Potential Effects of Large Floods on the Transport of Atrazine into the Alluvial Aquifer Adjacent to the Lower Platte River, Nebraska

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 96–4272

Prepared in cooperation with the
U.S. ENVIRONMENTAL PROTECTION AGENCY

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Lincoln, Nebraska
1997

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director

For additional information write to:

District Chief
U.S. Geological Survey
Room 406 Federal Building
100 Centennial Mall North
Lincoln, NE 68508

Copies of this report can be purchased from:

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
cubic foot (ft^3)	0.02832	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
inch	25.4	millimeter
mile (mi)	1.609	kilometer
pound (lb)	0.4536	kilogram
square mile (mi^2)	2.590	square kilometer

Degree Fahrenheit (°F) may be converted to degree Celsius (°C) by using the following equation:

$$°C = 5/9\ (°F - 32)$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—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.

ADDITIONAL ABBREVIATION

microgram per liter (µg/L)

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Abstract

Heavy rainfall and severe flooding from late June through early August 1993 flushed large amounts of sediment and other dissolved and suspended constituents into streams in the Upper Mississippi River Basin. In the Platte River Valley, the shallow alluvial aquifer is the major source of water for public, industrial, and agricultural use. During the 1993 flood, concentrations of atrazine detected in surface-water samples from the lower Platte River varied from 0.34 to 3.4 micrograms per liter (μg/L). As a result of the detection of herbicides in association with record flooding, the potential for recharge of floodwater containing herbicides and the potential change in the volume and quality of water in the shallow alluvial aquifer became a concern in the lower Platte River Valley.

Initially, several large rainfall-related floods were identified that occurred from 1970 to 1993 at the North Bend, Ashland, and Louisville gaging stations. Duration of inundation, depth of the floodwater, and recharge rates were determined for each flood. Because atrazine was the most frequently used and detected herbicide in the study area, it was used to estimate the effect of floodwater inundation on ground-water quality. On the basis of these data, the amount of water and atrazine present in the alluvial aquifer prior to and following flooding, and the potential amounts of water moved and atrazine transported into the ground water were analyzed to estimate the possible change in the volume and quality of water in the alluvial aquifer.

During the floods that exceeded the flood stage, the duration of inundation varied from 0.33 to 3.5 days. Average floodwater depths were estimated based on the area of floodwater and the width of inundation and ranged from 0.05 to 0.95 foot. The rate of recharge of floodwater to the aquifer was estimated for conditions under which the water table was at the land surface and at 5 feet or more below the land surface, using the permeability for the least permeable layer of soil and the average permeability for the 60-inch soil profile. The estimated rates of recharge using the least permeable layer of soil varied from 0.42 to 6.1 inches per day with the water table at the land surface, to 35 to 41 inches per day, with the water table 5 feet or more below the land surface. Using the average permeability of the 60-inch soil profile, the estimated rates of recharge varied from 1.4 to 19 inches per day with the water table at the land surface, and from 116 to 141 inches per day with the water table 5 feet or more below the land surface.

Within the area of inundation, atrazine has been detected in ground water since 1985. From 1985 to early 1993, atrazine was detected in 52 of 88 samples collected from 57 wells within the study area. The mean concentrations of atrazine in the samples collected prior to the 1993 flood ranged from 0.76 to 0.78 μg/L, and the median concentration was 0.24 μg/L. The amount of atrazine stored in the system prior to flooding, approximately 2,000 pounds, was estimated by multiplying the volume of the aquifer,

131 billion cubic feet of water, by the median concentration of atrazine.

An estimate of the amount of atrazine transported in the floodwater was based on three water samples collected at the Louisville gaging station during the 1993 flood. During this flood, atrazine concentrations in the floodwater ranged from 0.34 to 3.4 μg/L, with a median concentration of 1.0 μg/L. Potential movement of floodwater and transport of atrazine into the ground water was estimated using the median concentration of atrazine in the floodwater, recharge rates, duration of flooding, and area of inundation. The data compiled indicate that the volume of water and amount of atrazine in the alluvial aquifer could increase as a result of a flood with magnitude and duration similar to the 1993 flood; the change could be as much as a 24-percent increase in the quantity of atrazine and a corresponding 6-percent increase in the volume of water.

Although postflood sampling was limited, the data indicate the amount of atrazine in the aquifer did not increase following the 1993 flood. The median concentration of atrazine measured in six ground-water samples collected within 2 to 3 months after the 1993 flooding was about 0.2 μg/L. If a concentration of about 0.2 μg/L is assumed to be representative, approximately 1,600 pounds of atrazine would be present within the aquifer. This would be a decrease of about 20 percent from the preflood amount. Additional surface- and ground-water sampling during flooding could confirm that decreases in the atrazine in the ground water are a direct result of inundation from floodwater and not the result of other processes.

INTRODUCTION

Intense rainfall from late June through early August produced severe flooding in the Mississippi River Basin during 1993. Precipitation at many of the Missouri River tributaries upstream from Kansas City from January through July was 150 to 200 percent of normal (Wahl and others, 1993). The runoff from precipitation during this time caused record discharges on the Platte River in Nebraska. The Platte River at Ashland, Nebraska, had a peak discharge of 114,000 cubic feet per second (ft^3/s) with a peak stage of 21.45 ft, the highest stage on record. The peak discharge of the Platte River near Louisville, Nebraska, was 160,000 ft^3/s, which exceeded the previously recorded peak discharge and corresponded to a recurrence interval greater than 50 years (Parrett and others, 1993).

The large amount of rainfall and severe flooding flushed large amounts of sediment and other dissolved and suspended constituents into streams within the Mississippi River Basin. In 26 surface-water samples collected within the Mississippi River Basin, atrazine concentrations ranged from 1.3 to 3.3 μg/L, with a median concentration of 2.2 μg/L (Goolsby and others, 1993). The herbicides cyanazine and metolachlor also were detected frequently, with median concentrations of 1.2 and 0.81 μg/L, respectively. The concentrations of herbicides detected within the Mississippi River Basin indicated the record flooding had not diluted the concentrations of herbicides as was hypothesized (Goolsby and others, 1993).

In the lower Platte River Valley, the shallow alluvial aquifer is the major source of water for public, industrial, and agricultural use. The river is a source of recharge induced by pumping in the well fields of several large municipalities (Davis, 1992; Stamer, 1996). During the 1993 flood, concentrations of atrazine in surface-water samples collected from the lower Platte River ranged from 0.34 to 3.4 μg/L. As a result of the detection of herbicides in association with record flooding, the potential for recharge of floodwater containing herbicides from the flood plains into the alluvial aquifer became a growing concern in the lower Platte River Valley. Chemical data from a study along the Cedar River in Iowa indicated that large concentrations of herbicides could be introduced vertically to the top of an alluvial aquifer as a result of flooding (Squillace and others, 1994). The results of the study by Squillace and others indicate a need to further evaluate the potential for transport of contaminants into an alluvial system as a result of flooding from an event of the magnitude of the 1993 flood.

In cooperation with the U.S. Environmental Protection Agency, the U.S. Geological Survey (USGS) conducted a study to estimate the potential effects of large floods on the transport of atrazine into the alluvial aquifer adjacent to the lower Platte River in Nebraska. The results of this study will provide a better understanding of the effects of floodwater on the quality and volume of water in alluvial aquifers.

Purpose and Scope

This report describes the results of the study to estimate the transport of atrazine from floodwater into ground water adjacent to the lower Platte River in Nebraska. The study was limited to large rainfall-related flooding that occurred from 1970 to 1993, during the late spring or early summer when there was a greater likelihood that agricultural chemicals were present in the water. Historical hydrologic data and results from previous water-quality studies that investigated the presence of atrazine in the ground water or surface water within the lower Platte River Valley were analyzed to determine the concentrations of atrazine in surface water during floods and in ground water prior to and following floods. Atrazine was the most frequently used and detected herbicide in the study area; therefore, it was the constituent used to examine the effects of floodwater inundation on ground-water quality.

