements (TE shown, for example, in fig. SFD_1A), the effect of discharge on the streambed had to be removed. This was done by computing relations between discharge and the ABE and TE and then determining the residuals (the variation in the ABE and TE beyond that attributed to discharge) of each measurement (Helsel and Hirsch, 1992). The relations were computed by applying a LOWESS, LOcally WEighted Scatterplot Smoothing technique (Cleveland and McGill, 1984; Cleveland, 1985), to the data sets of ABE verses discharge and TE verses discharge (fig. SFD_1B). The residuals of each (ABE_{resid} for the ABE; TE_{resid} for the TE) then were computed as the deviation of each measurement from the LOWESS relation (fig. SFD_1C), which then were returned to a time-series data set for trend analyses (fig. SFD_1D). The relation and the resulting residuals all were calculated using S-Plus 2000 software, professional release version 1 (Mathsoft, Inc., 1999).

determined by such downstream channel conditions as area, geometry, slope, and roughness. As these change, so do the ratings. For computations of discharge from recorded stage measurements, temporary fluctuations in the rating are accounted for by using shifts from the rating. For persistent changes in the relation, a new rating curve is developed. By determining the WSE that corresponds to a given discharge—such as the median for the site (MWSE)—for each of the existing ratings, an indirect measure of the evolution of the downstream channel can be made. Because the median discharge is, generally, relatively small and contained in the lower part of the channel, the MWSE can be considered an indicator for determining changes in the channel bottom, as long as the channel width has not changed significantly. Chen and others (1999) did not use ratings if the gaging location had moved more than 300 meters. For this study, the Ashland site was updated with the addition of ratings that corresponded to its present site, at U.S. Highway 6, to those of its previous site (used by Chen and others, 1999), 0.5 mile upstream, although they were treated as separate data sets for trend-analysis purposes.

Short-Term Effects of High-Water Events

In addition to being able to show long-term trends, the individual measurements can reveal the local effects of high-water events, or peaks, on the stream channel. By considering measurements taken shortly before and after a peak, the magnitude of the disturbance to the channel and the time for it to recover from that disturbance can be evaluated. Disturbances to the ABE and the TE reflect changes to the channel in the vicinity of the bridge (where ABE and TE were measured). Another way to measure channel disturbances is by the use of shifts to the rating curve, which represent downstream channel changes relative to the conditions represented by the rating. When a discharge measurement is made, the shift is computed as the difference between the rating curve stage that is expected for the given discharge and the actual stage that is measured. When a shift is negative, there is less streamflow than that expected from the rating, which implies backwater or channel filling relative to the rating condition. When a shift is positive, there is more water flowing than is expected at that stage, which implies scour relative to the rating condition. Shifts can also be compared to one another in a time series to determine filling or scouring since the previous measurement.

For disturbances to the ABE and TE to be evaluated, ambient levels had to be determined for both. First, discharge measurements were selected that met the following criteria: (1) Streamflow was greater than the 90th percentile (or the discharge that has been exceeded 90 percent of the time) and less than the 10th percentile; (2) measurements were made during open channel flow (ice measurements were omitted); and (3) only measurements made near the gage were used (measurements at other bridges were omitted). As of water year 1999, the 90th and 10th percentile streamflows at the Ashland site (calculated using water years 1989 to1999) were 2,780 and 12,900 ft^3/s respectively, and at the Louisville site (calculated over the entire period of record) were 2,000 and 13,100 ft^3/s respectively (Boohar, 1999). Once the measurements were selected, they were separated further into groups according to the rating that was in place at the time of the measurement. This was done to remove long-term gradational effects from the short-term analysis of high-water events. Once these data sub-sets were created, the ambient lower confidence level (ALCL) (at the 2.5-percent significance level) was computed for the ABE ($ALCL_{ABE}$) and TE ($ALCL_{TE}$) on each sub-set according to the method of Helsel and Hirsch (1992). Based on the measurements of each sub-set, the ALCL was exceeded 97.5 percent of the time under ambient conditions, and this value was used as a reference point when evaluating the effects of a high-water event. The magnitudes of the measured disturbance to the ABE (d_{ABE}) and to the TE (d_{TE}) were computed by subtracting the minimum values of the ABE (ABE_{min}) and TE (TE_{min}) from their respective ALCL values:

$$d_{ABE} = ALCL_{ABE} - ABE_{min}$$

$$d_{TE} = ALCL_{TE} - TE_{min}$$

The times of recovery also were computed for the ABE (r_{ABE}) and the TE (r_{TE}) by recording the length of time after the peak before the ABE and TE returned to levels at or above their respective ALCL. By assuming an ambient shift value was zero, the relative disturbance to the rating (d_{shift}) and the time of recovery (r_{shift}) were determined. Because the streambed of the Platte River is very dynamic, the ambient conditions of the rating are also dynamic, which makes an explicit reference point difficult to identify. However, for relative comparisons between high-water events, this assumption was considered adequate. All of these computations of disturbance and recovery were limited by the frequency of the measurements. The actual disturbance and recovery times may have been different than those that were documented by the measurements. Lines were drawn to connect measurements and to estimate when the ALCL thresholds were met, but these lines were only as accurate as the number of measurements they comprised.

Six high-water events were selected from the period of record for both the Ashland and the Louisville sites. These events were selected such that most were in the time frame of the aerial photography analysis as well as covering a range of peak discharges (table SFD_1).

Table SFD_1. Platte River high-water events selected for analysis of their stream channel effects
[ft^3/s, cubic feet per second; ft, feet above sea level]

Platte River near Ashland, Nebraska			Platte River at Louisville, Nebraska		
Date	**Instantaneous peak discharge (ft^3/s)**	**Instantaneous peak stage (ft msl)**	**Date**	**Instantaneous peak discharge (ft^3/s)**	**Instantaneous peak stage (ft msl)**
2/21/97	38,000	1,060.86	2/21/97	46,000	1,015.43
3/5/94	45,000	1,059.10	5/29/95	70,500	1,016.22
7/25/93	114,000	1,061.45	7/25/93	160,000	1,019.00
6/17/90	80,600	1,059.85	6/17/90	67,000	1,016.26
6/1/51	49,900	1,058.42	10/11/73	42,400	1,014.95
6/12/44	107,000	Unknown	3/30/60	124,000	1,019.55

In addition to the analyses described previously relating to specific high-water events, another technique was performed on the measurement data for several entire water years to identify patterns, if any, to changes in the rating. By determining a mathematical equation that applied to the rating and then computing correction multipliers to translate the measurements back to that equation, changes to the rating (and therefore to the channel downstream) could be isolated. First, a rating equation was determined using discharge measurements. Any measurements affected by ice were omitted from the determination of this equation, because the effect of ice would disturb the stage-discharge relation. Once this data set was created, a power equation was fit to the data, based on the method described by Kennedy (1984). The general form of this equation was:

$$SFD = a(GH - e)^b$$

where: *SFD* is the streamflow discharge, in cubic feet per second,

a is a multiplier representing the intercept at (GH –e) = 1 when plotted on a logarithmic grid,

GH is the gage height, in feet,

e is a "scale offset" constant, usually representing the gage height of zero flow, and

b is a dimensionless exponent representing the slope when plotted on a logarithmic grid.

Arbitrary offsets of 10 for the Ashland site and 0 feet for the Louisville site were used to modify the gage heights for each measurement. Then, *a* and *b* values were computed using the entire data set to create the power equation for the site. This equation plotted as a straight line when set to a logarithmic grid, as shown by the example of the Ashland site (fig. SFD_2).

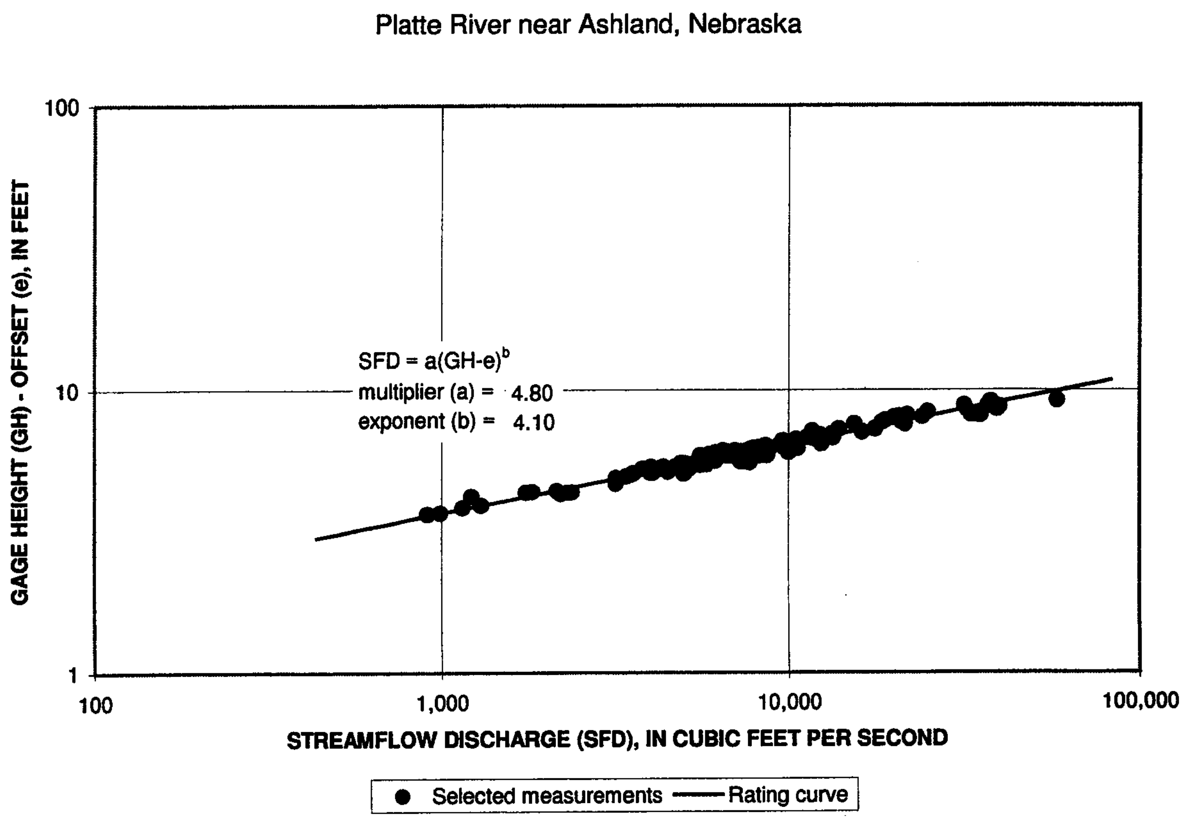


Figure SFD_2. Example of fitting a general power equation to the discharge measurements to determine the multiplier, *a*, which defines the intercept at (GH-e) = 1, and the exponent, *b*, which defines the slope of the curve.

Once the general equation was determined, the individual multipliers for each measurement were computed by assuming the exponent of the equation, *b*, remained constant. This assumption is based on the idea that variability in the stage-discharge relation is caused by temporary changes in the channel and does not alter the general shape of this relation. This assumption is also analogous to applying shifts to a rating, which is commonly performed by the USGS when computing discharges. Because the multiplier represents the intercept of the equation, changes to it resulted in translations upward or downward from the general equation (when plotted on a logarithmic grid) without changing the entire shape of the rating. Hence, multipliers were computed for each measurement, which provided indicators of disturbance to the rating and to the channel downstream. Unlike the analyses of the ABE, the TE, and the shifts, magnitudes of the disturbance and recovery times were not computed. Rather, these multipliers were used only to identify the presence of a disturbance to the rating in relation to the hydrographs. This was done by plotting the multipliers with the hydrographs to identify changes in value as the discharge changed (fig. SFD_3). As multipliers increased, more discharge was associated with the given gage height. These types of shifts could be a result of increased scour, but also could be related to anything else that may have allowed more discharge for the same gage height. When multipliers decreased, less discharge was associated with the gage height. This could be a result of aggradational processes, but also could be a function of anything decreasing the amount of flow associated with the gage height.

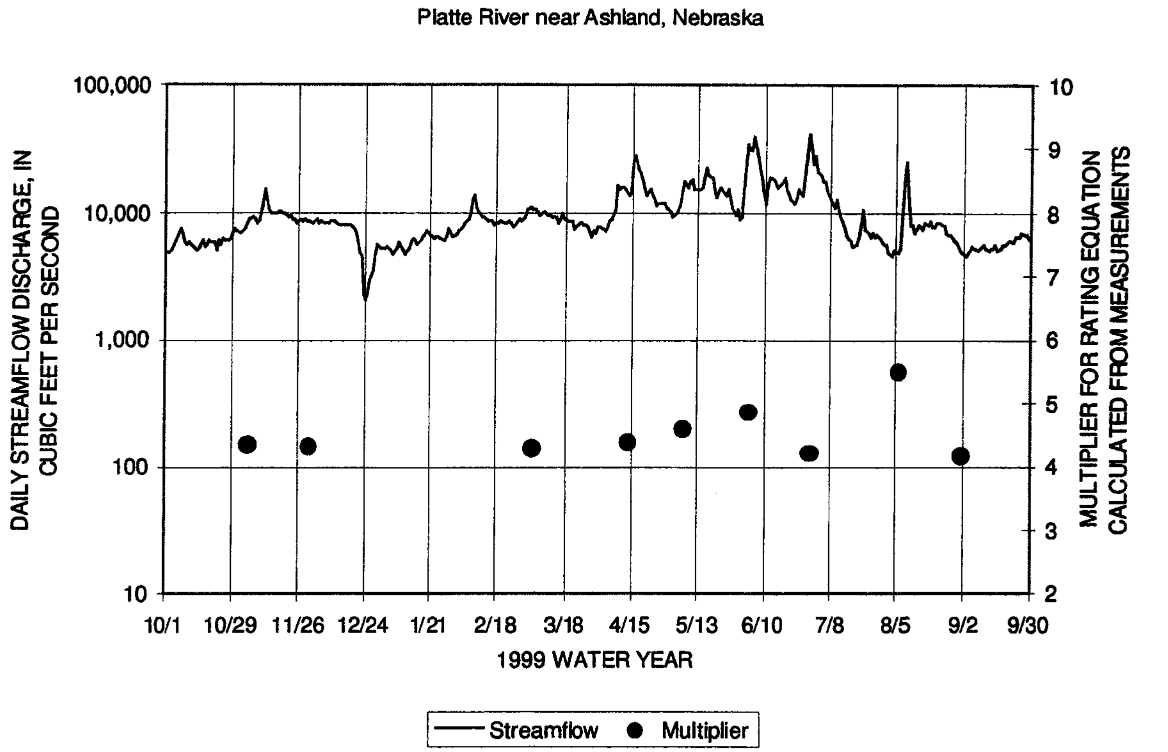


Figure SFD_3. Example of a plot of the multipliers associated with each streamflow discharge measurement and the corresponding hydrograph over the same period.

Statistical Trend Analysis

The presence of trend was tested using the procedure of Kendall's tau (Kendall, 1975). It is a rank-correlation method that tests whether a dependent variable increases or decreases with some independent variable (monotonic change) (Helsel and Hirsch, 1992). Because it is rank-based, the test is nonparametric and outliers or missing values present no problem in application of the test (Chen and others, 1999). Tau values can range from –1 to +1, with –1 indicating a pure downward trend, +1 indicating a pure upward trend, and 0 indicating no trend. Tau values that met a 95-percent confidence level (level of significance equals 0.05) were considered statistically significant. The attained significance level (p-value) of the tau value was computed, and if the p-value was less than 0.05, the trend was considered significant. For each trend analysis that was done, the number of observations (n), the Kendall's tau value, and the p-value are presented. For long-term gradational analyses on the entire period of record, locally weighted smoothing-regression lines also are included with figures when the associated tau value was significant. The tau values, the corresponding p-values, and the locally weighted smoothing-regression lines were all computed using S-Plus 2000 software, professional release version 1 (Mathsoft, Inc., 1999).

Results

Long-Term Gradational Trends—Platte River near Ashland

Long-term gradational analyses at this site were problematic because of the large gap in data collected between 1953 and 1988 (fig. SFD_4). This gap was caused by the gage being discontinued during that period. Additionally, the gage was operated 0.5 mile upstream from of its present site between 1928 and 1948, which separated long-term comparisons into two periods corresponding to the two gage locations. Measurements from the upstream site were not readily available, and long-term comparisons using the measurements from this location were not made. However, ABE and TE were calculated for most of the measurements made at the U.S. Highway 6 site, and the tau values were computed for each (fig. SFD_4A). For the entire period of record, the tau values indicated a statistically significant upward trend with time in the case of ABE, but an insignificant trend in TE. For the recent period (since 1988), the tau values indicated an upward trend in ABE and a downward trend in TE. A test for trend also was performed on the residuals (to remove the effect of discharge) of each with respect to time, which showed a significant upward trend (fig. SFD_4B) in both ABE and TE over the entire period of record, as well as in the residuals in the ABE for the recent period. However, trends in the residuals of the TE for the recent period were insignificant.

A	n	Kendall's tau	p-value	Period tested
ABE	252	0.37	0.000	Entire
TE	252	0.06	0.152	Entire
ABE	155	0.23	0.000	Since 1988
TE	155	-0.27	0.000	Since 1988

B	n	Kendall's tau	p-value	Period tested
ABE_{resid}	252	0.36	0.000	Entire
TE_{resid}	252	0.19	0.000	Entire
ABE_{resid}	155	0.19	0.000	Since 1988
TE_{resid}	155	-0.10	0.066	Since 1988

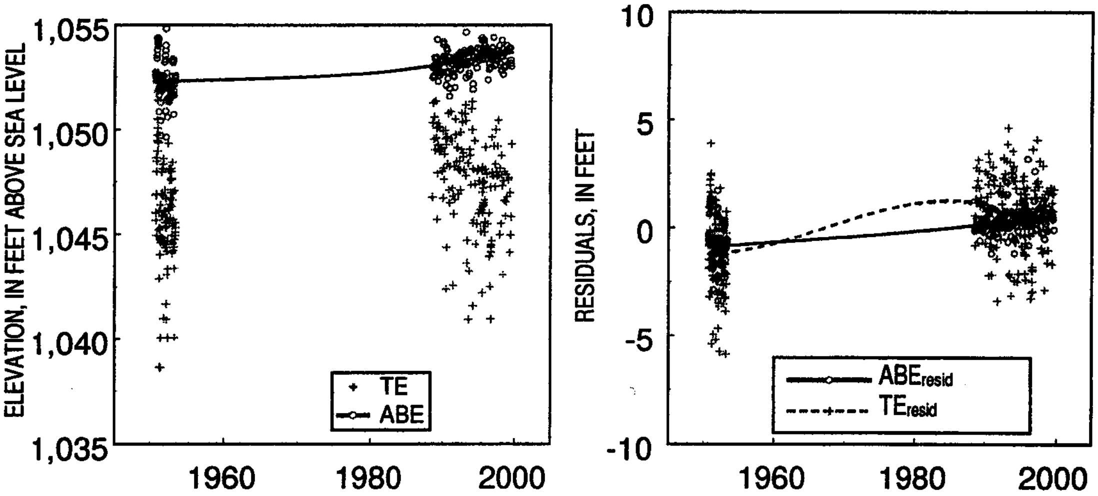


Figure SFD_4. Long-term trend analyses for Platte River near Ashland, Nebraska, on: (A) ABE and TE; and (B) the residuals of ABE (ABE_{resid}) and TE (TE_{resid}) to remove the influence of discharge. LOWESS lines are shown for comparisons with significant tau values.

Use of the ratings for gradational trend analyses extended the time period tested for the Ashland site because ratings were available for the site 0.5 miles upstream. The previous study by Chen and others (1999) used these ratings for trend analysis and did not find a significant trend at the upstream site, which covered the period 1928 to 1948. The ratings that correspond to the current site were added to those from the previous study by computing the MWSE for the same median discharge used in that study (fig. SFD_5). A trend analysis was not done on the combined data set, but rather was done on the MWSE data that corresponds to the present gage location. However, with only three ratings at the current location, the data set was not large enough to make significant conclusions regarding the trend between 1948 and 1999.

	Applicable years	n	Kendall's tau	p-value
At site 0.5 miles upstream	1928-1948	21	0.16	0.3188
At present site	1948-1953, 1988-1999	3	1.00	0.1172

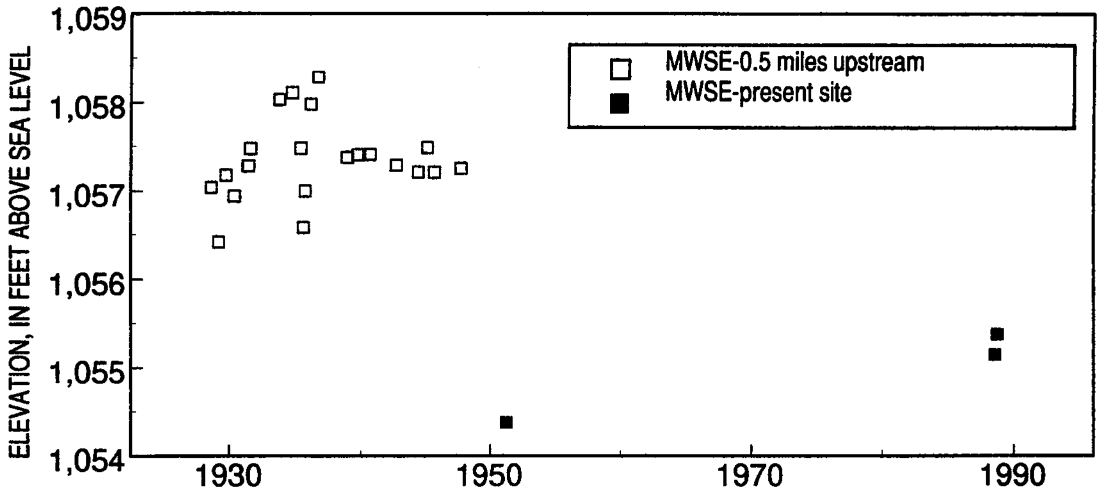


Figure SFD_5. Long-term trend analyses on the median water-surface elevation (MWSE) associated with individual ratings at the Platte River near Ashland, Nebraska (Data for upstream site from Chen and others, 1999).

Long-Term Gradational Trends—Platte River at Louisville

Like Ashland, the Louisville site was at another location for a part of its period of record. However, unlike Ashland, this site has been at its present location at the Nebraska Highway 50 bridge for the majority of its period of record. Measurements corresponding to the present site were compiled, ABEs and TEs were calculated from those measurements, and the tau values were computed for each (fig. SFD_6A). The tau values indicated a significant downward trend with time in the both ABE and TE over the entire period of record as well as the recent period (since 1973). The test for trend on the residuals of each with respect to time showed a significant downward trend (fig. SFD_6B) in both over the entire period of record. However, over the recent period, the residuals of the ABE showed a significant downward trend while those of the TE showed a significant upward trend. The difference in trend between TE and its residuals over the recent period could be explained by a dependence of the TE on flow. If the streamflow has increased over the recent time period and this dependence existed, then the TE would show a decrease over the recent time period. Additionally, the orientation of the LOWESS lines shows that the trend in the recent period is small in comparison to that for the entire period, suggesting that much of the change in the channel might have occurred over the data gap in the period tested. For the most part, though, the trends at the Louisville site were downward, which was the opposite direction of those found for the Ashland site (fig. SFD_4).

A

	n	Kendall's tau	p-value	Period tested
ABE	723	-0.43	0.000	Entire
TE	723	-0.34	0.000	Entire
ABE	487	-0.20	0.000	Since 1973
TE	487	-0.10	0.000	Since 1973

B

	n	Kendall's tau	p-value	Period tested
ABE_{resid}	723	-0.37	0.000	Entire
TE_{resid}	723	-0.23	0.000	Entire
ABE_{resid}	487	-0.12	0.000	Since 1973
TE_{resid}	487	0.13	0.000	Since 1973

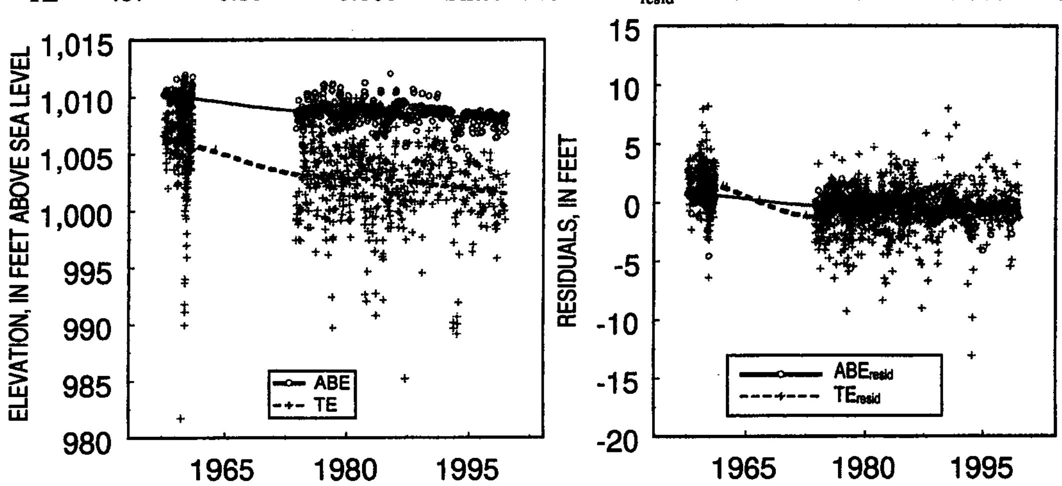


Figure SFD_6. Long-term trend analyses for Platte River at Louisville on (A) ABE and TE; (B) the residuals of ABE (ABE_{resid}) and TE (TE_{resid}) to remove the influence of discharge. LOWESS lines are shown for comparisons with significant tau values.

