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Surveys of Water Velocities in the Vicinity of the Discharge-Release Gates of Salamonie Lake Dam, Northeastern Indiana, Spring and Winter 1998

By Scott E. Morlock and James A. Stewart

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Conversion Factors, Unit Abbreviations, and Vertical Datum

Multiply	By	To obtain
foot (ft)	0.3048	meter
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
square mile (mi^2)	2.590	square kilometer
acre	0.4047	hectare
acre-foot (acre-ft)	1233	cubic meter

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 the United States and Canada, formerly called Sea Level Datum of 1929.

Surveys of Water Velocities in the Vicinity of the Discharge-Release Gates of Salamonie Lake Dam, Northeastern Indiana, Spring and Winter 1998

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Abstract

Two water-velocity surveys in the vicinity of the discharge-release gates were performed at the Salamonie Lake flood-control reservoir in northeastern Indiana during periods of high-discharge release. One survey was done in the spring when the reservoir pool was at a high elevation; the other survey was in the winter when the reservoir pool was low.

The maximum measured velocity was 2.4 feet per second for the spring survey and 1.9 feet per second for the winter survey. The maximum measured velocities occurred in the immediate vicinity of the spillway tower containing the discharge-release gates. Velocity-field magnitudes diminished rapidly with distance from the tower. Beyond an estimated 40 feet from the tower, velocity magnitudes were below 0.5 feet per second.

For the spring and winter surveys, data were collected along four transects that were parallel to the face of the spillway tower. The transects were at the following approximate distances from the spillway tower: 900, 600, and 300 feet and as close to the tower as practical. For the spring and winter surveys, velocity-contour plots were produced for the transects closest to the tower. Plots were not made for the transects at 900-, 600-, and 300-foot intervals because velocities were negligible at these distances.

An acoustic Doppler current profiler (ADCP) mounted on a boat was used to collect velocity and depth data and to compute positions of the velocity and depth data relative to the boat track. A global positioning system (GPS) mobile receiver was used to collect earth-referenced position data, and a GPS base-station receiver was used to improve the accuracy of the earth-referenced position data. The earth-referenced position data were used to transform the ADCP-computed positions (which were relative to the boat tracks) to positions referenced to a point on the spillway tower.

Introduction

Salamonie Lake is a flood-control reservoir in northeastern Indiana. The dam is an earthen structure, and the main spillway is a concrete tower with three submerged discharge-release gates. The reservoir dam and spillway are operated by the U.S. Army Corps of Engineers (USACE). The Indiana Department of Natural Resources, Division of Fish and Wildlife, expressed concern to the USACE that during high-discharge releases from the spillway gates, large numbers of fish might be drawn through the spillway, forcing them to migrate downstream from the lake. The USACE then requested the assistance of the U.S. Geological Survey (USGS) to perform two water-velocity surveys during periods of high release in the vicinity of the discharge-release gates, one in spring at a relatively high pool elevation and one in winter at a lower pool elevation.

To perform the surveys, the USGS used acoustic Doppler current profiler (ADCP) and global positioning system (GPS) technologies to collect water-velocity and position data. The ability of an ADCP to rapidly obtain vertical-velocity profiles from a moving boat and the ability of GPS receivers to accurately compute earth-referenced positions allowed the surveys to be completed much faster and with greater accuracy than if conventional methods (such as mechanical current-meter measurements) had been employed.

Purpose and Scope

This report describes the use of ADCP and GPS technology for water-velocity surveys and presents the results of two water-velocity surveys in the vicinity of the Salamonie Lake discharge-release gates.

