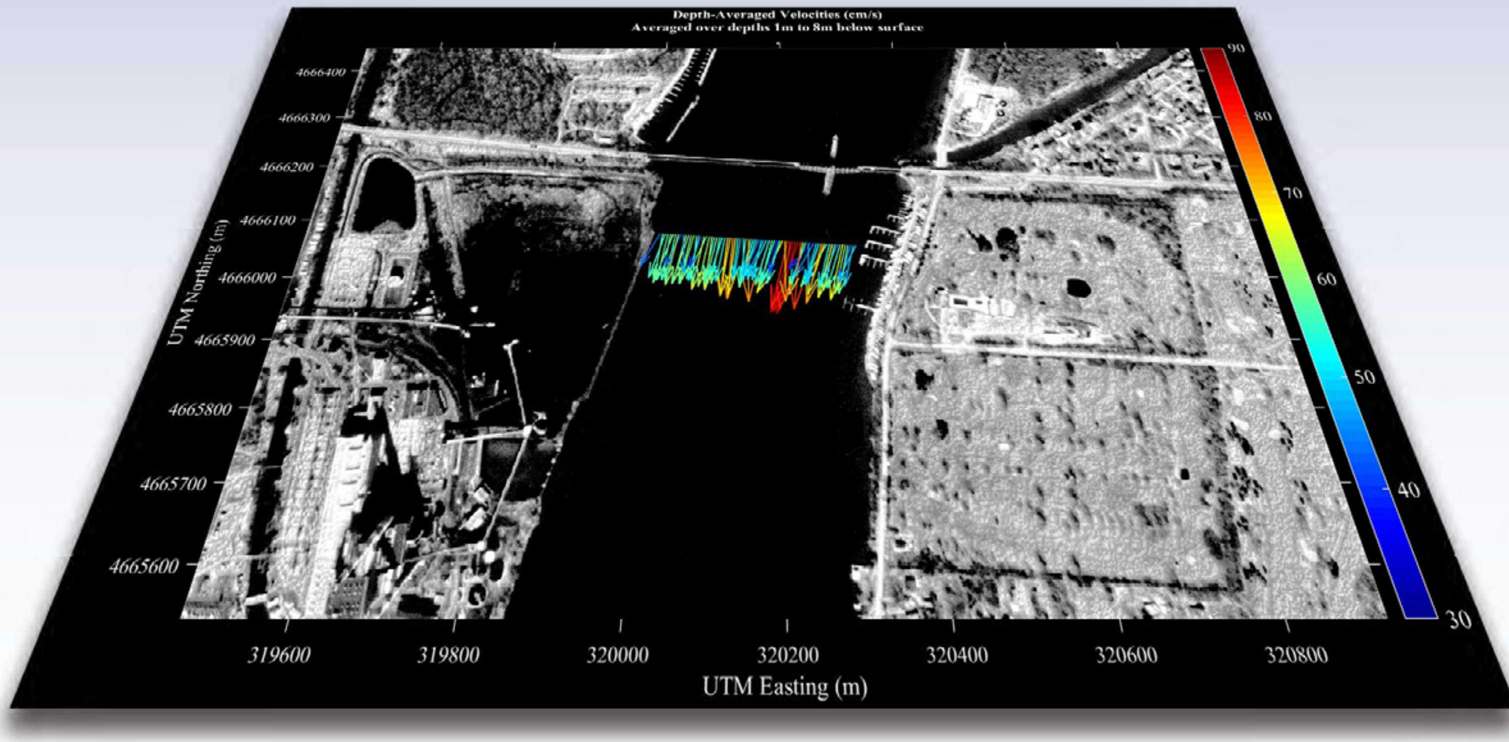
Prepared in cooperation with the
U.S. Environmental Protection Agency and Environment and Climate Change Canada

Spatial Distribution of Nutrients, Chloride, and Suspended Sediment Concentrations and Loads Determined by Using Different Sampling Methods in a Cross Section of the Trenton Channel of the Detroit River, Michigan, November 2014–November 2015



Scientific Investigations Report 2018–5141

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

Cover. Velocity map of ADCP data displayed using the Velocity Mapping Toolbox and a georeferenced background at U.S. Geological Survey station 041686401 Trenton Channel of Detroit River at Grosse Ile, Michigan.

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By Alexander R. Totten and Joseph W. Duris

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

U.S. Department of the Interior
DAVID BERNHARDT, Acting Secretary

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
	Mass	
kilogram (kg)	2.205	pound avoirdupois (lb)

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

$$°F = (1.8 \times °C) + 32.$$

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

$$°C = (°F - 32) / 1.8.$$

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Depth, as used in this report, refers to distance below the vertical datum.

Supplemental Information

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter (µg/L).

Abbreviations

ADCP	acoustic Doppler current profiler
EDI	equal-discharge-increment
EWI	equal width increment
HDPE	high density polyethylene
NWIS	National Water Information System
NWQL	National Water Quality Lab
MVDI	multiple-vertical depth integrated
EPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

Spatial Distribution of Nutrients, Chloride, and Suspended Sediment Concentrations and Loads Determined by Using Different Sampling Methods in a Cross Section of the Trenton Channel of the Detroit River, Michigan, November 2014–November 2015

By Alexander R. Totten and Joseph W. Duris

Abstract

The Detroit River separates the United States and Canada as it flows from Lake St. Clair to Lake Erie. The Trenton Channel is a 13-kilometer-long branch of the Detroit River that flows to the west of Grosse Ile before rejoining the Detroit River near its mouth, just before the Detroit River flows into Lake Erie. The U.S. Environmental Protection Agency has listed both the Trenton Channel and Detroit River as Areas of Concern because of a list of Beneficial Use Impairments such as interrupted drinking-water services, loss of aquatic life, and reduced recreational use. Phosphorus loading from tributaries such as the Trenton Channel is one of the primary drivers of eutrophication in Lake Erie. The complex flow patterns and variable distribution of chemical constituents in the Trenton Channel make it difficult to accurately characterize the concentrations and loads of nutrients and other constituents conveyed through the channel to Lake Erie.

In order to better understand the Trenton Channel's contributions of nutrients (total phosphorus, orthophosphate, total nitrogen, and ammonia), chloride, and suspended sediment to Lake Erie and evaluate differences in results obtained by using different sample methodologies, the U.S. Geological Survey, in cooperation with the U.S. Environmental Protection Agency and Environment Canada, completed 12 sampling campaigns on the Trenton Channel in Detroit, Michigan, from November 2014 through November 2015.

Acoustic Doppler current profiler (ADCP) techniques were used to characterize the distribution of velocity components within a cross section corresponding to a transect of the Trenton Channel at U.S. Geological Survey station 041686401 Trenton Channel of Detroit River at Grosse Ile, Mich. Three methods of collecting water-quality data at the same transect of the Trenton Channel were used: multiple-vertical depth-integrated (MVDI), fixed-point, and discrete samples. Horizontal and vertical variations in concentrations of nutrients, chloride, and suspended sediment were analyzed from discrete samples to better understand distributions of these constituents throughout the channel. Constituent loads were calculated by using individual sample concentrations and ADCP measurements for discharge made on the same day that the water-quality samples were collected. Constituent loads calculated from MVDI and fixed-point sampling methods were compared. The relation between MVDI and fixed-point samples helped quantify the differences between the sampling methods. Linear regression equations depicting the relation between concentrations measured by using MVDI and fixed-point samples were prepared.

ADCP data indicates that velocities throughout the sampled transect remain uniform except for one location around 200 meters from the west bank of the channel. Secondary flow vectors suggest the presence of counter-rotating helical flow cells, and these helical flow cells could affect the mixing of constituents in transport by preventing cross-channel mixing. Flow discharges throughout the sampling campaign showed small variations, although lower flow rates were observed in the early winter months than in the summer months. Discrete sampling methods results displayed both heterogeneity throughout the channel horizontally, representing limited horizontal mixing in the channel, and displayed homogeneity throughout vertical transects, indicating mixing vertically. Comparisons between MVDI and fixed-point methods found consistently higher concentrations were measured in MVDI samples compared to concentrations measured in fixed-point samples. To correct for this bias between MVDI and fixed-point sample results, simple linear-regression equations were developed for all major constituents to help estimate constituent concentrations from fixed-point samples equivalent to those measured by using MVDI sampling techniques. Instantaneous constituent loads were developed by using velocity and discharge data obtained from ADCPs and constituent concentrations obtained from MVDI and fixed-point samples.

Introduction

The Detroit River separates the United States and Canada as it flows from Lake St. Clair to Lake Erie. The Trenton Channel is a 13-kilometer (km) branch of the Detroit River that flows between the mainland of Michigan and the eastern edge of Grosse Ile before rejoining the Detroit River near its mouth just before the Detroit River flows into Lake Erie (fig. 1). The Detroit River splits at the northern tip of Grosse Ile; the Trenton Channel conveys about 22 percent of the flow to Lake Erie and is thus a major contributor to water quality in Lake Erie (Derecki, 1984). Since 1991 The U.S. Environmental Protection Agency (EPA) has listed both the Trenton Channel and the Detroit River as Areas of Concern because of Beneficial Use Impairments such as interrupted drinking-water services, loss of aquatic life, and reduced recreational use (EPA, 2015). Since 1991, remediation has helped shorten the list of Beneficial Use Impairments for the Detroit River and the Trenton Channel in hopes of ultimately removing these rivers from the list of Areas of Concern.

In the last decade, there has been intense focus on understanding eutrophication issues in Lake Erie. Persistent and widespread algal blooms have resulted in decreased recreational opportunities and increased human health risks (Francy and others, 2015). The primary eutrophication driver in Lake Erie is phosphorus loading to the lake from its tributaries and internal phosphorus loading from the lake sediment (Lake Erie Lakewide Management Plan , 2011). The International Joint Commission (IJC), EPA, Great Lakes Binational Committee (GLBC), and Ohio EPA (OHEPA) have recognized that estimating nutrient loads from tributaries is essential to understanding the recent changes in the lake ecosystem.

A previous study conducted by Environment Canada evaluated the phosphorus loading from the Detroit River and the Trenton Channel into Lake Erie from August through November 2007 (Burniston and others, 2010). Combinations of automated Isco samples and grab samples collected at five equal width increments along a transect at U.S. Geological Survey (USGS) station 041686401 Trenton Channel of Detroit River at Grosse Ile, Mich. (hereinafter referred to as the “Trenton Channel station”), were used by Burniston and others (2010) to develop estimated phosphorus concentrations throughout 2007. A two-dimensional hydrodynamic model of Lake St. Clair-Detroit River was used to estimate average flow per day in the southern part of the Trenton Channel throughout 2007 (Holtschlag and Koschik, 2002). The combination of estimated concentrations and flow was used to determine an annual phosphorus load.

Advances in technology have improved the ability to accurately measure flow in complex systems such as the Detroit River and Trenton Channel. During the last 10 years, the USGS has transitioned from using mechanical velocity meters to using Acoustic Doppler Current Profilers (ADCPs) for collecting discharge measurements in rivers that have complex directional patterns and unsteady-flow characteristics like the Trenton Channel.

The USGS uses standardized techniques to monitor water quality. One technique that provides scientists with a high level of confidence in water-quality monitoring data is the collection of depth- and width-integrated samples that can be analyzed for representative flow-weighted mean concentrations (U.S. Geological Survey, 2006).

In order to better understand the Trenton Channel’s contributions of nutrients (total phosphorus, orthophosphate, total nitrogen, and ammonia), chloride, and suspended sediment to Lake Erie and evaluate differences in results obtained by using different sample methodologies, the USGS, in cooperation with the EPA and Environment and Climate Change Canada, completed 12 sampling campaigns on the Trenton Channel in Detroit, Mich., from November 2014 through November 2015. In addition to fixed-point samples, a composited multiple-vertical depth-integrated (MVDI) sample was collected along a cross section approximately 130 meters (m) downstream from Grosse Ile Parkway. On 4 of the 12 sampling dates, 24 discrete samples were collected at 4 verticals across the cross section using a 1–L Van Dorn sampler. An ADCP was used directly after sampling to measure stream velocity, discharge, and bathymetry within the cross section. ADCP data were examined using the Velocity Mapping Toolbox to evaluate the velocity distribution and secondary flow patterns in the sampling cross section.