The previous study by Chen and others (1999) used ratings from the present site for trend analysis and found a significant downward trend in the MWSE, which covered the periods from 1953 to 1961 and from 1973 to 1999 (fig. SFD_7).

	Applicable years	n	Kendall's tau	p-value
At present site	1953-1961, 1973-1999	20	-0.60	0.000

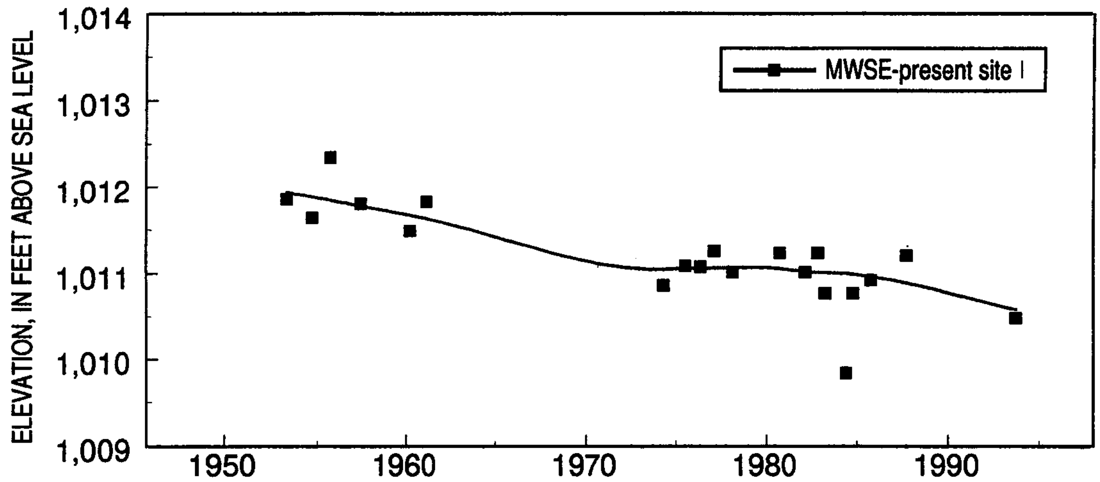
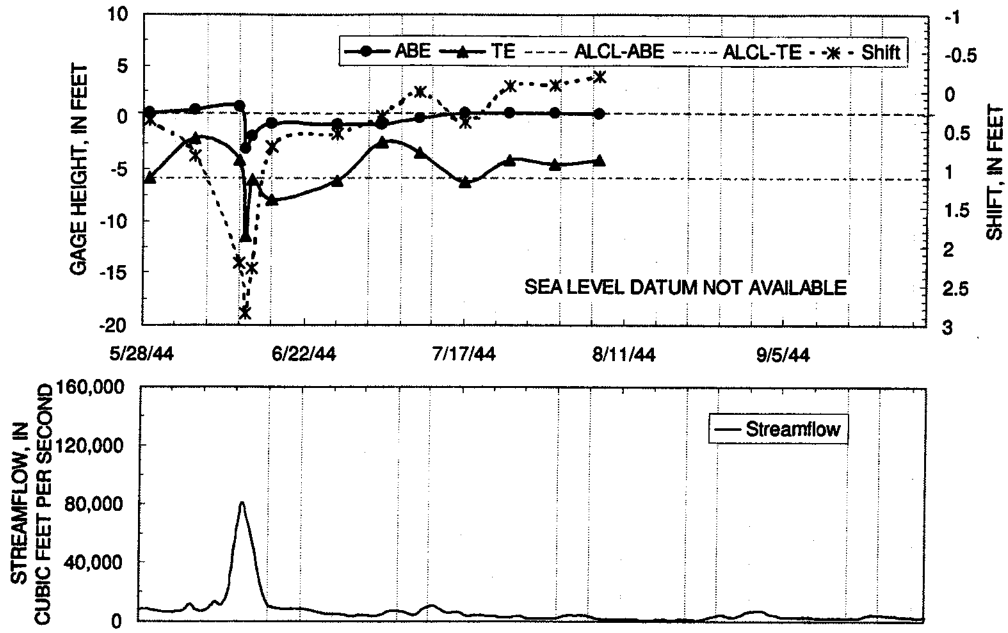


Figure SFD_7. Long-term trend analyses on the median water-surface elevation (MWSE) associated with individual ratings at the Platte River at Louisville, Nebraska (from Chen and others, 1999).

Effects of High-Water Events—Platte River near Ashland

Six different high-water events were analyzed for the Ashland site (fig. SFD_8) to determine the disturbance to the ABE and TE, both measured at the bridge, and to the rating (using shift values), which is a measure of the channel downstream of the bridge. These disturbances were based on the computed values of the ALCL for each, with the exception of the flood of June 12, 1944, for which the pre-flood measurements were assumed to be at ambient levels.

Peak of:	d_{ABE} (ft)	r_{ABE} (d)	d_{TE} (ft)	r_{TE} (d)	d_{shift} (ft)	r_{shift} (d)
6/12/44	3.42	35	5.66	19	2.85	28



Peak of:	d_{ABE} (ft)	r_{ABE} (d)	d_{TE} (ft)	r_{TE} (d)	d_{shift} (ft)	r_{shift} (d)
6/1/51	2.43	11	6.49	5	1.38	34

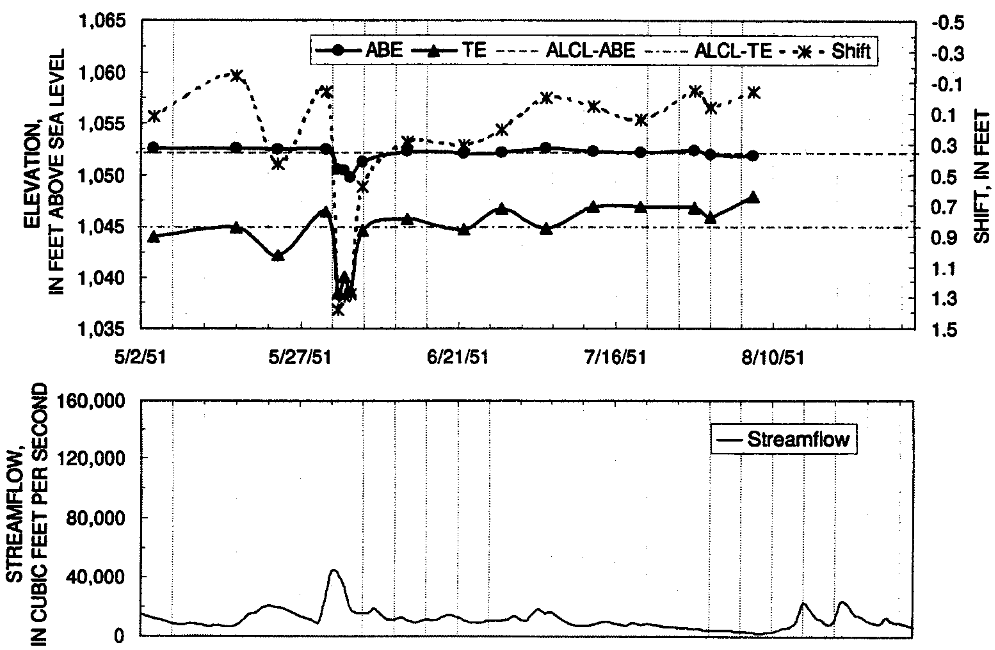
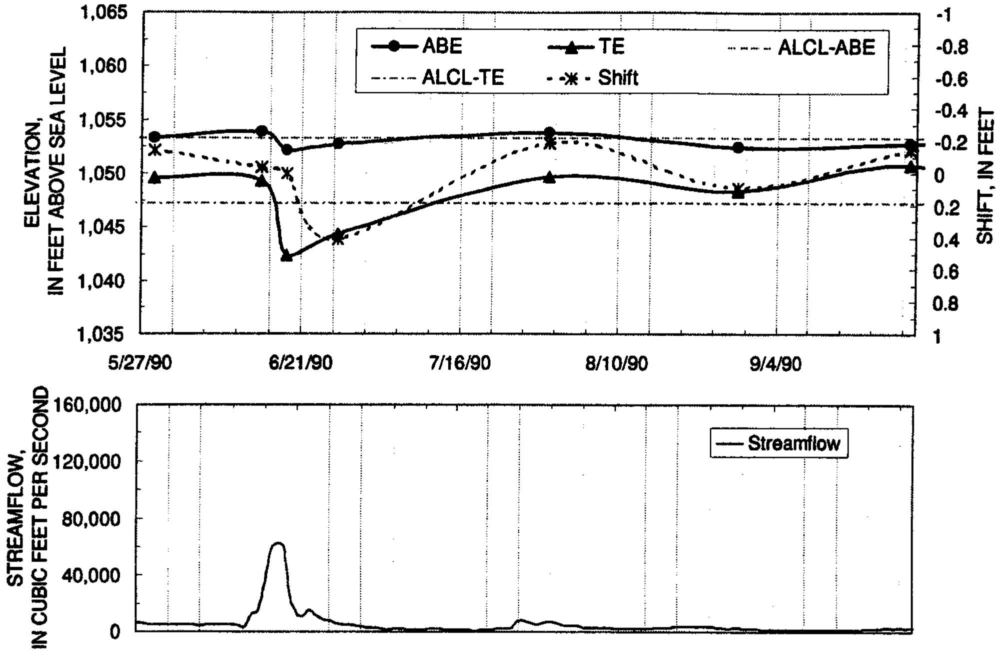


Figure SFD_8. Disturbances to the ABE, TE, and rating shift caused by six high-water events at Platte River near Ashland, Nebraska.

Peak of:	d_{ABE} (ft)	r_{ABE} (d)	d_{TE} (ft)	r_{TE} (d)	d_{shift} (ft)	r_{shift} (d)
6/17/90	1.21	26	4.86	26	0.41	14



7/25/93	0.76	57	6.33	57	IR[1]	IR[1]

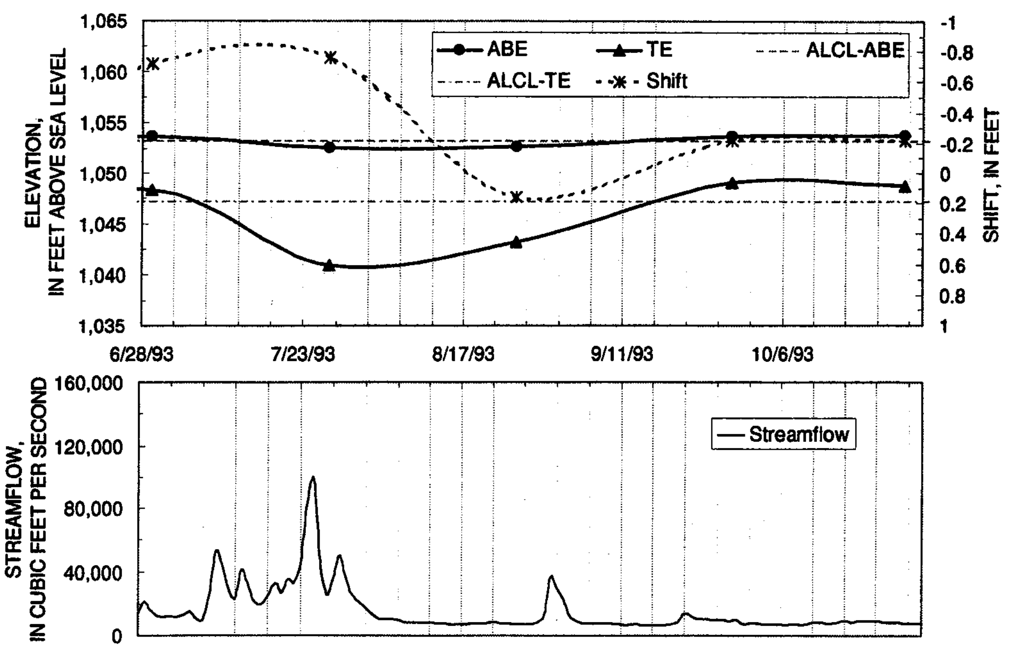
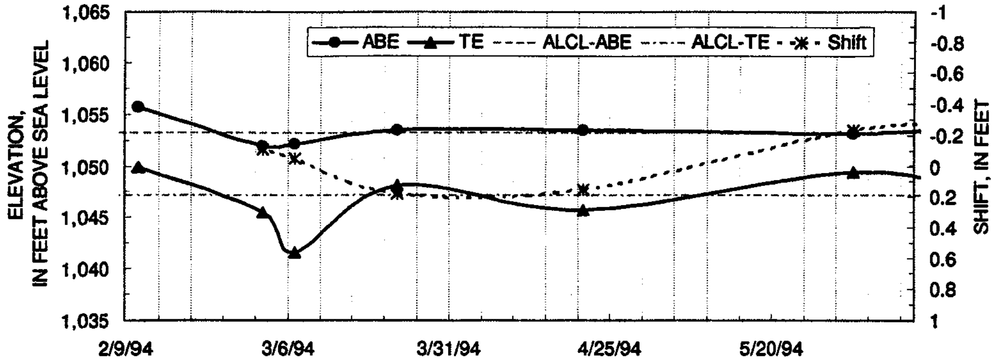
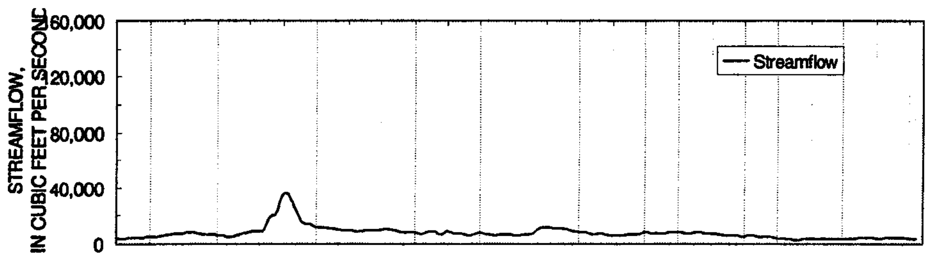


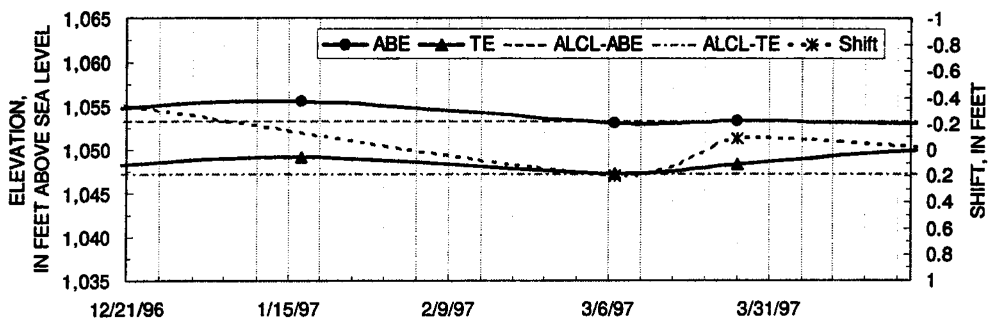
Figure SFD_8. Disturbances to the ABE, TE, and rating shift caused by six high-water events at Platte River near Ashland, Nebraska—Continued.

Peak of:	d_{ABE} (ft)	r_{ABE} (d)	d_{TE} (ft)	r_{TE} (d)	d_{shift} (ft)	r_{shift} (d)
3/5/94	1.14	18	5.67	18	IR[1]	IR[1]





Peak of:	d_{ABE} (ft)	r_{ABE} (d)	d_{TE} (ft)	r_{TE} (d)	d_{shift} (ft)	r_{shift} (d)
2/21/97	IR[1]	IR[1]	IR[1]	IR[1]	IR[1]	IR[1]



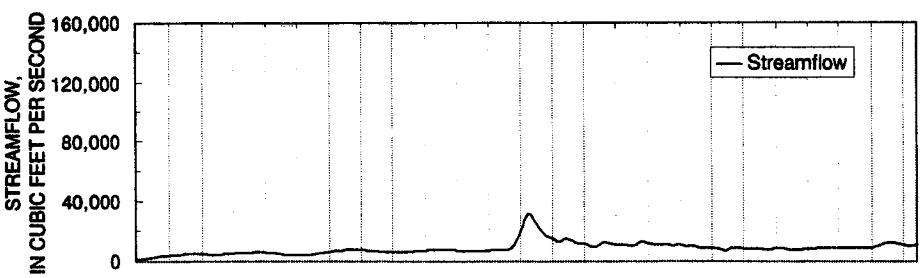


Figure SFD_8. Disturbances to the ABE, TE, and rating shift caused by six high-water events at Platte River near Ashland, Nebraska—Continued.

[1] Inconclusive results

Five of the six events that were analyzed showed a clear response to the high water. Measured disturbances to the ABE (d_{ABE}) ranged from 0.76 to 3.42 feet, and recovery times (r_{ABE}) ranged from 11 to 57 days (fig. SFD_8). The minimum d_{ABE} was associated with the maximum r_{ABE}. The measured TE disturbances (d_{TE}) ranged from 4.86 to 6.49 feet, with recovery times (r_{TE}) ranging from 5 to 57 days. Because of a lack of measurements, results for the flood of February 21, 1997, were inconclusive. The disturbances to the rating (d_{shift})(as shown through the shifts on fig. SFD_8) ranged from 0.41 to 2.85 feet, with recovery times ranging from 14 to 34 days. However, there were inconclusive results for three of the six events. Again, this could be because of a lack of measurements that accurately define the response, although it could be a signal that there are other unknown processes occurring. The greatest disturbance to the ABE and to the rating occurred after the flood on June 12, 1944, which also provided the greatest instantaneous peak discharge (107,000 ft^3/s) of the six events (table SFD_1). The 1944 flood was of special interest because levees that were containing the flood broke 1 day after the peak, allowing a direct comparison of the effects of contained flow with those of overbank flow. The TE spiked upward the day after the levee broke (fig. SFD_8), but the ABE and the shift to the rating both showed less dynamic responses to the transition to overbank flow. The greatest disturbance to the TE occurred after the event of June 1, 1951, although the TE recovery time for this event was also the fastest of all the events tested.

Three power equations relating gage height to discharge were fit to the measurements that were not affected by ice. The first equation was associated with the measurements from the recent period (1988 to present), and had the form:

$$SFD = 4.80(GH - 10)^{4.10}$$

The second equation was associated with measurements at the current site, but during the period from 1950 to 1953. Because the datum was different during this period, the gage heights were adjusted to the same datum as that of the recent period, and the resulting equation had the form:

$$SFD = 27.2(GH - 10)^{3.55}$$

The final equation was associated with measurements from water year 1944, for comparison to the analyses of ABE, TE, and shifts from the high-water event of June 12, 1944. The datum and location of the gage during this period were both different than that of the recent period, and gage heights were adjusted arbitrarily to reflect values on the same scale as that of the recent period. Because of the arbitrary nature of the offset, this equation does not relate to the hydrologic point of zero flow, but rather is intended for comparative purposes only. The equation had the form:

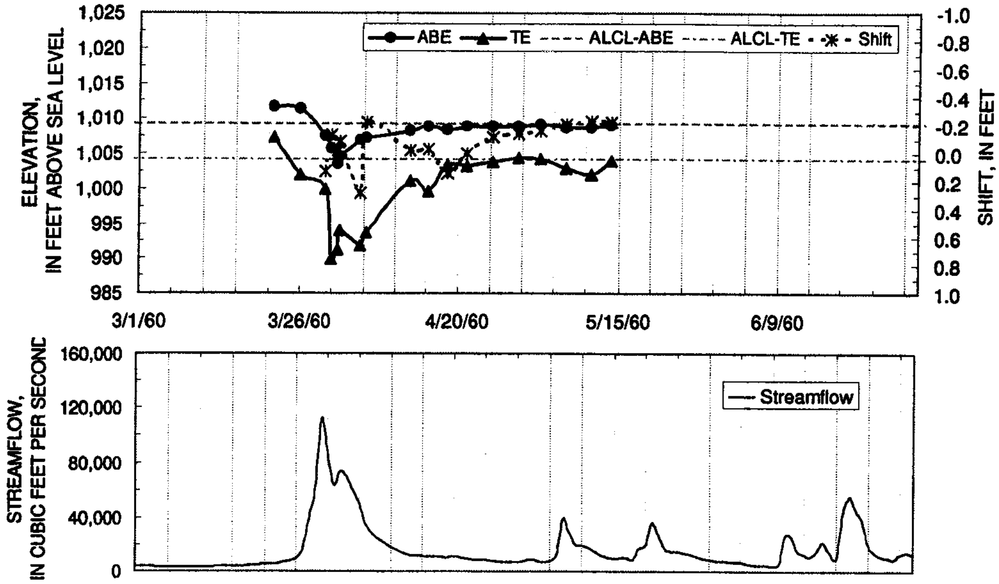
$$SFD = 4.55(GH + 3)^{4.06}$$

By applying the exponent that was computed for each general equation, multipliers then were determined for each measurement associated with the time frame of that equation. These multipliers then were plotted with the corresponding discharge hydrographs to identify the presence of (or lack of) disturbances to the rating (appendix B).

Effects of High-Water Events—Platte River at Louisville

Like the Ashland site, six different high-water events were analyzed for the Louisville site (fig. SFD_9) to determine the disturbances to the ABE, TE, and the rating (using shift values). All six events that were analyzed showed a response to the high water. Disturbances to the ABE (d_{ABE}) (fig. SFD_9) ranged from 0.29 to 5.77 feet, and recovery times (r_{ABE}) ranged from 9 to 120 days. The TE disturbances (d_{TE}) ranged from 1.8 to 14.33 feet, with recovery times (r_{TE}) ranging from 7 to 120 days. The disturbances to the rating (d_{shift}) (as shown by the shifts in fig. SFD_9) ranged from 0.12 to 0.29 feet, with recovery times (r_{shift}) ranging from 12 to 56 days, although there were inconclusive results for three of the six floods analyzed. The greatest disturbance to the ABE and TE occurred after the flood on March 30, 1960. The longest recovery times for the ABE and TE occurred after the flood of July 25, 1993. The rating shift did not show a consistent response to either of these two peaks. The greatest disturbance to the rating occurred after the event of February 21, 1997, although the longest recovery time for the rating occurred after the event of May 29, 1995.

Peak of:	d_{ABE} (ft)	r_{ABE} (d)	d_{TE} (ft)	r_{TE} (d)	d_{shift} (ft)	r_{shift} (d)
3/30/60	5.77	16	14.33	30	IR[1]	IR[1]



10/11/73	1.17	12	2.58	7	0.12	12

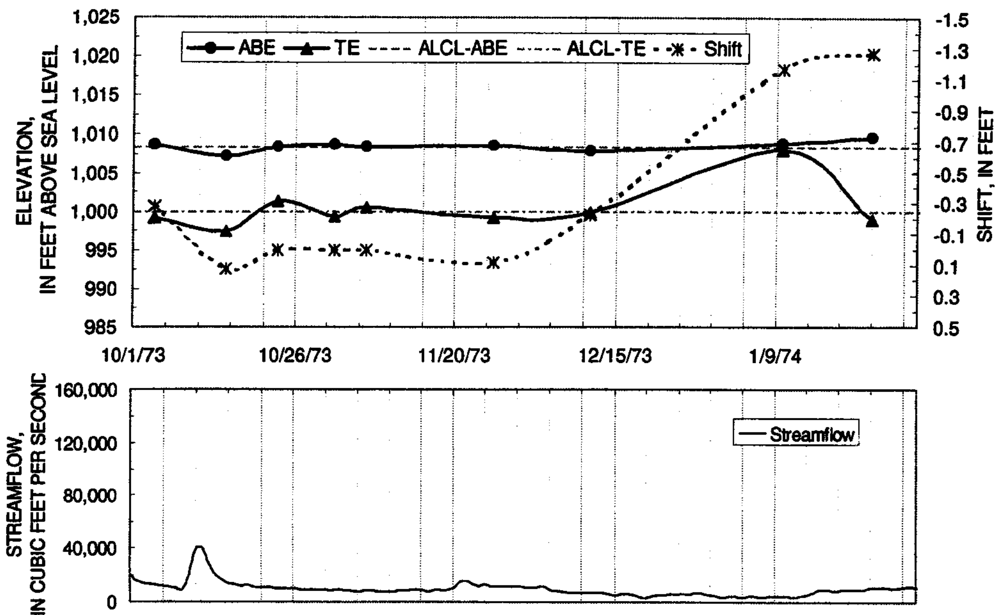
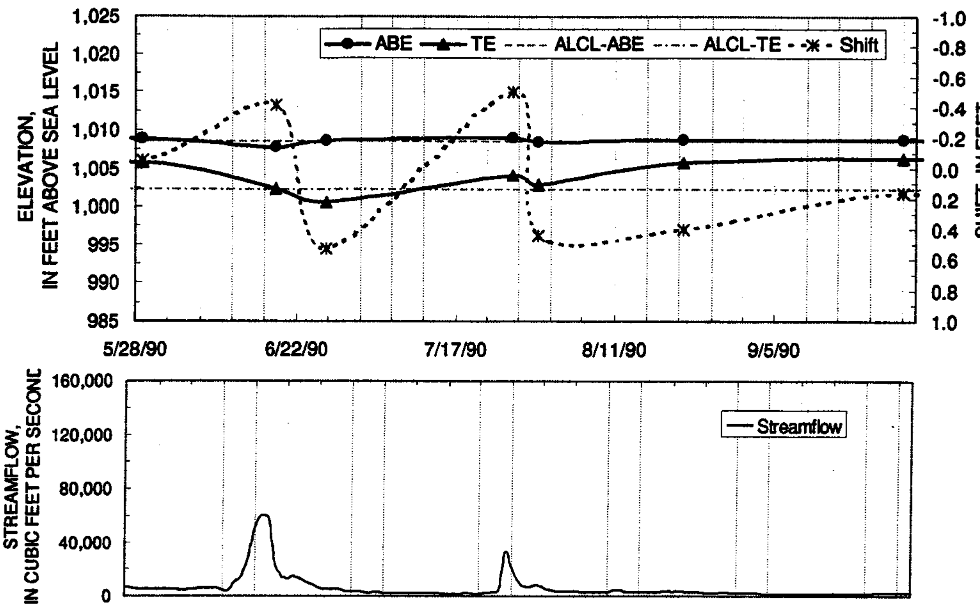


Figure SFD_9. Disturbances to the ABE, TE, and rating shift caused by six high-water events at Platte River at Louisville, Nebraska.