Physical Setting

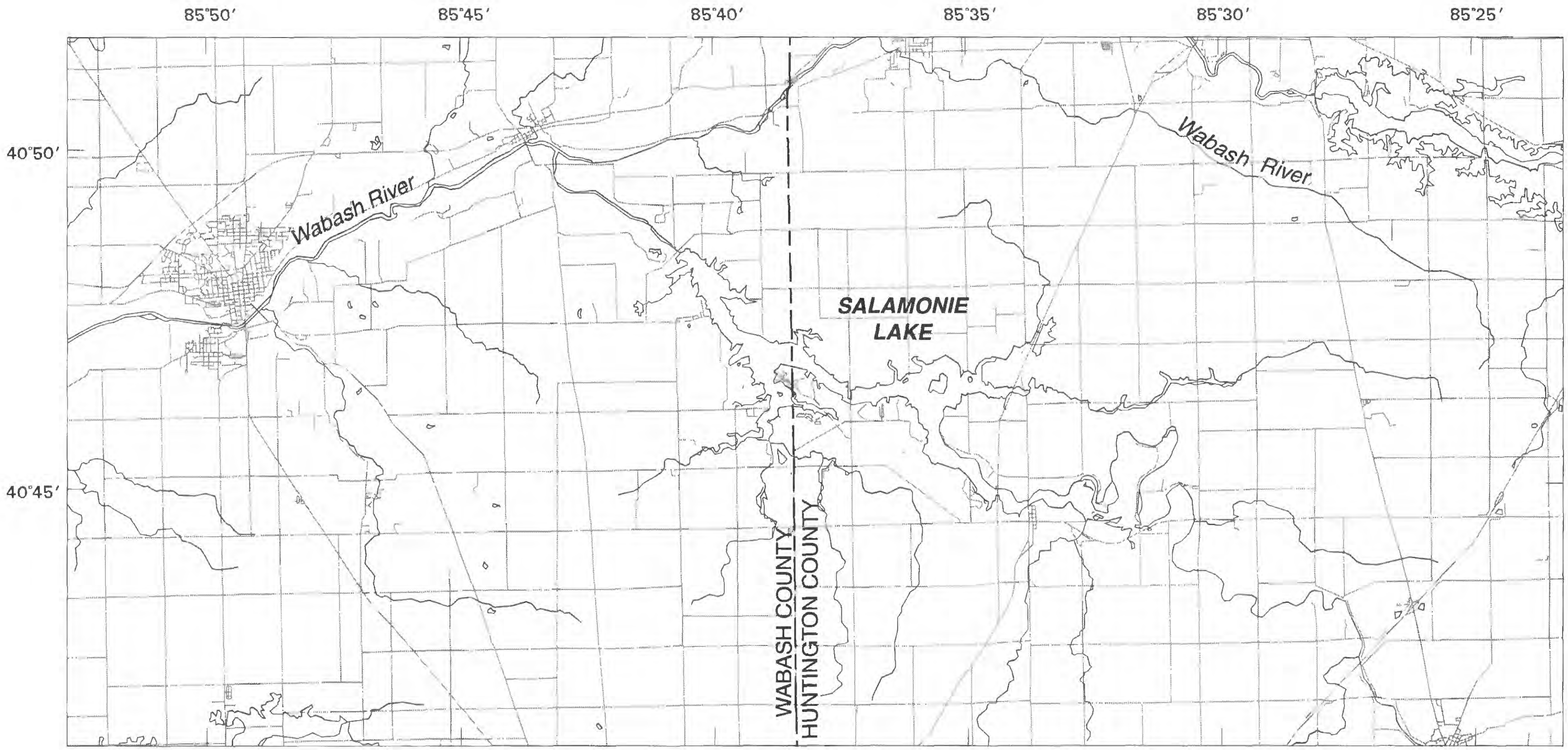
Salamonie Lake, a reservoir in northeastern Indiana (fig.1) formed by impoundment of the Salamonie River, was completed in 1966 for flood control and recreation. Salamonie Lake has a capacity of 13,100 acre-ft at the normal pool elevation of 730 ft, mean sea level (msl); a surface area of 980 acres (William Byron, U.S. Army Corps of Engineers, written commun., May 13, 1999); and a drainage area of 553 mi^2 (Ruddy and Hitt, 1990). Seasonal pool elevations range from 730 to 755 ft, msl (U.S. Army Corps of Engineers, 1998).

The Salamonie Lake dam is an earthen structure, and the main spillway is a concrete tower (fig. 2) with three submerged discharge-release gates. Each gate is 4.75 ft wide and 16 ft high, with an invert elevation of 684 ft, msl (William Byron, U.S. Army Corps of Engineers, oral commun., September 30, 1998).

Figure 2. Salamonie Lake dam spillway tower.

Methods of Investigation

A boat-mounted ADCP (fig. 3A) was used to collect velocity and depth data and compute positions of the velocity and depth data relative to the boat track. A GPS mobile receiver (fig. 3B) was used to collect earth-referenced position data, and a GPS base-station receiver was used to improve the accuracy of the earth-referenced position data. The earth-referenced position data were used to transform the ADCP-computed positions (which were relative to the boat tracks) to positions referenced to a point on the spillway tower.