Description of Study Area

The study area was defined by the extent of inundation from the 1993 flood, along the reach of the lower Platte River from the gaging station 1 mile (mi) south of North Bend to the gaging station 1 mi north of Louisville (fig. 1). The extent of the flooding within the study area was estimated using coverages from the Scientific Assessment and Strategy Team Database, Earth Resources Observation Systems (EROS) Data Center, Sioux Falls, South Dakota. Because a coverage documenting the extent of the flooding in July and August 1993 was not available, satellite imagery of the inundation pattern from the March 1993 flooding was used.

Soils found in terraces and uplands north of the Platte River are silty clay loams to silt loams, and the topography is generally rolling hills. Within the Platte River Valley and flood plain, the soils generally are loams to fine sands (Dugan, 1984). Soils south of the river generally have a higher clay content, and the topography changes abruptly from the nearly level Platte River Valley and flood plain to rolling hills, bluffs, and escarpments (Dugan, 1984).

Normal (1961–90) January through July precipitation for the study area was approximately 17 inches (National Oceanic and Atmospheric Administration, 1994). During these months in 1993, approximately 27 to 30 inches of rain fell within the lower Platte River Valley (Wahl and others, 1993), or approximately 160 to 175 percent of normal precipitation. At a National Oceanic and Atmospheric Administration weather station near Ashland, the normal precipitation for July is 3.25 inches. In 1993, approximately 16 inches of rain fell during July, with more than 5 inches of rain falling on July 23 (National Oceanic and Atmospheric Administration, 1994).

The primary aquifer within the study area consists of the Platte River Valley alluvial aquifer (Engberg and Druliner, 1988). This aquifer is the source of water for the cities of Fremont and Lincoln and is part of the water supply for Omaha (Ellis and others, 1985), and provides water for irrigation (Engberg and Druliner, 1988). The Platte River Valley alluvial aquifer is more than 30 ft thick and generally connected hydraulically to the river (Ellis and others, 1985).

Three active USGS gaging stations are located on the Platte River within the study area (fig. 1). The Platte River at North Bend, Nebraska, gage has been in operation continuously since April 1949. The drainage area for the gage is approximately 77,100 square miles (mi^2), with 63,300 mi^2 contributing to surface runoff. The gage on the Platte River near Ashland, Nebraska, was operated continuously from August 1928 to May 1953 and from July 1988 to the present. The drainage area for this gage is 84,200 mi^2. The gage on the Platte River at Louisville, Nebraska, has been in operation since May 1953, although from October 1961 to September 1973, it was identified as the Platte River at South Bend. The drainage area for the Louisville gage is approximately 85,800 mi^2, of which about 71,000 mi^2 contribute to surface runoff (Boohar and others, 1994).

Acknowledgments

The authors appreciate the information and cooperation provided by the Lower Platte North, Lower Platte South, and Papio-Missouri River Natural

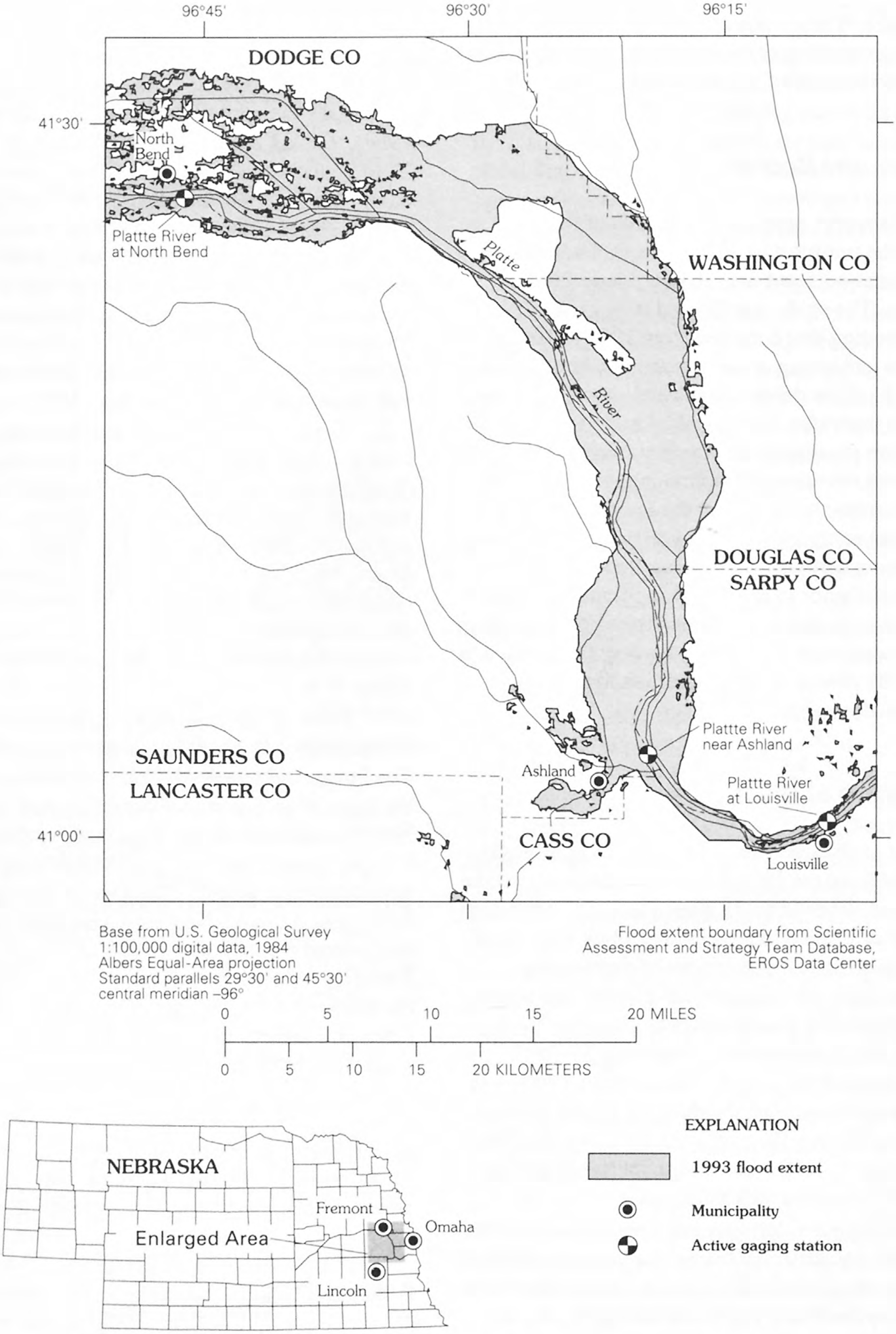

Figure 1. Extent of 1993 flood and locations of active gaging stations along the lower Platte River.

Resources Districts; the municipalities of Fremont, Lincoln, and Omaha; and the Metropolitan Utilities District.

METHODS

Historical data for the 1993 flood and several other rainfall-related floods were compiled and analyzed for each of the gages. Data compiled from USGS files included the rating and flood-frequency curves, as well as discharge and stage measurements for the major floods. These data were used to derive the channel and flood-plain geometry for each gaging station. The data also were used to estimate the elevations of the peak stage, flood stage, and time-weighted average floodwater stage during each flood, as well as the area, width, and depth of the floodwater (fig. 2). Because of differences in patterns of flooding and inundated soils, recharge rates were estimated for conditions under which the water table was at the land surface and at 5 ft or more below the land surface, for all floods that exceeded the flood stages. The recharge rates were used with estimates of flood duration and area of inundation to estimate potential volumes of floodwater and associated atrazine amounts entering the aquifer. Water-level data were obtained from Natural Resources Districts and municipalities in the study area and combined with data from the USGS's water-level data base. These data were used to verify the estimated average depths to water for wells throughout the study area that had at least 30 measurements over a minimum of 5 years.