Peak of:	d_{ABE} (ft)	r_{ABE} (d)	d_{TE} (ft)	r_{TE} (d)	d_{shift} (ft)	r_{shift} (d)
6/17/90	0.8	9	1.8	27	IR[1]	IR[1]



[2]7/25/93	1.0	120	10.4	120	IR[1]	IR[1]

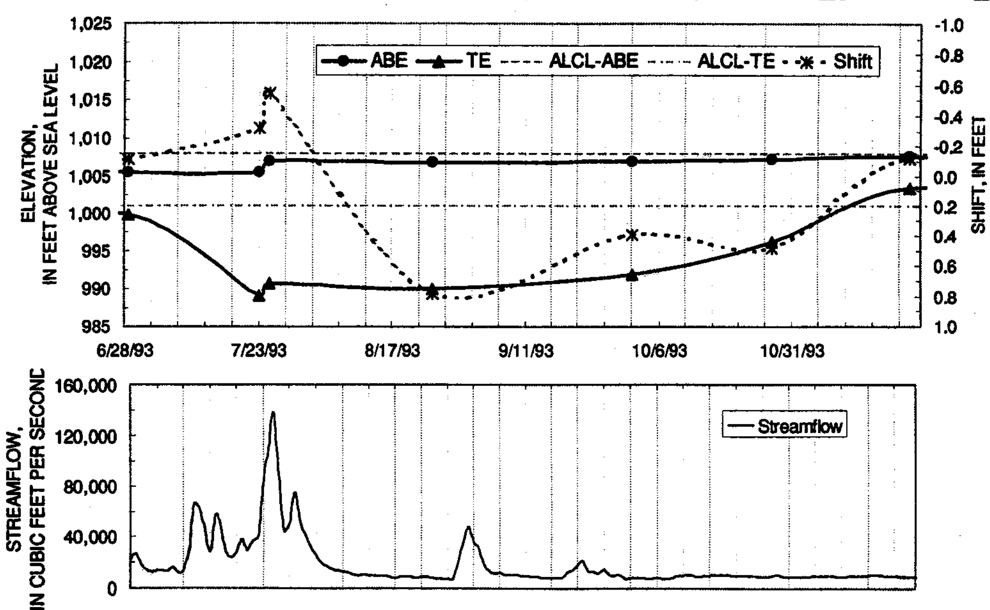
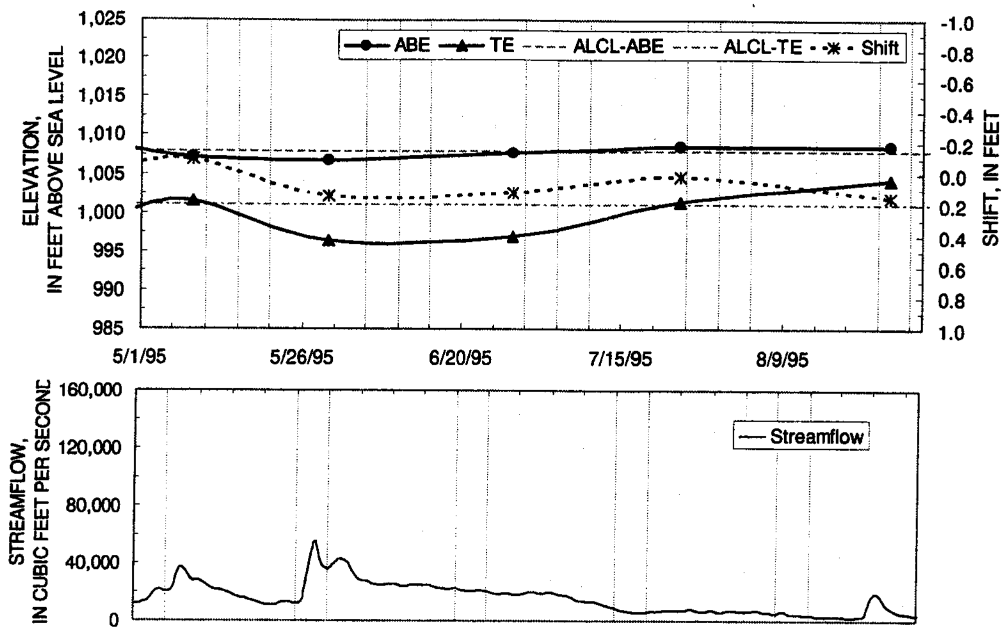


Figure SFD_9. Disturbances to the ABE, TE, and rating shift caused by six high-water events at Platte River at Louisville, Nebraska—Continued.

Peak of:	d_{ABE} (ft)	r_{ABE} (d)	d_{TE} (ft)	r_{TE} (d)	d_{shift} (ft)	r_{shift} (d)
5/29/95	1.25	30	4.7	56	0.14	56



Peak of:	d_{ABE} (ft)	r_{ABE} (d)	d_{TE} (ft)	r_{TE} (d)	d_{shift} (ft)	r_{shift} (d)
2/21/97	0.29	17	2.54	24	0.29	17

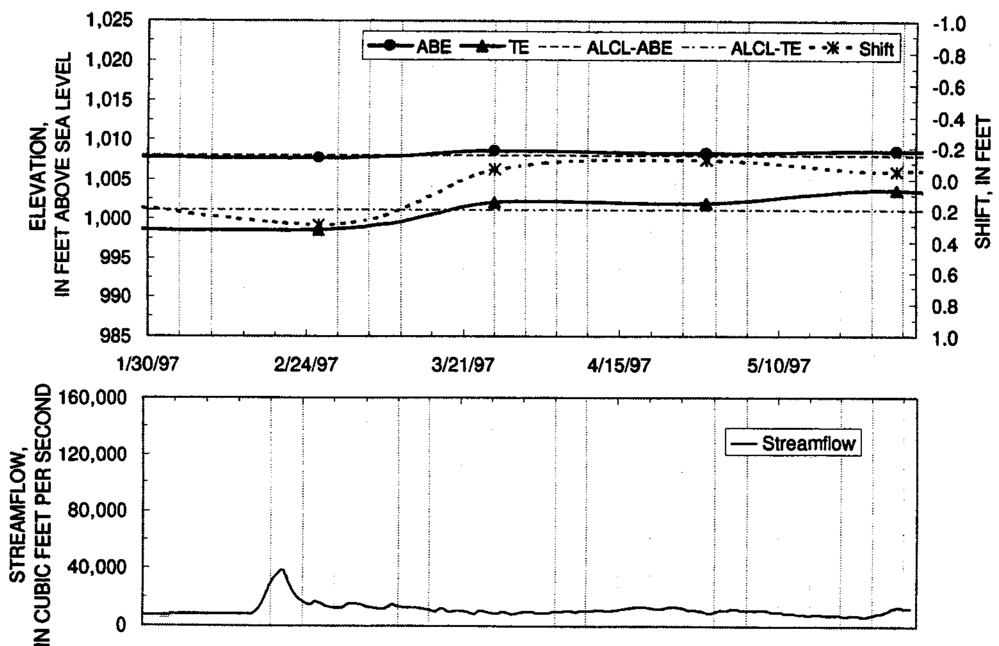


Figure SFD_9. Disturbances to the ABE, TE, and rating shift caused by six high-water events at Platte River at Louisville, Nebraska—Continued.

[1] Inconclusive results.

[2] Some measurements taken at bridge 13.6 miles downstream, then related back to the bridge.

Only one power equation relating gage height to discharge was fit to the measurements that were not affected by ice. It was created based on measurements from 1985 to the present, and had the form:

$$SFD = 135(GH - 0)^{2.76}$$

By applying the exponent from that equation, multipliers then were determined for each measurement. These multipliers then were plotted with the corresponding discharge hydrographs to identify the presence of (or lack of) disturbances to the rating (appendix C).

Interpretations

Although long-term trends in the stream channel appear to be conflicting between the Ashland and Louisville sites, both show localized responses to high-water events. The difference in the trends between the two sites could be explained by differences in hydrologic and hydraulic characteristics as well as the uncertainty introduced by the large data gap for the Ashland site. Both sites responded to high-water events with the majority of the recovery occurring shortly after the event.

Long-Term Gradational Trends

Trend analyses for the Ashland site demonstrated either upward trends with time (over the entire period of record for ABE, ABE_{resid}, and over the recent period for ABE and ABE_{resid}), downward trends (over the recent period for TE), or insignificant trends with time (over the entire period of record for TE, over the recent period for TE_{resid}, and for the ratings at both the present site and the site 0.5 mile upstream using the MWSE). Generally speaking, based on these results, it would appear that the channel at the Ashland site is aggrading. In contrast, most of the channel variables tested at the Louisville site (over the entire period of record for all variables and over the recent period for all variables except TE_{resid}, which was upward) showed significant downward trends with time. This difference in gradational patterns could be explained by temporal differences in the geomorphic variables that drive gradational processes, including but not limited to stream width, discharge, and local slope. If changes in these variables were different between the two sites, it is reasonable to assume that their gradational trends also would be different.

Effects of High-Water Events

Although long-term gradational patterns can be computed, "it is the manifestation of geologically instantaneous process that will dominate the sedimentary fill of [braided] channels" (Bristow and Best, 1993, p. 7). Hence, the analytical results of the effects of high-water events may be more important than the long-term gradational trends when characterizing the depositional aspects of the Platte River. However, evaluation of the historical effects of these instantaneous processes is limited by the number of discharge measurements taken. Generally speaking, the results show that bridge-channel characteristics (as measured by the ABE and the TE) are dependent on discharge; the characteristics of the reach immediately downstream (as measured by shift values and the multipliers) do not follow such an explicit relation to discharge. This would suggest that as the discharge increases, the local effects of bridge scour do change the channel in the vicinity of the bridge, but effects to the channel downstream are less evident.

For the six peak events that were analyzed, the ABE and TE typically responded to high flows at both the Ashland and the Louisville sites. Inspection of figures SFD_8 and SFD_9 indicates that the responses of the ABE and the TE were dependent on the duration of the peak as well as the magnitude. For the Ashland site, the two events that were well-defined by several measurements (June 12, 1944 and June 1, 1951) showed the ABE and TE both were disturbed substantially by the peaks, but also that the majority of the recovery occurred fairly quickly, roughly coinciding with the durations of the events. For the Louisville site, only one event was defined well enough (March 30, 1960), and it had the maximum disturbances for both the ABE and the TE. The majority of the recovery for both was delayed, however, presumably because of the extended duration of the high flow. The longest ABE and TE recovery times at both sites were associated with the 1993 peak, which may have been caused by the long durations as well as generally higher-than-normal base flows that occurred during the events of that year. Because these variables indicate channel characteristics only at the bridge, these responses could reflect local bridge-scour effects as well as general changes in the entire channel.

The indicators of the channel downstream, the shift values and the multipliers, did not consistently show a response to discharge. At both sites, the shift values showed a direct response for three of the six peak events analyzed. For the two well-defined events at the Ashland site, the shift values showed a clear relation to the discharge hydrographs, with fairly quick recovery times. However, the well-defined event at the Louisville site had shift values that indicated increased deposition during the peak, and increased scour conditions during recession. The multipliers also did not show a consistent response to discharge. For the Ashland site, the 1944 and 1951 water years both showed little correlation between discharge and multiplier, whereas the 1988 and 1994 water years did. The Louisville site showed a clear relation between multipliers and discharge for water year 1960, but this relation was not so evident in water years 1985 and 1998. These responses suggest that either the indicators used do not accurately represent the downstream channel characteristics, or that the downstream channel is not always directly affected by discharge.

SUSPENDED-SEDIMENT DISCHARGE ANALYSIS

Suspended-sediment discharge (*SSD*) rating curves were developed for the Platte River at Louisville using sample data collected during water years 1972 to 1999 and then tested for trends using the Kendall's tau procedure. No statistically significant trends were found at the 95-percent confidence level. The *SSD* rating curves and daily values of *SFD* were used to compute daily values of *SSD* for the Platte River at Louisville for water years 1972 to 1999. Values of annual total *SSD* were then computed and tested for trends using the Kendall's tau procedure; a statistically significant upward trend was found at the 95-percent confidence level. The corresponding average annual *SFD* values also were tested and found to have a significant upward trend.

Data

For the Platte River at Louisville (06805500), suspended-sediment sample data of concentration (SSC) and of *SSD* were available for February 1971 to September 1999. Daily mean SSC and *SSD* data were available for October 1971 to September 1981. From December 5, 1961 to September 1973, the *SFD* gage was located at Interstate Highway 80 (about 3 miles downstream from U.S. Highway 6) and data were published as Platte River near South Bend. Therefore, the sediment data from February 1971 to September 1973 are for that site also.

The SSC and *SSD* sample data and corresponding *SFD* data were downloaded from the USGS National Water Information Systems database and entered into Microsoft Excel spreadsheets. The data were checked against published values from the USGS annual reports of Water Resources Data—Nebraska. In addition, the data were plotted onto annual hydrographs of daily mean *SFD* data for further checking. Several discrepancies were found in data collected for a special research project, conducted by the USGS as part of a herbicide study in the upper Mississippi River and its major tributaries. The data were never published. Corrections were made to the spreadsheets and *SSD* values were recomputed from the SSC and *SFD* data.

Methods

Sediment-Discharge Rating Trends

A plot of *SFD* and *SSD* sample data was made, and curves for linear, power, and exponential equations were fit to the data. The power equation was the best fit and was chosen for further use (fig. SSD_1). The form of the equation is shown next.

$$SSD = a(SFD)^b$$

where: *SSD* is the suspended-sediment discharge, in tons per day,

a is a multiplier representing the intercept when plotted on a logarithmic grid,

SFD is streamflow discharge, in cubic feet per second, and

b is a dimensionless exponent representing the slope when plotted on a logarithmic grid.

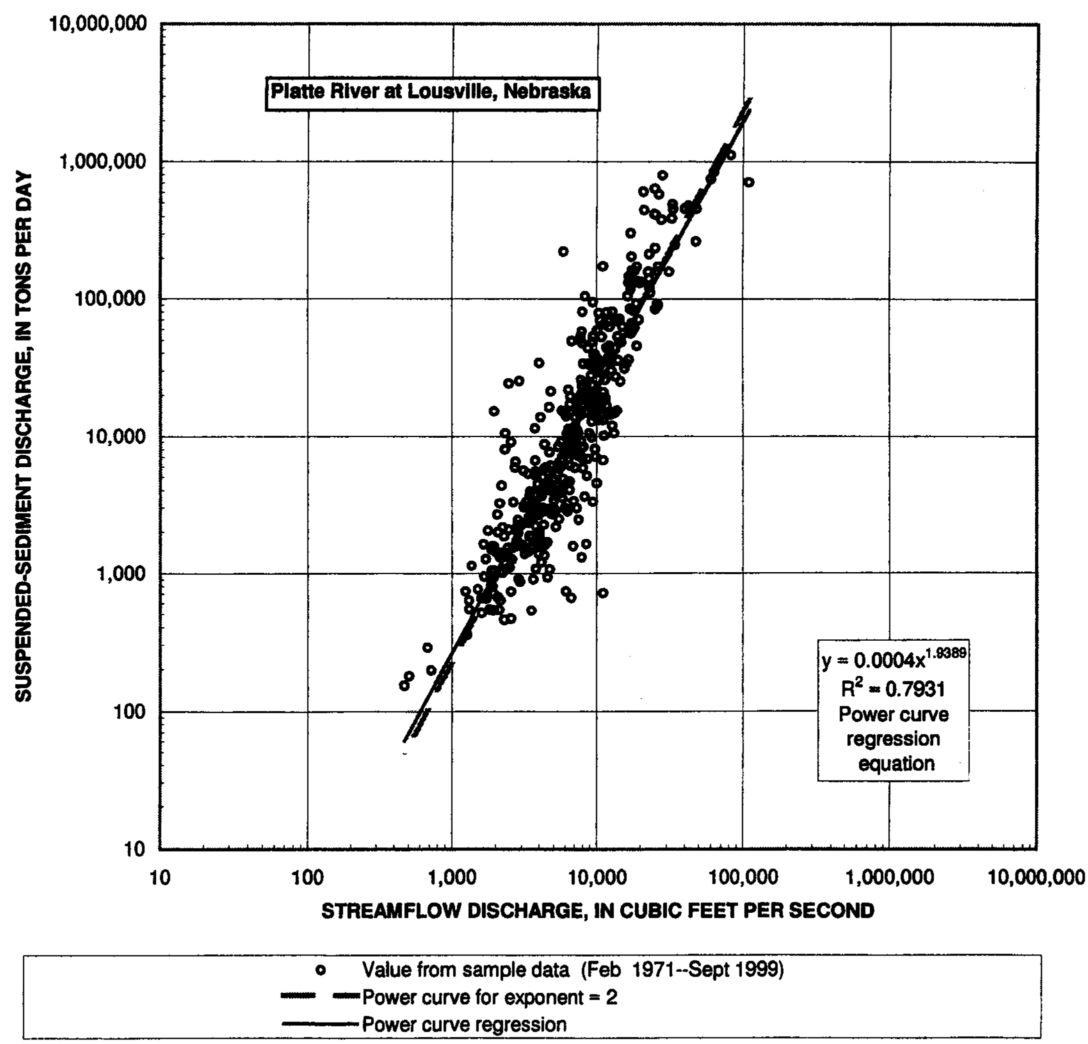


Figure SSD_1. Power equation fit to data points of streamflow and suspended-sediment discharge for samples collected from the Platte River at Louisville, Nebraska, for the period February 1971 to September 1999.

Glysson (1987) reports that some researchers have expressed concern about statistical bias in sediment-discharge estimates using this method, and that some solutions have been proposed. Glysson (1987) also reports that one of the solutions is flawed and that none have been tested thoroughly. No attempts have been made here to correct for this possible bias.

Power equations were fit to the data spanning each water year. The first data point before and after each water year were included, except 1999, for which published data were not available after September 1999. Because the exponent values varied less than the multiplier values, it was decided to hold the exponent b in the equation constant, at an arbitrary value of "2", and compute the multiplier a for each sample point based on the *SFD* and *SSD* data (appendix D). This is analogous to adjusting the slope of the line in figure SSD_1 slightly upward and then holding the line steady while sliding the line up and down through the individual data points. The farther up the *SSD* scale the line is, the larger the value of the multiplier. The multiplier values and sample dates then were used to help determine if there were any trends in the *SFD–SSD* relation with time.

Because the sampling frequencies and operational modes under which samples were collected have varied, the multiplier data from the individual samples are probably biased. Additional sampling to provide equivalent data through time would be useful. Samples collected during storm runoff events have a greater likelihood of having a higher concentration of sediment for a given discharge than do samples collected during non-event periods. Therefore, when sampling frequency is increased, or the sampling mode is focused on storm-related events, more data with higher sediment concentrations are likely to be collected. This is evident from figure SSD_2 which shows the power equation multiplier values (with exponent set to 2) for all of the samples. During water years 1971 to 1981, daily sediment records were published. Sampling frequency was much higher and with a greater proportion of event samples than during water years 1983 to 1990, when only quarterly samples were obtained. Beginning in water year 1991 and continuing through water year 1994, sampling frequency was increased substantially for a special herbicide research project conducted by the USGS. From water year 1994 on, sampling frequency has varied from 4 to 28 samples per year, but with apparently more emphasis on events than during the quarterly only sampling period. To reduce the effects of the unequal event sampling frequency on the multiplier values to be tested for trends, the median value for each water year was determined. This gives equal weight to each year and should reduce the effects of the few high multiplier values, obtained during years with increased sampling frequency. The Kendall's tau test, described previously, was applied to the annual median values of the power equation multiplier values.

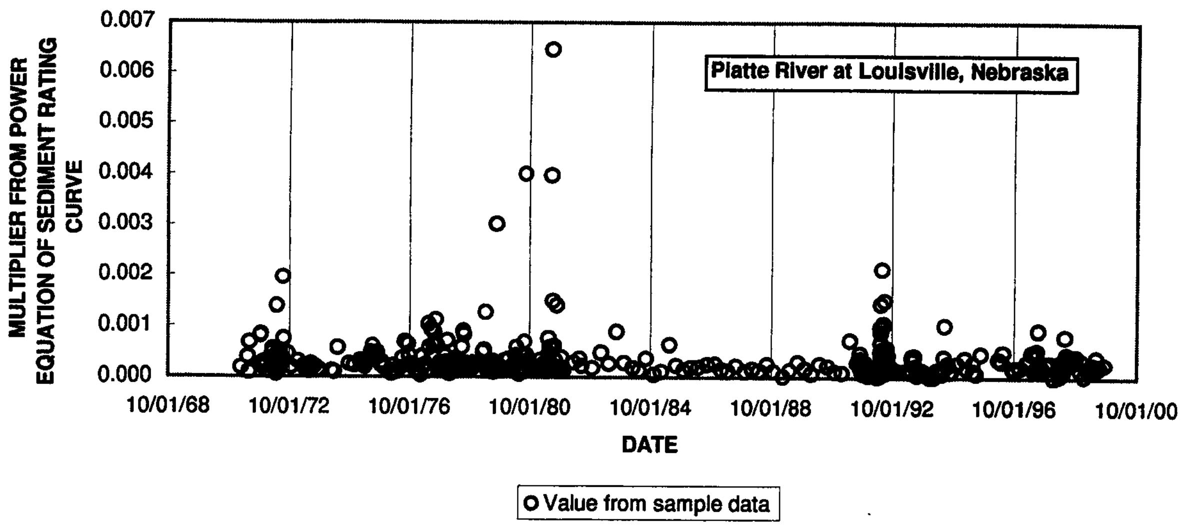


Figure SSD_2. Multiplier values for power equation, with exponent set to "2", computed from streamflow and suspended-sediment discharge rating data for samples collected from the Platte River at Louisville, Nebraska, during water years 1972 to 1999.

Annual Suspended-Sediment Discharge

The periodic *SFD* and *SSD* sample data from water years 1972 to 1999 were entered into spreadsheets containing daily values of *SFD*. The multiplier from the equation was calculated at each *SFD–SSD* sample point and interpolated for the days between samples, providing a daily multiplier. This daily multiplier was applied along with the daily *SFD* in the power equation to calculate a daily *SSD*. Values of annual total *SSD* were computed from the calculated daily *SSD*, and the annual mean daily *SSD* was calculated from the calculated daily *SSD*.

This calculated daily *SSD* can be compared to the published daily *SSD* for water years 1972 to 1981 in several ways. The published and calculated cumulative *SSD* for the Louisville gage were compared (fig. SSD_3). While there were periods of over- and under-estimation from the equation, there is good agreement in the cumulative estimate for the 10-year period. The residuals for the published and calculated daily *SSD* were compared (fig. SSD_4). Through the majority of the period, the residuals are negligible. Periods with large residuals seem to be event-based. The calculated and published values of *SSD* also were compared (fig. SSD_5); the slope of the regression line through the data is 0.8797. A perfect correlation of the calculated and published values of *SSD* would yield a slope of 1, which is shown for comparison.

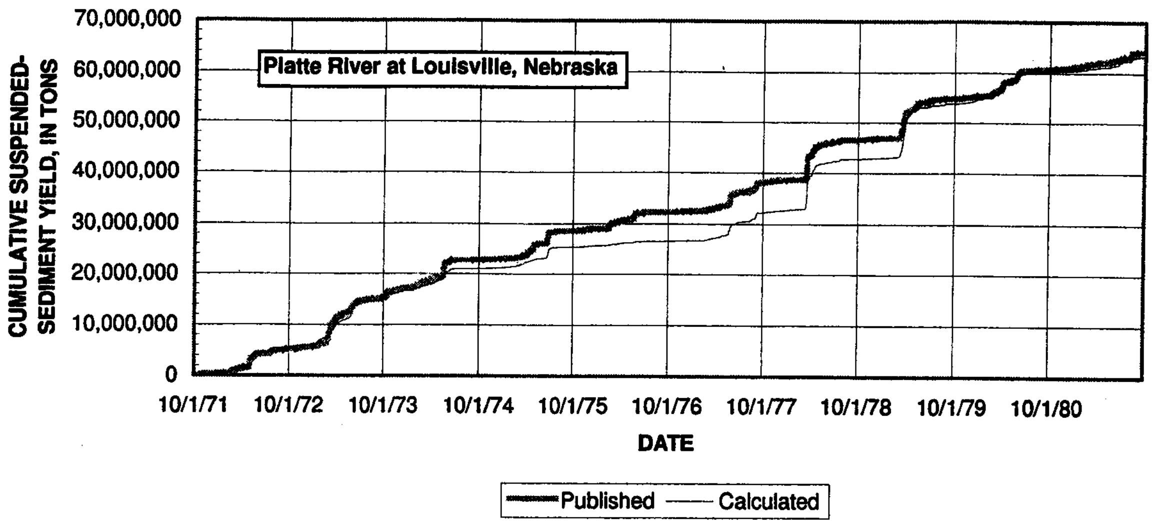


Figure SSD_3. Published and calculated cumulative yields of suspended-sediment discharge for Platte River at Louisville, Nebraska, for water years 1972 to 1981.