Base from U.S. Geologcal Survey digital data, 1:100,000, 1983
Albers Equal-Area Conic projection
Standard parallels 29°30′ and 45°30′, central meridian -86

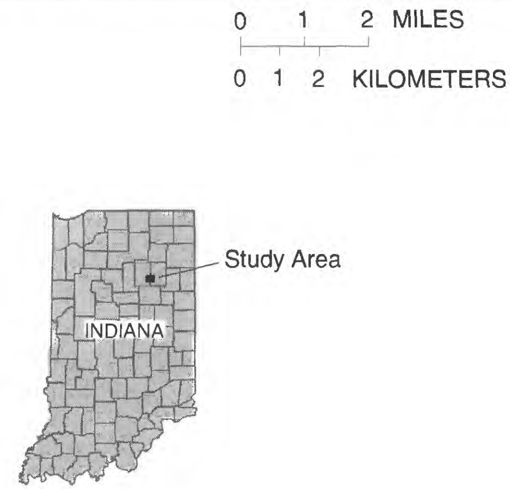


Figure 1. Location of the study area.

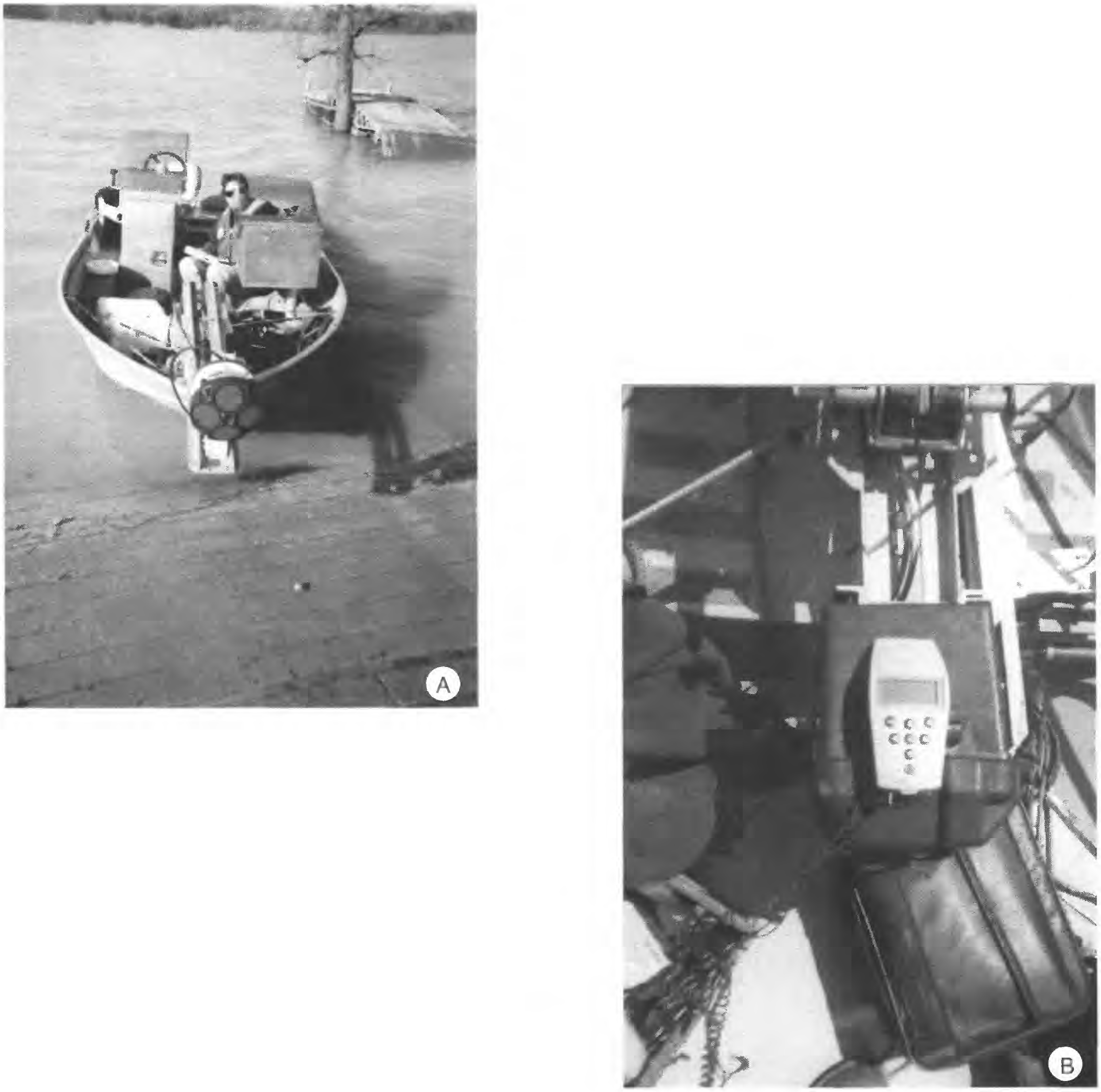


Figure 3. Boat-mounted acoustic Doppler curent profiler (A) and global positioning system mobile receiver (B).