Analytical results for surface- and ground-water samples collected and analyzed for atrazine were obtained from Natural Resources Districts and municipalities and retrieved from data bases maintained by the USGS and the U.S. Environmental Protection Agency. Because Zelt and Jordan (1993) had compiled data for samples collected prior to 1990, the additional compilation of water-quality data for this study was generally limited to analytical results for samples collected within the study area since 1990. All data were combined and used to estimate the concentrations of atrazine in ground water and floodwater. The recharge rates and concentrations of atrazine in the floodwater then were used to estimate the amount of water and atrazine that may have been introduced to the aquifer during a flood of a given magnitude. This estimated quantity of atrazine was compared to the estimated quantity of atrazine in the aquifer prior to and following flooding.

ANALYSIS AND RESULTS

Historical Flood Data

Flood-frequency analyses were completed for the gages in the study area and used to identify several large rainfall-related floods from 1970 to 1993 (table 1). Of the five floods identified for the North Bend gaging station, events in May 1973, June 1984, and July 1993 had stages that exceeded the flood stage of 8 ft. Of the four floods identified for the gaging station near Ashland, only flooding in July 1993 exceeded the flood stage of 21 ft. Of the five floods identified for the Louisville gage, only the flooding from the June 1991 event failed to exceed the flood stage of 9 ft.

Rate of Recharge

Recharge to the aquifer, as defined for this study, is the floodwater that reaches the water-table surface, assuming that water present in the soil prior to flooding will not affect the volume or quality of water in the aquifer. Factors that can affect recharge rates include the initial soil moisture content, the storage capacity of the aquifer, and the clogging of soil pores with sediment transported with the floodwater. To simplify recharge calculations, it was assumed that the soil was saturated, soil pore clogging was negligible, and the aquifer was capable of accepting available floodwater. As part of the ground-water flow model developed by McDonald and Harbaugh (1988), the "River Package" simulates the effects of flow between the surface- and ground-water systems. For floods that exceeded the flood stage, the rates of recharge to the alluvial aquifer were calculated using an adaptation of the "River Package" equation which follows:

$$Q = \frac{K_v\,(H_f - H_{aq})}{M}$$

where

Q = rate of recharge to the aquifer, in inches per day;
K_v = permeability, in inches per day;
H_f = average floodwater head, in feet;
H_{aq} = head in the aquifer, in feet; and
M = thickness of the soil profile, in feet.

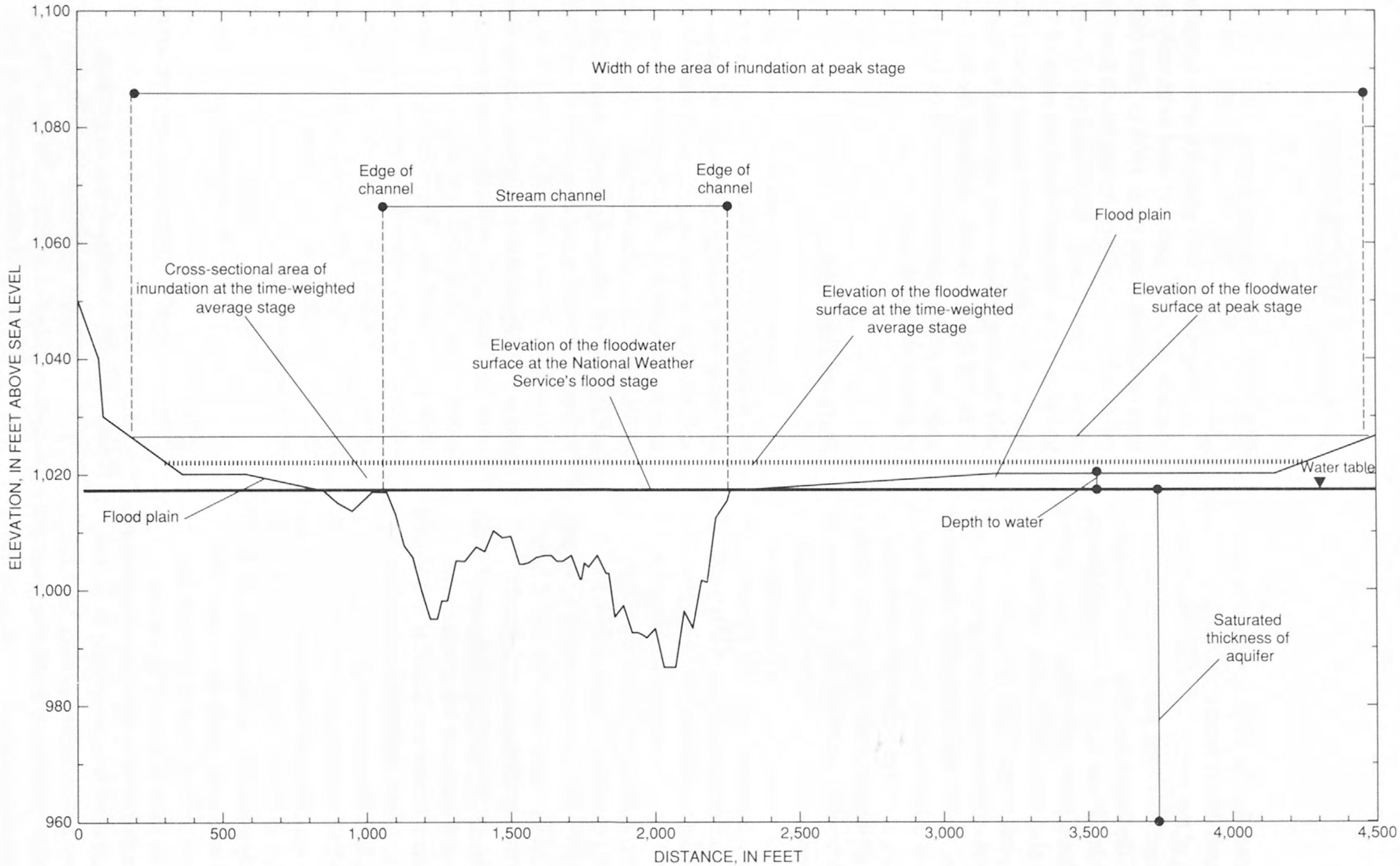

Figure 2. Schematic cross section of a river valley illustrating selected hydrologic terms.

Table 1. Data pertaining to selected large floods at three gaging stations on the lower Platte River, 1970–93

Gaging station (station number)	Date of flood peak	Relative magnitude of the flood[1]	Peak stage of floodwater at the gage (feet above arbitrary datum)	Peak floodwater elevation[2] (feet above sea level)	Maximum discharge (cubic feet per second)	Recurrence interval[3] (years)
North Bend (06796000)	May 28, 1973	FL3	8.12	1,272.44	36,300	3.1
	August 6, 1981	FL5	7.44	1,271.76	30,000	2.3
	June 13, 1984	FL1	9.13	1,273.45	65,200	11
	June 17, 1990	FL4	7.71	1,272.03	37,300	3.2
	July 28, 1993	FL2	8.60	1,272.92	48,600	5.4
Ashland (06801000)	June 17, 1990	FL2	19.85	1,061.35	80,600	10
	June 5, 1991	FL3	18.82	1,060.32	46,000	2.6
	June 17, 1992	FL4	18.15	1,059.65	26,100	1.3
	July 25, 1993	FL1	21.45	1,062.95	114,000	38
Louisville (06805500)	June 19, 1983	FL3	9.36	1,017.46	69,000	4.3
	June 14, 1984	FL2	11.34	1,019.44	144,000	50
	June 17, 1990	FL4	9.16	1,017.26	67,000	3.8
	June 6, 1991	FL5	8.72	1,016.82	55,500	2.7
	July 25, 1993	FL1	11.90	1,020.00	160,000	80

[1] Several large rainfall-related floods were selected for each gage and ranked on the basis of floodwater elevation. At each gaging station, the flood with the highest elevation was assigned FL1. The flood with the next highest elevation was assigned FL2, and so on.
[2] At a typical section upstream from the gage; includes datum and slope adjustments.
[3] The recurrence interval is the average interval (in years) between events equaling or exceeding a given magnitude.