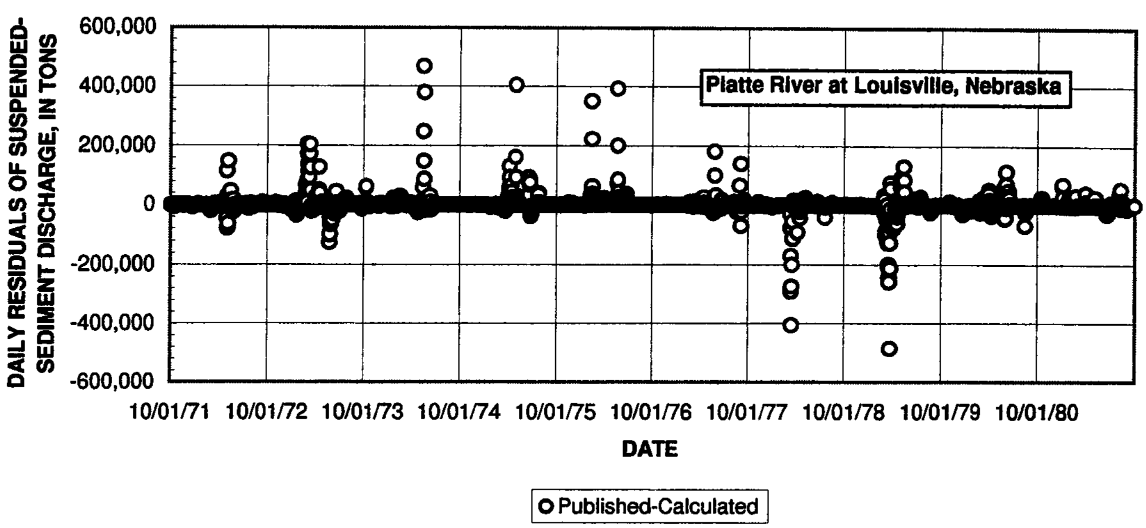


Figure SSD_4. Residuals of published and calculated values of daily suspended-sediment discharge for Platte River at Louisville, Nebraska, for water years 1972 to 1981.

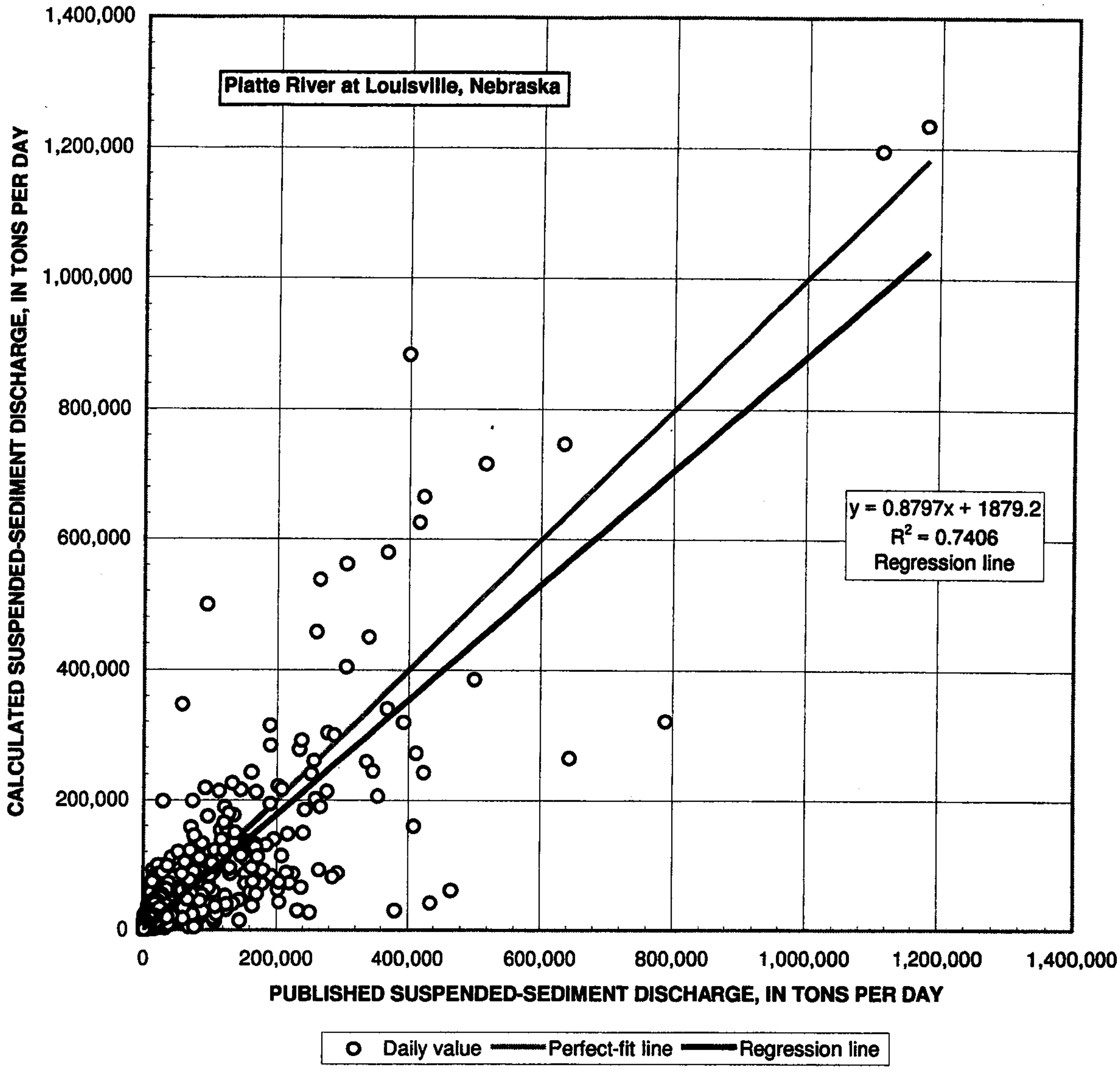


Figure SSD_5. Comparison of published and calculated values of daily suspended-sediment discharge for Platte River at Louisville, Nebraska, for water years 1972 to 1981.

Results

Sediment-Discharge Rating Trends

A trend test of the multiplier from the power equation (fig. SSD_6) shows a negative value of tau, the trend is not statistically significant. When the years with quarterly-only sampling are eliminated from the test (fig. SSD_7), the tau value is even less and the p-value is even greater than for the previous case. Based on these results, there appears to be no statistically significant trend in the *SSD* rating curves for the Platte River at Louisville during water years 1972 to 1999.

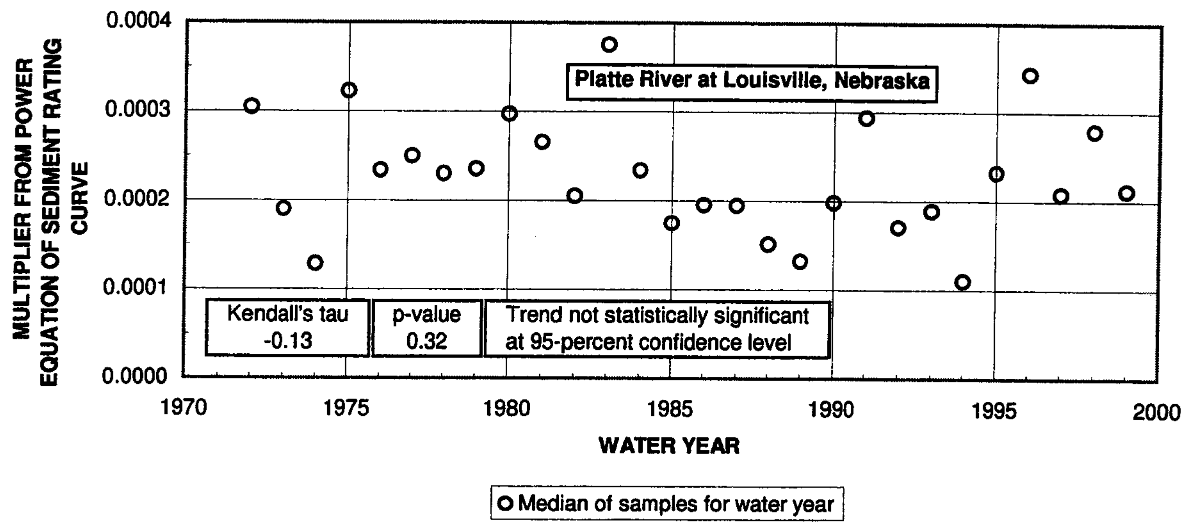


Figure SSD_6. Trend results for annual median values of multiplier for power equation with exponent set to 2 and computed from streamflow and suspended-sediment discharge rating data for samples collected from the Platte River at Louisville, Nebraska, during water years 1972 to 1999.

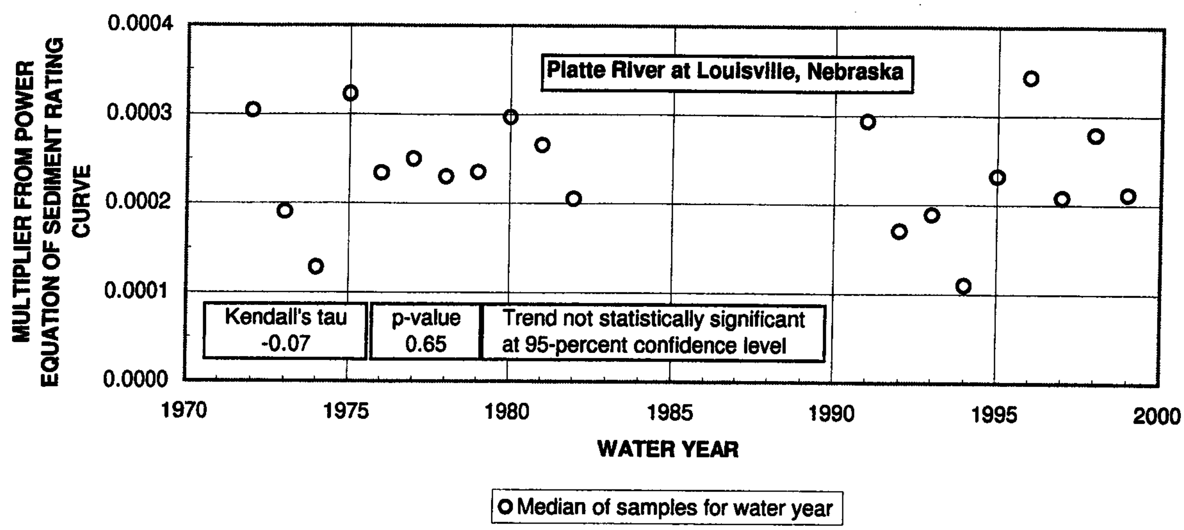


Figure SSD_7. Trend results for annual median values of multiplier for power equation with exponent set to 2 and computed from streamflow and suspended-sediment discharge rating data for samples collected from the Platte River at Louisville, Nebraska, during water years 1972 to 1982 and 1991 to 1999. Water years 1983 to 1990 were excluded because of quarterly-only sampling.

Annual Suspended-Sediment Discharge

The annual total *SFD* and calculated annual total *SSD* were analyzed (table SSD_1, fig. SSD_8), using the Kendall's tau procedure previously described, to determine if there were any statistically significant trends. The tau value for annual total *SFD* is 0.33 with a p-value of 0.01, indicating an increase of annual total *SFD* with time. The tau value for annual total *SSD* is 0.28 with a p-value of 0.04, also indicating an increase of annual total *SSD* with time. These results are statistically significant. Because the *SSD* ratings did not change, the increase in sediment yield is probably caused by the increase in *SFD*. Climatologically, the 28-year period examined is considered short and the upward trend in *SFD* may not be representative of the true long-term *SFD*.

Table SSD_1. Annual suspended-sediment discharge
[*SFD*, streamflow discharge; *SSD*, suspended-sediment discharge; --, no data]

Water year	Calculated average mean daily *SSD* (tons per day)	Calculated annual total *SSD* (tons per year)	Published annual total *SSD* (tons per year)	Published total *SFD* yield (cubic feet per second days)
1972	15,170	5,552,197	5,150,881	1,917,690
1973	25,698	9,379,867	10,103,297	3,351,850
1974	16,681	6,088,431	7,578,586	2,839,241
1975	11,913	4,348,242	5,781,874	1,729,123
1976	3,383	1,238,255	3,694,518	1,410,819
1977	15,476	5,648,684	5,813,609	1,719,774
1978	28,985	10,579,676	8,579,738	2,389,940
1979	30,258	11,044,252	8,166,238	2,080,635
1980	17,705	6,480,160	5,924,561	2,444,211
1981	8,165	2,980,216	3,402,599	1,375,162
1982	33,347	12,171,598	--	2,916,010
1983	129,665	47,327,567	--	5,004,680
1984	95,777	35,054,558	--	5,932,300
1985	32,422	11,834,184	--	3,225,230
1986	27,144	9,907,675	--	3,631,590
1987	41,890	15,289,847	--	4,403,510
1988	6,995	2,560,100	--	2,141,882
1989	5,609	2,047,255	--	1,876,822
1990	14,597	5,327,794	--	2,088,150
1991	25,997	9,514,828	--	1,916,662
1992	14,328	5,244,209	--	2,345,340
1993	60,023	21,908,338	--	5,369,590
1994	20,260	7,394,998	--	3,060,750
1995	40,515	14,787,987	--	3,910,680
1996	53,206	19,473,406	--	3,560,040
1997	30,803	11,243,214	--	3,226,430
1998	42,175	15,393,943	--	4,104,740
1999	42,057	15,350,703	--	4,236,870

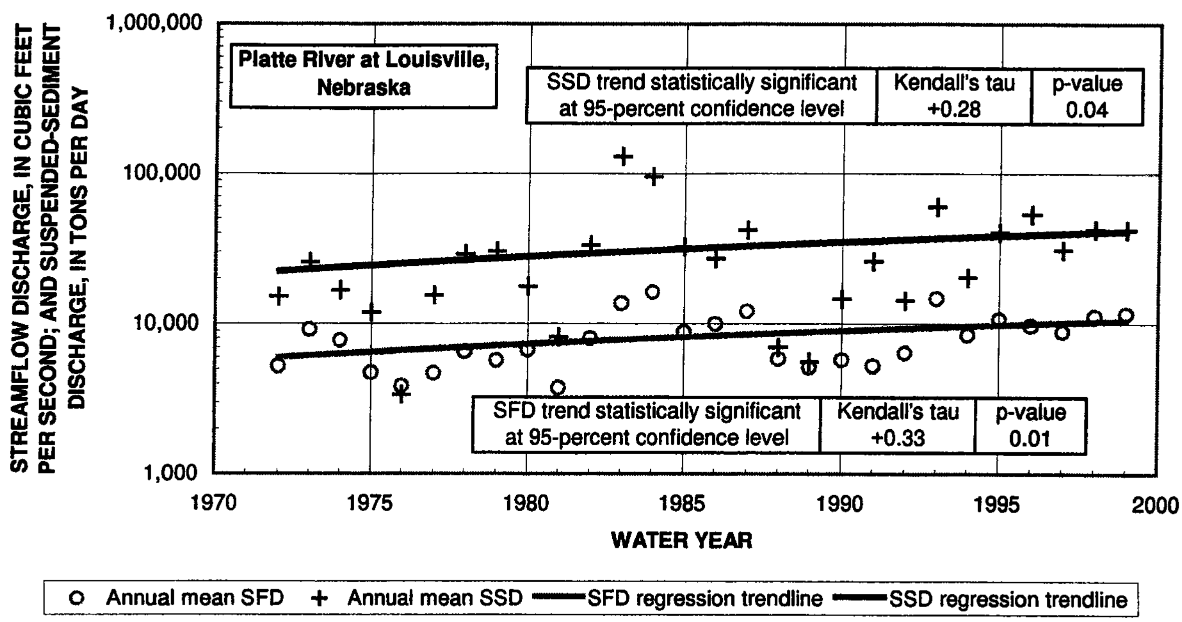


Figure SSD_8. Trend results for annual mean values of streamflow discharge (*SFD*), from published data, and suspended-sediment discharge (*SSD*), calculated from power-equation method for Platte River at Louisville, Nebraska.

SUMMARY AND CONCLUSIONS

The Omaha District of the U.S. Army Corps of Engineers is studying the possible impacts that upgrading and raising existing levees might have on channel morphology, and on emerged and submerged sandbars along a reach of the Platte and Elkhorn Rivers upstream from of U.S Highway 6 in eastern Nebraska. Three Federally designated endangered species use the river and sandbars as habitat for nesting and foraging. There is concern that the increased constriction of flow by the proposed levees might have detrimental effects on the areas used by these species. As part of the study, the U.S. Geological Survey (USGS) has performed a qualitative geomorphological assessment along a reach of the Platte and Elkhorn Rivers.

A literature search was conducted to gather information on levee impacts including applicable general alluvial process theory, and case studies and assessments of similar projects. From the literature search, it appears that a minimum amount of scouring of the sandbars is required to keep them mobile and free of permanent vegetation. If the bars become stabilized, they can eventually become islands, reducing the open habitat required for some of the endangered species. Width and discharge of rivers are related. Confining the channel to a width that is narrower than the historic width for a given discharge may cause an adjustment in other hydraulic variables, such as depth or slope.

Four sets of aerial photographs for 1973, 1990, 1994, and 1997 were obtained and analyzed using a geographic information system (GIS). The photographs were analyzed to determine the number, area, and shoreline length of three types of emerged sandbars in the study reach, as well as of islands. Islands were defined as vegetated, while sandbars were defined as open with no vegetation. There appears to be no relation between the number or area of sandbars and river stage (gage height) or streamflow discharge; there were also no definite trends with time.

Both long-term gradational trends and short-term responses to high-water events were analyzed using data from the two USGS stream-gaging stations on the Platte River near Ashland and at Louisville. The long-term trends were analyzed for temporal changes to the channel at the gage (using the average bed elevation (ABE) and the thalweg elevation (TE) from discharge measurements) and changes to the channel downstream of the gage (using the water-surface elevation for the median discharge from each stage-discharge relation used at the gage).

Based on these comparisons, it appears that the Ashland site has aggraded over time, whereas the Louisville site has degraded over time. This difference in gradational patterns could be explained by temporal differences in the variables that drive the gradational processes between the two sites (including, but not limited to, stream width, discharge, and local slope). The responses to high-water events of the channel at the gage (using the ABE and TE) and to the channel downstream (using shift values and multiplier values) also were analyzed. The analytical results indicated that the channel at the bridge was affected by changes in discharge, whereas the channel downstream of the bridge did not show a consistent response.

Suspended-sediment discharge (*SSD*) rating curves were developed for the Platte River at Louisville using sample data collected during water years 1972 to 1999 and tested for trends using the Kendall's tau procedure. No statistically significant trends were found at the 95-percent confidence level. The *SSD* rating curves and daily values of streamflow discharge (*SFD*) were used to compute daily values of *SSD* for the Platte River at Louisville for water years 1972 to 1999. Annual values of sediment yield then were computed and tested for trends using the Kendall's tau procedure; a statistically significant upward trend was found at the 95-percent confidence level. The corresponding average annual *SFD* values also were tested and found to have a significant upward trend. This may, at least in part, explain why Rodekohr and Engelbrecht (1998) note that the stability of the barren islands increases downstream of the Elkhorn River. Because the *SSD* rating curves have not changed significantly, the increase in sediment yield probably was caused by the corresponding increase in *SFD*. Climatologically, the 28-year period examined is considered short and the upward trend in *SFD* may not be representative of the true long-term *SFD*.

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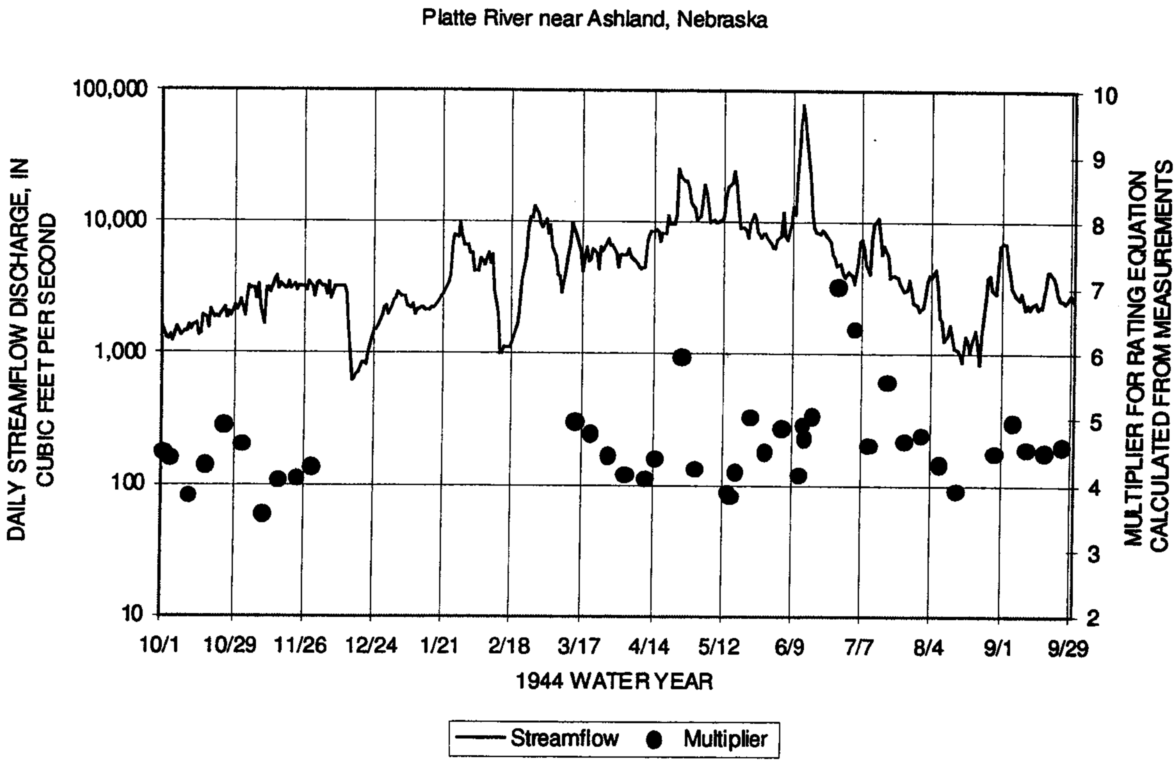
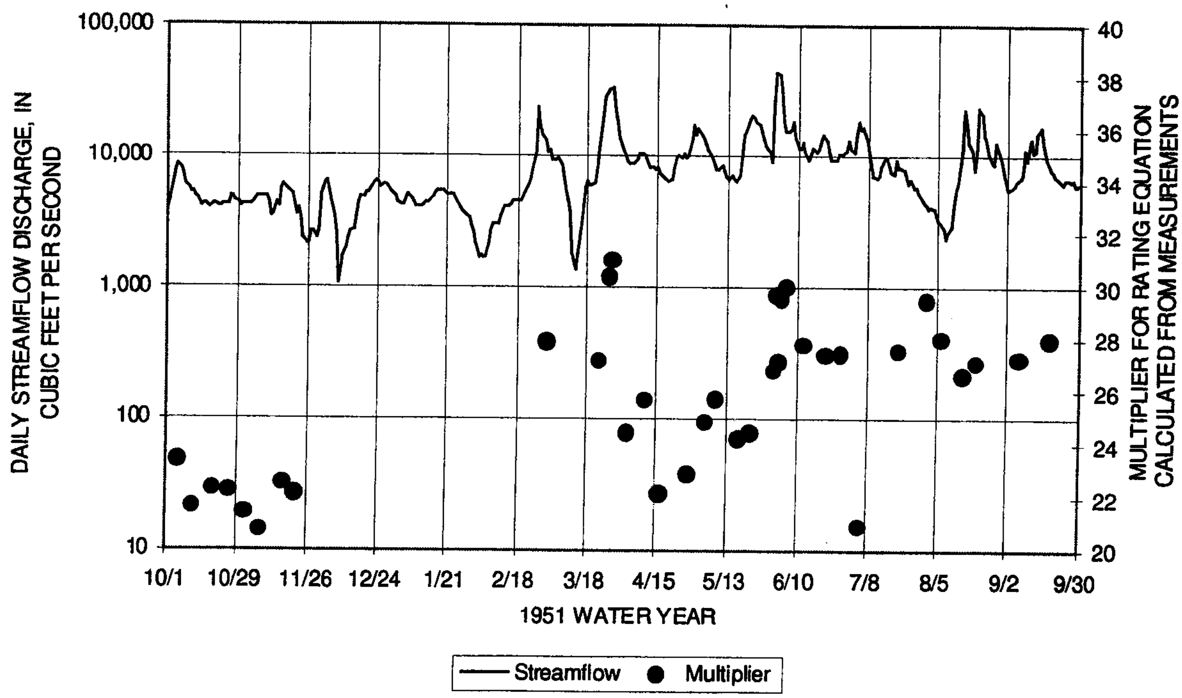
APPENDIX B—STREAMFLOW DISCHARGE ANALYSIS

