Estimating Sediment Flux to Jamaica Bay, New York

Scientific Investigations Report 2019–5085

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By Richard A. Cartwright and Amy E. Simonson

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Acknowledgments

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
inch (in.)	2.54	centimeter (cm)
inch (in.)	25,400	micrometer (μm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
pound per second (lb/s)	0.4536	kilogram per second (kg/s)
mile per hour (mi/hr)	1.609	kilometer per hour (km/hr)

Datum

Vertical coordinate information is referenced to the National Geodetic Vertical Datum 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27), the North American Datum of 1983 (NAD 83), or the World Geodetic System of 1984 (WGS 84).

Elevation, as used in this report, refers to distance above the vertical datum.

Supplemental Information

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

Turbidity is given as formazin nephelometric units (FNU).

Abbreviations

ADCP	acoustic Doppler current profiler
ADVM	acoustic Doppler velocity meter
EDI	equal discharge increment
NYCDEP	New York City Department of Environmental Protection
NYSDEC	New York State Department of Environmental Conservation
SSC	suspended-sediment concentration
USGS	U.S. Geological Survey

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Abstract

Tidal wetland loss in Jamaica Bay, New York, is well documented. Maintaining wetlands is important from an environmental and ecological perspective and because wetlands buffer coastal communities from storm damage. An estimate of suspended-sediment flux through Rockaway Inlet is needed to improve understanding of sediment dynamics in Jamaica Bay and could be used in salt marsh restoration efforts. To estimate sediment flux, an index-velocity station and turbidity sensor were installed and operated in Rockaway Inlet near the mouth of Jamaica Bay from November 2014 to December 2016 and point and cross-sectional suspended-sediment samples were collected and analyzed. Index-velocity data coupled with cross-sectional acoustic Doppler current profiler measurements were used to develop an index-velocity rating. A simple linear regression rating with a strong coefficient of determination (R^2 of 0.981) was developed. Discharge was computed from the stage-area and index-velocity relations, and a low-pass Godin filter was used to remove the tidal aliasing. A second simple linear regression (R^2 of 0.75) between fixed-point suspended-sediment concentration (SSC) samples and turbidity allowed for the calculation of SSC through Rockaway Inlet, and then sediment flux was found by multiplying SSC and discharge for continuous (6-minute) data. Turbidity values were low in the near-ocean conditions at Rockaway Inlet, with daily means ranging from 0.6 to 8.2 formazin nephelometric units during the period of November 2014 through December 2016. During this time, computed daily mean suspended-sediment concentrations ranged from 3 to 13 milligrams per liter. High sediment loads generally occurred during incoming tides, during both storm and nonstorm conditions, suggesting a net inward sediment flux into Jamaica Bay. The fate of sediment after it enters Jamaica Bay was not investigated. Trends in sediment flux during major storms could not be evaluated because no major storms occurred during this investigation.

Introduction

Tidal wetlands provide many environmental and ecological benefits, such as acting to buffer coastal communities from storm damage. However, wetland loss along the Atlantic coast of the United States is well documented (Dahl and Stedman, 2013). Similar wetland loss is also reported for Jamaica Bay (Hartig and others, 2002), one of the largest tidal wetland ecosystems in New York State (fig. 1). In 2001, mapping analysis by the New York State Department of Environmental Conservation (NYSDEC) showed that between 1924 and 1999, half of the bay's vegetated marsh islands disappeared and that the rate of loss was increasing. Assuming that rate of loss continues baywide into the future, it was calculated that the marsh islands would completely vanish by 2024 (NYSDEC, 2001).

Recent salt marsh restoration efforts in Jamaica Bay by the New York City Department of Environmental Protection (NYCDEP), along with many other government agencies such as the NYSDEC, the U.S. Army Corps of Engineers, the National Park Service, the New York City Department of Parks and Recreation, and the Port Authority of New York and New Jersey, are part of an ongoing restoration and ecological improvement plan for Jamaica Bay, as outlined in the Jamaica Bay Watershed Protection Plan (NYCDEP, 2007). The health and sustainability of these restored and existing tidal salt marshes is driven by many dynamic processes, of which sediment supply "may be the most critical" (Hartig and others, 2002, p. 87). Therefore, understanding sediment-flux dynamics within the wetland is a crucial part of restoration and stability.