Permeability (K_v) is the rate that soil, under saturated conditions, transmits water in a vertical direction under a unit head of pressure (Dugan, 1984). The permeability values for the area of inundation were retrieved from the State Soil Geographic Data Base (STATSGO) created by the U.S. Department of Agriculture's Natural Resources Conservation Service (formerly the Soil Conservation Service). The soil maps for STATSGO were created by generalizing the soil survey maps (Soil Conservation Service, 1993). Both the permeability of the least permeable layer of soil within the 60-inch soil profile and average permeability of the 60-inch soil profile were used in calculations of recharge rates. The permeability of the least permeable layer of soil will have the greatest effect on the recharge rate, but the extent, thickness, and continuity of the least permeable layer were not known. To simplify the calculation of the rate of recharge, the permeability of the least permeable layer was assigned to the 60-inch soil profile. Due to this assumption, the estimated recharge rate may be lower than the actual recharge rate. In contrast, calculations using the average permeability of the 60-inch soil profile could yield recharge rates that are too high. It is assumed that the actual vertical recharge rates within the study area will probably be within the range defined by the permeabilities of the least permeable layer of soil and average of the 60-inch soil profile.

For each flood that exceeded the flood stage, the area-weighted average permeability was calculated using the methodology outlined by Dugan (1984). The area weighting of the values was based on the area defined by the length of the stream reach represented by a given gaging station and the width of the inundated area, assuming that the inundation pattern for the area was uniform. The width of the inundated area was calculated as the distance across the inundated area when floodwaters were at peak stage. The following are the definitions of the lengths of the three stream reaches within the study area as shown in figure 3.

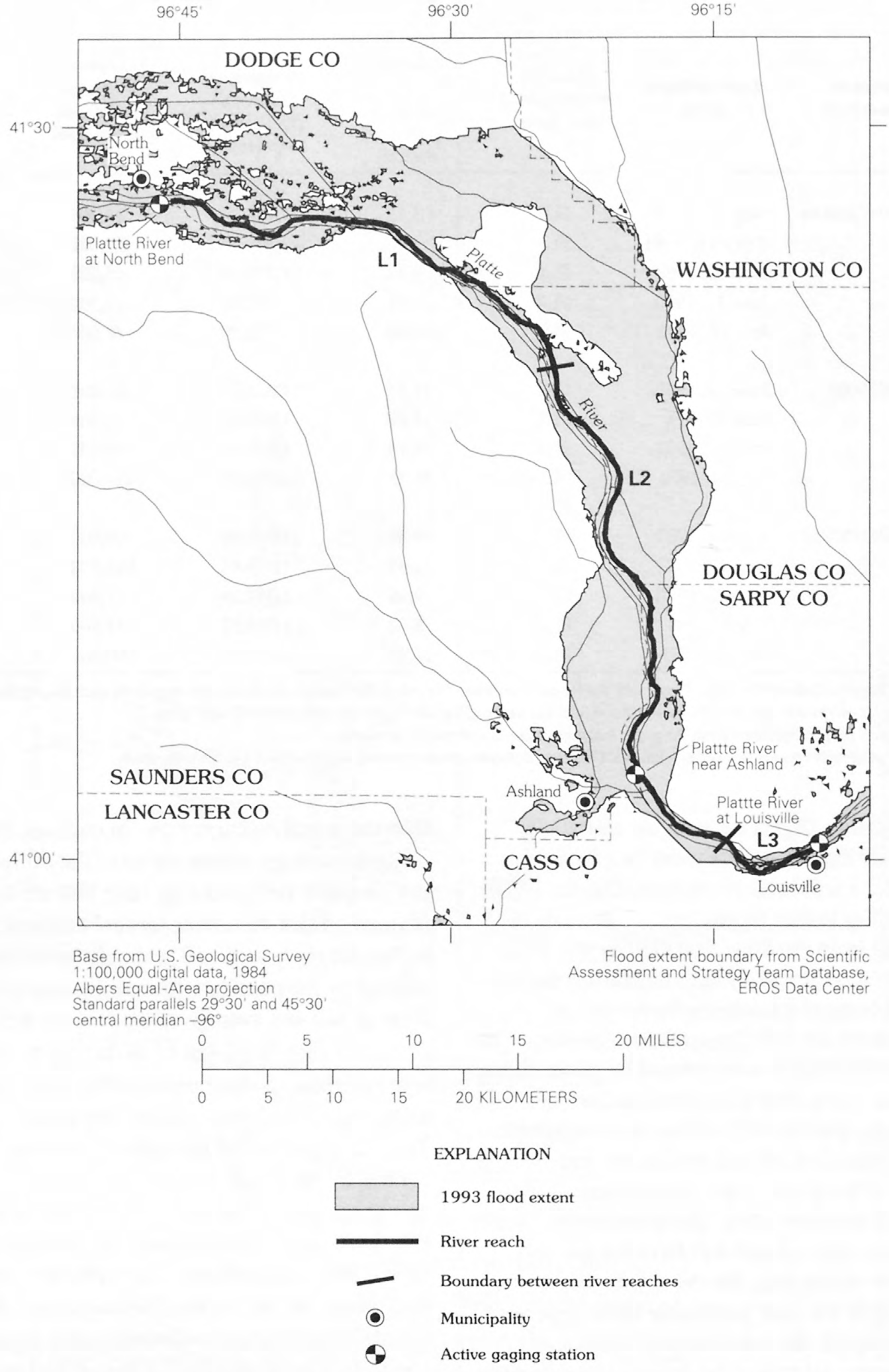

Figure 3. Stream-reach lengths (L1, L2, and L3) between active gaging stations along the lower Platte River.

L1 = from North Bend gage to a point halfway between the North Bend and Ashland gaging stations;

L2 = from a point halfway between North Bend and Ashland gages to a point halfway between the Ashland and Louisville gaging stations; and

L3 = from a point halfway between the Ashland and Louisville gages to the Louisville gage.

The area-weighted average permeabilities of the 60-inch soil profile ranged from 102 to 134 inches per day for the eight floods that exceeded the flood stages (table 2). The area-weighted average permeabilities based on the least permeable layer of soil ranged from 32 to 39 inches per day, considerably less than the 60-inch soil profile permeabilities (table 2).

The average depth of floodwater was calculated as the cross-sectional area of floodwater divided by the width of the inundated area at peak stage. The cross-sectional area of floodwater was calculated as the area below the time-weighted average stage (fig. 2). The time-weighted average stage is the average of the stage measurements made during a flood event over the duration of inundation. Initially, composite cross sections were developed to represent the flood reach in the vicinity of each gage. To avoid distortions in the channel geometry due to bridges, the cross-sectional geometry was estimated for cross sections three channel-widths upstream from each gage. Data from discharge measurements made during the 1993 flood were used, with streambed slope adjustments, to approximate the channel geometry, assuming that although the specific locations and depths of the channels would vary during each flood, the general shape of the river would change little. The slope adjustments were based on the slope upstream

Table 2. Average area-weighted permeabilities, average depths of floodwater, recharge rates, and duration of inundation for selected historical floods exceeding the flood stage at the North Bend, Ashland, and Louisville gaging stations on the lower Platte River

Flood event[1]	Area-weighted average permeability (inches per day)		Average depth of floodwater (feet)	Rate of recharge (inches per day)				Duration of inundation (days)
				Least permeable layer of soil		60-inch soil profile		
	Least permeable layer of soil	60-inch soil profile		Water table at the land surface	Water table more than 5 feet below land surface	Water table at the land surface	Water table more than 5 feet below land surface	
				North Bend (06796000)				
FL1	38	130	0.41	3.1	41	11	141	2.2
FL2	36	125	.30	2.2	39	7.5	132	1.2
FL3	39	133	.05	.42	39	1.4	135	.42
				Ashland (06801000)				
FL1	39	134	.21	1.7	41	5.7	140	.92
				Louisville (06805500)				
FL1	32	102	.95	6.1	38	19	121	3.5
FL2	33	105	.61	4.0	37	13	118	2.5
FL3	35	114	.21	1.5	36	4.9	118	1.1
FL4	35	114	.06	.42	35	1.4	116	.33

[1] Several large rainfall-related floods were selected for each gage and ranked on the basis of floodwater elevation. At each gaging station, the flood with the highest elevation was assigned FL1. The flood with the next highest elevation was assigned FL2, and so on.

from the gage. Because the cross-sectional data from the discharge measurement were limited to the river channel, the flood-plain geometry was estimated from topographic maps. Finally, time-weighted average stage values were converted to elevations using the datum for the gaging station and an adjustment of 1 to 2 ft based on the slope. GIS coverages of the cross-sectional channel and flood-plain geometry and the time-weighted average elevation values were created and used to calculate the cross-sectional area of floodwater (fig. 4).