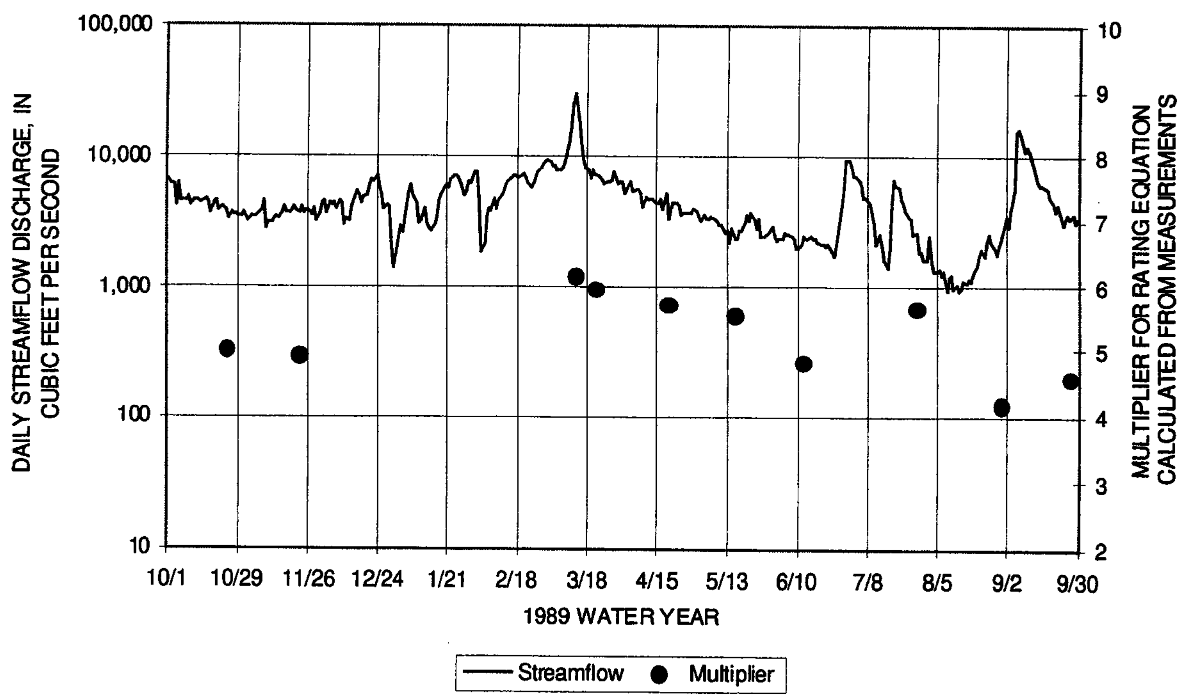
PLOTS OF MULTIPLIERS AND DISCHARGE HYDROGRAPHS—PLATTE RIVER NEAR ASHLAND, NEBRASKA



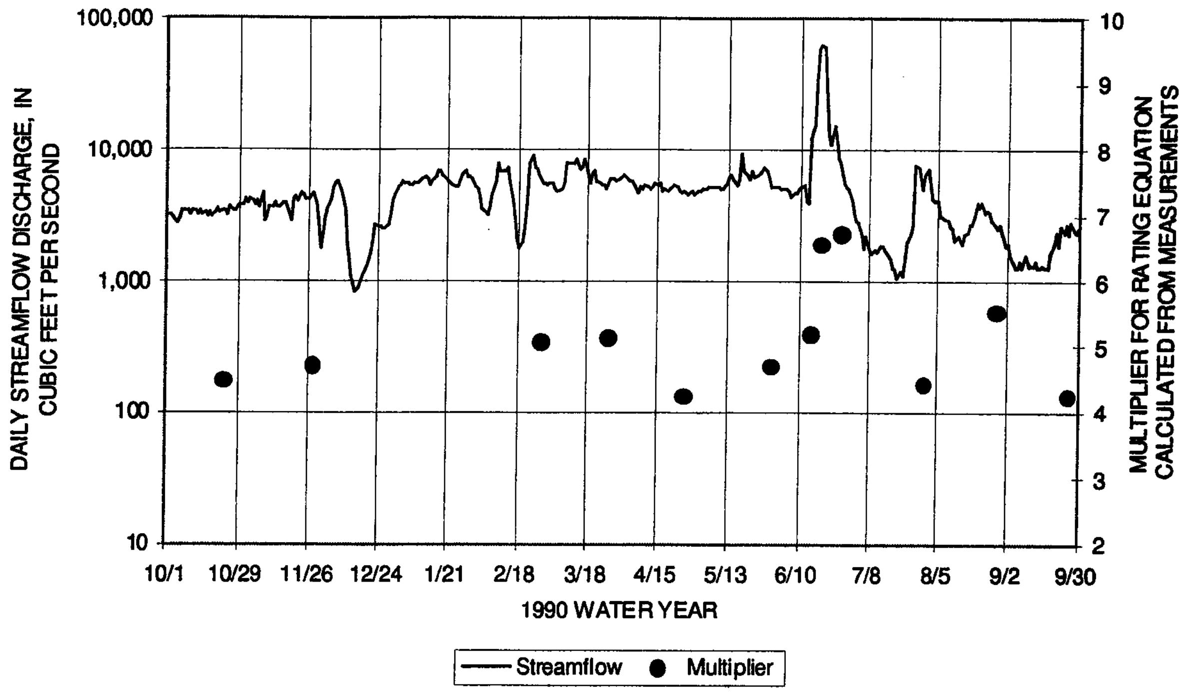
Platte River near Ashland, Nebraska



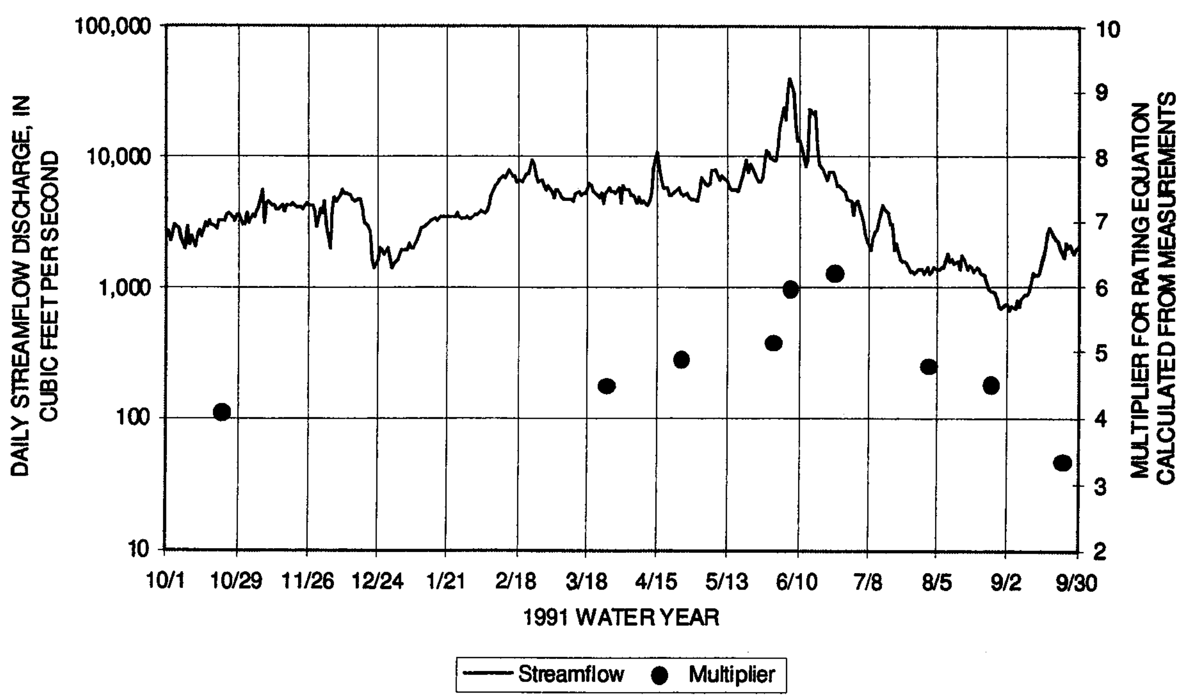
Platte River near Ashland, Nebraska

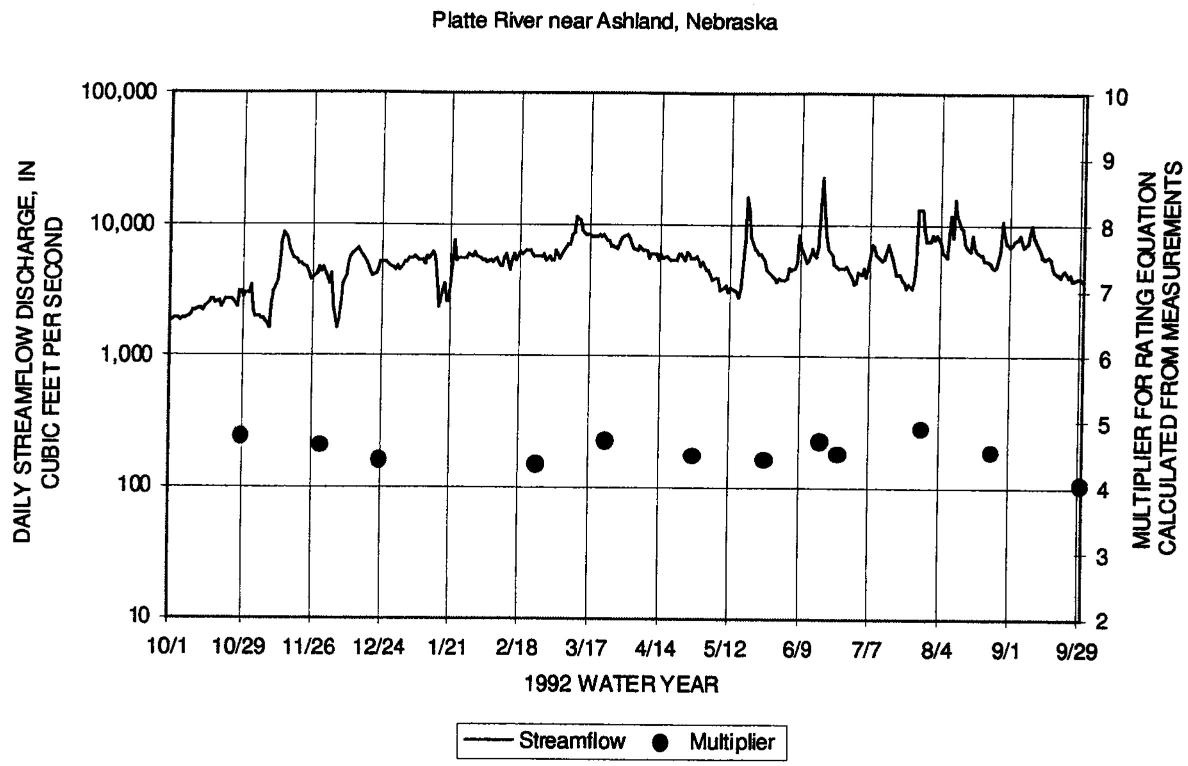


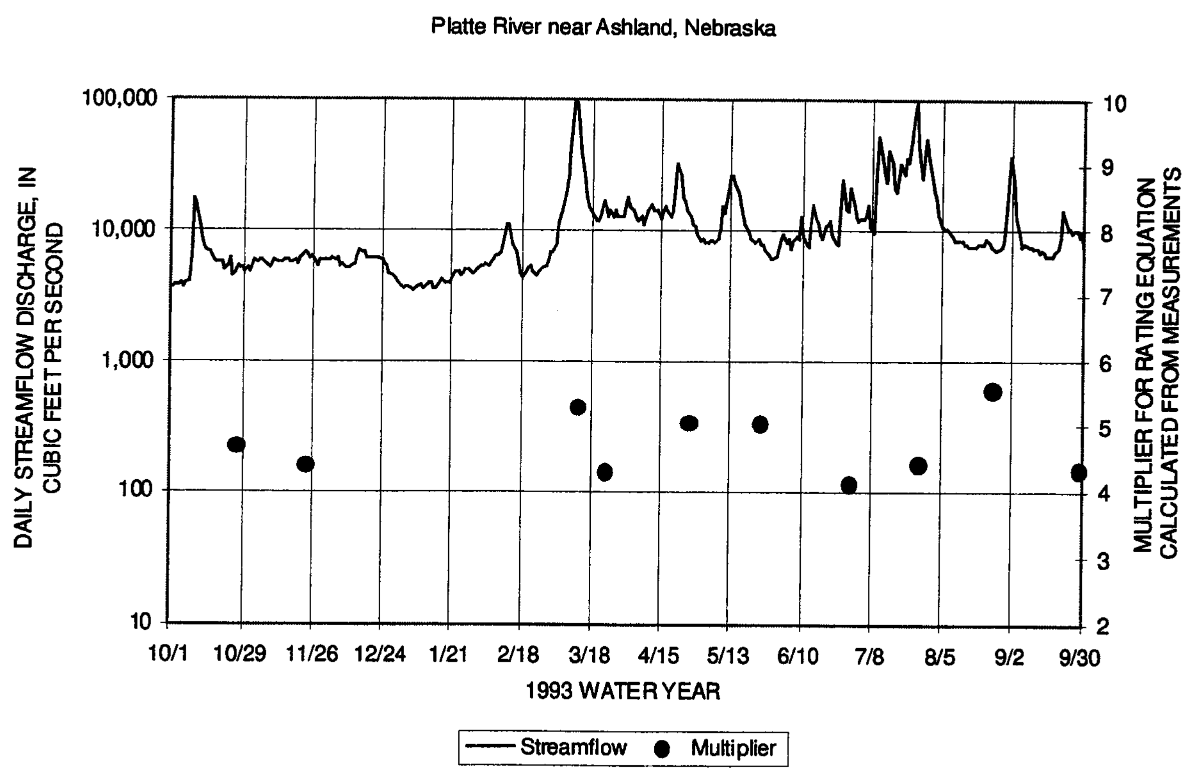
Platte River near Ashland, Nebraska



Platte River near Ashland, Nebraska




Platte River near Ashland, Nebraska
100,000
10,000
1,000
100
10
DAILY STREAMFLOW DISCHARGE, IN CUBIC FEET PER SECOND
MULTIPLIER FOR RATING EQUATION CALCULATED FROM MEASUREMENTS
10/1 10/29 11/26 12/24 1/21 2/18 3/17 4/14 5/12 6/9 7/7 8/4 9/1 9/29
1992 WATER YEAR
Streamflow
Multiplier


Platte River near Ashland, Nebraska
100,000
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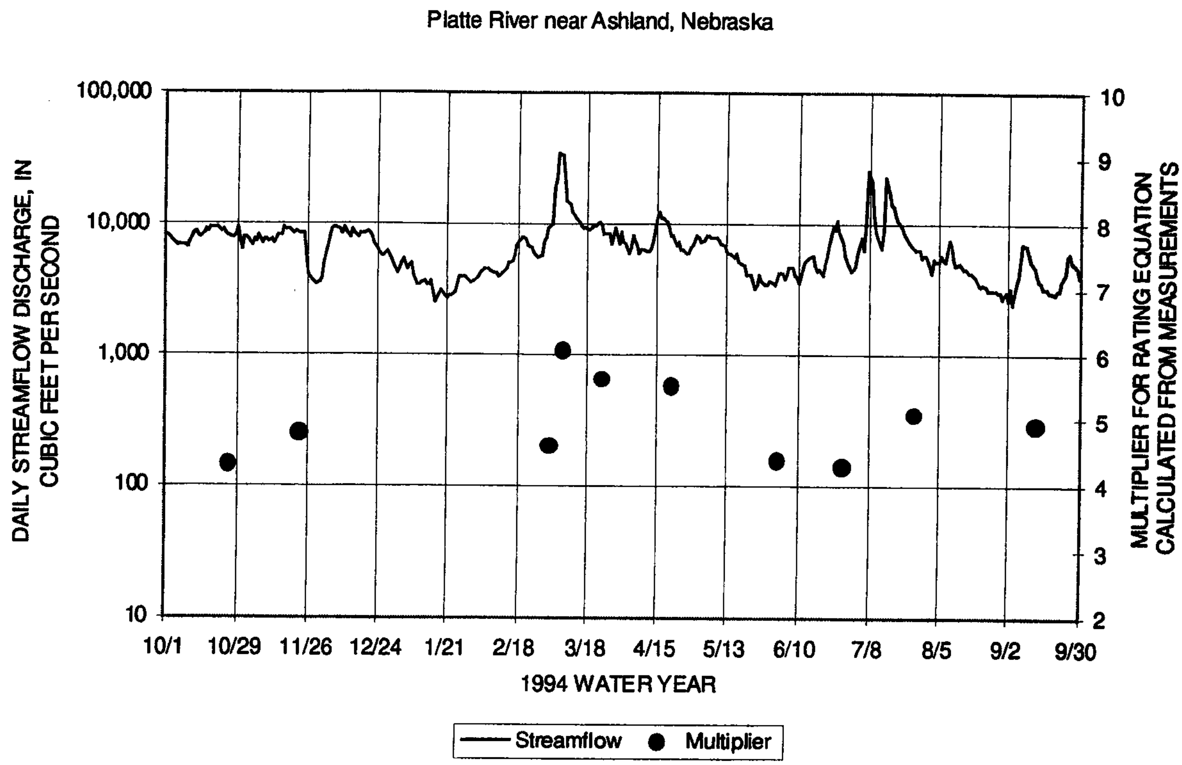
1,000
100
10
DAILY STREAMFLOW DISCHARGE, IN CUBIC FEET PER SECOND
MULTIPLIER FOR RATING EQUATION CALCULATED FROM MEASUREMENTS
10/1 10/29 11/26 12/24 1/21 2/18 3/18 4/15 5/13 6/10 7/8 8/5 9/2 9/30
1993 WATER YEAR
Streamflow
Multiplier


Platte River near Ashland, Nebraska
100,000
10,000
1,000
100
10
DAILY STREAMFLOW DISCHARGE, IN CUBIC FEET PER SECOND
10
9
8
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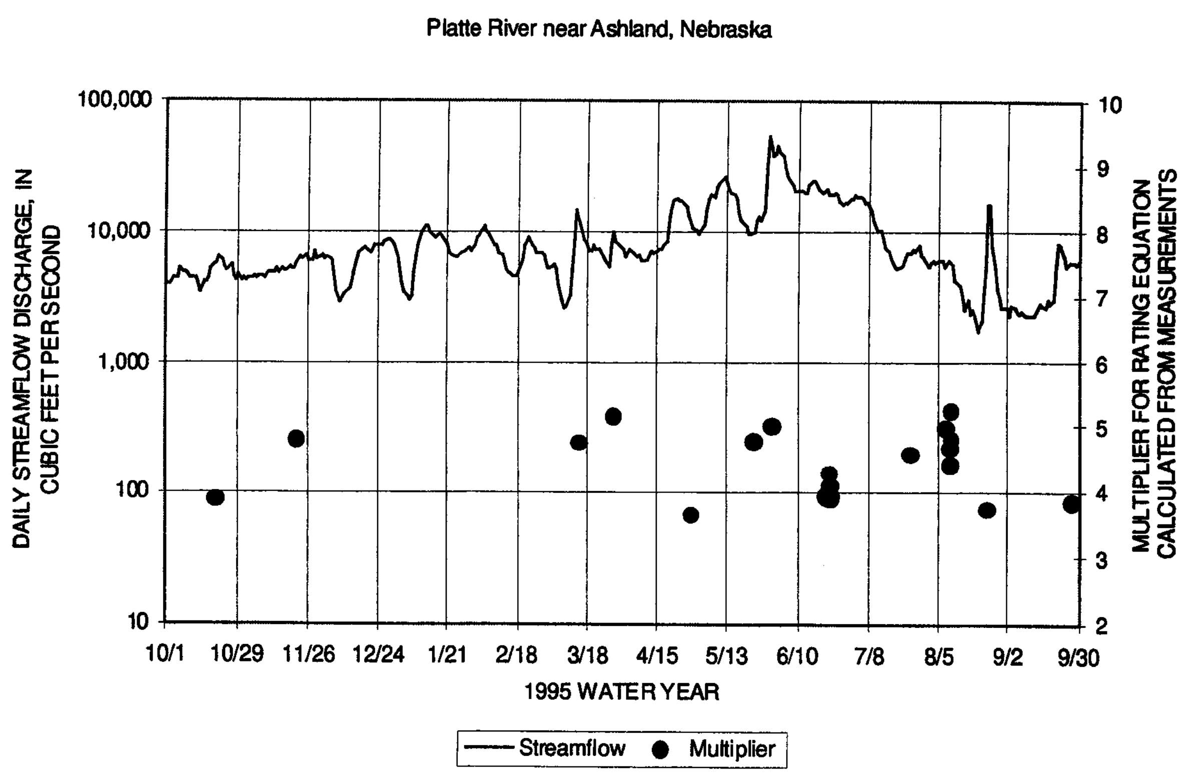
2
MULTIPLIER FOR RATING EQUATION CALCULATED FROM MEASUREMENTS
10/1 10/29 11/26 12/24 1/21 2/18 3/18 4/15 5/13 6/10 7/8 8/5 9/2 9/30
1994 WATER YEAR
Streamflow
Multiplier


Platte River near Ashland, Nebraska
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DAILY STREAMFLOW DISCHARGE, IN CUBIC FEET PER SECOND
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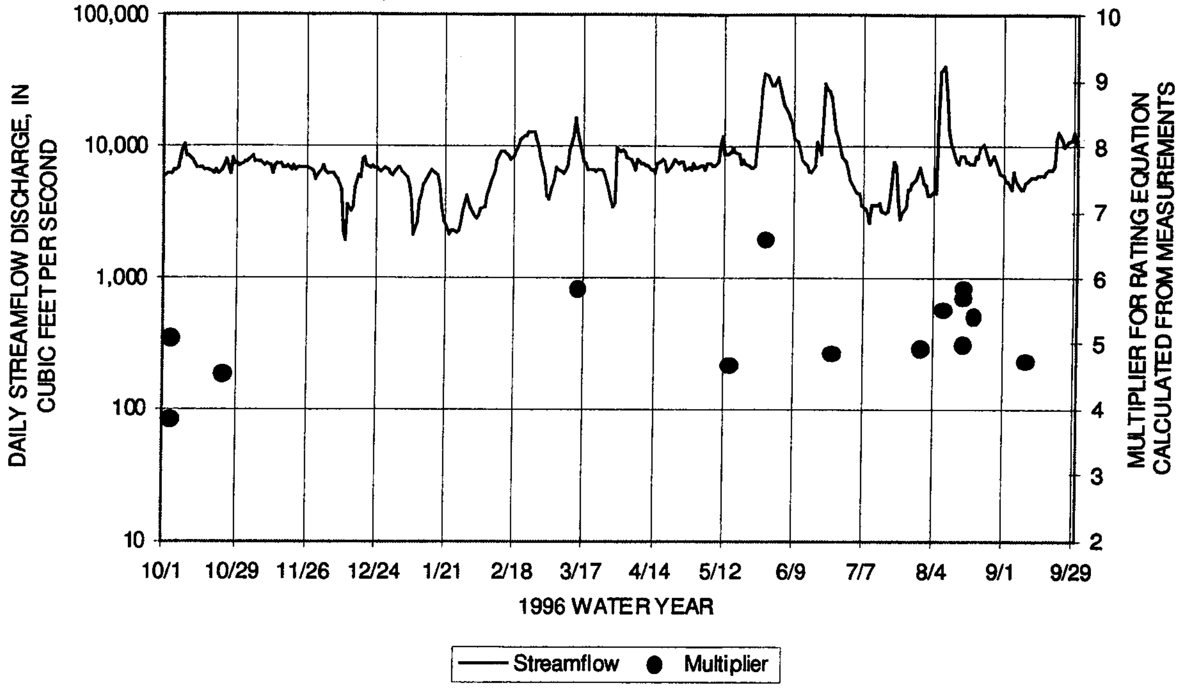
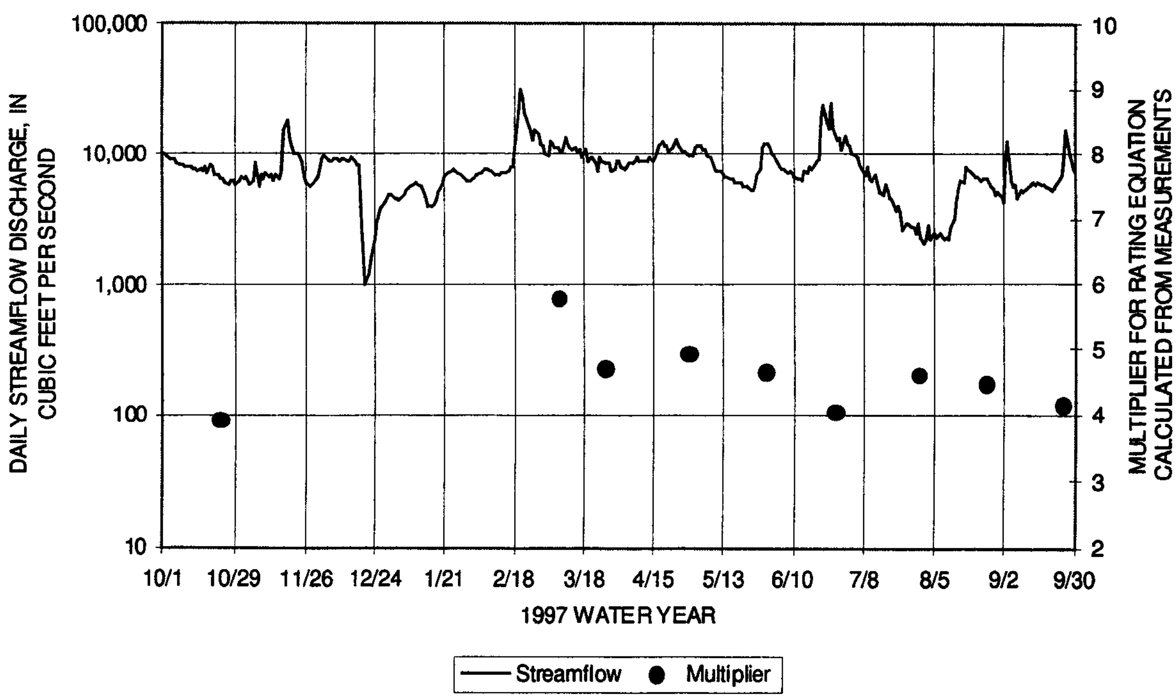
MULTIPLIER FOR RATING EQUATION CALCULATED FROM MEASUREMENTS
10/1 10/29 11/26 12/24 1/21 2/18 3/18 4/15 5/13 6/10 7/8 8/5 9/2 9/30
1995 WATER YEAR
Streamflow
Multiplier