Purpose and Scope

This report describes the results of discharge measurements and water-quality sampling done by the USGS in cooperation with the EPA and Environment Climate Change Canada in the southern part of the Trenton Channel from November 2014 through November 2015 to characterize nutrient loads. This report (1) compares analytical results for nutrients (total phosphorus, orthophosphate, total nitrogen, and ammonia), chloride, and suspended sediment measured with MVDI, fixed-point, and discrete sample methods in a cross section of the Trenton Channel; (2) describes the spatial distribution of velocities and major constituent concentrations within the cross section; and (3) compares loading estimates computed with concentrations obtained from MVDI and fixed-point samples.

Description of Study Area

The Detroit River separates the United States and Canada as it flows from Lake St. Clair to Lake Erie. The Trenton Channel of the Detroit River is located on the eastern side of Michigan’s Lower Peninsula (fig. 1). Grosse Ile separates Trenton Channel from the main channel of the Detroit River, creating a 13-km channel starting near Wyandotte, Mich., on the American side originating in the Detroit River, and terminating 8 km from Lake Erie near Gibraltar, Mich. The

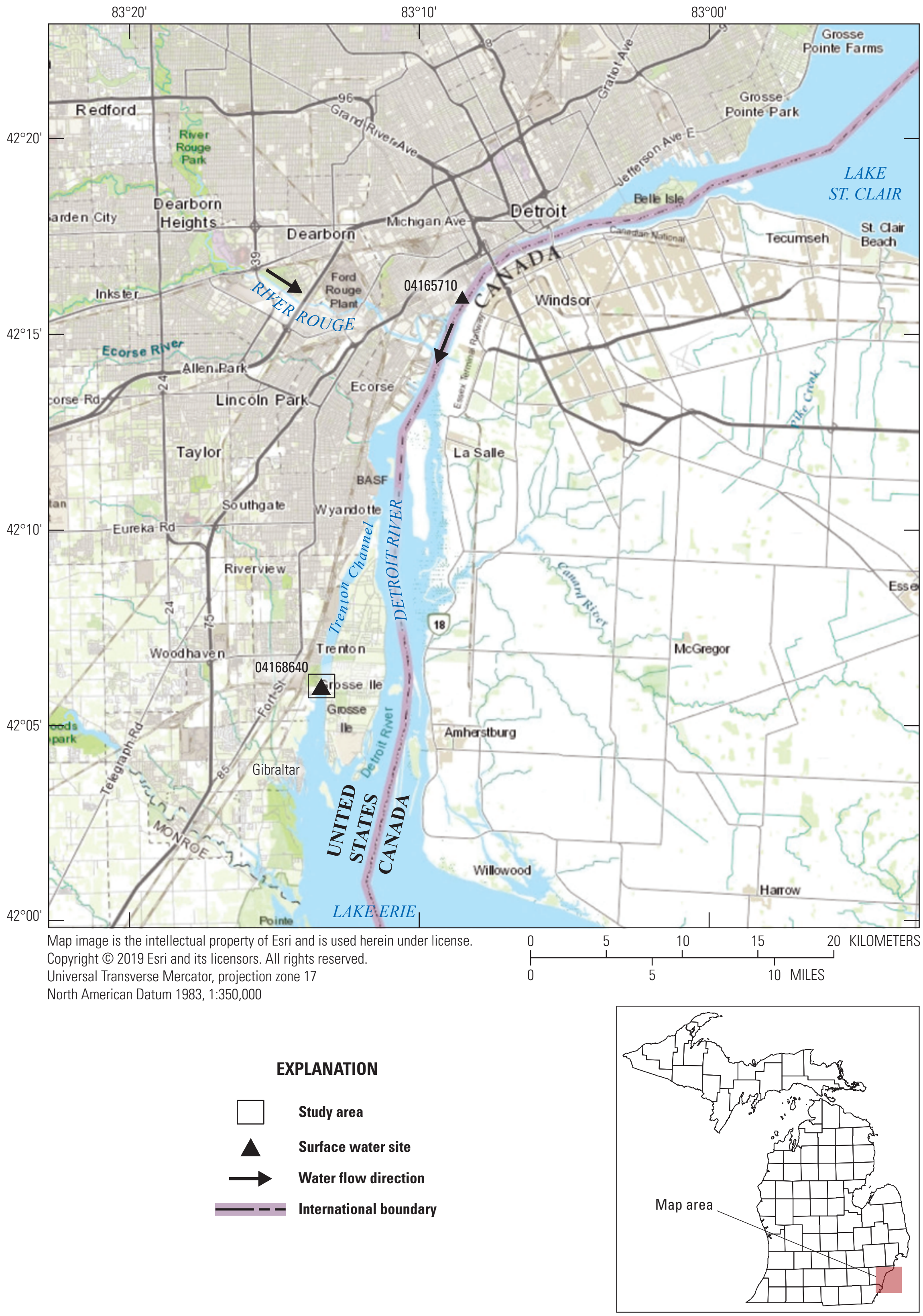

Figure 1. Trenton Channel of the Detroit River study area between Lake St. Clair and Lake Erie.

Trenton Channel generally flows from north to south, although the direction of flow in the Trenton Channel can be reversed or stopped temporarily by oscillating standing waves (seiches) on Lake Erie caused by strong winds or changes in atmospheric pressure (National Oceanic and Atmospheric Administration, 2018). The Trenton Channel is deep (average depth is 8.5 m) and wide (average width is 330 m), with an average discharge of approximately 1,370 cubic meters per second (m^3/s). Urban and industrial land cover of Detroit and the surrounding areas make up a majority of the Trenton Channel's watershed (Homer and others, 2015). Trenton Channel is frequently used by local anglers, recreationists, and commercial transport vessels. The Rogue River is one of the primary local tributaries contributing to the Detroit River and enters the Detroit River from the west, approximately 9 km upstream from the northern end of the Trenton Channel (fig. 1).

Methods

From November 2014 through November 2015, the USGS collected data to characterize nutrient loads in the Trenton Channel. In order to accurately measure nutrient loads in the Trenton Channel, accurate measurements of stream velocity, discharge, and channel bathymetry are needed. The methods used to measure stream velocity and bathymetry are described in Mueller and Wager (2009) and Mueller and others (2013). The water-quality sampling techniques used to measure physical properties, nutrients, chloride, and suspended sediment concentrations are described. Quality assurance and quality control measures pertaining to the sampling techniques are also described. The water quality processing techniques that were used to ensure reproducible results are described, as well as the laboratory analytical methods. All of the data used in this assessment were collected by the USGS and are stored in the National Water Information System (NWIS) database (U.S. Geological Survey, 2018).

Determination of Stream Velocity, Discharge, and Channel Bathymetry

An ADCP was used to measure stream velocity, discharge, and bathymetry in a cross section of the Trenton Channel downstream from the Grosse Ile Parkway Bridge at the Trenton station. ADCPs produce beams of ultrasonic sound that bounce off small particles of material in the water and the bed of the channel before traveling back to the ADCP. The frequency and travel time of the reflected acoustic signals are measured upon arrival back at the ADCP. Velocity is calculated from the change in frequency of the acoustic signal reflected to the ADCP, resulting from the Doppler effect (Mueller and Wagner, 2009). Bathymetry is measured based on the two-way travel time of the signals. Stream discharge is computed from the product of velocity and area of the channel. ADCPs use four transducers in a Janus configuration to send and receive acoustic signals (Mueller and others, 2013). The use of four beams to detect velocity at four different angles gives the ADCP the ability to calculate bathymetry and three-dimensional velocity. The ADCP was deployed at a depth of approximately 0.75 m below the water surface; a "blank zone" in which accurate acoustic signals could be measured extended approximately 0.5 m below the depth at which the ADCP was deployed. The combined depth (approximately 1.25 m) is considered the superficial zone and no velocity measurements could be made within this zone. Because of a high amount of interference produced by bed sediment, known as side-lobe interference, the ADCP cannot develop velocity measurements near the bed of the channel (Mueller and others, 2013). Side-lobe interference affects about 6 to 13 percent of the measured system, and data cannot be accurately collected in this area. However, extrapolation of velocities and discharge can be calculated for this area.

A boat-mounted ADCP was used. In order to compensate for the velocity of the moving boat while making the measurement, a global positioning system was mounted over the ADCP to determine the boat velocity. The ADCP was configured and calibrated onsite before every sample. Movement of near-bed sediment during the ADCP data collection can produce errors in the discharge measurement. A moving-bed test is done at every sampling site before the discharge measurement begins to compensate for this possible source of error. For each sampling effort a measurement consisted of four separate ADCP transects made along the cross section for which velocity and discharge were calculated. If the discharge measurements from the four transects did not differ from each other by more than 5 percent, they were used to compute an average velocity and discharge (U.S. Geological Survey 2002). None of the 12 ADCP discharge measurements during sampling campaigns had differences between individual transects that exceeded 5 percent. Average velocity and total discharge data for the measurements can be found on the NWIS website at https://waterdata.usgs.gov/nwis/measurements/?site_no=041686401.

Version 4.0.9 of the Velocity Mapping Toolbox (VMT) was used to display and examine the data collected with the ADPCs (Parsons and others, 2013). VMT is a Matlab-based software used for processing and visualizing ADCP data. The software produces transverse three-dimensional flow models and plan-view depth-averaged flow maps (Lane and others 2000). Velocity maps were produced for every viable ADCP measurement with available global positioning systems and complete flow data.

Water-Quality Sample Collection

Similar to the velocity and discharge measurement, all of the water-quality samples were collected at the Trenton station downstream from the Grosse Ile Parkway Bridge. A water-quality sonde (YSI ProPlus) (Xylem Inc., 2018) was used to make onsite measurements of selected physical properties of the water (temperature, pH, specific conductance, and dissolved oxygen). The water-quality sonde was calibrated before each sampling event in accordance with standard USGS procedures (Gibs and others, 2007). Concurrent with MVDI and fixed-point sample collection, the water-quality sonde was placed 0.5 m below the water surface to obtain point physical-property measurements traversing the cross section from which discharge data and water-quality samples were collected. Results were stored in the NWIS database (U.S. Geological Survey, 2018). Physical properties were recorded at each discrete location concurrent with discrete sampling. A weighted DH–2 sampler was used to obtain physical properties at each discrete location. The YSI ProPlus was attached to the DH–2 sampler with zip-ties and lowered to the depth corresponding to the discrete sampling location.

Three methods were used to collect water-quality samples: (1) a MVDI method; (2) a fixed-point sampling method; and (3) a discrete sampling method. The MVDI method consisted of 10 vertical isokinetic depth-integrated samples collected by using a DH–2 sampler; the 10 depth-integrated samples were subsequently composited to form a single sample. For the fixed-point sampling method, sequential samples were collected about 20 m from the east bank by using a DH–2 sampler positioned 2 m below the water surface. Discrete samples collected using a 1–L Van Dorn sampler at four locations along the transect. At three locations along the transect, the discrete samples were collected at increments of 1 m of depth; at a fourth location near the west bank, discrete samples were collected at increments of 0.5 m of depth. USGS personnel carried out all three of these water-quality sampling techniques in a consistent manner along the same sampling transect at the Trenton Channel station. A total of 12 MVDI and 12 fixed-point samples were collected during the November 2014–November 2015 sampling period. On four dates within the sampling period, 24 discrete samples were collected in four verticals along the sampling transect of Trenton Channel (fig. 2). After all water-quality samples had been collected, a series of 4 boat mounted ADCP measurements were averaged to produce velocities, bathymetry, and discharge in the sampling cross section.