Based on the estimated area of the floodwater and width of inundation for each flood with peak stages exceeding the flood stage, the average depths of floodwater varied from 0.05 to 0.95 ft (table 2). It was assumed that these depths were maintained throughout the area for the duration of inundation.

Historical water-level measurements were compiled for wells within the flood extent to determine average depths to water. The data indicated that, whereas the average depth to water within the flood extent ranged from 3.5 to 19 ft (fig. 5), the average depth to water in most wells was more than 5 ft. Hydrographs of depth to water over time for selected wells show that the average depths to water calculated were representative of the actual depths to water, and that actual values generally did not vary substantially from the average values used in the analysis of recharge (fig. 6).

Rates of recharge were calculated for two conditions—water table at the land surface, and water table 5 ft or more below the land surface. With the water table at the land surface, the difference in the average floodwater head (H_f) and the head in the aquifer (H_{aq}) is the average depth of the floodwater (table 2). With the water table 5 ft below the land surface, the difference in the average floodwater head (H_f) and the head in the aquifer (H_{aq}) is the average depth of the floodwater plus 5 ft. With the water table more than 5 ft below the land surface, calculated rate of recharge does not increase further because an unsaturated zone develops above the water table and $H_f - H_{aq}$ remains the appropriate head difference to apply.

Calculated aquifer recharge rates varied among gaging stations and among floods (table 2). Using the area-weighted average permeability for the 60-inch soil profile, the rates of recharge varied from 1.4 to 19 inches per day with the water table at the land surface, and 116 to 141 inches per day with the water table 5 ft or more below the land surface. The recharge rates calculated using the permeability of the least permeable layer of soil were considerably lower than those calculated with the average permeability of the 60-inch soil profile (table 2). With the water table at the land surface, the rates of recharge in the least permeable layer of soil varied from 0.42 to 6.1 inches per day (table 2). With the water table 5 ft or more below the land surface, the estimated recharge rates varied from 35 to 41 inches per day. Actual recharge rates of floodwater to the shallow aquifer probably will be less than these calculated estimates.

Amount of Atrazine in the Aquifer Prior to 1993 Flood

The amount of atrazine in the aquifer prior to the 1993 flood was estimated based on the volume of water in the aquifer and an assumed representative concentration of atrazine in the aquifer. The volume of water stored in the alluvial aquifer was estimated as the specific yield of the aquifer (0.18) (Davis, 1992), multiplied by the surface area and an area-weighted saturated thickness of the aquifer prior to determination of potential storage of atrazine. The surface area of the alluvial aquifer was calculated using a coverage of the Platte River Valley boundary; it was assumed that the boundary of the aquifer would be approximately that of the river valley. Area-weighted saturated thickness was based on depth to bedrock and water-level measurements from drilling logs for several test holes in the study area; the individual saturated-thickness values varied from approximately 20 to 270 ft (with rounding) (fig. 7). The total volume of water in the aquifer adjacent to the lower Platte River was estimated to be 131 billion cubic feet.

From 1985 to early 1993, atrazine had been detected in 52 of 88 samples collected from 57 wells within the study area. The mean concentrations of atrazine detected in samples collected prior to the 1993 flood ranged from 0.76 to 0.78 μg/L, and the median concentration was 0.24 μg/L. The range for the mean was computed by first assigning the "less than" values to zero and then assigning the "less than" values to the detection limit of 0.05 μg/L. Six percent of the wells sampled prior to the 1993 flood had concentrations of atrazine greater than 3.0 μg/L. The amount of atrazine in the aquifer

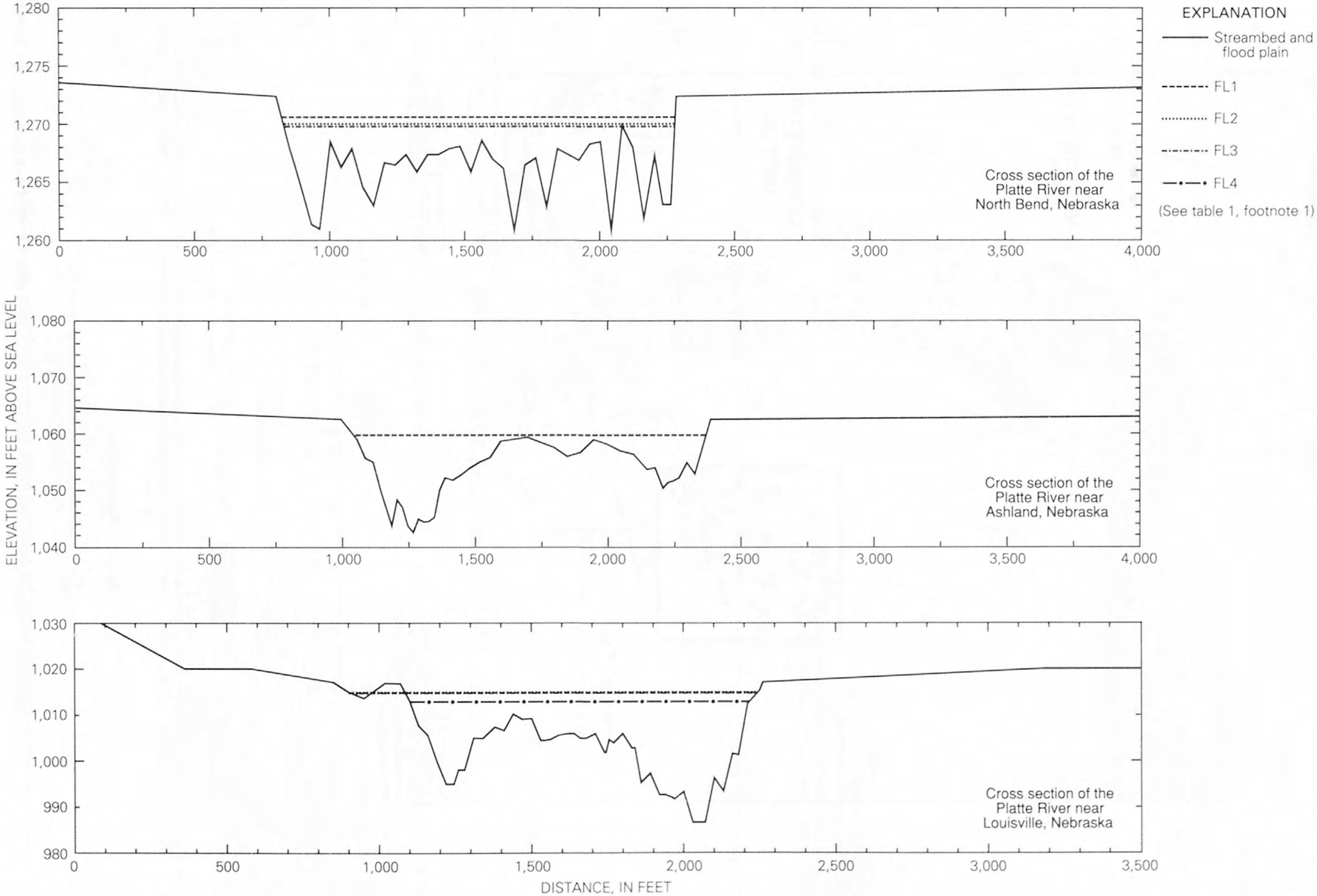

Figure 4. Channel and flood-plain geometry and the time-weighted average elevations of floodwater for historic floods near gaging stations on the lower Platte River.