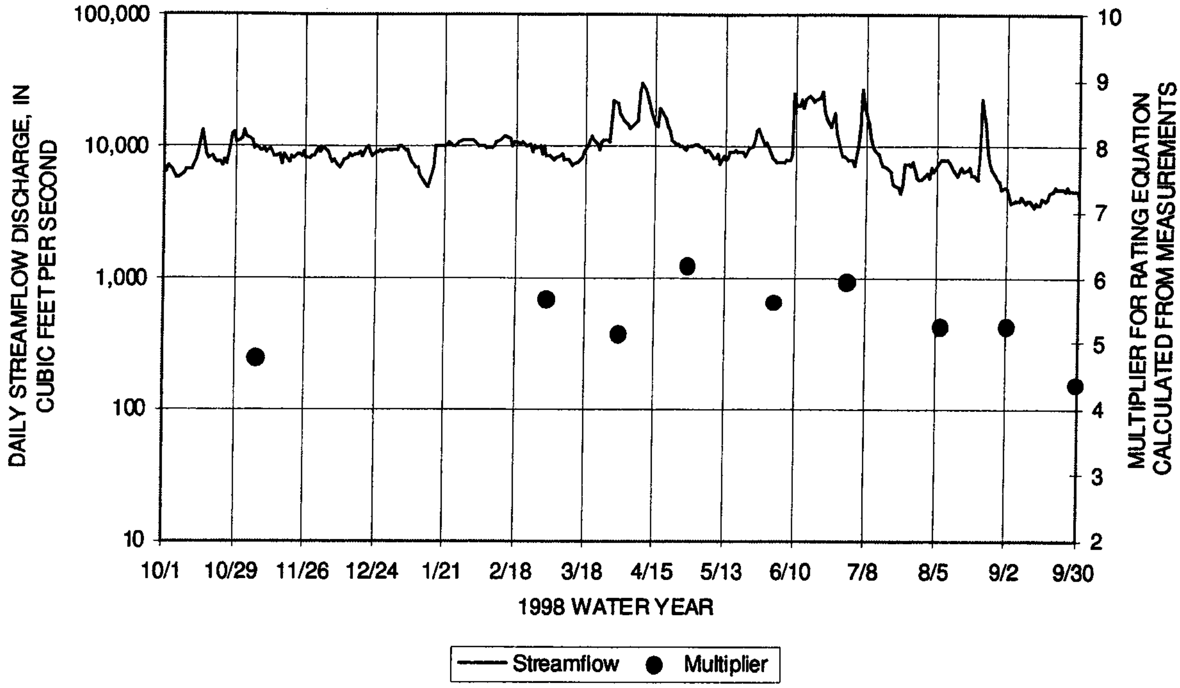
Platte River near Ashland, Nebraska



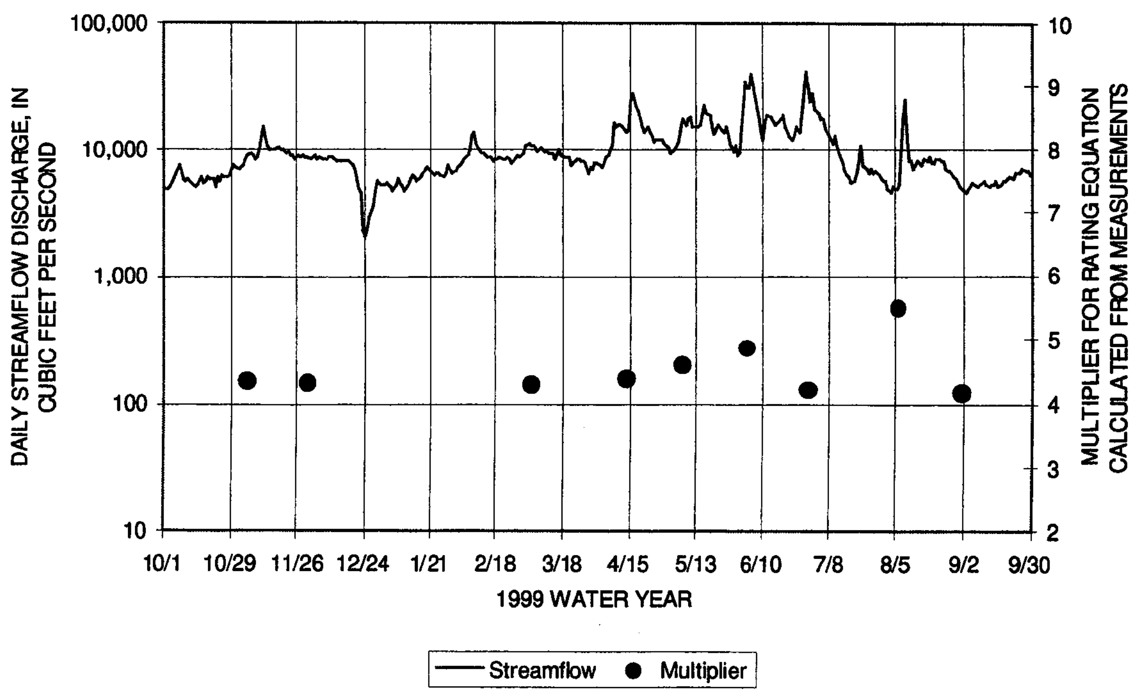
Platte River near Ashland, Nebraska



Platte River near Ashland, Nebraska

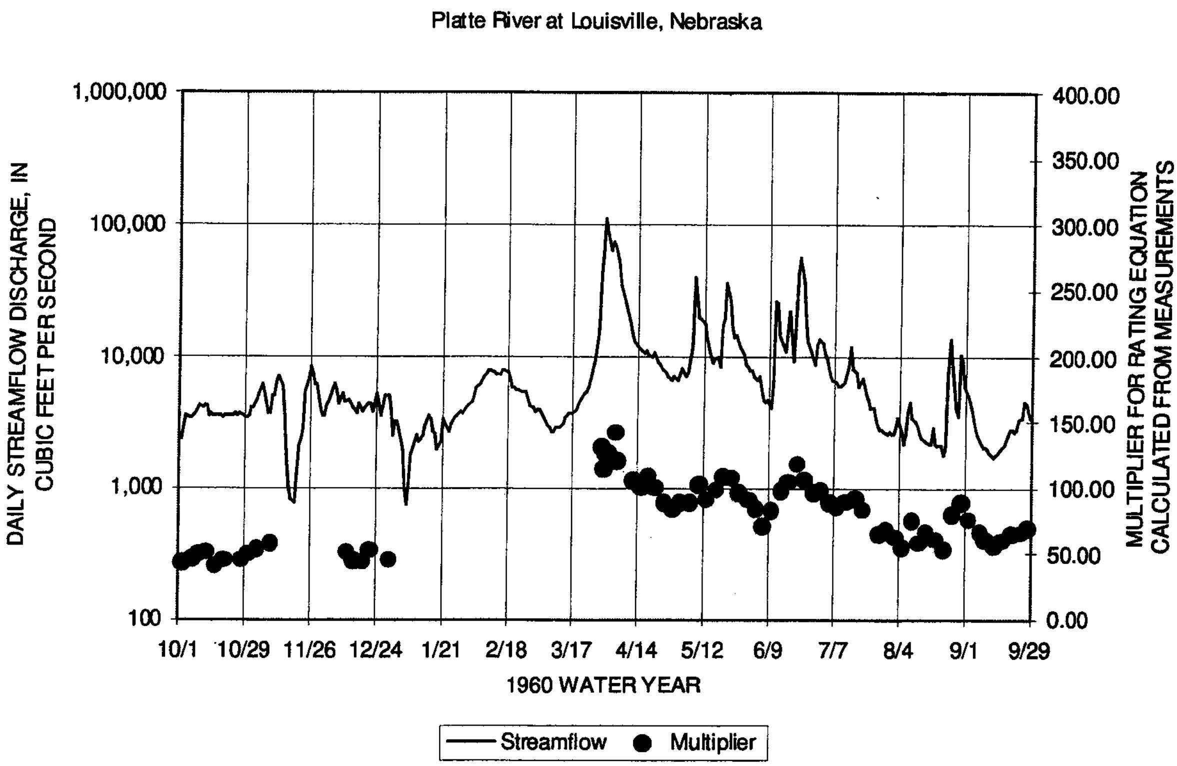


Platte River near Ashland, Nebraska

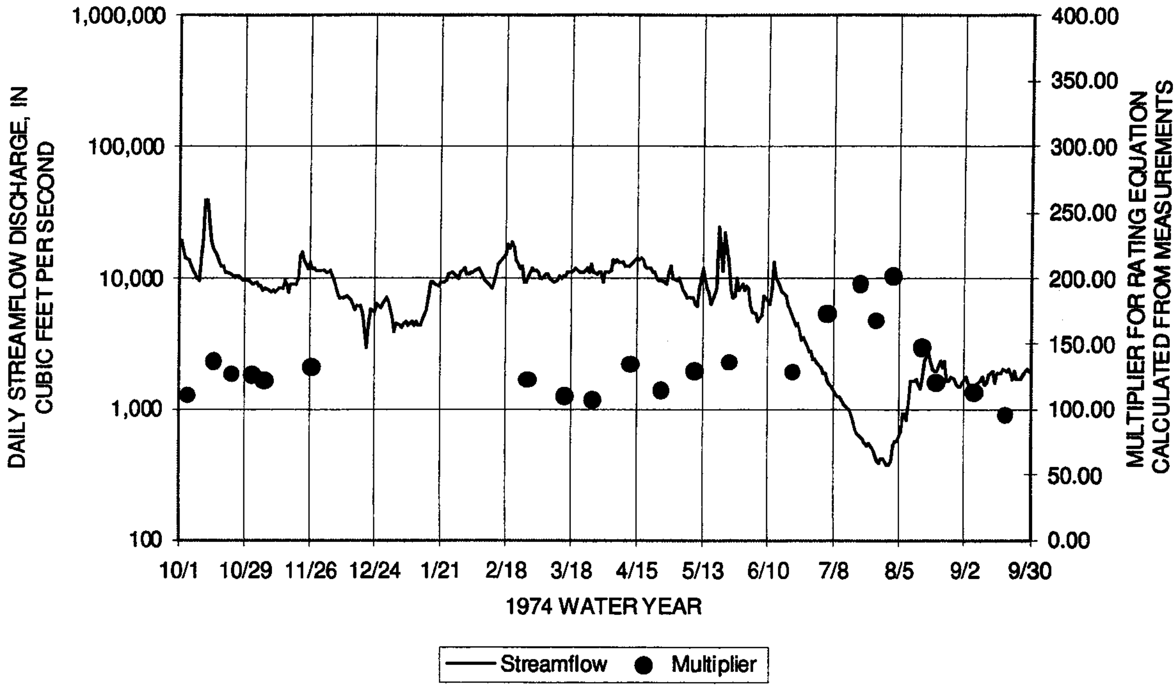


APPENDIX C—STREAMFLOW DISCHARGE ANALYSIS

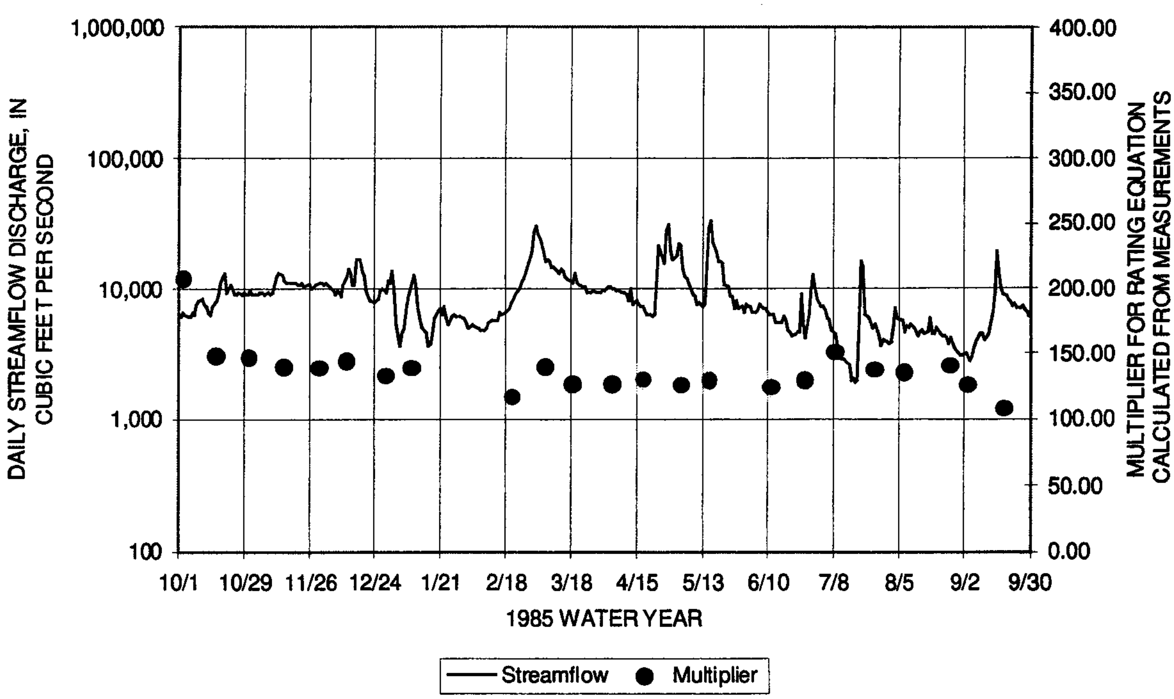
PLOTS OF MULTIPLIERS AND DISCHARGE HYDROGRAPHS—PLATTE RIVER AT LOUISVILLE, NEBRASKA