Multiple-Vertical Depth-Integrated Sampling

The USGS commonly uses MVDI sampling methods in water-quality analysis because MVDI sampling provides an accurate depth integrated isokinetic sample that spatially characterizes the cross section (Topping and others, 2011). MVDI samples were collected 12 times during the sampling period from a cross section about 100 m downstream from Grosse Ile Pkwy road (figs. 2 and 3; fixed-point and discrete samples were also collected from this cross section). Because of interference from a marina, it was not possible to collect MVDI samples from a small section of the channel near the east bank, and as a result the sampling method is better categorized as a MVDI than a common equal width increment (EWI) sample. The approximately 310-m-wide sampling cross section was subdivided into 10 approximately equal-width intervals. Vertical sampling profiles along the sampling transect were collected at the 10 points of intersection between adjacent intervals. Based on the velocity of the river and river depth, a single vertical transit rate was calculated and used at each vertical (U.S. Geological Survey, 2006). At each MVDI vertical, a boat-mounted crane was used to lower the DH–2 sampler at the specified transit rate to just above the bed of the channel then back up. A DH–2 sampler was used because of the depth of the Trenton Channel exceeded 7 m in some locations. A DH–2 bag sampler is used instead of a bottle sampler if the sampling depth exceeds 7 m to offset the water pressure at such deep depths (Davis, 2005). The sample obtained from each vertical profile was emptied into a 14-L polyethylene churn splitter. After all 10 verticals were sampled and emptied into the churn splitter, the mixture was homogenized using the churn paddle, and individual bottles for analysis were filled from the churn.

Fixed-point Sampling

Fixed-point samples were collected from a boat using a DH–2 weighted bag sampler lowered by a crane to a discrete depth of 2 m. Ambient water flowed into a 1-liter (L) high-density polyethylene (HDPE) bag through a 5/16-inch diameter nozzle (7.94 millimeter) attached to the DH–2 bag sampler. The sampling location was approximately 20 m from the east bank and about 130 m downstream from Grosse Ile Pkwy Bridge (figs. 2 and 3). The DH–2 sampler is not a point sampler; it was quickly lowered to a depth of 2 m below the surface so that most of the water it collected was from the desired sampling depth. Because the DH–2 sampler is not a true point sampler, the samples collected with the DH–2 sampler are referred to herein as “fixed-point samples.” The water collected from each sample bag constituting a fixed-point sample was poured into a 14–L HDPE churn. The 5 sample bags were collected over a 5-minute time period. A total of 5 sample bags were composted into the 14–L churn and then the sample was homogenized using the churn paddle and decanted individual bottles for analysis. The USGS often deploys automated samplers in order to obtain accurate temporal water-quality results. Automated samplers can provide temporally accurate data, but at a cost of bias in spatial representation of sample area (Anderson and Rounds, 2010). The location and methods used for collecting fixed-point samples were selected for the purpose of obtaining samples similar to those obtained by using an automated sampler. Cross sectionally composited sampling methods like MVDI sampling provide a sample that represents the sample

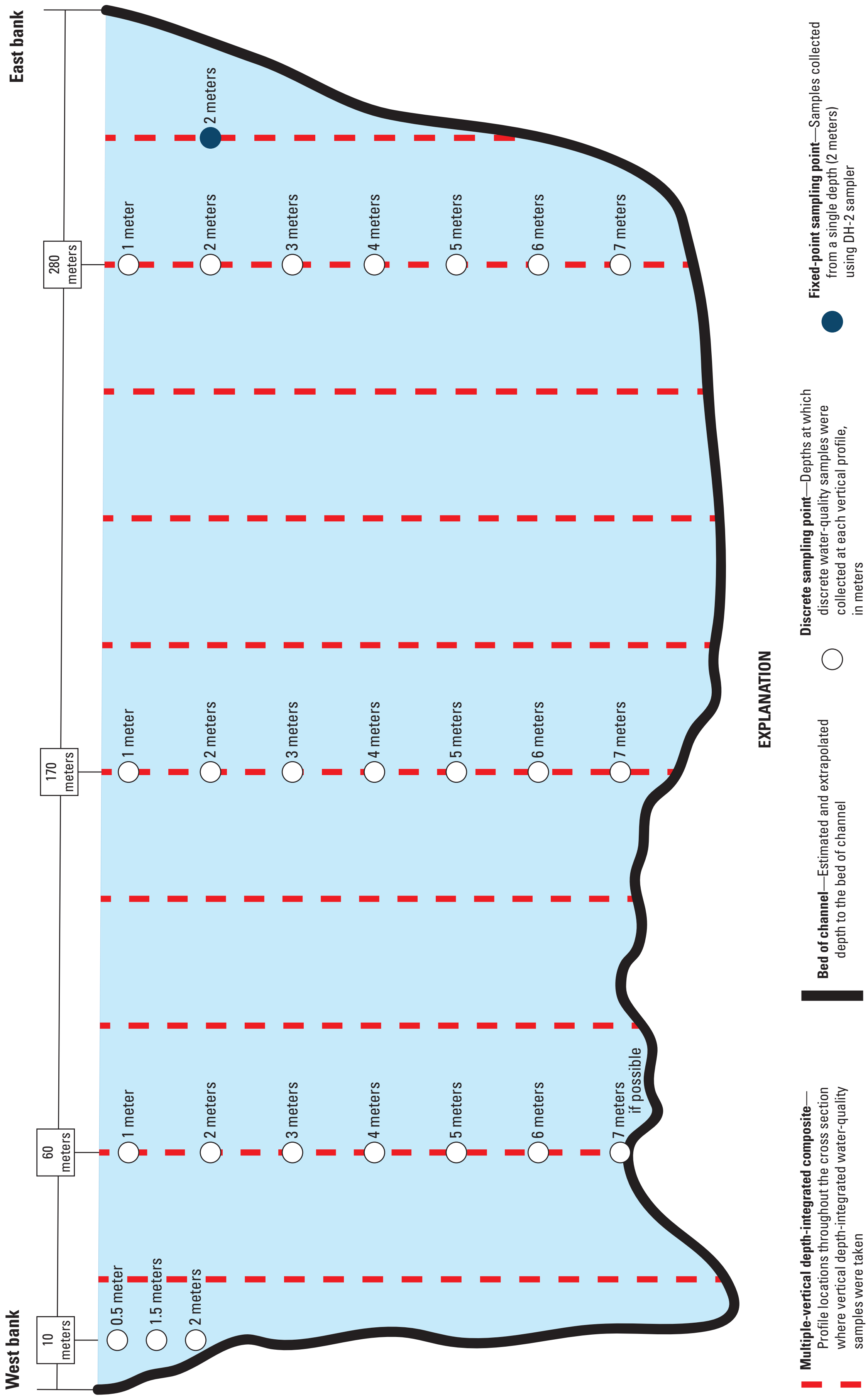

Figure 2. Multiple-vertical depth-integrated composite profiles, discrete locations, and fixed-point sample locations in the Trenton Channel of the Detroit River downstream from the Grosse Ile Parkway Bridge from November 2014 through November 2015 (west bank is on the left).

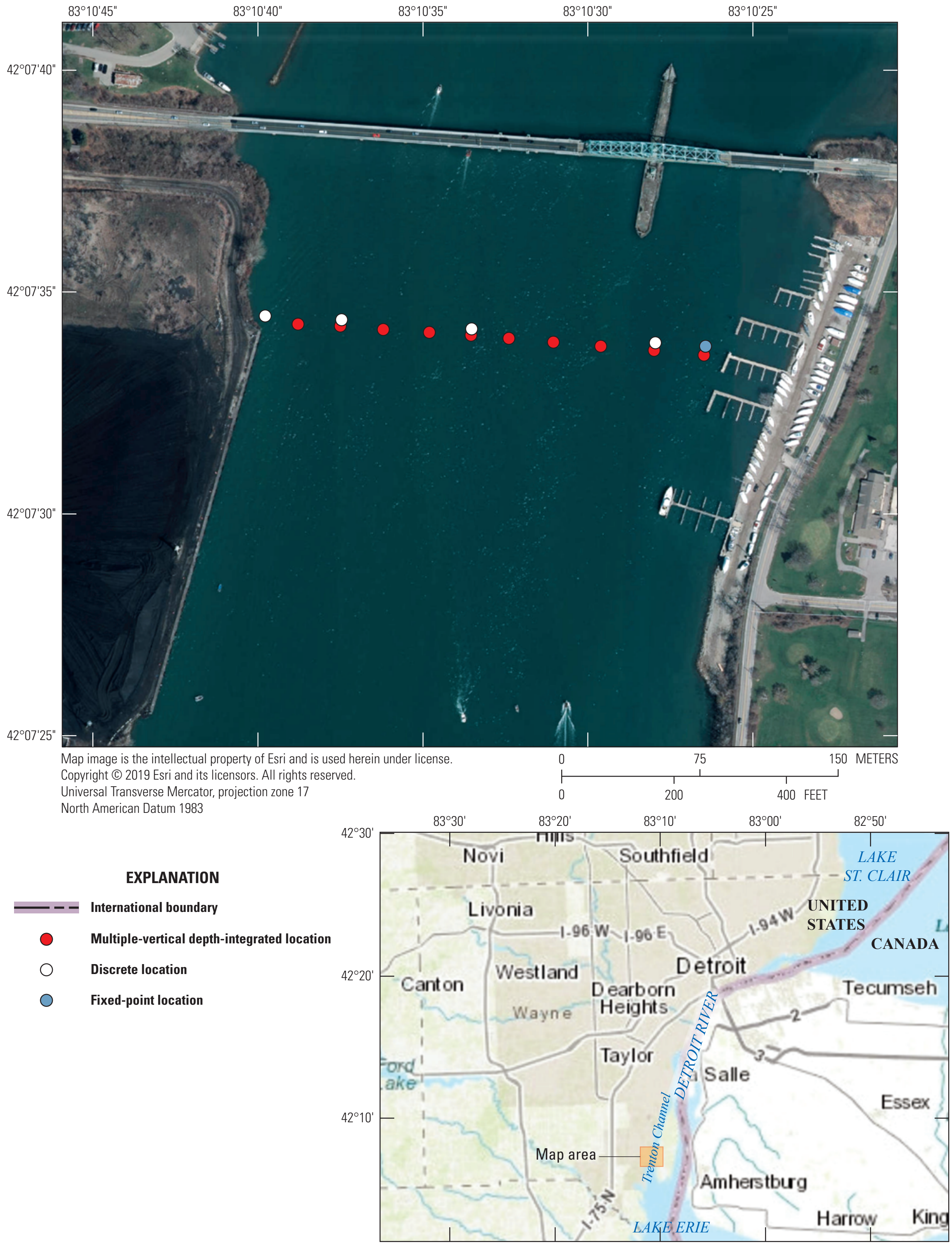

Figure 3. Fixed-point, multiple-vertical depth-integrated, and discrete locations on the sampling transect of Trenton Channel downstream from Grosse Ile Parkway Bridge.

cross section spatially (Topping and others, 2011). The purpose for deploying the fixed-point method was to statistically build a linear regression between the fixed-point and MVDI methods.

Discrete Sampling

Multiple discrete samples were collected throughout the cross section to help describe the distribution of nutrients, chloride, and suspended sediment in the Trenton Channel. A total of 24 discrete samples were collected at four verticals along the sampling cross section using a 1–L Van Dorn sampler. These verticals were located at 10 m, 60 m, 170 m, and 280 m from the west bank of the channel (figs. 2 and 3). At most verticals, discrete samples were collected at 1-m intervals below the water surface to the bed of the channel (fig. 2). At the western-most vertical, samples were collected at intervals ranging from 0.5 to 1 m because of the shallow waters at this vertical transect. For each discrete sample, the open Van Dorn sampler was lowered to the indicated depth along with a messenger weight that follows the suspension line and triggers sample acquisition. The sample obtained from the Van Dorn sampler was then decanted into a sterile 1-L HDPE bottle for later processing. During two of the four discrete sampling dates, the water was too shallow to collect a 7-m deep sample at the 60-m location.