Acoustic Doppler Current Profiler

An ADCP transmits acoustic pulses into the water column, receives reflected pulses from suspended particles, and then computes the frequency shift between the transmitted and reflected pulses. The frequency shift is used to compute particle velocities; because the particles are suspended in the water column and move at the same velocity as the water, water velocities can be computed. By timing the receipt of reflected pulses, the ADCP computes velocities in successive, uniformly spaced volumes called "depth cells" down through the water column. Thus the ADCP obtains vertical-velocity profiles, with the velocities reported in terms of magnitude and direction at uniformly spaced depths. The time it takes to collect a full vertical-velocity profile from the ADCP to the bottom of the water column is called an "ensemble." Because of limitations in ADCP technology, the instruments cannot measure velocities close to the surface or bottom of the water column (a detailed explanation of these limitations is given in Morlock, 1996).

The ADCP uses the frequency shift between transmitted and reflected pulses from a river or lake bottom in conjunction with an electronic compass and tilt and roll sensors to compute the speed. distance, and direction the boat travels over the bottom; this process is called "bottom tracking." Total depth of water also is computed. The bottom-tracking feature allows the ADCP to compute the relative horizontal position of each ensemble in terms of an x-y coordinate system (the x-y coordinate system is the distance north and east from the starting point of data collection). A boat-mounted ADCP therefore is able to collect many ensembles in a short time, with each ensemble containing a complete vertical-velocity profile with a known depth and x-y coordinate. A complete set of ensembles collected along a particular boat track is called a "transect."

A portable computer is required to operate the ADCP software. The ADCP software allows an operator to configure the ADCP and collect, view, and store all data in real time (for a more detailed description of ADCP theory and operation, see Gordon, 1996).

Global Positioning System

GPS relies on a constellation of 25 earth-orbit satellites. A GPS receiver calculates its position on earth through "satellite trilateration," the process of computing the intersection of three or more spheres, the centers of which are GPS satellites. In the interests of national security, the Department of Defense can degrade the quality of GPS signals with Selective Availability (SA). The absolute accuracy of GPS positions is between 25 and 100 meters because of SA and atmospheric errors (for more detailed information, see Baker and Morlock, 1996).

The absolute accuracy of data collected with a GPS mobile receiver can be improved by differentially correcting the data with a GPS base-station receiver. The mobile and base-station receivers operate simultaneously. Within 500 kilometers, the mobile receiver and base station are influenced equally by SA and atmospheric errors (Wilson, Morlock, and Baker, 1997). If the location of the base-station receiver is known, the positions collected by the mobile receiver can be corrected by applying the difference between the known and computed location of the base-station receiver to the data collected by the mobile receiver. If real-time communication between the mobile and base-station receivers is possible, the data can be differentially corrected as data are collected by the mobile receiver. If real-time communication is not used, the differential corrections are applied in post-processing.

Water-Velocity Surveys

Two water-velocity surveys were made, both during periods of maximum release from the main spillway. The first survey took place on April 24, 1998, at a pool elevation of 761.5 ft, msl (normal pool elevation is 730 ft, msl), and the second took place on December 4, 1998, at a pool elevation of 740.2 ft, msl.

Data Collection

The data were collected in the same manner for each of the two water-velocity surveys. The USACE had specified that velocity data were required along four transects at the following approximate distances from the spillway tower: 900, 600, and 300 ft and as close to the tower as practical. The transects were run parallel to the face of the spillway tower containing the three submerged discharge-release gates.

A laser range finder was used to place marker buoys at specified distances from the spillway tower. A 600-kilohertz-frequency ADCP deployed from a 16-ft aluminum boat (fig. 3A) was used for the surveys. Each ADCP transect was started at a marker buoy, and the boat was steered so that the boat track was parallel to the face of the spillway tower. Transects were terminated when velocities appeared to be negligible or when the water depth became too shallow for the ADCP to operate.

The transects had lengths that ranged from 450 to 650 ft for the spring survey and from 250 to 450 ft for the winter survey. During the winter survey, the pool elevation was lower than for the spring survey; subsequently, the reservoir in the vicinity of the spillway tower was not as wide and the transects were shorter. The depth-cell length was set so the ADCP reported a velocity about every 3 ft in the vertical, starting at a depth of about 8 ft. The ADCP used for the surveys could not measure velocities within about 8 ft from the surface and 4 ft from the lake bottom. The accuracy of the velocity measurements was estimated to be 0.10 ft/s.