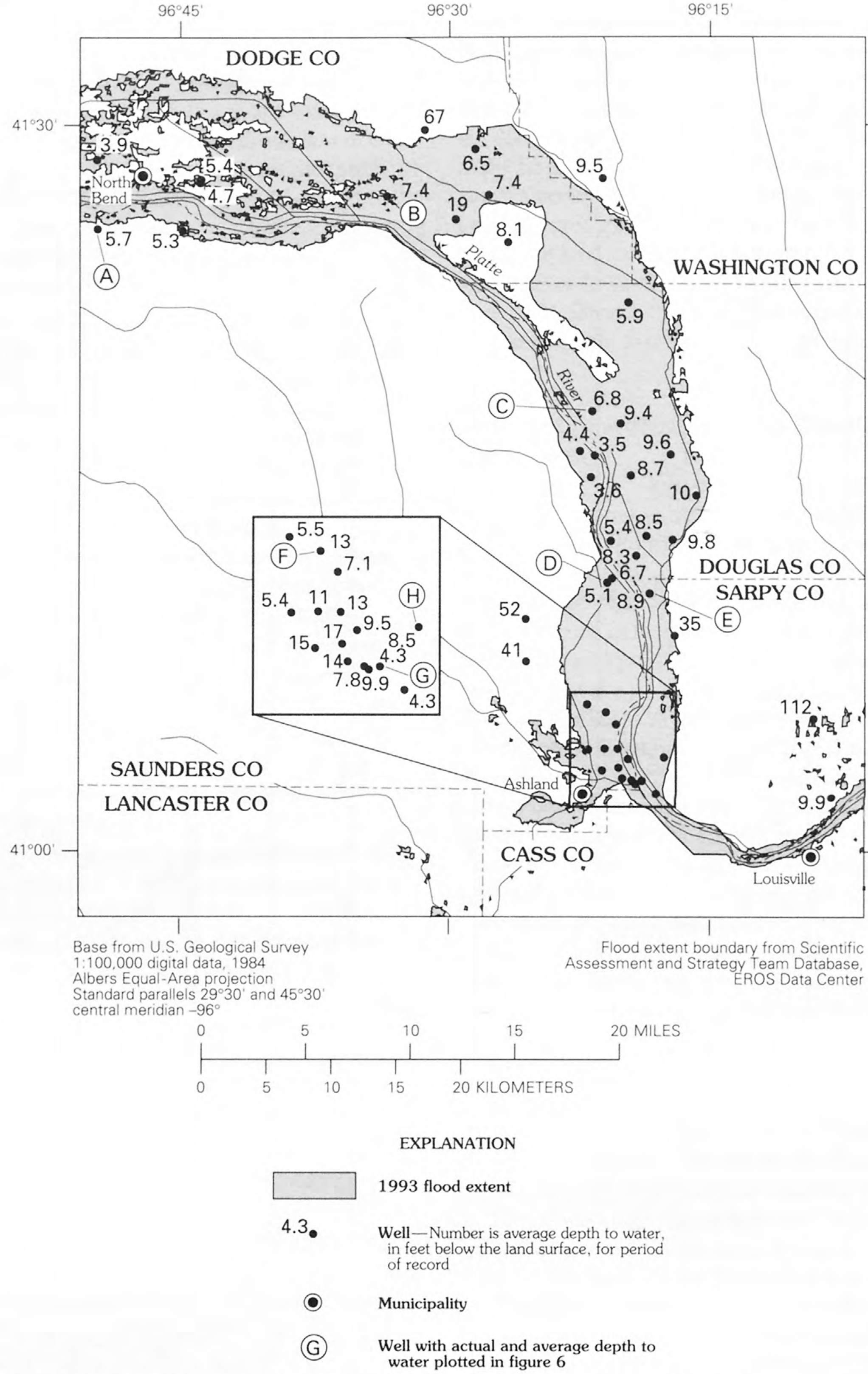

Figure 5. Average depth to water for selected wells in the lower Platte River Valley.

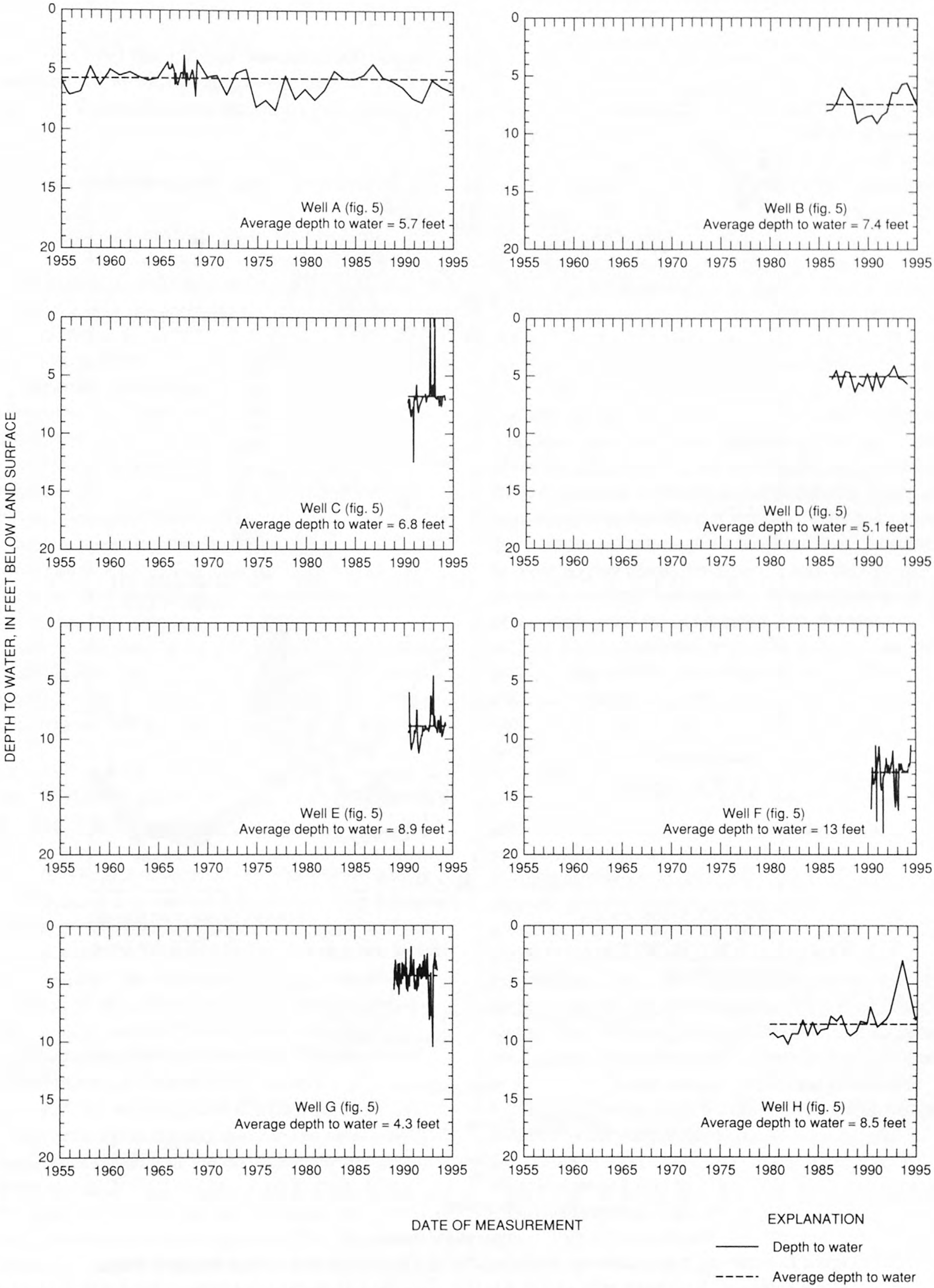

Figure 6. Actual and average depth to water in selected wells within the lower Platte River Valley.