Processing Water-Quality Samples

Prior to each sample event, 500-milliliter HDPE sample bottles were rinsed with deionized water to condition the bottles for sampling. The capsule filter with 0.45 micrometer pore size used in the processing of filtered samples was flushed with approximately 2 L of deionized water to condition the filter. All sample splitting, decanting, filtering, and processing was done in a mobile laboratory van. Filtering was done by pumping water through the capsule filters using a peristaltic pump with clean tubing. One milliliter of 1:7 sulfuric acid preservation was done after samples were split. Samples were shipped on ice the day of collection to the USGS National Water Quality Laboratory (NWQL) for processing and analysis for all constituents except turbidity.

A conditioned 250-milliliter HDPE bottle was used to store the turbidity sample until analysis. Turbidity was measured at the USGS Water Science Center in Lansing, Mich. by using a Hach 2100Q turbidity meter (Hach Company, 2018). The median value of three separate quantifications was entered into the NWIS database. All water-quality results can be obtained from the NWIS: Web Interface (NWISWeb) (https://nwis.waterdata.usgs.gov/usa/nwis/qwdata). To retrieve the water-quality data, check the box next to Site Number and click the Submit button. Enter 041686401 as the Site Number and click on the Submit button. From the resulting web page, a variety of options are offered for retrieving the water-quality data.

Analytical Methods

All water samples collected by USGS personnel were analyzed and processed by the NWQL located in Lakewood, Colorado, in accordance with analytical procedures as described in the USGS methods of analysis by the USGS NWQL (Fishman, 1993). All suspended sediment samples collected by the USGS were analyzed for suspended-sediment concertation by the USGS Kentucky Sediment Laboratory located at the Kentucky Water Science Center in Louisville. Suspended sediment samples analysis was conducted according to the USGS methods and procedures, as described in the Quality Assurance Plan for the Kentucky Water Science Center Sediment Laboratory (Shreve and Downs, 2005; Guy, 1969).

Quality Assurance for Water Quality

A part of producing accurate and unbiased data is implementing some form of quality assurance and quality control (QA/QC). For this study, 5 percent of all samples were QA/QC samples in the form of blanks or replicates. Three blanks and one replicate were collected during the sampling period to assess possible bias, as well as variability and reproducibility of the results. Blank sample concentrations were below the equipment's observed limits or near estimated detection levels. The field blank collected on May 29, 2015, had a total phosphorus concentration of 0.0072 milligrams per liter (mg/L) which is above the NWQL minimum reporting level of 0.004 mg/L. The minimum reporting level is the smallest concentration of a substance that can be reliably measured by a given analytical method (Childress and others, 1999). The field blank collected on August 26, 2015, had an ammonia as nitrogen concentration of 0.012 mg/L which is above the NWQL minimum reporting level of 0.010 mg/L. Blanks collected in this study demonstrated that field sample collection did not show evidence of gross contamination. Study results were not censored because of detections in field blanks, because the exceedance was close to NWQL detection limits. Replicate sample concentrations were found to be within 5 percent of concentrations in the corresponding environmental samples.

Velocity and Discharge

A summary of average channel velocity and discharge measured in a cross section of the Trenton Channel at the Trenton Channel station is provided (table 1). Example plots of depth-average velocity vectors and cross-sectional velocity distribution with vectors that show transverse velocity patterns are shown in figures 4 and 5. ADCP velocity measurements ranged from 20–100 centimeter per second (cm/s) as depicted by VMT (fig. 5).

The discharge measured at Trenton Channel for this study ranged from 1,200 to 1,450 m^3/sec (table 1). Average channel velocities ranged from 0.515 to 0.640 m/sec (table 1). Flow velocities throughout the sampling campaign varied little with no seasonal pattern evident; some of highest discharge values of 1,450 m^3/sec and 1,440 m^3/sec were measured during the winter (December 17, 2014, and March 18, 2015, respectively). Some of the lowest discharge values of 1,210 m^3/sec and 1,260 m^3/sec were measured in fall mid-winter (October 21, 2015, and January 18, 2015, respectively).

Figure 4 shows depth-averaged velocity vectors measured on November 18, 2015, displayed in plan view (shown with the western edge of the river on the left). The velocity vectors were superimposed onto a georeferenced tagged image file format, or GeoTIFF, plan-view image of the Trenton Channel. Plots for measurements made on the other dates looked similar to figure 4. The length and color of the vectors are indicative of the velocity magnitudes. It should be noted that the measurement cross section did not extend across the entire channel because of the presence of docks on the east bank, and so velocities were not measured throughout the entire cross section. Even so, discharge was computed by estimating the discharge in the unmeasured area using a ratio-interpolation method based on velocities and depths in the measured portion of the channel and measurements of distance from the bank (Fulford and Sauer, 1986). Depth-averaged velocity vectors were fairly uniform in magnitude and direction along most of the cross section; however, a few sections had noticeably higher average velocity. Depth-averaged velocities in those sections ranged from approximately 85 to 108 centimeters per second (cm/s) as compared to the rest of the cross section where depth-averaged velocities typically ranged from about 45 to 65 cm/s.

Table 1. Average channel velocity and discharge at U.S. Geological Survey station 041686401 Trenton Channel of Detroit River at Grosse Ile, Michigan, from November 2014 to November 2015.

[m/sec, meter per second; m^3/sec, cubic meter per second]

Date	Average channel velocity (m/sec)	Trenton Channel discharge (m^3/sec)
December 17, 2014	0.631	1,450
March 18, 2015	0.640	1,440
April 9, 2015	0.548	1,390
May 4, 2015	0.564	1,340
May 29, 2015	0.585	1,330
August 12, 2015	0.579	1,420
August 26, 2015	0.582	1,420
September 1, 2015	0.554	1,330
September 23, 2015	0.557	1,350
September 30, 2015	0.600	1,450
October 21, 2015	0.515	1,210
November 18, 2015	0.542	1,260

VMT was used to plot streamwise velocities (that is, velocities perpendicular to the transect) obtained from ADCP data collected at the Trenton Channel station. The different colors indicate the streamwise velocities throughout the cross section of the Trenton Channel (fig. 5). The black arrows in figure 5 represent the magnitudes and directions of components of velocity vectors in the plane of the cross section referred to as secondary flow. Secondary flow is orientated perpendicular to the streamwise flow and plays an important role in sediment routing and mixing of flow (Lane and others, 2000). The bold white line represents the bottom bathymetry of the cross section corresponding to the bed of the channel. Discrete sampling locations are shown to illustrate their depths and position within the cross section. Like figure 4, the streamwise velocity map shown in figure 5 was developed from data collected on November 18, 2015.

This section of the Trenton Channel shares characteristic of alluvial rivers for two reasons: (1) subcritical flow can be seen near the edges of the transect and near the bed of the channel, and (2) the highest flows are at surface throughout the cross section of the river (Magirl and others, 2009). The plan and streamwise figures have many traits in common. Sections of higher than average velocities can be seen in both types of figures. One particular high-velocity section, located approximately 200 m from left bank plus or minus 10 m, stands out in both plan and streamwise view maps. This particular section of river had the highest velocities, accounting for about 25 percent of the flow. Secondary flow vectors suggest the presence of counter-rotating helical flow cells. These helical flow cells could affect the mixing of constituents in transport by preventing cross-channel mixing.

Bathymetry displayed in velocity maps show a depth range of about 4.75 m to 8.75 m in the cross section. About 50 percent of the cross section (east side) had an approximate depth of 8 m and the remaining portion (west side) was approximately 6 m in depth. Transverse velocity maps can also be used to help define an appropriate sampling method for this section of the Trenton Channel based on velocity distribution and presence of secondary flow. If the depth and velocities are highly variable along the cross section, an equal-discharge-increment (EDI) sampling method is necessary because the EDI method uses varying transit rates to accommodate for varying of depths and velocities. If the flow and depths are uniform throughout the cross section, then an Equal Width Increment sample is appropriate (U.S. Geological Survey, 2006). Based on the variability of the depth and velocities on the Trenton Channel, an EDI sampling method is most appropriate for future sampling.

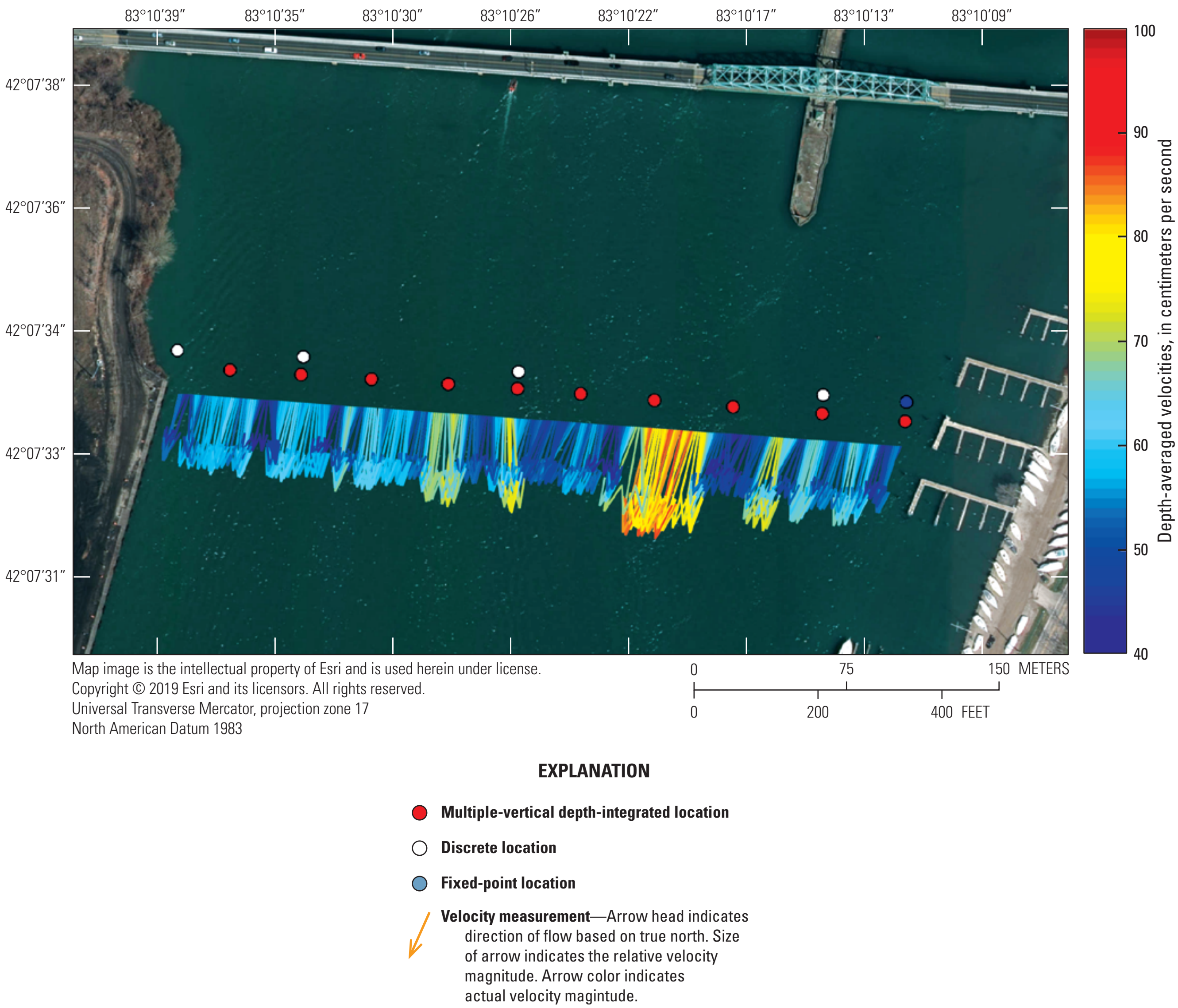

Figure 4. Plan view velocity map of ADCP data at a range of 40–100 centimers per second displayed by using the Velocity Mapping Toolbox (VMT) and a geospatial reference background at U.S. Geological Survey station 041686401 Trenton Channel of Detroit River at Grosse Ile, Michigan, November 18, 2015.