A GPS mobile receiver (fig. 3B) was used to collect earth-position data for each of the corners of the spillway tower and at the marker buoys that identified the start of each ADCP transect. The GPS mobile receiver did not have real-time telemetry with the GPS base-station receiver; the position data were differentially corrected in post-processing.

Data Processing

The ADCP processing software was used to output the following data for each ensemble to text files: ensemble number, ensemble position, depth of velocity measurement, and velocity magnitude and direction. The GPS-collected data were differentially corrected with a first-order base-station receiver at the USGS Indianapolis office. A "first-order station" means that the position of the station is known with an accuracy of 10 centimeters over 10 kilometers (Baker and Morlock, 1996).

Because ADCP positions are referenced relative to the start of an individual transect, a common coordinate system was needed for all survey data. The surveys were undertaken to provide data on the effect of high-discharge release through the spillway-tower gates upon the velocity field; all data, therefore, were referenced to a point on the spillway tower. The southwest corner of the spillway tower was selected as the reference. The GPS position provided latitude-longitude points for the southwest corner of the spillway tower and the start points of each transect. Knowing that 1 second of latitude equals 101 ft and 1 second of longitude equals 77.6 ft at the study location (Wilson, Morlock, and Baker, 1997), the distance of each transect start point in feet north-south and east-west from the southwest spillway-tower corner was computed. ADCP ensemble positions, which were referenced to the transect start points, then were transformed with computer spreadsheet programs so that all data collected with the ADCP were referenced to the southwest corner of the spillway tower. The text files that contained the ADCP data with positions referenced to the spillway tower then were ready for analysis and for use in generating velocity-contour plots. A computer software package, ARC/INFO (a geographic information system), was used to generate graphics plots of the velocity-survey data.

Spring Water-Velocity Survey

The spring survey took place on April 24, 1998, at a pool elevation of 761.5 ft, msl (Jamie Evans, U.S. Army Corps of Engineers, oral commun., May 7, 1999). The discharge released from the spillway during the survey was 4,700 ft^3/s (William Byron, written commun., May 13, 1999). The four transects used for the survey were assigned numbers 1S through 4S. Transect 1S was about 20 ft from the tower face; transects 2S through 4S were about 300, 600, and 900 ft, respectively, from the tower face (fig. 4).

The greatest velocity measured was along transect 1S (the velocities in this and subsequent discussions are horizontal velocities; vertical-velocity magnitudes were generally less than 0.5 ft/s for all collected velocity data). The magnitude of this velocity was 2.4 ft/s, and the direction was 350 degrees (referenced to true north). The velocity occurred at a depth of 67 ft (694.5 ft, msl), about 3 ft south and 15 ft east of the spillway-tower southwest corner. Velocities were greatest within about 40 ft of the spillway tower; beyond this distance, velocities at all measurement depths decreased below 0.5 ft/s. The magnitudes, depths, and directions of the velocities within 40 ft of the spillway tower were consistent with a flow pattern into the submerged discharge-release gates. The figure 5 plot shows velocity contours along transect 1S. Velocities measured along transects 2S, 3S, and 4S were less than 0.5 ft/s and did not have consistent directions.

Winter Water-Velocity Survey

The winter survey took place on December 4, 1998, at a pool elevation of 740.2 ft, msl (Jamie Evans, oral commun., May 7, 1999). The discharge released from the spillway during the survey was 3,200 ft^3/s (William Byron, written commun., May 13, 1999). The four transects used for the survey were assigned numbers 1W through 4W. Transect 1W was about 30 ft from the tower face; transects 2W through 4W were similar distances from the tower as the corresponding spring-survey transects (fig. 4).

The greatest velocity measured was along transect 1W. The magnitude of this velocity was 1.9 ft/s and the direction was 300 degrees, true north. This velocity occurred at a depth of 34 ft (706 ft, msl), about 3 ft south and 35 ft east of the spillway-tower southwest corner. Velocities were greatest within about 40 ft of the spillway tower. As in the spring survey, the magnitudes, depths, and directions of the velocities within 40 ft of the spillway tower were consistent with a flow pattern into the submerged discharge-release gates. Beyond this distance, velocities at all measurement depths dropped below 0.5 ft/s. The figure 6 plot shows velocity contours along transect 1W. Velocities measured along transects 2W, 3W, and 4W were less than 0.5 ft/s and did not have consistent directions.