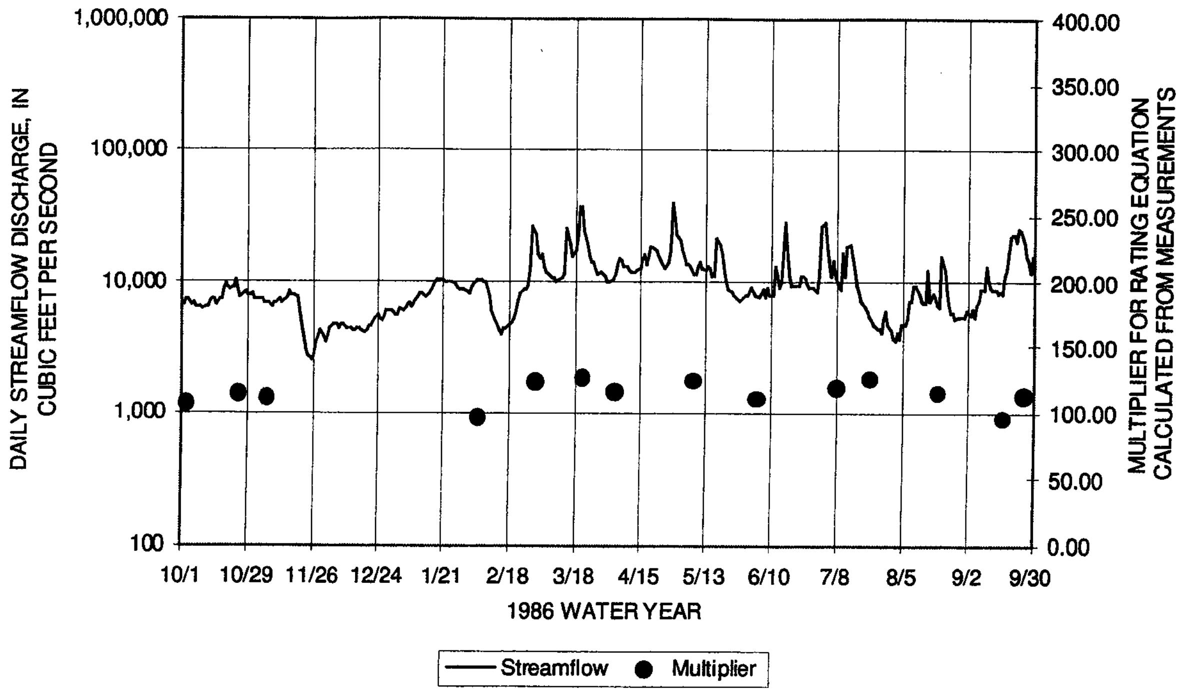
Platte River at Louisville, Nebraska



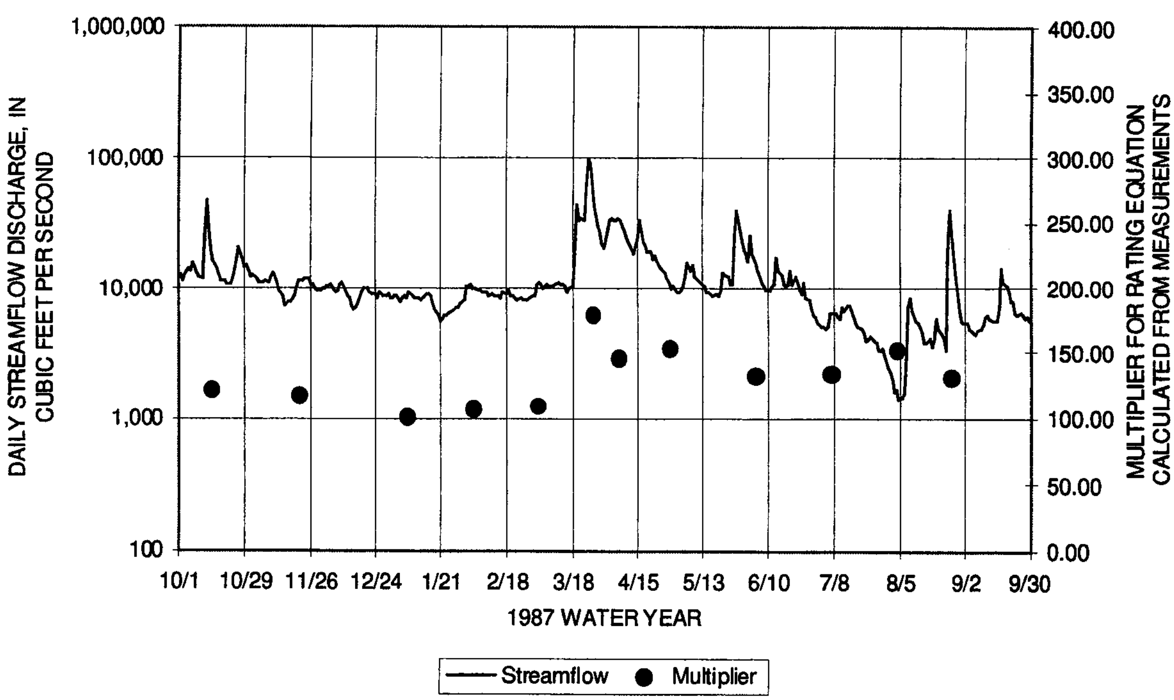
Platte River at Louisville, Nebraska



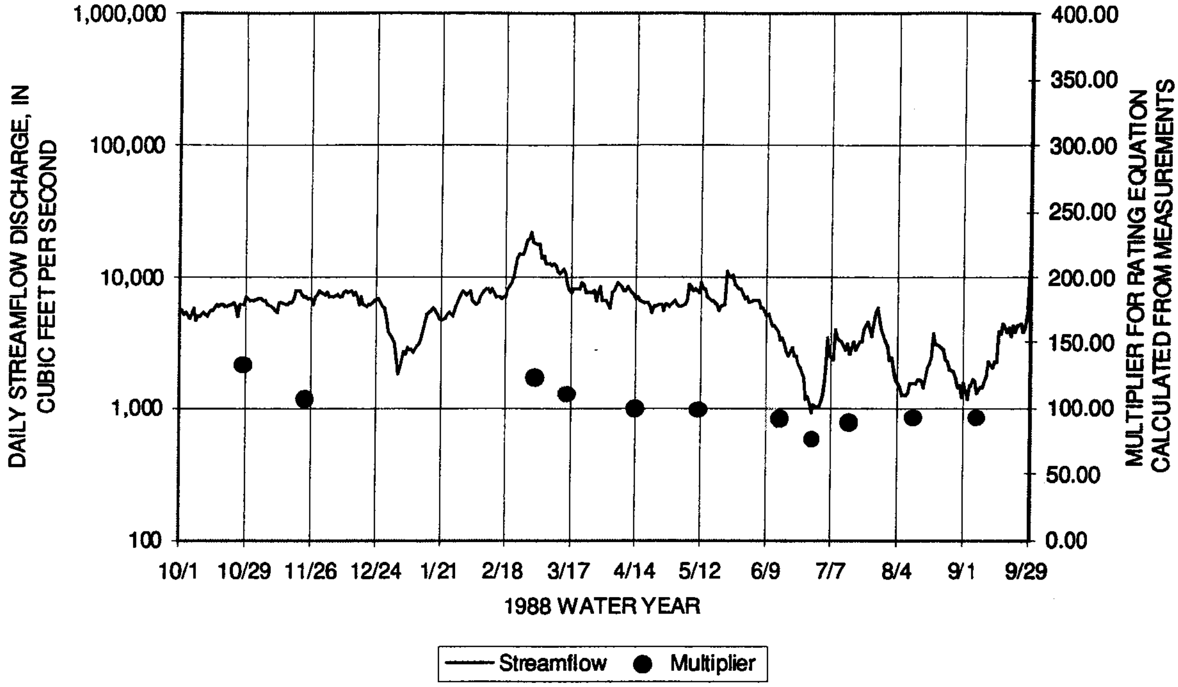
Platte River at Louisville, Nebraska



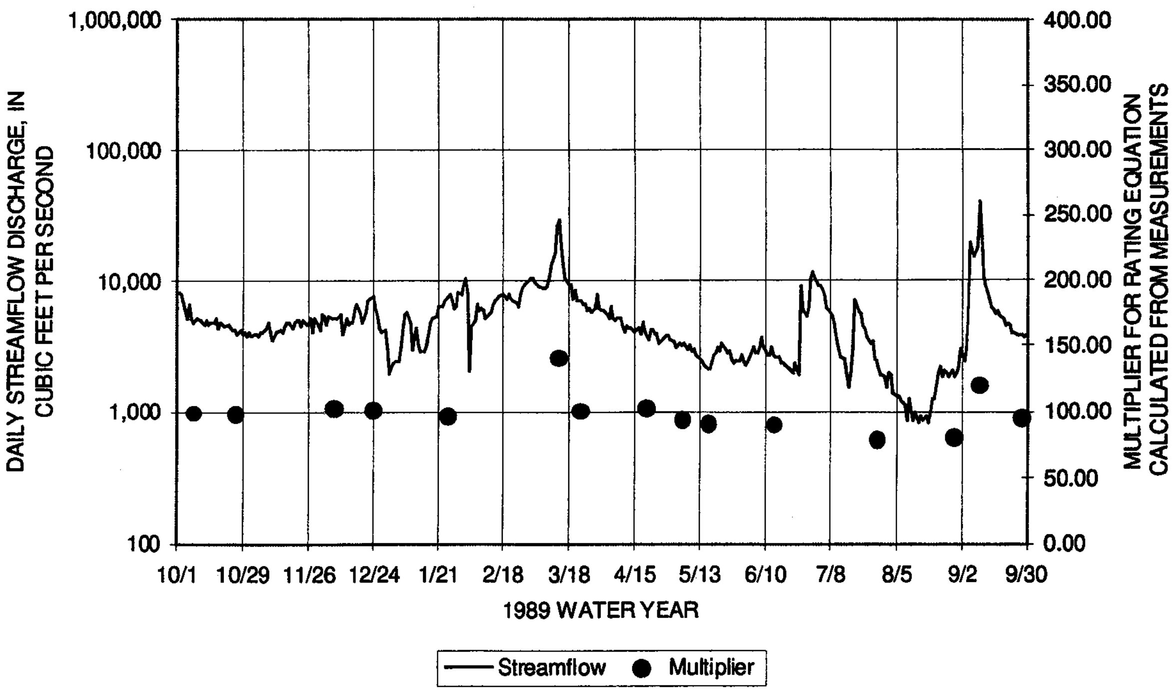
Platte River at Louisville, Nebraska



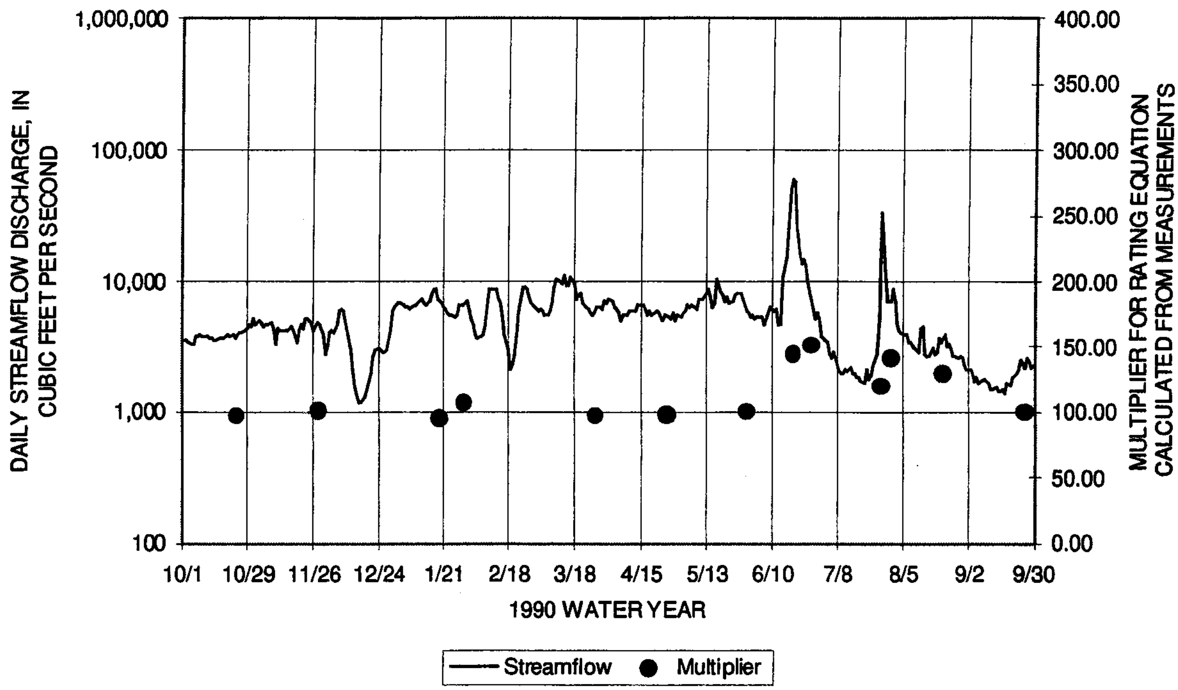
Platte River at Louisville, Nebraska



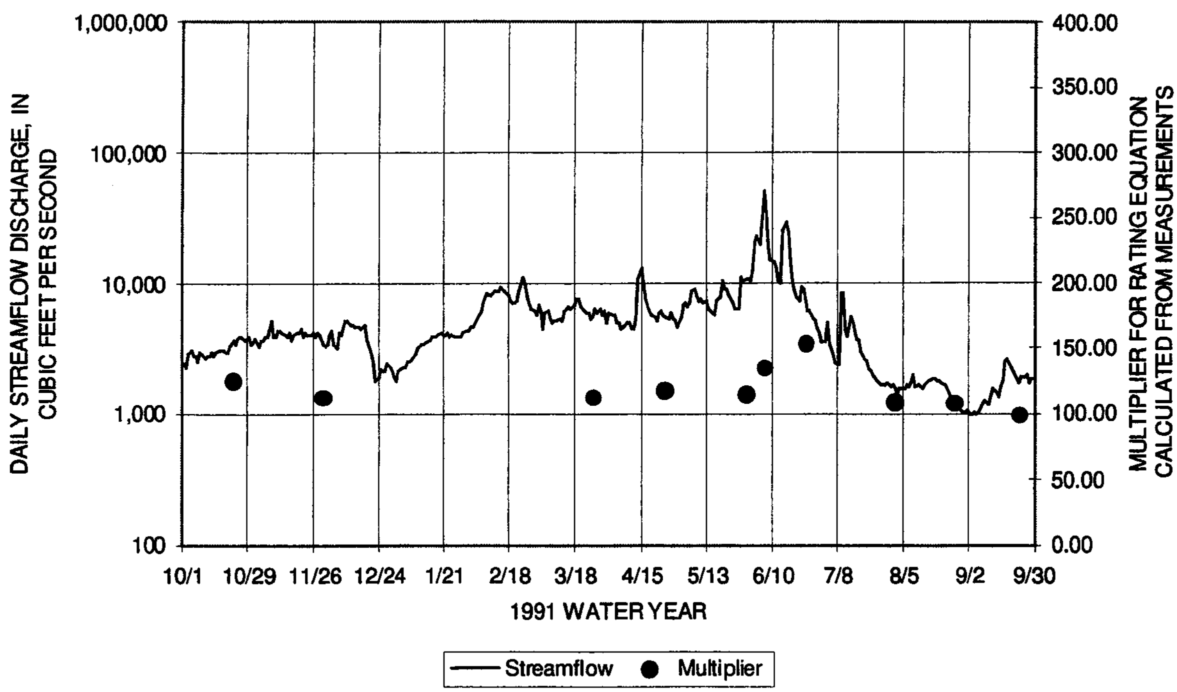
Platte River at Louisville, Nebraska



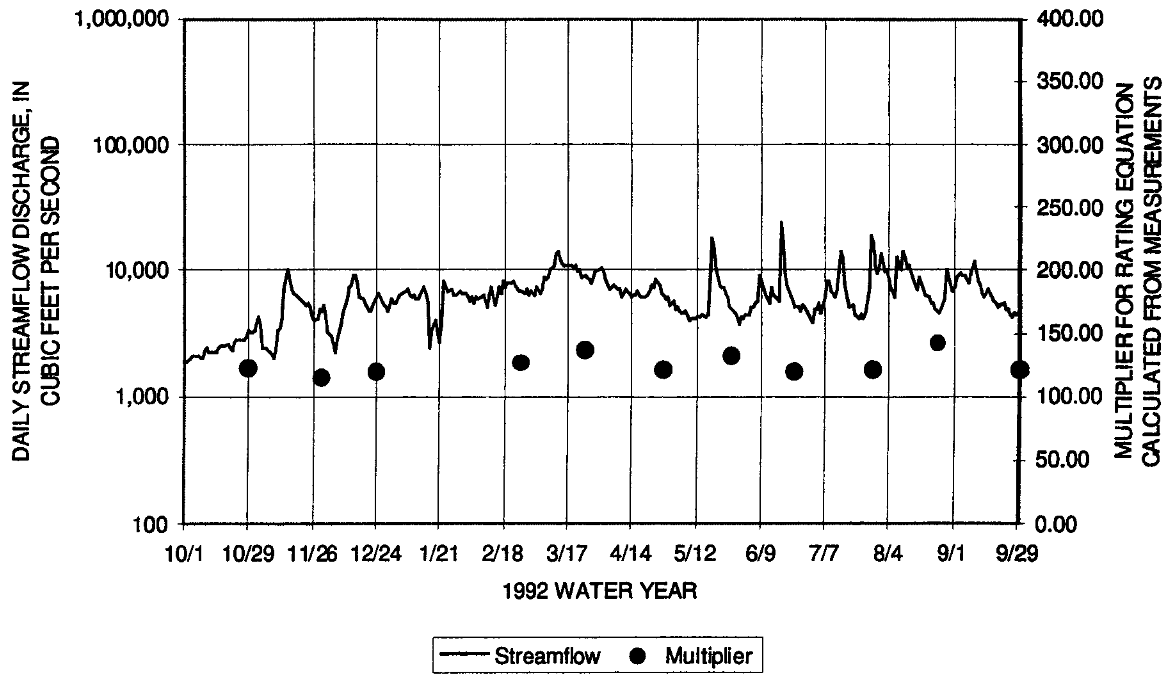
Platte River at Louisville, Nebraska



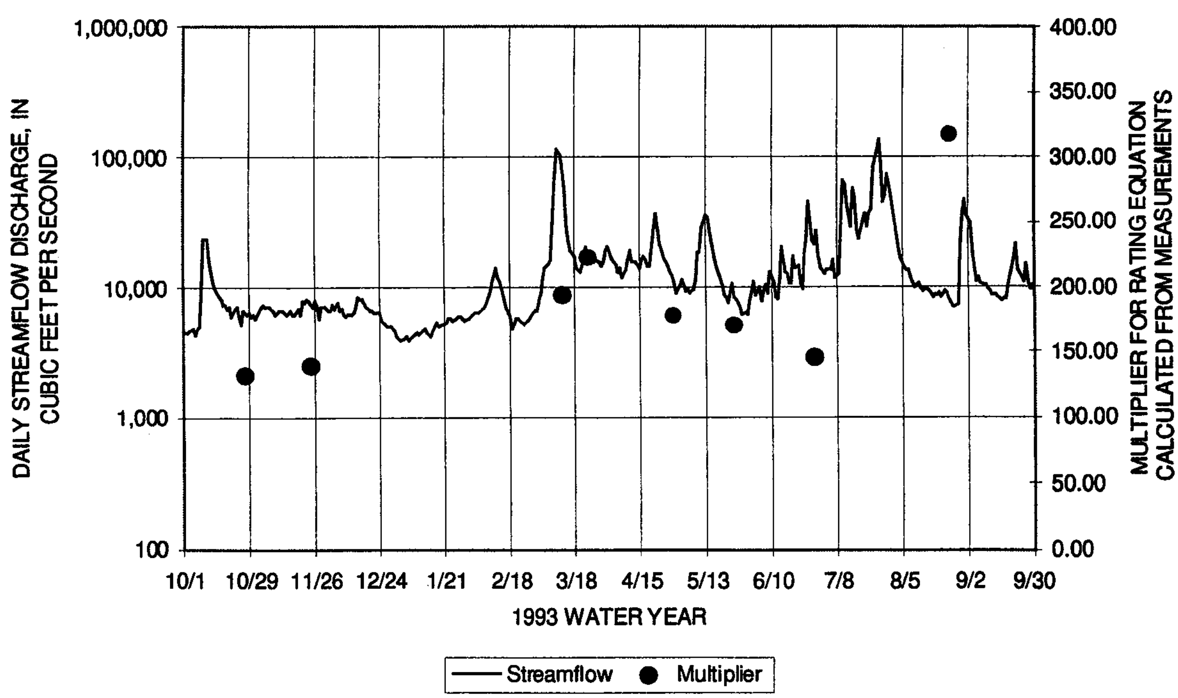
Platte River at Louisville, Nebraska

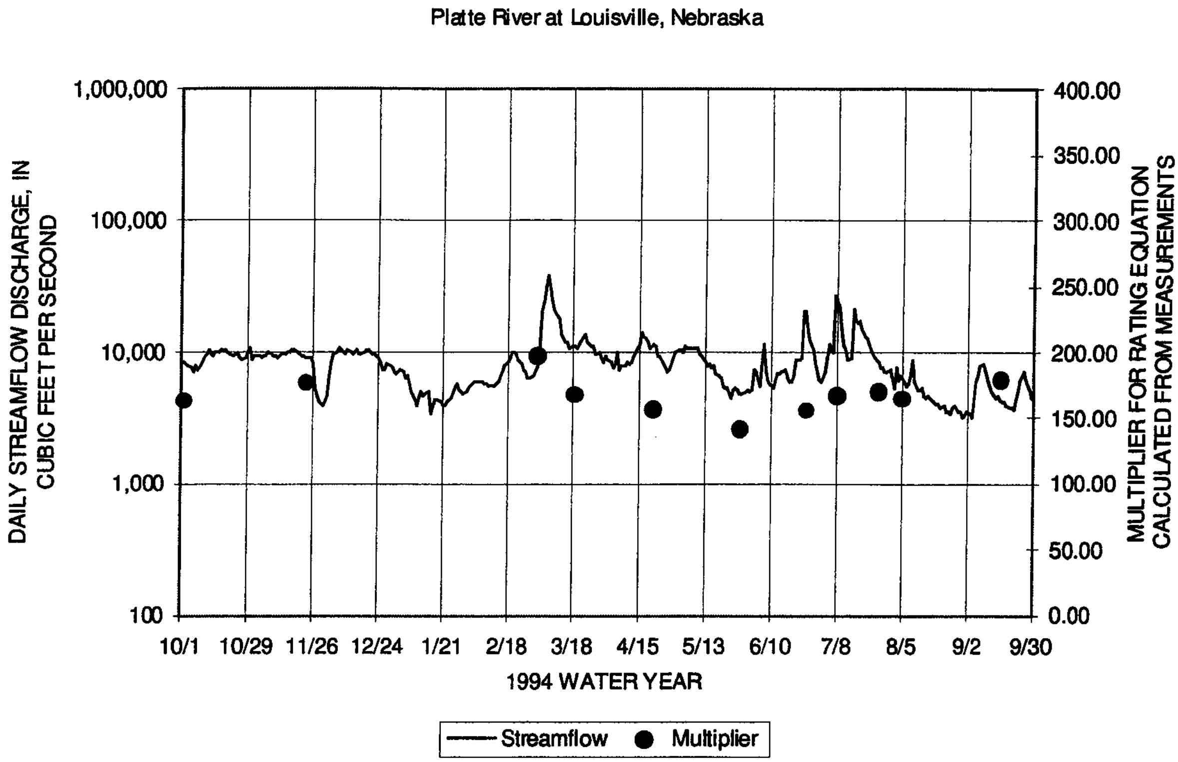


Platte River at Louisville, Nebraska



Platte River at Louisville, Nebraska




Platte River at Louisville, Nebraska
1,000,000
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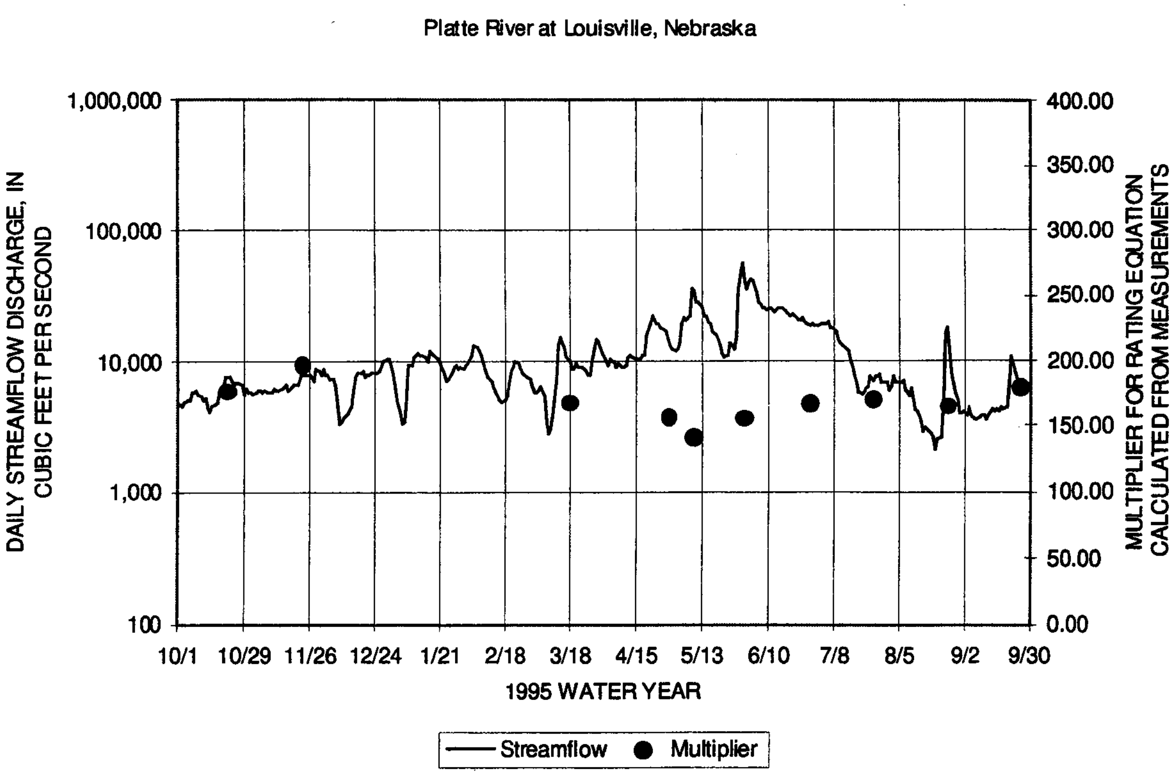
DAILY STREAMFLOW DISCHARGE, IN CUBIC FEET PER SECOND
MULTIPLIER FOR RATING EQUATION CALCULATED FROM MEASUREMENTS
10/1 10/29 11/26 12/24 1/21 2/18 3/18 4/15 5/13 6/10 7/8 8/5 9/2 9/30
1994 WATER YEAR
Streamflow
Multiplier


Platte River at Louisville, Nebraska
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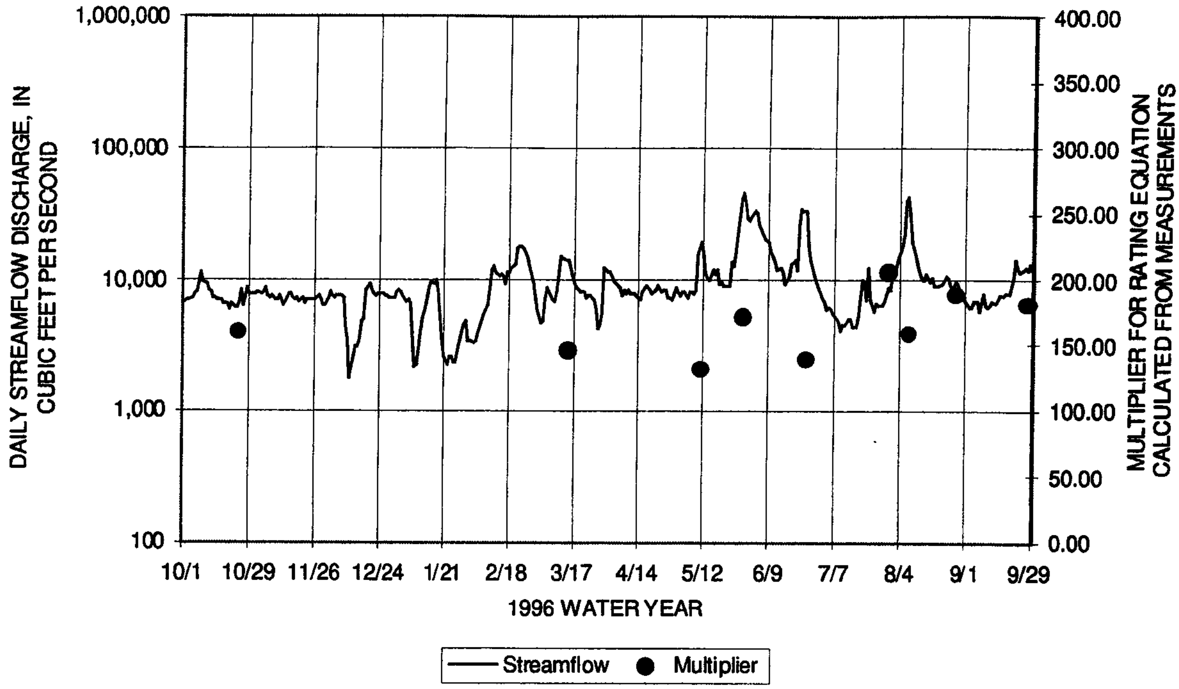
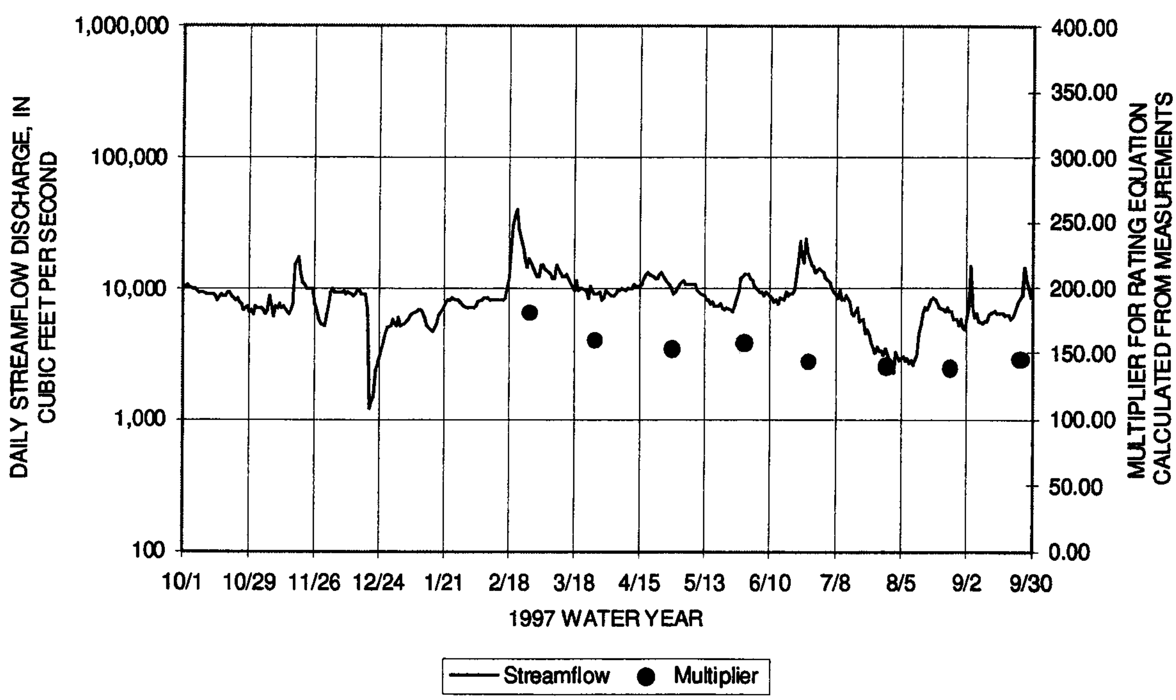
DAILY STREAMFLOW DISCHARGE, IN CUBIC FEET PER SECOND
MULTIPLIER FOR RATING EQUATION CALCULATED FROM MEASUREMENTS
10/1 10/29 11/26 12/24 1/21 2/18 3/18 4/15 5/13 6/10 7/8 8/5 9/2 9/30
1995 WATER YEAR
Streamflow
Multiplier

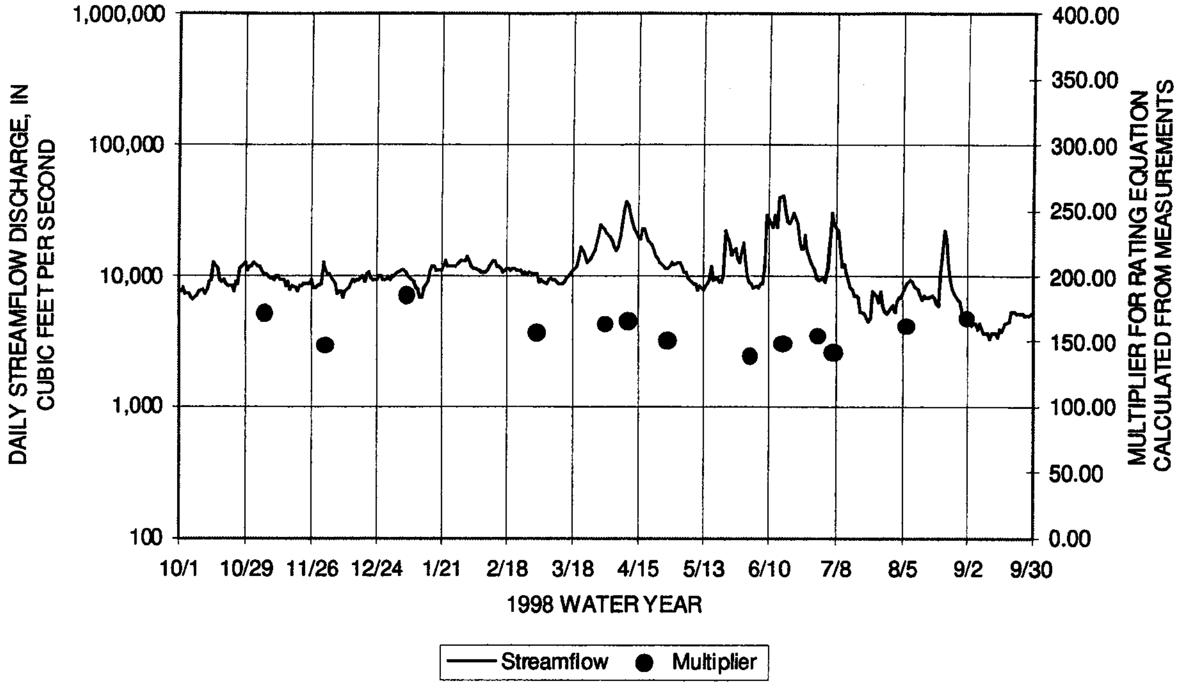
Platte River at Louisville, Nebraska



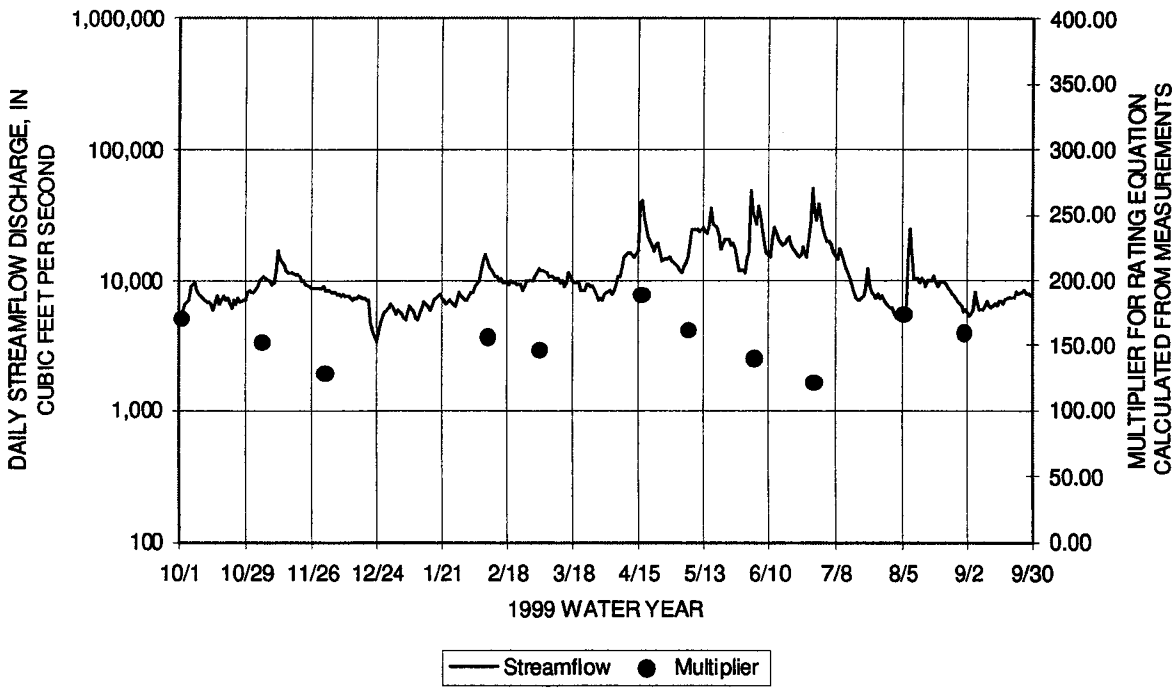
Platte River at Louisville, Nebraska



Platte River at Louisville, Nebraska



Platte River at Louisville, Nebraska



APPENDIX D—SUSPENDED-SEDIMENT DISCHARGE ANALYSIS

Table AppD_1. Suspended-sediment discharge sample and analysis data, Platte River at Louisville, Nebraska