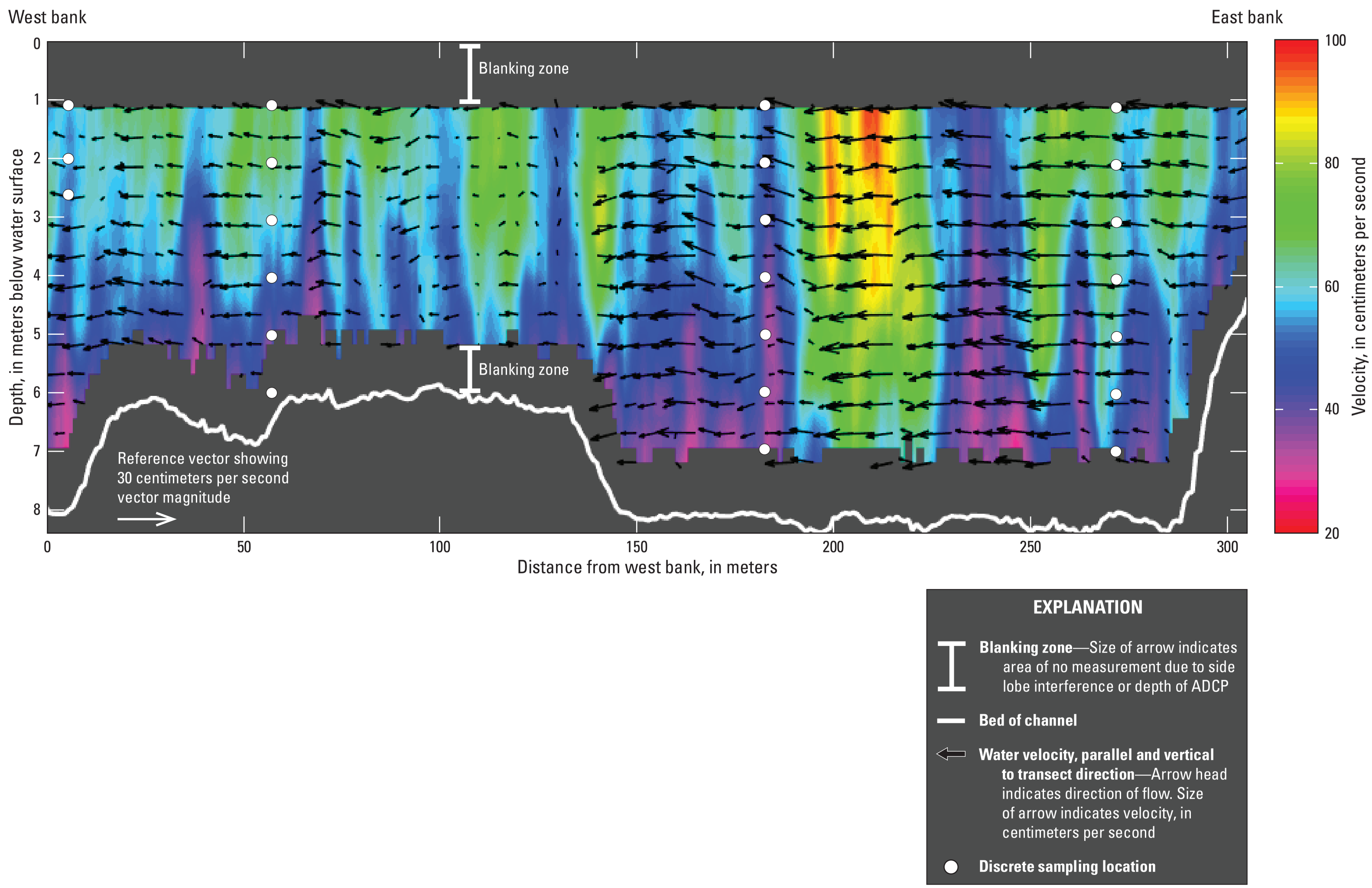

Figure 5. Relation between streamwise velocity and secondary flow at U.S. Geological Survey station 041686401 Trenton Channel of Detroit River at Grosse Ile, Michigan, November 18, 2015.

Concentrations and Loads of Nutrients, Chloride, and Suspended Sediment

A summary of nutrients, chloride, suspended-sediment, and physical-property concentrations measured at the Trenton Channel cross section at various distances from the west bank is provided (tables 2 and 3). Statistical differences in the analytical results for nutrients (total phosphorus, orthophosphate, total nitrogen, and ammonia), chloride, and suspended sediment measured with MVDI, fixed-point, and discrete sample methods are also assessed in this section. The relation between concentrations of nutrients, chloride, and suspended sediment measured by using the MVDI and fixed-point sampling methods is determined by linear regression. Tile graphs and boxplots are used to depict the spatial distribution of constituent concentrations within the cross section. Estimates of the loads of nutrients, chloride, and suspended-sediment conveyed through the Trenton Channel are also provided.

Constituent Concentrations Measured in Paired MVDI and Fixed-point Samples

Differences in constituent concentrations obtained from paired MVDI and fixed-point samples were evaluated by using the Wilcoxon signed-rank test (Helsel and Hirsch, 2002). The Wilcoxon signed-rank test was applied to the data because this test is not sensitive to the distributions of the data. The null hypothesis is that the median difference between the paired observations is zero. The Wilcoxon signed-rank test is used to evaluate for a statistically significant difference between two datasets based on the probability of rejecting the null hypothesis when it is true (referred to as the alpha value). An alpha value of 0.05 was used for tests of significance; if the probability value (p-value) is less than or equal to the alpha value, the difference is considered statistically significant and the null hypothesis is rejected (Helsel and Hirsch, 2002). The null hypothesis was rejected for total phosphorus, total nitrogen, ammonia, and chloride, but not for suspended sediment or orthophosphate (table 4). In this case, rejection of the null hypothesis implies that concentrations in the MVDI samples tended to be significantly larger or smaller than those in the corresponding fixed-point samples. The most representative type of future sampling would include a combination of these two methods or a method that is more representative of the sample area considering the statistically significant difference observed in median values for total phosphorus, total nitrogen, ammonia, and chloride.

Liner regression analysis was used to determine the relation between constituent concentrations measured by using MVDI and fixed-point sampling methods. Correlations between methods and constituents have been fitted with a black 1:1 line and a red best-fit line. Sample size (n) and coefficient of determination (R^2) summary statistic information is provided for each regression equation (fig. 6).

Linear regressions produced from the comparison of MVDI and fixed-point methods represent the relation between the concentrations measured by the two methods. The 1:1 line represents line of agreement between the two methods. An overall pattern of higher constituent concentrations measured using the MVDI method compared to the constituent concentration measured using the fixed-point samples is evident in the regression analyses. Suspended sediment shows a pattern of sporadic distribution of points around the 1:1 line with few high MVDI concentrations. Higher concentrations from MVDI samples in relation to fixed-point samples likely represent the heterogeneity of constituent distributions in the Trenton Channel. MVDI samples consist of a composite of equal sections of the channel. Therefore, MVDI samples represent a much larger portion of the channel and flow in comparison to fixed-point samples. Higher MVDI concentrations than fixed-point samples also indicate a distribution of higher constituent concentrations west of the fixed-point sampling location in Trenton Channel. Constituents such as chloride, phosphorus, and orthophosphate show a strong correlation (R^2 values greater than 0.70) and represent a consistently higher concentration from the MVDI sampling method per those constituents. Correlations between these three particular constituents could provide a relation between the MVDI and fixed-point methods, providing data for future sampling method applications in Trenton Channel.

A simple linear regression equation was produced for each major constituent measured in samples obtained from the Trenton Channel during the sampling campaign (table 5). These simple linear regressions can be used to estimate instantaneous concentrations, daily loads, or annual loads in Trenton Channel. All linear models were produced in R Programming language (R Core Team, 2018). Residual standard error, adjusted-R^2, and p-values were developed to assess the fit of each regression equation to the major constituent concentrations. For each major constituent, the fit of the regression equation was statistically significant. Regression equations are expressed as:

$$y_i = b + mx_i \tag{1}$$

where

- y_i is the ith observation of the response (dependent) variable (concentration);
- x_i is the independent variable (observed fixed-point sample);
- m is the slope; and
- b is the intercept.

Table 2. Summary statistics for constituents measured in water-quality samples collected by multiple-vertical depth-integrated (MVDI), fixed-point, and discrete sampling methods at U.S. Geological Survey station 041686401 Trenton Channel of Detroit River at Grosse Ile, Michigan, November 2014 to November 2015.

[mg/L, milligram per liter; P, phosphorous; N, nitrogen; n, number of samples collected from November 2014 to November 2015; Min., minimum; Max., maximum; Avg., average; m, meter]

Sample type and distance from bank	Total phosphorus (mg/L as P)			Orthophosphate (mg/L as P)			Total nitrogen (mg/L as N)			Ammonia (mg/L as N)			Chloride (mg/L)			Suspended sediment (mg/L)			n
	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	
MVDI– various distances from west bank	0.01	0.032	0.017	0.004	0.011	0.005	0.52	0.82	0.64	0.12	0.26	0.18	10.6	31.8	15.1	1	27	8	12
Fixed-point– about 20 m from east bank	0.09	0.026	0.014	0.004	0.006	0.004	0.46	0.71	0.57	0.08	0.20	0.13	9.5	25.5	13.2	2	17	6	12
Discrete– 10 m from west bank	0.01	0.037	0.026	0.004	0.007	0.006	0.62	0.90	0.77	0.15	0.27	0.23	16.0	38.7	22.2	2	21	8	12
Discrete– 60 m from west bank	0.01	0.049	0.024	0.004	0.011	0.007	0.59	0.88	0.73	0.14	0.29	0.23	14.6	38.0	20.7	1	31	8	26
Discrete– 170 m from west bank	0.01	0.035	0.020	0.004	0.011	0.006	0.500	0.81	0.666	0.120	0.24	0.189	10.600	34.2	17.814	2	22	8.53	28
Discrete– 280 m from west bank	0.01	0.035	0.018	0.004	0.009	0.006	0.470	0.90	0.618	0.100	0.20	0.151	10.400	30.6	16.164	2	20	7.75	28

Table 3. Summary statistics for physical properties measured in water-quality samples collected by multiple-vertical depth-integrated (MVDI), fixed-point, and discrete sampling methods at U.S. Geological Survey station 041686401 Trenton Channel of Detroit River at Grosse Ile, Michigan, November 2014 to November 2015.

[°C, degrees Celsius; µS/cm, microsiemen per centimeter at 25°C; mg/L, milligram per liter; n; number of samples; Min., minimum; Max., maximum; Avg., average; m, meter]

Sample type and distance from bank (fig. 2)	Water temperature (°C)			Specific conductance (µS/cm)			pH (standard units)			Dissolved oxygen (mg/L)			n
	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	
MVDI– various distances from west bank	1.40	22.9	13.68	228.00	322	249.50	7.90	8.5	8.09	8.00	16.3	10.91	12
Fixed-point– about 20 from east bank	1.00	22.7	13.55	226.00	294	243.08	7.80	8.5	8.09	8.00	16.1	10.90	12
Discrete– 10 m from west bank	1.90	21.7	12.38	255.00	347	281.42	7.80	8.2	7.91	7.20	14.4	10.88	12
Discrete– 60 m from west bank	1.30	21.7	12.50	252.00	336	270.92	7.80	8.2	7.93	7.70	14.3	11.18	26
Discrete– 170 m from west bank	1.40	21.5	12.16	228.00	325	260.25	7.90	8.4	8.06	8.00	14.2	11.35	28
Discrete– 280 m from west bank	1.30	21.5	11.94	225.00	310	253.19	7.90	8.4	8.12	8.00	14.5	11.49	8

Table 4. Wilcoxon signed-rank test of differences in median concentrations for samples collected by use of multple-vertical depth-integrated (MVDI) and fixed-point methods at U.S. Geological Survey station 041686401 Trenton Channel of Detroit River at Grosse Ile, Michigan.