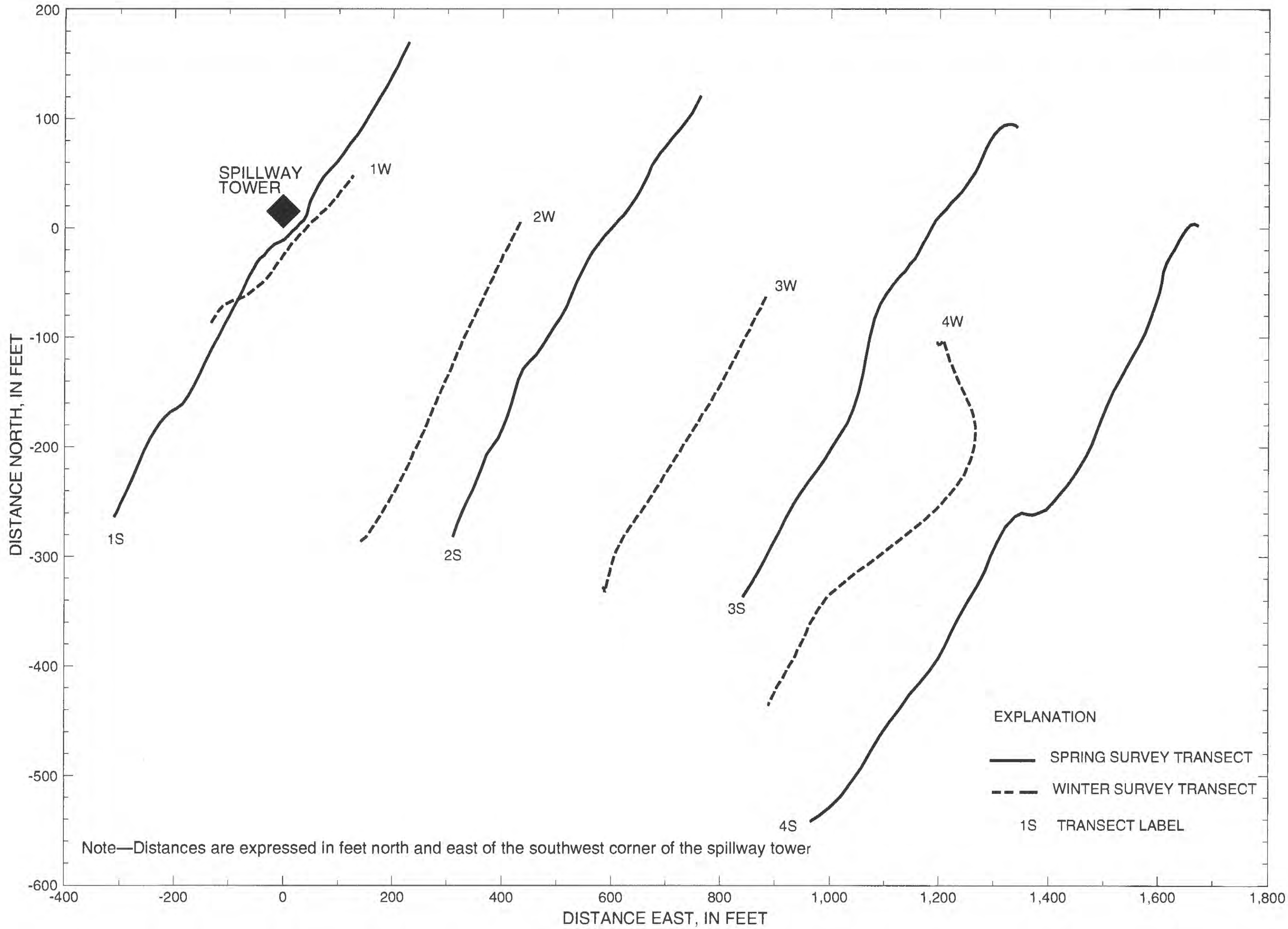


Figure 4. Diagram showing locations of acoustic Doppler current profiler transects collected during a spring and a winter water-velocity survey at Salamonie Lake, northeastern Indiana.