[Highlighted numbers have been revised from those published in the USGS National Water Information System database]

Date	Streamflow discharge (cubic feet per second) *SFD*	Suspended sediment concentration (milligrams per liter)	Suspended sediment discharge (tons per day) *SSD*	Equation multiplier "*a*" computed as $a = SSD(SFD)^{-2}$	Remarks
02/26/71	17,700	1,220	58,300	0.00018609	
05/19/71	16,300	2,390	105,000	0.00039520	
06/04/71	12,500	431	14,500	0.00009280	
06/07/71	24,800	6,240	418,000	0.00067963	
10/12/71	2,620	219	1,550	0.00022580	
10/15/71	2,700	815	5,940	0.00081481	
10/21/71	4,080	1,260	13,900	0.00083502	
10/28/71	4,780	473	6,100	0.00026698	
11/11/71	4,810	339	4,400	0.00019018	
11/18/71	6,990	479	9,040	0.00018502	
12/06/71	5,990	451	7,290	0.00020318	
12/14/71	4,430	496	5,930	0.00030217	
01/17/72	3,650	158	1,560	0.00011710	
03/06/72	5,700	1,010	15,500	0.00047707	
03/07/72	8,480	1,050	24,000	0.00033375	
03/08/72	7,940	1,090	23,400	0.00037117	
03/10/72	6,300	1,290	21,900	0.00055178	
03/16/72	6,740	559	10,200	0.00022453	
03/27/72	7,240	818	16,000	0.00030524	
04/18/72	4,980	222	2,990	0.00012056	
04/21/72	5,030	250	3,400	0.00013438	
04/28/72	8,240	163	3,630	0.00005346	
05/01/72	20,900	10,700	604,000	0.00138275	
05/08/72	14,300	1,850	71,400	0.00034916	
05/15/72	17,100	2,530	117,000	0.00040012	
05/17/72	12,500	1,030	34,800	0.00022272	
05/25/72	18,900	3,390	173,000	0.00048431	
06/01/72	8,780	743	17,600	0.00022831	
06/05/72	5,800	312	4,890	0.00014536	
06/08/72	4,160	364	4,090	0.00023634	
06/12/72	3,320	594	5,320	0.00048265	
06/15/72	2,840	320	2,450	0.00030376	
06/22/72	3,420	400	3,690	0.00031548	
06/26/72	2,140	229	1,320	0.00028823	
06/29/72	2,040	258	1,420	0.00034121	
07/12/72	2,330	1,680	10,600	0.00195251	
07/14/72	4,580	440	5,440	0.00025934	

Table AppD_1. Suspended-sediment discharge sample and analysis data, Platte River at Louisville, Nebraska—Continued

Date	Streamflow discharge (cubic feet per second) *SFD*	Suspended sediment concentration (milligrams per liter)	Suspended sediment discharge (tons per day) *SSD*	Equation multiplier "*a*" computed as $a = SSD(SFD)^{-2}$	Remarks
07/18/72	1,670	210	947	0.00033956	
07/25/72	4,670	1,300	16,400	0.00075199	
09/13/72	10,800	1,820	53,100	0.00045525	
10/25/72	5,250	370	5,240	0.00019011	
01/15/73	4,340	494	5,790	0.00030740	
03/28/73	17,400	1,410	66,200	0.00021866	
04/11/73	9,940	561	15,100	0.00015283	
05/03/73	9,500	725	18,600	0.00020609	
05/19/73	13,400	752	27,200	0.00015148	
05/21/73	18,900	890	45,400	0.00012710	
05/25/73	14,500	640	25,100	0.00011938	
05/28/73	47,800	3,540	457,000	0.00020001	
06/06/73	25,300	1,230	84,000	0.00013123	
06/22/73	12,100	1,160	37,900	0.00025886	
07/12/73	3,930	278	2,950	0.00019100	
08/10/73	2,480	194	1,300	0.00021137	
09/21/73	7,860	395	8,380	0.00013564	
10/15/73	16,000	782	33,800	0.00013203	
03/15/74	10,300	474	13,200	0.00012442	
04/12/74	12,400	449	15,000	0.00009755	
05/24/74	8,700	1,870	43,900	0.00058000	
10/09/74	2,420	236	1,540	0.00026296	
12/04/74	3,200	270	2,330	0.00022754	
02/12/75	3,100	370	3,100	0.00032258	
03/28/75	9,260	948	23,700	0.00027639	
04/10/75	9,980	734	19,800	0.00019879	
05/30/75	3,240	377	3,300	0.00031436	
06/13/75	6,070	862	14,100	0.00038269	
06/25/75	18,200	3,270	161,000	0.00048605	
07/18/75	1,360	310	1,140	0.00061635	
08/01/75	2,080	354	1,990	0.00045997	
09/12/75	1,230	222	737	0.00048714	
10/29/75	2,840	256	1,960	0.00024301	
11/12/75	5,400	578	8,430	0.00028909	
12/10/75	5,340	366	5,280	0.00018516	
03/10/76	8,520	223	5,130	0.00007067	
03/23/76	7,090	589	11,300	0.00022479	
04/06/76	7,640	360	7,430	0.00012729	
05/06/76	5,140	205	2,840	0.00010750	
06/09/76	2,480	164	1,100	0.00017885	
07/14/76	726	100	196	0.00037186	
08/10/76	468	120	152	0.00069399	
09/14/76	1,780	425	2,040	0.00064386	

Table AppD_1. Suspended-sediment discharge sample and analysis data, Platte River at Louisville, Nebraska—Continued

Date	Streamflow discharge (cubic feet per second) *SFD*	Suspended sediment concentration (milligrams per liter)	Suspended sediment discharge (tons per day) *SSD*	Equation multiplier "*a*" computed as $a = SSD(SFD)^{-2}$	Remarks
09/28/76	1,720	273	1,270	0.00042929	
10/13/76	2,930	282	2,230	0.00025976	
10/27/76	2,790	230	1,730	0.00022225	
11/10/76	2,760	214	1,590	0.00020873	
11/22/76	3,530	304	2,900	0.00023273	
12/15/76	3,160	163	1,390	0.00013920	
02/02/77	3,940	131	1,390	0.00008954	
02/16/77	4,570	76	938	0.00004491	
03/08/77	6,020	918	14,900	0.00041114	
03/23/77	6,280	461	7,820	0.00019828	
04/06/77	7,660	692	14,300	0.00024371	
04/21/77	6,580	624	11,100	0.00025637	
05/02/77	6,130	272	4,500	0.00011975	
05/23/77	17,100	6,560	303,000	0.00103622	
06/01/77	10,100	2,160	58,900	0.00057739	
06/27/77	4,770	1,660	21,400	0.00094054	
07/06/77	2,230	361	2,170	0.00043637	
07/19/77	2,060	484	2,690	0.00063390	
08/01/77	2,720	886	6,510	0.00087992	
08/18/77	6,660	2,760	49,600	0.00111824	
09/02/77	10,600	2,440	69,800	0.00062122	
09/14/77	3,050	195	1,610	0.00017307	
09/28/77	3,400	254	2,330	0.00020156	
10/11/77	5,630	596	9,060	0.00028583	
10/25/77	4,590	376	4,660	0.00022119	
11/08/77	3,410	202	1,860	0.00015996	
11/23/77	4,240	256	2,930	0.00016298	
12/13/77	1,950	298	1,570	0.00041289	
12/23/77	3,900	424	4,460	0.00029323	
01/04/78	2,130	562	3,230	0.00071194	
02/01/78	3,630	92	902	0.00006845	
03/20/78	59,800	4,620	746,000	0.00020861	
03/21/78	82,000	5,060	1,120,000	0.00016657	
03/24/78	25,900	2,290	160,000	0.00023852	
04/11/78	19,100	2,630	136,000	0.00037280	
04/20/78	18,700	1,820	91,900	0.00026280	
05/03/78	9,320	612	15,400	0.00017729	
05/16/78	5,600	256	3,870	0.00012341	
05/31/78	7,580	882	18,100	0.00031502	
06/13/78	3,570	192	1,850	0.00014516	
06/29/78	3,090	674	5,620	0.00058860	
07/14/78	2,200	733	4,350	0.00089876	
07/26/78	3,720	1,140	11,500	0.00083102	
08/08/78	1,610	117	509	0.00019637	

Table AppD_1. Suspended-sediment discharge sample and analysis data, Platte River at Louisville, Nebraska—Continued

Date	Streamflow discharge (cubic feet per second) *SFD*	Suspended sediment concentration (milligrams per liter)	Suspended sediment discharge (tons per day) *SSD*	Equation multiplier "*a*" computed as $a = SSD(SFD)^{-2}$	Remarks
08/24/78	1,970	197	1,050	0.00027056	
09/12/78	1,270	104	357	0.00022134	
09/27/78	1,900	156	800	0.00022161	
10/12/78	2,360	170	1,080	0.00019391	
10/28/78	3,710	323	3,240	0.00023539	
11/07/78	4,230	440	5,030	0.00028112	
11/18/78	4,740	336	4,300	0.00019139	
03/12/79	16,800	3,080	140,000	0.00049603	
03/27/79	16,600	3,290	147,000	0.00053346	
04/12/79	7,960	3,730	80,200	0.00126575	
04/24/79	8,580	658	15,200	0.00020648	
05/08/79	7,640	355	7,320	0.00012541	
05/22/79	7,440	526	10,600	0.00019150	
06/13/79	4,690	332	4,200	0.00019094	
06/28/79	9,120	836	20,600	0.00024767	
06/30/79	11,700	1,400	44,200	0.00032289	
07/09/79	7,950	320	6,870	0.00010870	
07/24/79	2,920	110	867	0.00010168	
08/07/79	3,200	352	3,040	0.00029688	
08/21/79	2,890	3,230	25,200	0.00301721	
09/05/79	1,920	178	923	0.00025038	
09/23/79	1,730	139	649	0.00021685	
10/06/79	2,210	170	1,010	0.00020679	
10/27/79	3,370	158	1,440	0.00012680	
11/14/79	4,180	267	3,010	0.00017227	
12/05/79	3,450	423	3,940	0.00033102	
01/15/80	2,270	305	1,870	0.00036290	
02/28/80	16,900	1,310	59,800	0.00020938	
03/13/80	16,600	807	36,200	0.00013137	
04/01/80	15,000	1,550	62,800	0.00027911	
04/09/80	17,200	2,680	124,000	0.00041915	
04/22/80	9,500	2,080	53,400	0.00059169	
05/07/80	8,000	270	5,830	0.00009109	
05/23/80	13,100	299	10,600	0.00006177	
05/30/80	16,900	1,860	84,900	0.00029726	
06/10/80	13,200	417	14,900	0.00008551	
06/24/80	9,640	646	16,800	0.00018078	
07/09/80	1,880	295	1,500	0.00042440	
07/31/80	506	130	178	0.00069521	
08/12/80	2,460	3,660	24,300	0.00401547	
08/26/80	1,910	306	1,580	0.00043310	
09/10/80	1,310	153	541	0.00031525	
09/26/80	1,500	188	761	0.00033822	
10/06/80	1,590	152	653	0.00025830	

Table AppD_1. Suspended-sediment discharge sample and analysis data, Platte River at Louisville, Nebraska—Continued

Date	Streamflow discharge (cubic feet per second) *SFD*	Suspended sediment concentration (milligrams per liter)	Suspended sediment discharge (tons per day) *SSD*	Equation multiplier "*a*" computed as $a = SSD(SFD)^{-2}$	Remarks
10/23/80	2,570	181	1,260	0.00019077	
11/17/80	3,750	218	2,210	0.00015716	
11/25/80	3,880	262	2,740	0.00018201	
12/09/80	3,120	180	1,520	0.00015615	
02/12/81	2,460	312	2,070	0.00034206	
02/25/81	6,960	414	7,780	0.00016061	
03/09/81	5,140	265	3,680	0.00013929	
04/02/81	6,170	623	10,400	0.00027319	
04/14/81	4,220	343	3,910	0.00021956	
04/29/81	3,840	178	1,850	0.00012546	
05/19/81	7,940	2,240	48,000	0.00076138	
05/27/81	4,350	746	8,760	0.00046294	
06/09/81	1,660	364	1,630	0.00059152	
06/16/81	5,870	14,100	223,000	0.00647185	
06/25/81	1,960	2,900	15,300	0.00398272	
07/08/81	2,320	1,280	8,020	0.00149004	
07/23/81	682	156	287	0.00061704	
08/07/81	19,900	2,440	131,000	0.00033080	
08/14/81	4,140	326	3,640	0.00021237	
08/25/81	2,540	1,320	9,050	0.00140275	
09/11/81	3,590	164	1,590	0.00012337	
10/01/81	2,110	94	536	0.00012039	
10/13/81	2,950	202	1,610	0.00018500	
10/20/81	3,760	542	5,500	0.00038903	
11/04/81	5,670	397	6,080	0.00018912	
11/18/81	3,860	182	1,900	0.00012752	
03/23/82	12,100	1,320	43,100	0.00029438	
06/01/82	32,600	4,420	389,000	0.00036603	
06/30/82	6,590	541	9,630	0.00022175	
11/02/82	4,760	315	4,050	0.00017875	
02/15/83	16,500	2,970	132,000	0.00048485	
05/20/83	23,000	2,270	141,000	0.00026654	
08/15/83	7,710	2,560	53,300	0.00089664	
11/14/83	2,820	295	2,250	0.00028293	
02/27/84	18,200	1,250	61,400	0.00018536	
05/14/84	26,200	1,300	92,000	0.00013402	
08/07/84	3,720	514	5,160	0.00037288	
11/14/84	11,000	224	6,650	0.00005496	
02/07/85	4,870	206	2,710	0.00011426	
05/15/85	25,300	6,040	413,000	0.00064522	
08/07/85	4,340	378	4,430	0.00023519	
11/05/85	7,340	391	7,750	0.00014385	
02/04/86	10,200	723	19,900	0.00019127	
05/07/86	11,400	840	25,900	0.00019929	

Table AppD_1. Suspended-sediment discharge sample and analysis data, Platte River at Louisville, Nebraska—Continued

Date	Streamflow discharge (cubic feet per second) *SFD*	Suspended sediment concentration (milligrams per liter)	Suspended sediment discharge (tons per day) *SSD*	Equation multiplier "*a*" computed as $a = SSD(SFD)^{-2}$	Remarks
08/19/86	6,350	593	10,200	0.00025296	
11/20/86	12,300	1,220	40,400	0.00026704	
02/03/87	10,400	609	17,100	0.00015810	
04/28/87	11,600	541	16,900	0.00012559	
08/03/87	1,870	160	808	0.00023106	
11/25/87	7,020	312	5,910	0.00011993	
02/17/88	6,740	423	7,700	0.00016950	
05/10/88	7,380	363	7,230	0.00013275	
08/10/88	1,860	178	894	0.00025841	
10/25/88	4,290	194	2,250	0.00012226	
02/24/89	6,050	45	735	0.00002008	
05/16/89	1,940	102	534	0.00014189	
08/29/89	2,150	243	1,410	0.00030503	
11/21/89	3,940	251	2,670	0.00017200	
02/07/90	4,340	115	1,350	0.00007167	
05/16/90	7,480	746	15,100	0.00026988	
08/20/90	3,370	280	2,550	0.00022453	
11/14/90	4,010	172	1,860	0.00011567	
02/13/91	8,600	296	6,870	0.00009289	
05/21/91	10,400	2,810	78,900	0.00072947	
08/16/91	1,890	205	1,050	0.00029394	
09/10/91	1,300	179	628	0.00037160	
09/17/91	2,640	462	3,290	0.00047205	
09/24/91	1,950	133	700	0.00018409	
10/01/91	1,830	109	539	0.00016095	
10/08/91	2,150	108	627	0.00013564	
10/15/91	2,280	74	456	0.00008772	
10/24/91	2,540	107	734	0.00011377	
11/05/91	2,540	68	466	0.00007223	
11/15/91	8,300	914	20,500	0.00029758	
12/05/91	2,070	119	665	0.00015520	
12/20/91	4,720	84	1,070	0.00004803	
12/30/91	6,290	402	6,830	0.00017263	
01/14/92	6,430	234	4,060	0.00009820	
01/28/92	6,430	268	4,650	0.00011247	
02/11/92	6,240	168	2,830	0.00007268	
02/19/92	8,070	385	8,390	0.00012883	
02/27/92	7,220	153	2,980	0.00005717	
03/05/92	6,870	181	3,360	0.00007119	
03/09/92	10,600	599	17,100	0.00015219	
03/17/92	11,000	446	13,200	0.00010909	
03/23/92	9,400	130	3,300	0.00003735	
03/31/92	11,200	334	10,100	0.00008052	
04/07/92	8,460	72	1,640	0.00002291	

Table AppD_1. Suspended-sediment discharge sample and analysis data, Platte River at Louisville, Nebraska—Continued

Date	Streamflow discharge (cubic feet per second) *SFD*	Suspended sediment concentration (milligrams per liter)	Suspended sediment discharge (tons per day) *SSD*	Equation multiplier "*a*" computed as $a = SSD(SFD)^{-2}$	Remarks
04/14/92	6,190	193	3,230	0.00008430	
04/23/92	7,480	122	2,460	0.00004397	
04/29/92	5,960	186	2,990	0.00008417	
05/01/92	5,430	169	2,480	0.00008411	
05/07/92	4,380	240	2,840	0.00014804	
05/11/92	4,010	151	1,630	0.00010137	
05/12/92	3,520	56	532	0.00004294	
05/14/92	3,790	106	1,080	0.00007519	
05/16/92	3,820	161	1,660	0.00011376	
05/18/92	21,200	7,760	444,000	0.00098790	
05/19/92	17,300	4,380	205,000	0.00068495	
05/20/92	11,000	5,850	174,000	0.00143802	
05/21/92	7,540	2,490	50,700	0.00089180	
05/22/92	8,070	1,560	34,000	0.00052207	
05/24/92	6,480	1,120	19,600	0.00046677	
05/26/92	4,680	608	7,680	0.00035065	
05/30/92	3,550	253	2,430	0.00019282	
06/01/92	3,490	165	1,550	0.00012726	
06/03/92	4,010	3,170	34,300	0.00213307	
06/05/92	4,970	213	2,860	0.00011579	
06/07/92	5,690	232	3,560	0.00010996	
06/08/92	9,400	1,940	49,200	0.00055681	
06/09/92	9,660	1,300	33,900	0.00036328	
06/10/92	6,010	899	14,600	0.00040421	
06/11/92	6,320	666	11,400	0.00028541	
06/13/92	9,600	772	20,000	0.00021701	
06/15/92	7,120	473	9,090	0.00017931	
06/17/92	28,000	10,500	794,000	0.00101276	
06/19/92	9,470	3,710	94,900	0.00105820	
06/23/92	4,800	334	4,330	0.00018793	
06/29/92	4,380	136	1,610	0.00008392	
07/07/92	8,350	4,660	105,000	0.00150597	
07/14/92	12,000	2,120	68,700	0.00047708	
07/20/92	3,730	315	3,170	0.00022785	
07/22/92	4,070	359	3,940	0.00023785	
07/24/92	3,880	170	1,780	0.00011824	
07/26/92	27,700	5,080	380,000	0.00049525	
07/28/92	11,700	2,520	79,600	0.00058149	
07/30/92	9,930	590	15,800	0.00016024	
08/01/92	10,200	1,320	36,400	0.00034987	
08/03/92	7,910	1,070	22,900	0.00036600	
08/05/92	6,480	862	15,100	0.00035961	
08/07/92	14,700	1,220	48,400	0.00022398	
08/09/92	14,300	1,250	48,300	0.00023620	

Table AppD_1. Suspended-sediment discharge sample and analysis data, Platte River at Louisville, Nebraska—Continued

Date	Streamflow discharge (cubic feet per second) *SFD*	Suspended sediment concentration (milligrams per liter)	Suspended sediment discharge (tons per day) *SSD*	Equation multiplier "*a*" computed as $a = SSD(SFD)^{-2}$	Remarks
08/11/92	10,500	1,170	33,200	0.00030113	1 of 2 samples this day
08/11/92	9,930	1,170	31,400	0.00031844	
08/13/92	8,750	1,430	33,800	0.00044147	
08/15/92	6,620	418	7,470	0.00017045	2 of 2 samples this day
08/17/92	8,130	777	17,100	0.00025871	
08/19/92	5,470	394	5,820	0.00019451	
08/21/92	4,920	301	4,000	0.00016525	
08/23/92	4,490	241	2,920	0.00014484	
08/25/92	4,010	184	1,990	0.00012376	
08/27/92	4,920	219	2,910	0.00012022	
09/24/92	5,010	360	4,870	0.00019402	
11/13/92	6,480	351	6,140	0.00014622	
02/25/93	5,600	270	4,080	0.00013010	
04/26/93	15,500	747	31,300	0.00013028	
05/11/93	31,200	1,890	159,000	0.00016334	
05/24/93	9,230	392	9,770	0.00011468	
06/01/93	9,730	1,440	37,800	0.00039927	1 of 2 samples this day
06/01/93	9,600	1,490	38,600	0.00041884	2 of 2 samples this day
06/02/93	12,200	1,910	62,900	0.00042260	
06/03/93	8,300	1,110	24,900	0.00036145	
06/04/93	7,800	979	20,600	0.00033859	
06/22/93	7,750	1,230	25,700	0.00042789	
06/29/93	23,100	1,940	121,000	0.00022676	
07/10/93	62,400	4,960	836,000	0.00021470	
07/24/93	110,000	2,380	707,000	0.00005843	
08/12/93	9,730	306	8,040	0.00008492	
09/28/93	11,400	611	18,800	0.00014466	
10/25/93	9,770	269	7,100	0.00007438	
11/30/93	4,140	108	1,210	0.00007060	
12/28/93	7,800	62	1,310	0.00002153	
01/27/94	5,200	155	2,180	0.00008062	
02/14/94	6,600	37	659	0.00001513	
03/18/94	11,400	597	18,400	0.00014158	1 of 2 samples this day
03/18/94	11,400	624	19,200	0.00014774	2 of 2 samples this day
04/22/94	12,700	349	12,000	0.00007440	
05/27/94	4,530	138	1,690	0.00008236	
06/16/94	6,470	987	17,200	0.00041088	
06/23/94	25,000	9,470	639,000	0.00102240	
08/04/94	7,050	633	12,000	0.00024144	
08/04/94	7,050	730	13,900	0.00027966	1 of 2 samples this day
08/24/94	2,870	117	907	0.00011011	2 of 2 samples this day
09/15/94	3,810	185	1,900	0.00013089	
11/22/94	8,570	885	20,500	0.00027912	
02/22/95	13,500	1,910	69,600	0.00038189	

Table AppD_1. Suspended-sediment discharge sample and analysis data, Platte River at Louisville, Nebraska—Continued

Date	Streamflow discharge (cubic feet per second) *SFD*	Suspended sediment concentration (milligrams per liter)	Suspended sediment discharge (tons per day) *SSD*	Equation multiplier "*a*" computed as $a = SSD(SFD)^{-2}$	Remarks
11/24/98	9,260	517	12,900	0.00015044	
12/16/98	7,600	947	19,400	0.00033587	
01/13/99	6,800	86	1,580	0.00003417	
02/10/99	12,500	898	30,300	0.00019392	
03/17/99	9,550	552	14,200	0.00015570	
04/14/99	17,200	1,210	56,200	0.00018997	
04/16/99	42,500	4,170	479,000	0.00026519	
05/13/99	23,300	1,760	111,000	0.00020446	
06/04/99	26,400	2,430	173,000	0.00024822	
06/07/99	23,000	3,470	215,000	0.00040643	
06/17/99	19,600	1,330	70,400	0.00018326	
07/14/99	9,770	798	21,000	0.00022000	
09/09/99	6,330	629	10,800	0.00026954	