[p-value, probability value, bold values are significant (p-value ≤ 0.05); mg/L, milligram per liter; ≤, less than or equal to]

Constituent	MVDI versus fixed-point	
	p-value	Median difference (mg/L)
Phosphorus	**0.020**	0.001
Suspended sediment	0.355	0.5
Orthophosphate	0.056	0
Total nitrogen	**0.004**	0.095
Ammonia	**0.008**	0.05
Chloride	**0.025**	1.3

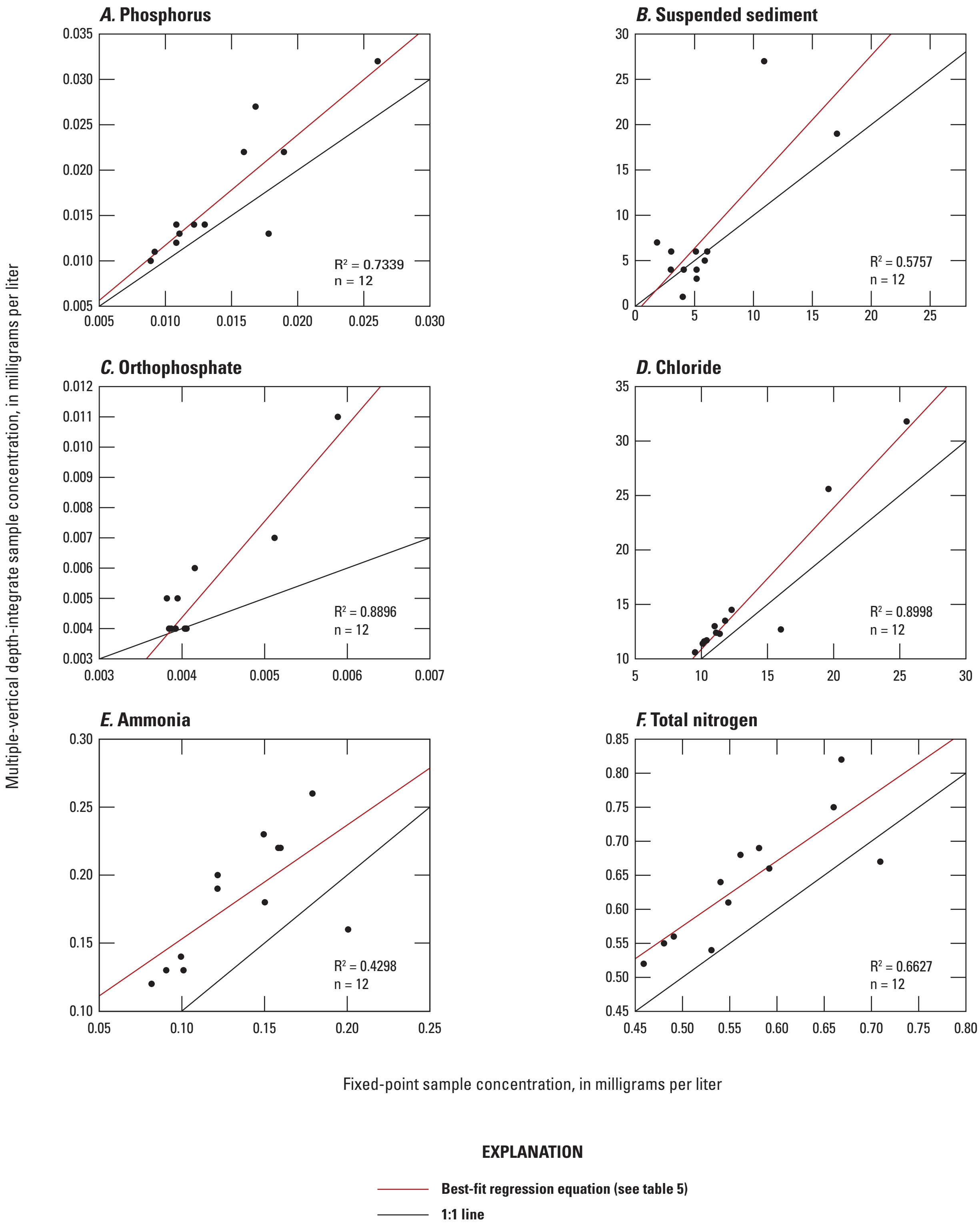

Figure 6. Relations between multiple-vertical depth-integrate (MVDI) and fixed-point samples for selected constituent concentrations in milligrams per liter at U.S. Geological Survey station 041686401 Trenton Channel of Detroit River at Grosse Ile, Michigan, November 2014 to November 2015. (R^2, coefficient of determination; n, sample size)

Table 5. Simple linear regression equations for all major constituents collected at U.S. Geological Survey station 041686401 Trenton Channel of Detroit River at Grosse Ile, Michigan, November 2014 to November 2015.

[R^2, coefficient of determination; p-value, probability value, bold values are significant (p-value ≤ 0.05); *n*, number of observations; ≤, less than or equal to]

Constituent	Regression equation	Residual standard error	Adjusted-R^2	p-value	*n*
Phosphorus	$y_i = -0.00043 + 1.2165x_i$	0.003628	0.7339	**2.284×10^{-4}**	12
Suspended sediment	$y_i = -0.7215 + 1.4177x_i$	4.909	0.5757	**2.556×10^{-3}**	12
Orthophosphate	$y_i = -0.00833 + 3.1764x_i$	0.0006917	0.8896	**2.619×10^{-6}**	12
Chloride	$y_i = -2.128 + 1.3003x_i$	2.08	0.8998	**1.604×10^{-6}**	12
Ammonia	$y_i = 0.06924 + 0.9579x_i$	0.03465	0.4298	**1.228×10^{-2}**	12
Total nitrogen	$y_i = 0.0964 + 0.9579x_i$	0.05245	0.6627	**7.745×10^{-4}**	12

Chemical Constituent Distribution

Discrete samples were collected at 1-m intervals at profile locations 10 m, 60 m, 170 m, and 280 m from the west bank to help describe the distribution of nutrients, chloride, and suspended sediment at the Trenton Channel station. R packages were used to create tile graphs of constituent concentrations throughout the horizontal and vertical planes sampled in Trenton Channel (Wickham, 2009). The tile graphs display color-scale tiles representing observed discrete constituent concentrations (fig. 7). ADCP channel depth data are graphed in a solid black line and extrapolated depths estimated from initial site investigation are graphed in dashed black lines. Graphs display data collected on March 18, 2015.

Tile graphs are displayed for all major constituents collected and represent constituent concentrations collected at each discrete sample location. Although concentrations varied between sampling dates, there are some patterns in the distribution of concentrations that were typical. Constituent concentrations where generally highest near the west bank of the channel. All constituents except suspended sediment display a distribution of higher concentrations near the west bank than the east bank and in some cases, concentrations near the west bank are three times as high (phosphorus). Chloride is considered a conservative ion: when ionized in the environment it stays in that particular ionic state and is rarely affected by sediment and other particles. Because chloride is a conservative ion, it is a good indicator of point sources of chemicals (Mullaney and others, 2009). The distribution of higher concentrations (especially chloride) near the west bank could indicate a source influence upstream on the Michigan side of the channel, but more data would need to be collected throughout the channel to make any determination. Tile graphs also show the distribution of concentrations vertically through the water column. There is less than 10 percent vertical variation of constituent concentrations and in some cases less than a 5 percent difference vertically among concentrations (orthophosphate, ammonia, and chloride). The concentration of suspended sediment had no consistent pattern of vertical or horizontal distribution across sampling dates.

In general, the tile graphs show horizontal heterogeneity and vertical homogeneity. A distribution of higher concentrations to the west side of the channel is present for all major constituents except suspended sediment. This horizontal distribution could be the result of a source influence upstream near the west side of the channel. Discrete samples show little change in concentrations vertically throughout the transect of Trenton Channel for all major constituents. Patterns in horizontal and vertical distribution can provide insight for the application of future sampling methods in this part of the Trenton Channel, potentially focusing sampling efforts to capture the unique horizontal distribution of constituent concentrations.

Boxplot summaries of constituent concentrations collected throughout the sampling campaign using the MVDI method are displayed in figures 7 and 8. Median constituent concentrations are shown by a bold line in the middle of the boxplot, the upper 75th percentile is represented by the top of the boxes, and the lower 25th percentile by the bottom of the box. Vertical lines located above the box represent samples within the 90th percentile. Vertical lines located below the box represent samples within the 10th percentile. Numbers of sample values indicated at the top of each boxplot represent sample sizes. Constituent concentrations are color-coded by date for reference. Constituents summarized in figures 7 and 8 include phosphorus, suspended sediment, orthophosphate, total nitrogen, ammonia, and chloride.

Discrete sampling results are depicted with boxplot graphs for each constituent (fig. 8). All constituents showed that samples collected at the 280 m transect had the lowest median concentrations, except suspended sediment. Suspended sediment did not exhibit the same pattern as other constituents, and suspended-sediment mean concentrations did not vary much throughout the transect. The 280 m sample generally represents water quality from the eastern and upper most parts of the channel, and the locality of the 10 m samples generally represent the western most part of the Trenton Channel. The highest average constituent concentrations at the 10 m location and the lowest concentrations at the 280 m location is evidence the highest constituent concentrations are near

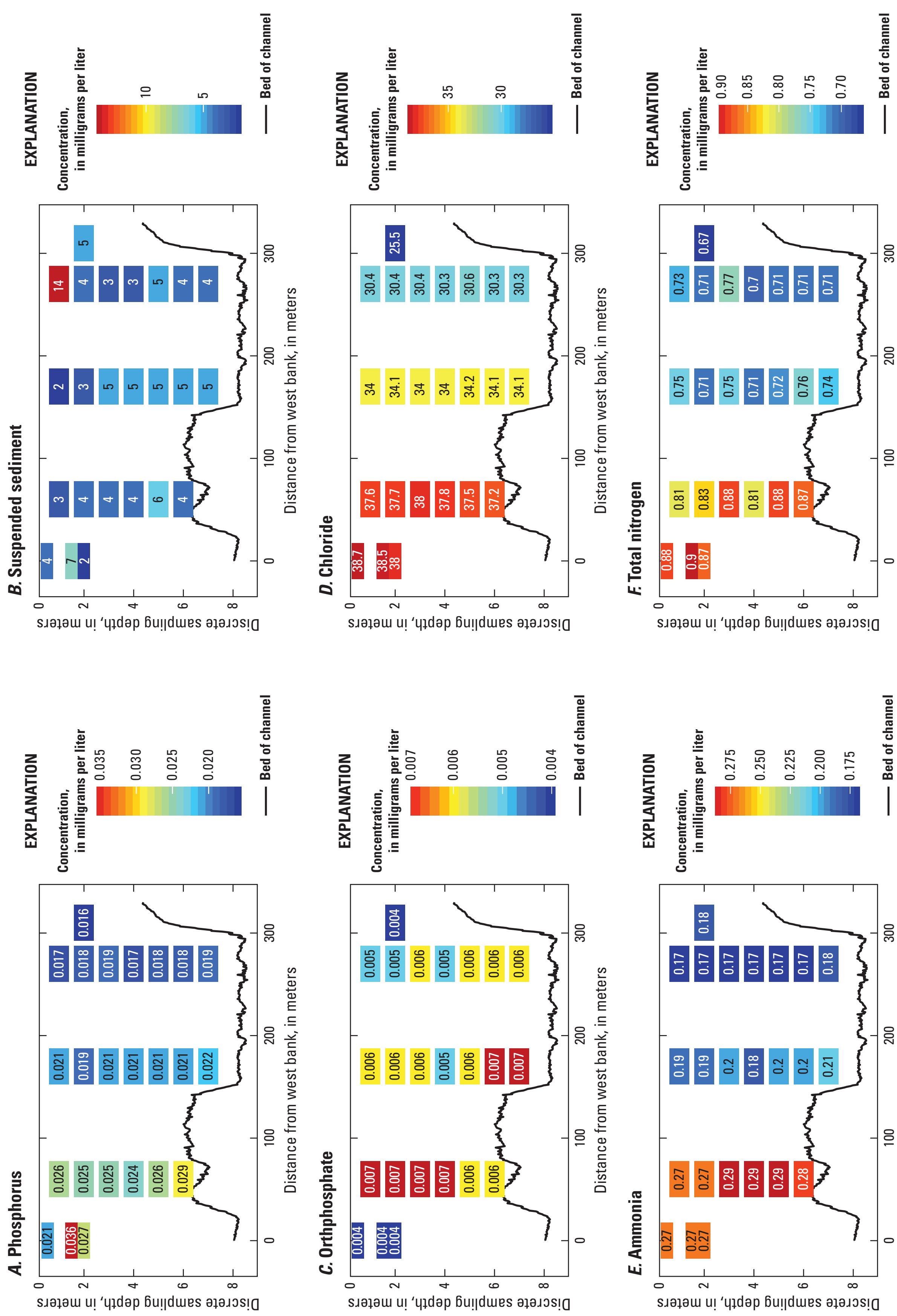

Figure 7. Discrete constituent concentrations measured at U.S. Geological Survey station 041686401 Trenton Channel of Detroit River at Grosse Ile, Michigan, March 18, 2015.