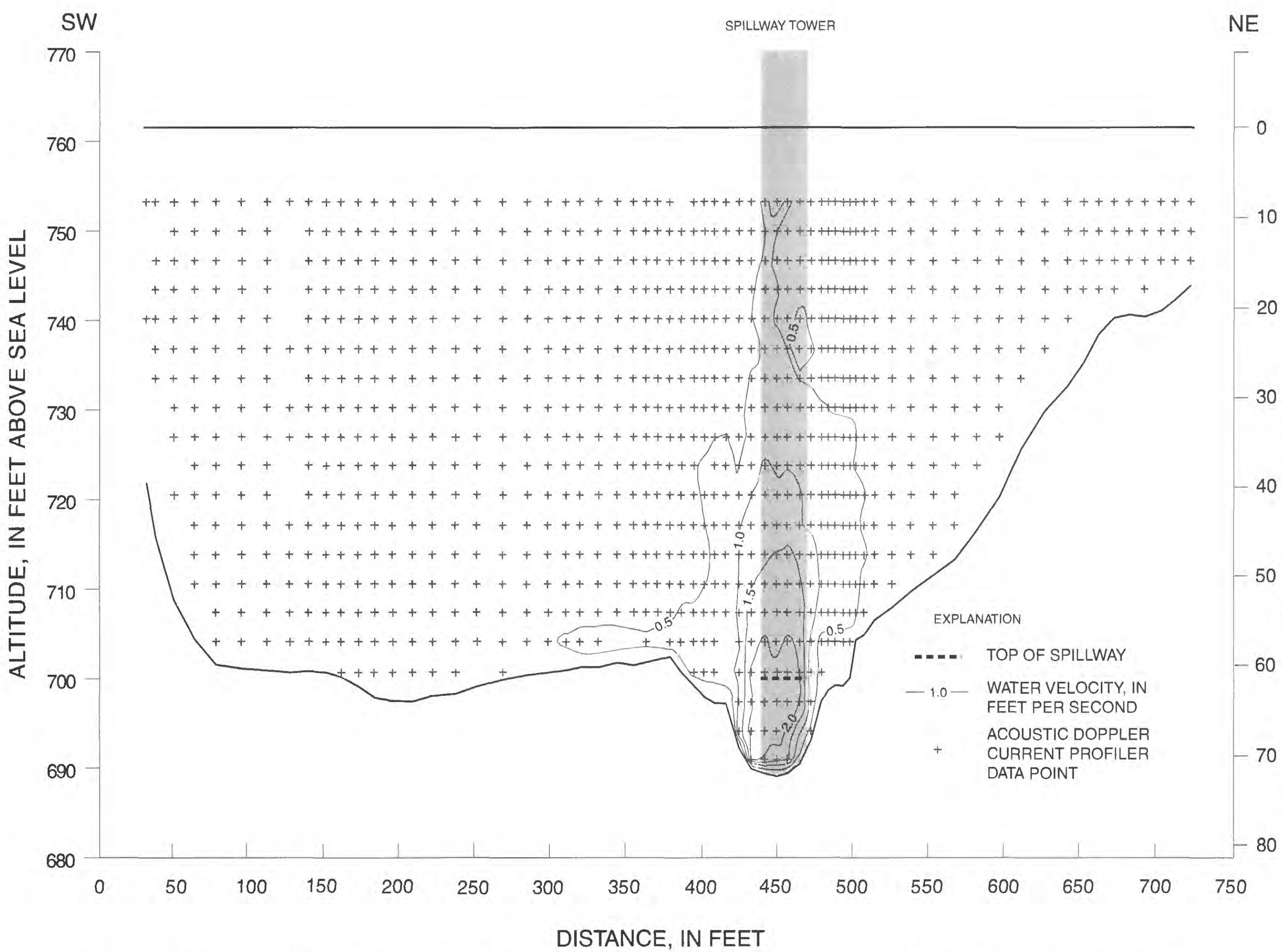


Figure 5. Water-velocity-contour plot along a transect in the vicinity of the Salamonie Lake spillway tower, northeastern Indiana, on April 24,1998, during a period of discharge release of 4,700 cubic feet per second.