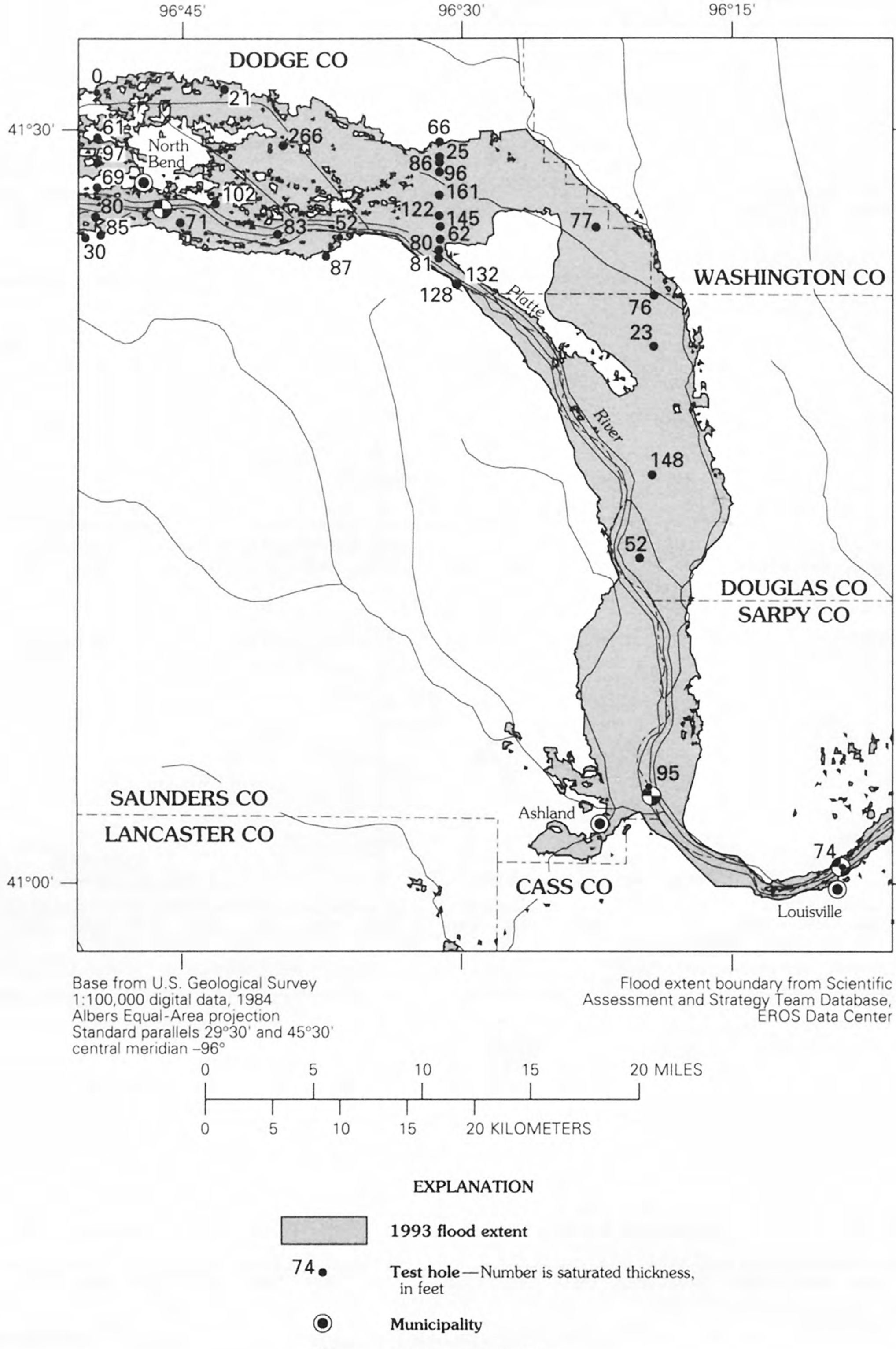

Figure 7. Saturated thickness of the alluvial aquifer at selected test holes within the lower Platte River Valley.

prior to the 1993 flood, approximately 2,000 pounds (lb), was estimated by multiplying the volume of water in the aquifer by the median concentration of atrazine.

Concentrations of Atrazine in Floodwater

Atrazine concentrations in surface water were determined only in samples collected at the gaging station near Louisville during the 1991 and 1993 floods. Because the 1991 flood did not result in overbank flooding, only the data from the 1993 flood were included in this analysis. It was assumed, due to the proximity of the other gaging stations, that concentrations of atrazine detected at the Louisville gage would be representative of the study area.

Concentrations of atrazine detected in three samples collected at the Louisville gage during the 1993 flood ranged from 0.34 to 3.4 µg/L. The median concentration during the flood was 1.0 µg/L. Higher concentrations of atrazine may have been detected during the 1993 flood had it occurred earlier in the growing season. The highest concentrations of atrazine are commonly detected in floods occurring in late spring and early summer, immediately following the application of herbicides to the fields (Goolsby and Battaglin, 1993; Stamer, 1996).

Potential Effects of Floodwater Movement into the Alluvial Aquifer

Floodwater movement into the aquifer during the 1993 flood was estimated by multiplying the rates of recharge when the water table was at the land surface and when the water table was 5 ft or more below the land surface by duration and area of inundation. The duration of inundation (table 2) was estimated from the stage records for the flood. During the floods that exceeded the flood stage, the duration of inundation varied from 0.33 to 3.5 days.

With the water table at the land surface and the permeability of the soil equal to the area-weighted average permeability of the 60-inch soil profile, it was estimated that a flood of the magnitude of the 1993 flood could result in the movement of 1.2 billion cubic feet of water into the aquifer. The estimated volume of water that could be moved into the aquifer increases to 7.7 billion cubic feet with the water table 5 ft or more below the land surface. If the soil overlying the aquifer had permeabilities equal to that of the least permeable layer, the volume of water that could be moved into the aquifer during a flood of the magnitude of the 1993 flood, with the water table at the land surface or 5 ft or more below the land surface, is 390 million and 2.4 billion cubic feet, respectively.

The amount of atrazine that could be moved into the aquifer during a flood of the magnitude of the 1993 event was estimated by multiplying the potential volume of the water moving into the aquifer within the study area by the median concentration of atrazine in the floodwater, assuming the amount of atrazine present in the pore water prior to flooding would have little effect. With the water table at the land surface and with the permeabilities of the 60-inch soil profile, a median concentration of atrazine of 1.0 µg/L, and a flood the magnitude of the 1993 flood, approximately 77 lb of atrazine in the floodwater could be transported downward into the alluvial aquifer. With the water table 5 ft or more below the land surface, the amount of atrazine potentially transported into the system increases to more than 485 lb. Approximately 24 lb of atrazine could be transported with the water table at the land surface, when calculated using the permeability of the least permeable layer. This potential amount increases to approximately 152 lb with the water table 5 ft or more below the land surface.

The data compiled indicate that volume of water and amount of atrazine in the alluvial aquifer could increase as a result of a flood with magnitude and duration similar to the 1993 flood. A flood of this magnitude could result in as much as a 24-percent increase in the quantity of atrazine and a corresponding 6-percent increase in water in the alluvial aquifer with the water table 5 ft or more below the land surface if the permeability was equal to that of the 60-inch soil profile. Although postflood sampling was limited, the data indicate the amount of atrazine in the aquifer did not increase following the 1993 flood. In six ground-water samples collected within 2 to 3 months after the 1993 flooding, the median concentration of atrazine detected was about 0.2 µg/L. If this concentration is assumed to be representative, approximately 1,600 lb of atrazine would be present within the aquifer. This would be a decrease of about 20 percent compared to the preflood amount. Additional surface- and ground-water sampling during the course of a flood could verify that decreases in the atrazine in the ground water are directly related to inundation from floodwater and not a result of other anthropogenic or metabolic processes.