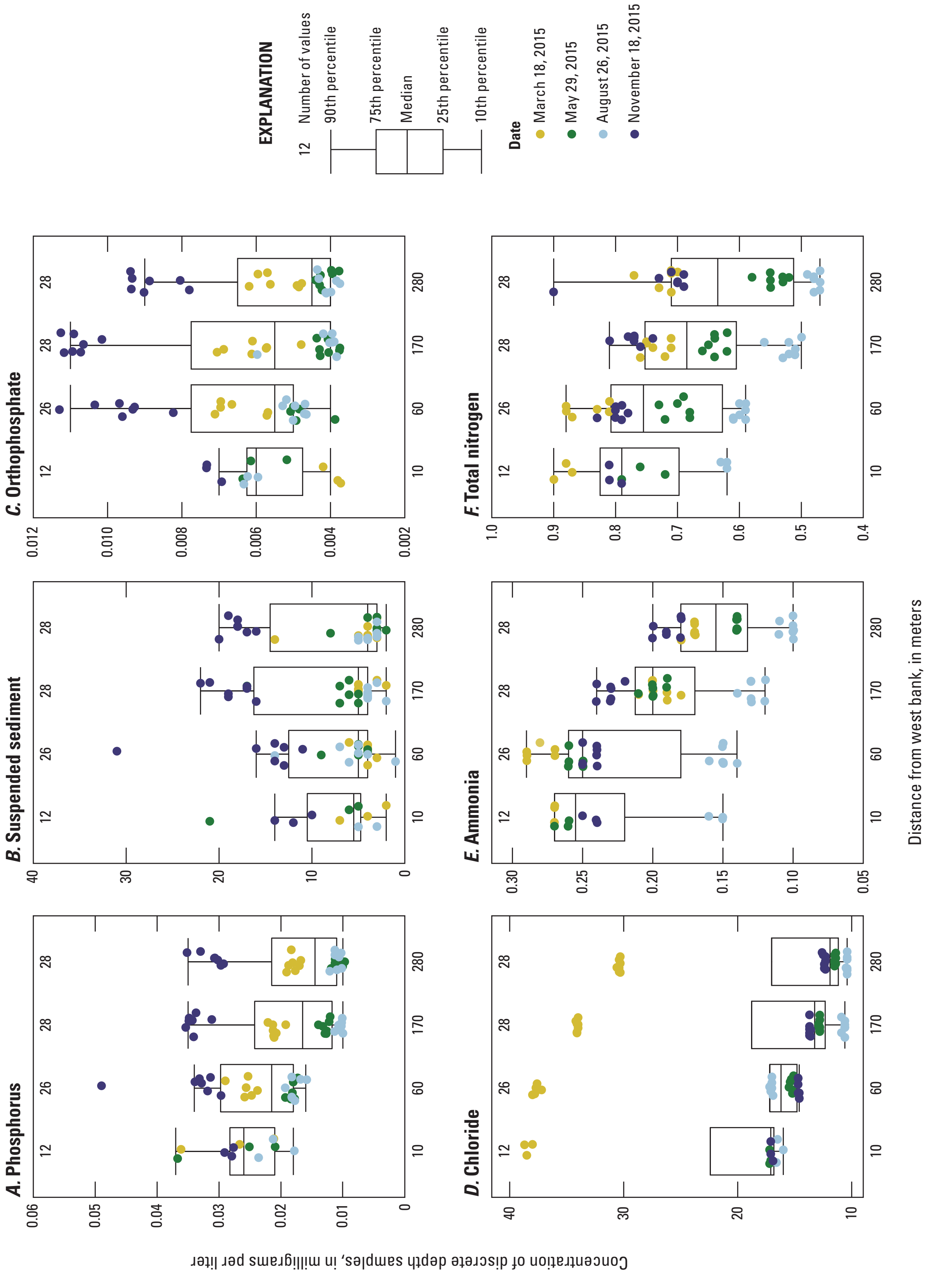

Figure 8. Selected constituent concentrations based on horizontal location or type of sample at U.S. Geological Survey station 041686401 Trenton Channel of Detroit River at Gross Ile, Michigan, November 2014 to November 2015. Vertical-transect distances in meters from the west bank.

the west side of the channel. Higher-than-average concentrations of nutrients, chloride, and suspended sediment at the 10 m sampling location could be because of source influence upstream in the tributary, but without more data this cannot be confirmed. The distribution of constituent concentrations within the sampling period is indicative of lower concentrations for all constituents in the summer through fall period (May through October) and higher concentrations in the winter through spring period (November through April). More data (a longer sampling period) would need to be collected to confirm the seasonal distribution of constituents. Spikes of chloride concentrations around the March 28, 2015, sample date may represent road salting in the winter months. Road salting has increased since 1950 for deicing roads, parking lots, and other impervious sources (Mullaney and others, 2009). Road salt can directly increase the concentrations of chloride in surface water from runoff.

Boxplot summaries displaying the horizontal distribution of constituents in this section of Trenton Channel can help to provide appropriate and representative methods for categorizing major nutrient, chloride, and suspended-sediment concentrations based on scope and purpose of analysis. Sample results obtained throughout the study were grouped by vertical discrete transect locations then summarized using boxplots (fig. 9). Boxplots of vertical discrete samples were developed for each constituent sampled. The boxplots display generally consistent vertical distribution of average concentrations for all constituents for each sampling date. The consistent constituent concentrations vertically indicate mixing and homogeneity throughout the water column. Differences in concentrations throughout the sampling period follow a distinct pattern of vertical symmetry; distribution of concentrations vertically by sample date is apparent for almost all major constituents. Higher concentrations are typical in the winter through spring and lower concentrations are typical in the summer through fall; this same pattern is seen at every discrete location throughout the water column. Homogeneity throughout the water column provides evidence for diversification of samples horizontally instead of vertically to capture the distribution of constituent concentrations more efficiently in the future.

The horizontal boxplots (fig. 8) show constituent concentrations tended to be highest near the west side of the channel and lowest near the east side of the channel. There was no consistent pattern of concentration varying by depth in the water column; vertical homogeneity was evident (fig. 9). Higher-than-average constituent concentrations were observed in the winter through spring and lower-than-average concentrations were observed in the summer through fall. Documented differences in constituent concentrations horizontally indicates a sampling method which captures horizontal differences in water quality would likely be most effective for determining the water chemistry of the Trenton Channel at this location. Cross sectional methods like EDI or Equal Width Increment would likely be most effective for capturing horizontal distribution of constituent concentrations in the southern part of the Trenton Channel.

Constituent Loads

An estimated daily constituent load was calculated using all major constituent concertation values from MVDI and fixed-point methods, as well as discharge values from ADCP data collected on all 12 sampling dates. Daily loads in kilograms per day were aggregated by summing instantaneous loads throughout the course of a day. Instantaneous loads were calculated using equation 2.

$$TCL_i = TC_i \times Q_i \times C \tag{2}$$

where

TCL_i is daily constituent load, in kilograms per day;

TC_i is instantaneous constituent concentration, in milligrams per liter;

Q_i is instantaneous discharge, in cubic meters per second; and

C is the constant 86.4 to convert units of load to kilograms per day.

Table 6 lists estimated constituent loads based on MVDI and fixed-point concentrations and measured discharges. All concentrations obtained from MVDI and fixed-point sampling techniques were above the laboratory minimum reporting levels and thus represent a quantifiable value reported by the NWQL.

Phosphorus load calculations in Trenton Channel were further analyzed because of its contribution and relation to eutrophication in Lake Erie (Ohio EPA, 2013). Phosphorus loads calculated using the MVDI method produced higher loads in comparison to fixed-point methods on all sampling dates except one (fig. 10). This pattern of higher MVDI estimated loads is likely the result of the difference in sampling approach between MVDI and fixed-point methods. The MVDI method incorporates transects from the entire channel and represents more channel area than the fixed-point method. Compared to the fixed-point method, the MVDI method is able to better represent the overall phosphorus concentration by incorporating the gradients in phosphorus concentration found in the channel (fig. 9), which results in a higher and more representable phosphorus load. Phosphorus loads obtained from both the MVDI and fixed-point methods are closely related to streamflow patterns because of a direct relation between streamflow and load. During the sampling interval, phosphorus loads tended to be lower during the summer months than the winter months, likely because of the high concentrations observed during these times (fig. 10). Overall, we can conclude from these data that fixed-point sampling produces results that are biased low for most of the sampling period.

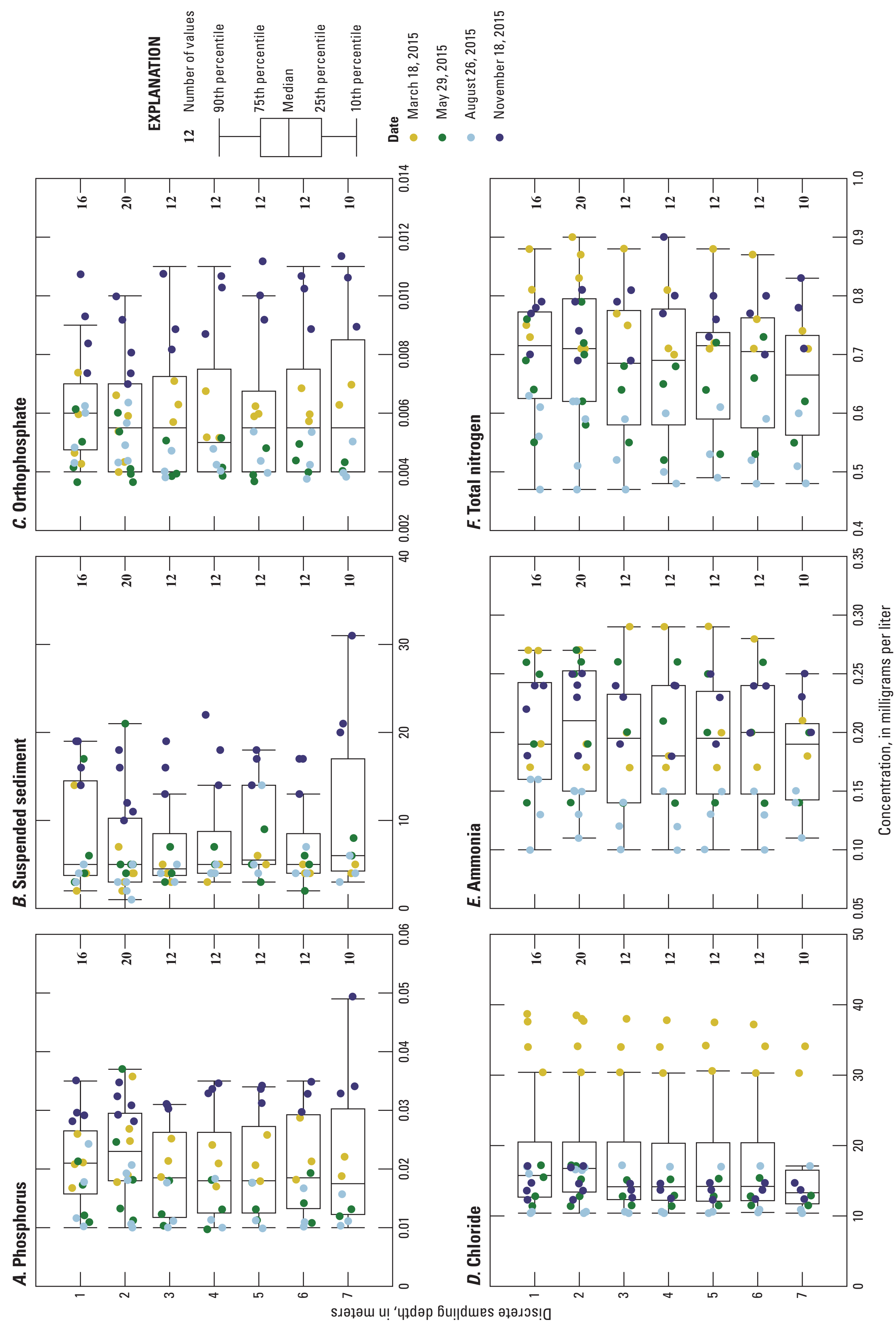

Figure 9. Selected constituent concentrations based on vertical location at U.S. Geological Survey station 041686401 Trenton Channel of Detroit River at Grosse Ile, Michigan, November 2014 to November 2015. Discrete samples were collected at vertical depths of 1, 2, 3, 4, 5, 6, and 7 meters (m).