The U.S. Geological Survey (USGS) Woods Hole Coastal and Marine Science Center was awarded U.S. Department of the Interior Hurricane Sandy supplemental funding (project GS2–2D) to assess the estuarine and adjacent wetland responses of three Atlantic lagoonal estuaries to major storm events such as Hurricane Sandy, one of which is Jamaica Bay. This assessment includes the measuring and comparing of net sediment fluxes to the wetland complex and estuary with modeled sediment fluxes. The assessment also includes the testing of high-resolution models of hydrodynamics and sediment transport in vegetated salt marshes to evaluate depositional patterns as well as vulnerability of salt marsh shorelines to wave attack.

To provide data for the above-mentioned model design and calibration, a tide-gaging station, at which an index-velocity meter and a continuous turbidity monitor were installed, was operated in Rockaway Inlet (USGS tide-gaging station 01311875; fig. 2) during a 2-year period from November 2014 to December 2016. Data at the station were correlated with cross-channel acoustic Doppler current profiler (ADCP) measurements for velocity and suspended-sediment concentration (SSC) samples for turbidity. SSC samples were collected by using two methods: depth-integrated equal discharge increment (EDI) sampling across Rockaway Inlet, and fixed-point SSC samples at the monitoring location.
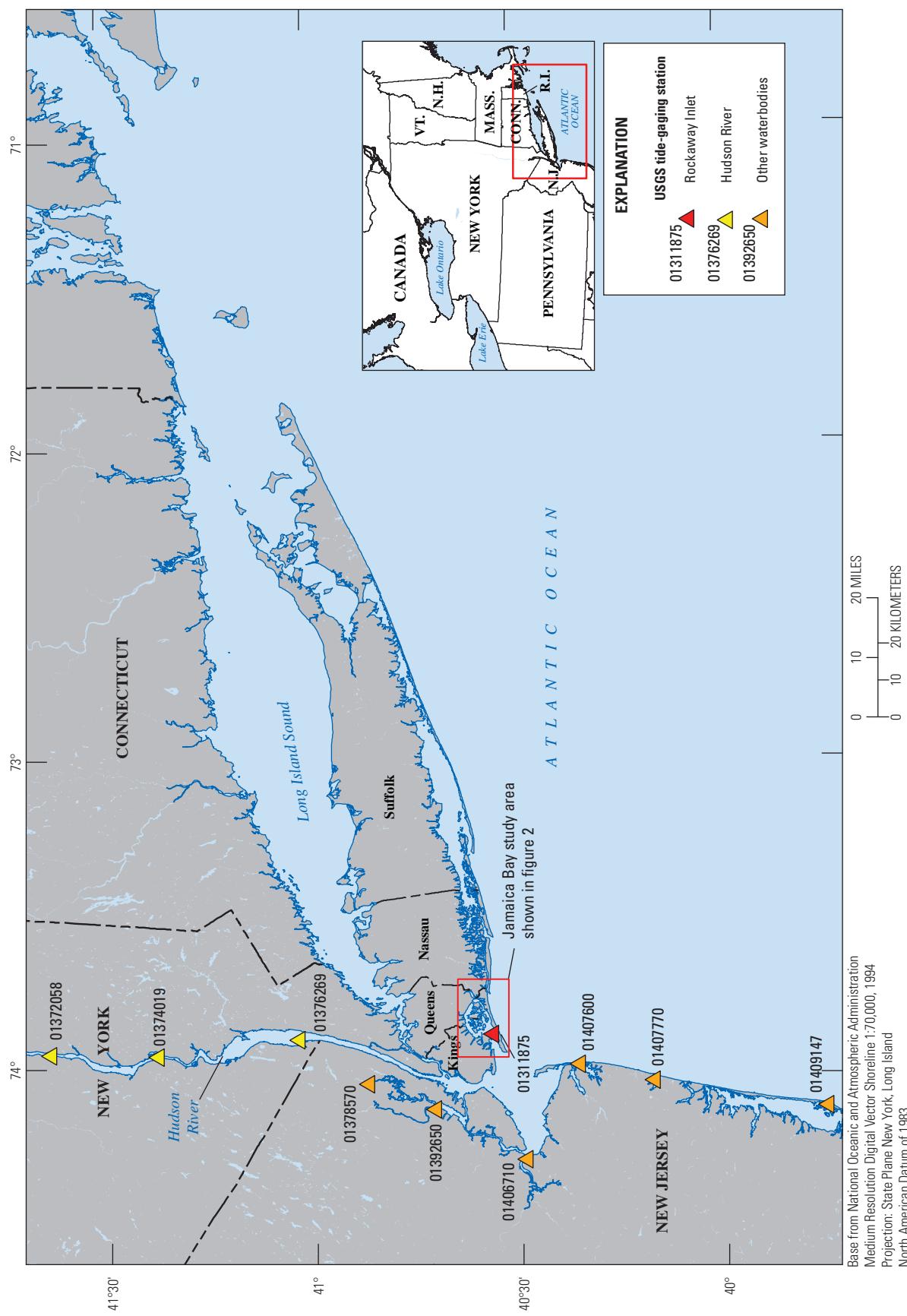
Figure 1.   Part of the northeastern United States, including U.S. Geological Survey (USGS) tide-gaging stations along the Hudson River and other waterbodies that drain into the Atlantic Ocean, and location of the Jamaica Bay study area.
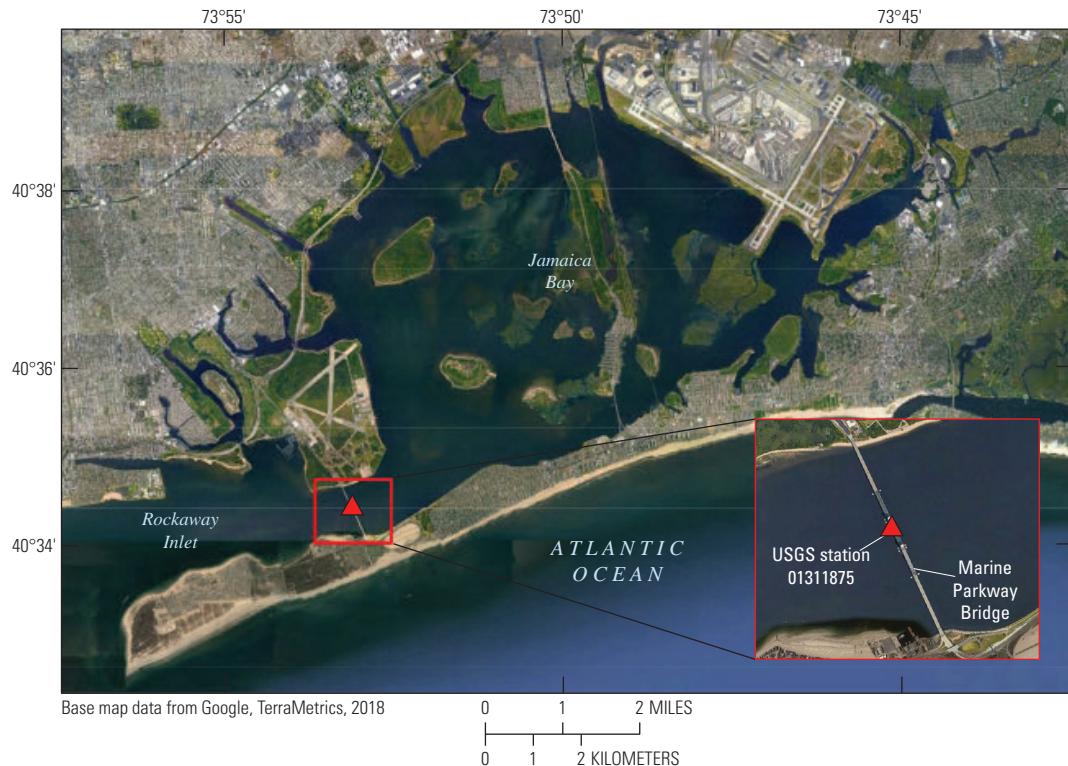
Figure 2.   The Jamaica Bay study area, with wetlands (salt marsh) in Jamaica Bay (within the Gateway National Recreation Area), and U.S. Geological Survey (USGS) tide-gaging station 01311875 near the center of Rockaway Inlet, Jamaica Bay, New York.