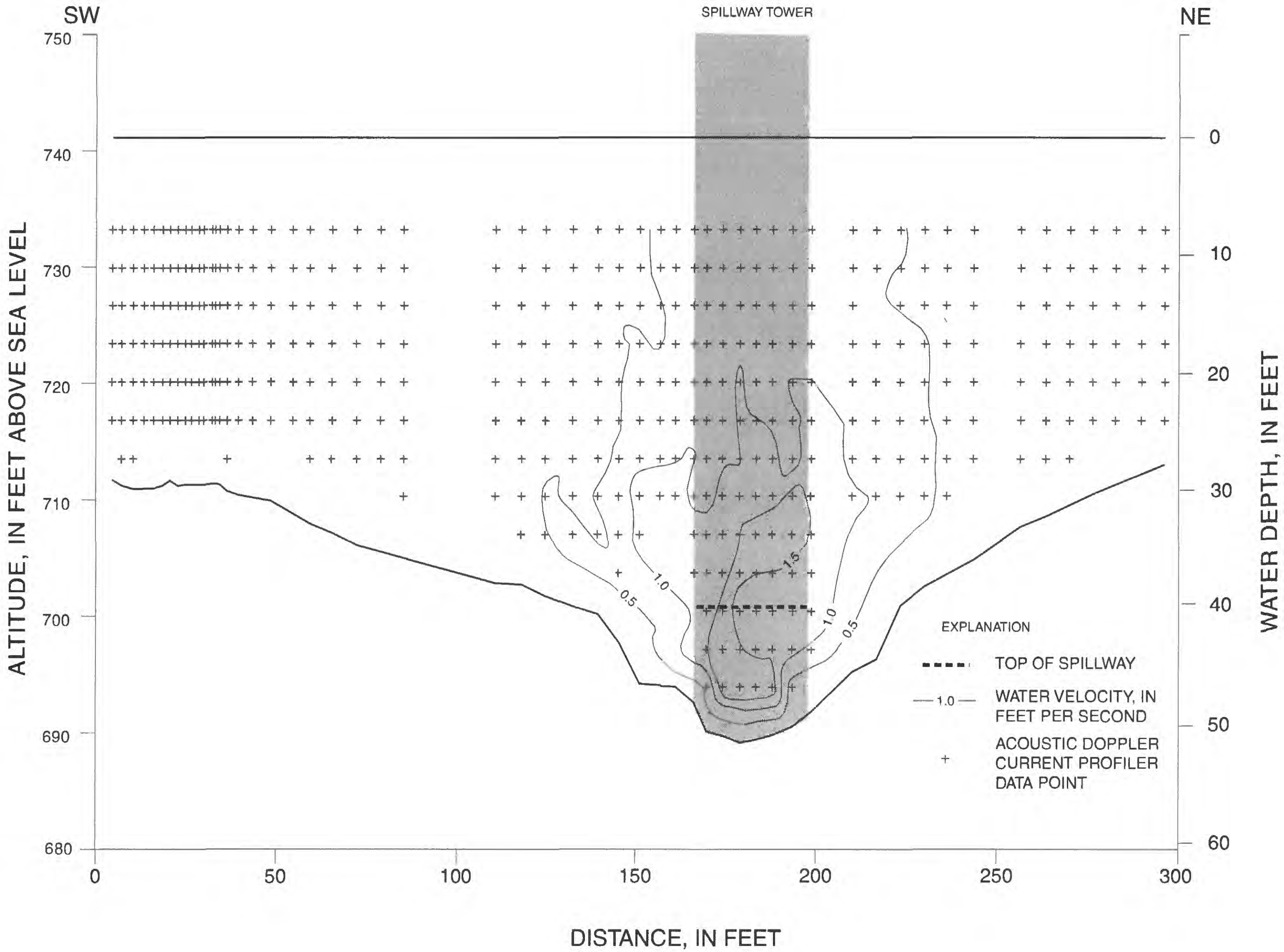


Figure 6. Water-velocity-contour plot along a transect in the vicinity of the Salamonie Lake spillway tower, northeastern Indiana, on December 4,1998, during a period of discharge release of 3,200 cubic feet per second.

Summary and Conclusions

Water velocities in the vicinity of the Salamonie Lake discharge-release gates were surveyed on April 24, 1998, and December 4, 1998; each survey was made during periods of maximum release. ADCP and GPS technologies were used to complete the surveys. For each survey, velocity data were collected along transects made as close as possible to the spillway tower containing the discharge-release gates and at approximate distances of 900, 600, and 300 ft from the tower. The survey data were collected and prepared for generation of velocity-contour plots with the computer software package ARC/INFO.

The maximum velocities measured during the spring and winter surveys were 2.4 and 1.9 ft/s, respectively. For both surveys, the velocity-field magnitudes diminished rapidly with distance from the spillway tower. At distances greater than about 40 ft from the tower, velocity magnitudes were less than 0.5 ft/s.

The velocity surveys could be improved by modifying the field-data-collection scheme. Instead of running just four transects, a grid of transects parallel and orthogonal to the spillway tower could be used. The interval between transects could be reduced to 50 or 100 ft, which would allow horizontal-velocity-contour maps for different depths to be produced.

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