SUMMARY

Heavy rainfall and severe flooding from late June through early August 1993 flushed large amounts of sediment and other dissolved and suspended constituents into streams in the Upper Mississippi River Basin. In the Platte River Valley, the shallow alluvial aquifer is the major source of water for public, industrial, and agricultural use. During the 1993 flood, concentrations of atrazine detected in surface-water samples from the lower Platte River varied from 0.34 to 3.4 µg/L. As a result of the detection of herbicides in association with record flooding, the potential for recharge of floodwater containing herbicides and the potential change in the volume and quality of water in the shallow alluvial aquifer became a concern in the lower Platte River Valley.

The study area was defined by the extent of inundation from the 1993 flood along the reach of the lower Platte River and includes the North Bend, Ashland, and Louisville gaging stations. Initially, several large rainfall-related floods that occurred from 1970 to 1993 were identified for each gaging station. Duration of inundation, depth of the floodwater, and recharge rates were determined for each flood. Because atrazine was the most frequently used and detected herbicide in the study area, it was used to estimate the effect of floodwater inundation on ground-water quality. On the basis of these data, the volume of water and amount of atrazine present in the alluvial aquifer prior to and following flooding, and the amount that could be introduced from the floodwater were estimated.

During the floods that exceeded the flood stage, the duration of inundation varied from 0.33 to 3.5 days. Average floodwater depths were estimated on the basis of area of floodwater and the width of inundation, and ranged from 0.05 to 0.95 ft. The rate of recharge of floodwater to the aquifer was estimated for conditions under which the water table was at the land surface and at 5 ft or more below the land surface, using the permeability for the least permeable layer of soil and the average permeability of the 60-inch soil profile. The estimated rates of recharge using the least permeable layer of soil varied from 0.42 to 6.1 inches per day with the water table at the land surface to 35 to 41 inches per day with the water table 5 ft or more below the land surface. Using the average permeability of the 60-inch soil profile, the estimated rates of recharge varied from 1.4 to 19 inches per day with the water table at the land surface, and from 116 to 141 inches per day with the water table 5 ft or more below the land surface.

Within the area of inundation, atrazine has been detected in ground water since 1985. From 1985 to early 1993, atrazine had been detected in 52 of 88 samples collected from 57 wells within the study area. The mean concentrations of atrazine in the samples collected prior to the 1993 flood ranged from 0.76 to 0.78 µg/L, and the median concentration was 0.24 µg/L. The range for the mean was computed by first assigning the "less than" values to zero and then assigning the "less than" values to the detection level of 0.05 µg/L. The amount of atrazine stored in the system prior to flooding, approximately 2,000 lb, was estimated by multiplying the volume of the aquifer, or 131 billion cubic feet of water, by the median concentration of atrazine.

An estimate of the amount of atrazine transported in the floodwater was based on water samples collected at the Louisville gaging station during the 1993 flood. During this flood, atrazine concentrations in the floodwater ranged from 0.34 to 3.4 µg/L, with a median concentration of 1.0 µg/L. Potential movement of floodwater and transport of atrazine into the ground water was estimated using concentrations of atrazine detected in surface-water samples, recharge rates, duration of flooding, and area of inundation. It is estimated that, with the water table at the land surface and using the area-weighted average permeability of the 60-inch soil profile, a flood the magnitude of the 1993 flood could result in the movement of 1.2 billion cubic feet of water and the transport of 77 lb of atrazine into the ground water. With the water table 5 ft or more below the land surface, the estimated volume of water moved into the alluvial aquifer increases to 7.7 billion cubic feet, and the quantity of atrazine transported into the ground water increases to more than 485 lb. With permeabilities in the soil overlying the alluvial aquifer equal to the least permeable soil layer and the water table at the land surface, the estimated volume of water moved and atrazine transported into the ground water is 390 million cubic feet and 24 lb, respectively. With the water table 5 ft or more below the land surface, the estimated quantities moved and transported increase to 2.4 billion cubic feet of water and 152 lb of atrazine.

The data compiled indicate that the volume of water and amount of atrazine in the alluvial aquifer could increase as a result of a flood with magnitude and duration similar to the 1993 flood; the change could be as much as a 24-percent increase in the quantity of atrazine and a corresponding 6-percent increase in water. Although postflood sampling was limited, the data indicate the amount of atrazine in the aquifer did not increase following the 1993 flood. The median concentration of atrazine measured in six ground-water samples collected within 2 to 3 months after the 1993 flooding was about 0.2 μg/L. If a concentration of about 0.2 μg/L is assumed to be representative, approximately 1,600 lb of atrazine would be present within the aquifer. This would be a decrease of about 20 percent from the preflood amount. Additional surface- and ground-water sampling during flooding could confirm that decreases in the atrazine in the ground water are a direct result of inundation from floodwater and not the result of other anthropogenic or metabolic processes.

REFERENCES

Boohar, J.A., Hoy, C.G., and Steele, G.V., 1994, Water resources data, Nebraska, water year 1993: U.S. Geological Survey Water-Data Report, NE–93–1, 403 p.

Davis, R.K., 1992, The waters edge—Hydrochemical interactions between the Platte River and the Lincoln Municipal well field, Ashland, Nebraska: University of Nebraska-Lincoln, Ph.D. dissertation, 245 p.

Dugan, J.T., 1984, Hydrologic characteristics of Nebraska soils: U.S. Geological Survey Water-Supply Paper 2222, 19 p.

Ellis, M.J., Engberg, R.A., Kastner, W.M., and Steele, E.K., Jr., 1985, Nebraska: Ground-water resources, *in* National water summary—Hydrologic events, selected water-quality trends, and ground-water resources: U.S. Geological Survey Water-Supply Paper 2275, p. 291–296.

Engberg, R.A. and Druliner, A.D., 1988, Nebraska—Ground-water quality, *in* National water summary—Hydrologic events and ground-water quality: U.S. Geological Survey Water-Supply Paper 2325, p. 347–354.

Goolsby, D.A., and Battaglin, W.A., 1993, Occurrence, distribution, and transport of agricultural chemicals in surface waters of the midwestern United States, *in* Selected papers on agricultural chemicals in water resources of the midcontinental United States: U.S. Geological Survey Open-File Report 93–418, p. 1–24.

Goolsby, D.A., Battaglin, W.A., and Thurman, E.M., 1993, Occurrence and transport of agricultural chemicals in the Mississippi River basin, July through August, 1993: U.S. Geological Survey Circular 1120–C, 22 p.

McDonald, M.G., and Harbaugh, A.W., 1988, A modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Techniques of Water-Resources Investigations, book 6, chap. A1, 576 p.

National Oceanic and Atmospheric Administration, 1994, Climatological data, Nebraska annual summary 1993: Asheville, North Carolina, National Climatic Data Center, v. 98, no. 13, 41 p.

Parrett, Charles, Melcher, N.B., and James, R.W., Jr., 1993, Flood discharges in the Upper Mississippi River basin, 1993: U.S. Geological Survey Circular 1120–A, 14 p.

Soil Conservation Service, 1993, State soil geographic data base (STATSGO) data users guide: Soil Conservation Service Miscellaneous Publication 1492, 88 p.

Squillace, P.J., Caldwell, J.P., Schulmeyer, P.M., and Harvey, C.A., 1994, Movement of agricultural chemicals between surface water and ground water, Lower Cedar River Basin, Iowa: U.S. Geological Survey Water-Supply Paper 94–W–0058, 103 p.

Stamer, J.K., 1996, Water supply implications of herbicide sampling: Journal American Water Works Association, v. 88, no. 2, p. 76–85.

Wahl, K.L., Vining, K.C., and Wiche, G.J., 1993, Precipitation in the upper Mississippi River basin, January 1 through July 31, 1993: U.S. Geological Survey Circular 1120–B, 13 p.

Zelt, R.B., and Jordan, P.R., 1993, Water-quality assessment of the central Nebraska basins—Summary of data for recent conditions through 1990: U.S. Geological Survey Open-File Report 93-422, 179 p.

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