Table 6. Constituent load estimates from multiple-vertical depth-integrated and fixed-point sampling methods at U.S. Geological Survey station 041686401 Trenton Channel of Detroit River at Grosse Ile, Michigan, November 2014 to November 2015.

[m^3/sec, cubic meters per second; kg/day, kilogram per day]

Date	Discharge (m^3/sec)	Multiple-vertical depth-integrated sampling						Fixed-point sampling					
		Total phosphorus (kg/day)	Suspended sediment (kg/day)	Orthophos-phate (kg/day)	Total nitrogen (kg/day)	Ammonia (kg/day)	Chloride (kg/day)	Phosphorus (kg/day)	Suspended sediment (kg/day)	Orthophos-phate (kg/day)	Total nitrogen (kg/day)	Ammonia (kg/day)	Chloride (kg/day)
December 17, 2014	1,450	1,630	751,000	501	83,900	20,000	1,590,000	2,250	751,000	501	88,900	25,000	2,000,000
March 18, 2015	1,440	2,740	374,000	749	102,000	32,400	3,970,000	2,000	624,000	499	83,600	22,500	3,180,000
April 9, 2015	1,380	1,320	719,000	479	79,100	21,600	3,070,000	1,080	360,000	479	70,700	18,000	2,350,000
May 4, 2015	1,340	1,160	116,000	463	79,800	22,000	1,680,000	1,040	463,000	463	67,100	13,900	1,420,000
May 29, 2015	1,330	1,610	460,000	460	73,500	23,000	1,490,000	1,260	345,000	460	62,100	13,800	1,260,000
August 12, 2015	1,420	1,720	613,000	490	67,400	14,700	1,510,000	1,590	735,000	490	58,800	9,800	1,400,000
August 26, 2015	1,420	1,470	490,000	490	63,700	15,900	1,400,000	1,350	613,000	490	56,400	12,300	1,240,000
September 1, 2015	1,330	1,610	804,000	575	64,400	14,900	1,420,000	1,380	230,000	460	56,300	10,300	1,280,000
September 23, 2015	1,350	1,510	466,000	466	62,800	16,300	1,350,000	1,280	466,000	466	61,700	11,600	1,190,000
September 30, 2015	1,350	2,750	750,000	875	76,200	27,500	1,460,000	2,370	625,000	625	68,700	20,000	1,300,000
October 21, 2015	1,200	2,820	2,820,000	522	71,000	24,000	1,110,000	1,780	1,150,000	418	58,500	15,700	993,000
November 18, 2015	1,260	3,500	2,080,000	1,200	82,000	24,000	1,480,000	2,840	1,860,000	656	72,100	17,500	1,290,000

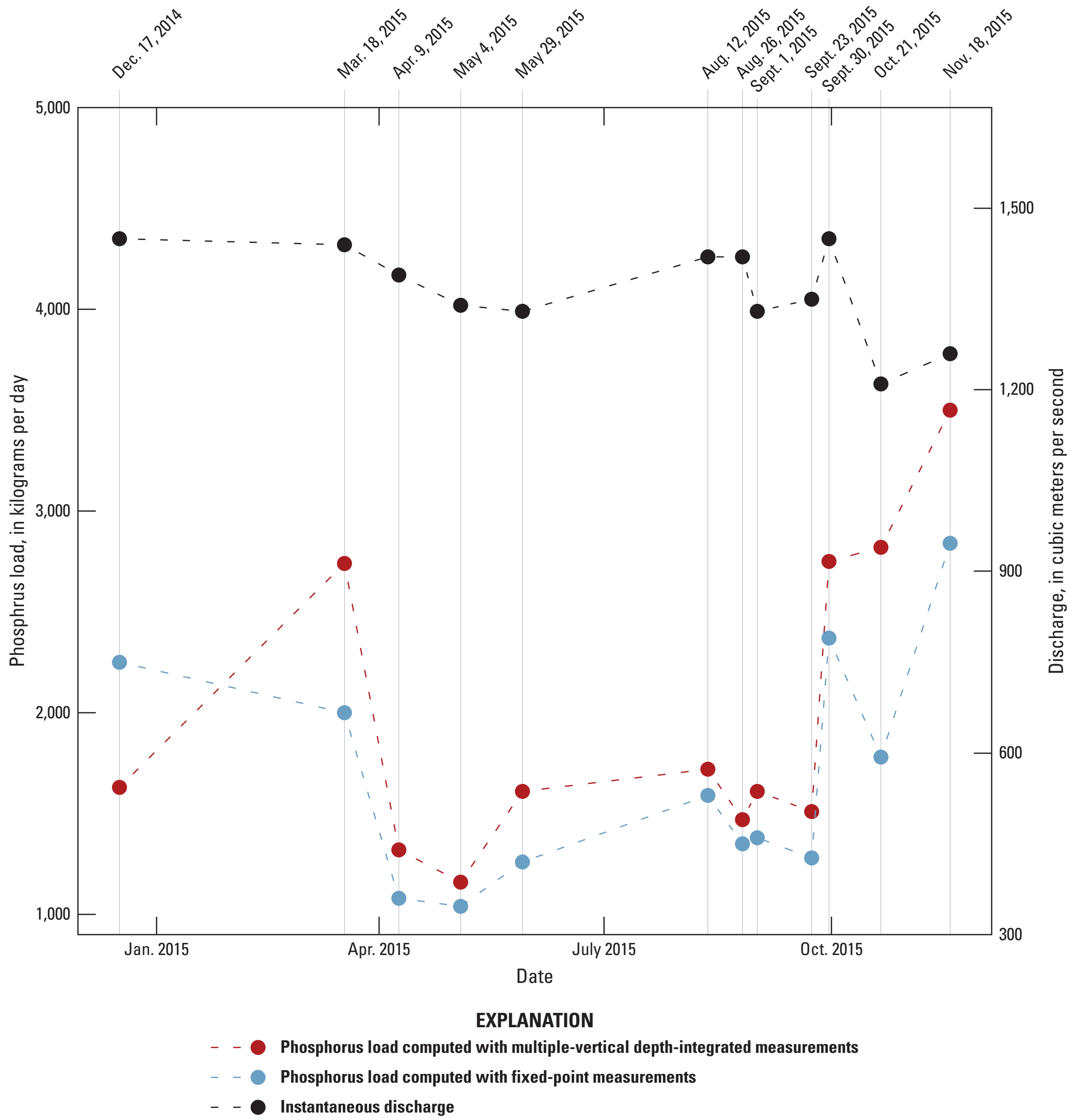

Figure 10. Comparison of phosphorus loads computed by use of multiple-vertical depth-integrated (MVDI) and fixed-point measurements and instantaneous discharge at U.S. Geological Survey station 041686401 Trenton Channel of Detroit River at Grosse Ile, Michigan, November 2014 to November 2015.

Summary

The Detroit River separates the United States and Canada as it flows from Lake St. Clair to Lake Erie. The Trenton Channel is a 13-kilometer-long branch of the Detroit River that flows to the west of Grosse Ile before rejoining the Detroit River near the mouth of Lake Erie. The U.S. Environmental Protection Agency has listed both the Trenton Channel and Detroit River as Areas of Concern because of Beneficial Use Impairments such as interrupted drinking-water services, loss of aquatic life, and reduced recreational use. About 22 percent of the Detroit River flows past the western side of Gross Ile through the Trenton Channel. Flow from the Trenton Channel rejoins the Detroit River near its mouth, just before it flows into Lake Erie. The U.S. Geological Survey, in cooperation with the U.S. Environmental Protection Agency and Environment Canada, investigated concentrations and loads of nutrients (total phosphorus, orthophosphate, total nitrogen, and ammonia), suspended sediment, and flow velocities at U.S. Geological Society station 041686401 Trenton Channel of Detroit River at Grosse Ile, Mich., (Trenton Channel Site) from November 2014 through November 2015. The site was selected to better understand the distribution of constituents and loading that is contributing to eutrophication in Lake Erie. Also, the site was chosen for study to improve future sampling efforts in Trenton Channel. Three water-quality sampling methods—multiple-vertical depth-integrated (MVDI), fixed-point sampling, and discrete sampling—were compared to describe the distribution of nutrients, chloride, and suspended sediment. Also, flow velocity data were collected by acoustic Doppler current profiling (ADCP) throughout this study period to understand the distribution of velocity in the sampled transect of Trenton Channel.

Maps of flow velocities were developed using the Velocity Mapping Toolbox and are displayed in plan and streamwise view near the sampling cross section. Plan view velocity maps display depth averaged velocity in comparison to sampling locations, where higher than average velocities are apparent approximately 200 meters (m) from the west bank of Trenton Channel. Transverse streamwise velocity components as well as secondary flow patterns confirm plan view velocity maps and show the distribution of velocity. Secondary flow vectors suggest the presence of counter-rotating helical flow cells, these cells could contribute to distribution of constituents. Flow depths at the Trenton Channel Sampling Cross Section range from 4.75 to 8.75 m, with an average depth of 6–8 m. Velocity maps provide the velocity and bathymetry throughout the sampled cross section of Trenton Channel.

MVDI, fixed-point, and discrete samples were collected on 12 different days from November 2014 to November 2015. MVDI and fixed-point samples were collected for each sampling event, and four sampling events included a set of discrete samples. All sampling methods tested for selected nutrients, chloride, and suspended sediment. Both tile and boxplot graphs of constituent concentrations show heterogeneity horizontally and homogeneity vertically throughout the cross section.

Differences between MVDI and fixed-point sampling results likely arise in part from the unsampled part of the cross section not accounted for in the fixed-point sample. Simple linear-regressions models developed regression equations to estimate MVDI concentrations for future sampling.

Constituent loads were developed using ADCP discharge values and concentrations derived from MVDI and fixed-point methods. Constituent loads closely followed trends in concentrations collected from both MVDI and fixed-point methods. Phosphorus loads in particular were analyzed and higher loads were seen in the winter months of this study, directly related to higher phosphorus concentrations are evident in both MVDI and fixed-point methods. This relation of phosphorus loads and concentrations directly relates to the influence of concentrations on phosphorus loads.

In conclusion, this investigative study was intended to provide information to our cooperators regarding the distribution of constituents, velocities, and sampling applications for the Trenton Channel. The importance of continuing future investigations to fully understand the Trenton Channel of the Detroit River is paramount, but the information in this report begins to pave the way for effective management decisions and potential for a healthy water system.

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