Purpose and Scope

The purpose of this report is to document and describe the methodologies used to design, install and operate a sediment-flux monitoring system for estimating sediment flux to Jamaica Bay, New York, and to analyze how the resulting estimates may correlate with storms and other factors.

Jamaica Bay Study Area

Jamaica Bay comprises about 31 square miles in southern parts of Kings, Queens, and western Nassau Counties, N.Y. (figs. 1 and 2). It is one of the largest tidal wetland ecosystems in New York State and is a component of the National Park Service's Gateway National Recreation Area. The bay is a diverse ecological resource that supports multiple habitats, including open water, salt marshes, grasslands, coastal woodlands, maritime shrublands, and brackish and freshwater wetlands. These habitats support 91 fish species, 325 bird species, and many reptile, amphibian, and small mammal species (NYCDEP, 2007).

During the last 150 years, wetlands have been removed as a result of extensive filling operations; shorelines have been hardened and bulk-headed; deep channels and borrow areas have been dredged, altering bottom contours and affecting natural flows; and natural tributaries have essentially disappeared, leaving behind deposits of silts and particulates from urban runoff. These activities have synergistically affected historical flow and sediment deposition and removal patterns in the bay, damaged natural habitat, affected water quality, and changed the once rich ecosystem (NYCDEP, 2007).

Methods of Data Collection and Analysis

To quantify net sediment flux to Jamaica Bay though Rockaway Inlet, a continuous monitoring system, composed of the following three permanently mounted components, was employed: (1) a tide-gaging station, (2) an acoustic Doppler velocity meter (ADVM), and (3) a water-quality monitor. Components 1 and 2 make up the index-velocity station. The index-velocity method is a way to compute continuous records of discharge (Levesque and Oberg, 2012), especially in a tidally affected environment (Ruhl and Simpson, 2005). Discharge is computed as the product of cross-sectional area and mean velocity. The cross-sectional area is based on a water elevation (or stage) versus area relation that is determined from a detailed channel survey. The mean cross-sectional

velocity is computed from discharge measurements made with an ADCP (Mueller and Wagner, 2009) and is related to the index velocity recorded by the station's ADVM. All continuous time-series data are recorded at 6-minute intervals, stored onsite, and then transmitted to USGS offices by satellite and telephone telemetry. The continuous data are correlated with cross-sectional ADCP data and SSC data to estimate sediment flux.

Tide-Gaging Station

The tide-gaging station was designed and installed on a bridge protection pier near the middle of Rockaway Inlet on the Marine Parkway-Gil Hodges Memorial Bridge in 2002. The station was equipped with a Sutron Accubar Constant Flow Bubble Gauge connected to a Sutron 9210 data-collection platform mounted several feet above the 100-year coastal-flood elevation inside a reinforced shelter (fig. 3). A 2-inch-diameter, brass standpipe extending into the water column protects the pressurized orifice line from damage and minimizes biofouling.

Acoustic Doppler Velocity Meter and Water-Quality Monitor

In November 2014, a 500-kilohertz side-looker ADVM (Sontek SL500) and a water-quality monitor (YSI 6600 multiparameter monitor) were installed adjacent to the orifice line standpipe for the tide-gaging station. A stainless-steel mount with sliding assembly was custom-designed and fabricated so that the ADVM and water-quality equipment could be raised and lowered for routine maintenance, cleaning, and calibration (fig. 4). Considerations for site selection, installation procedures, and data processing follow guidelines outlined in Levesque and Oberg (2012). The monitor provides continuous water temperature, specific conductance (used to compute salinity) and turbidity data from near midwater depth. To minimize biofouling, the monitor body and probes are enclosed in either brass or copper (fig. 5). A sponge wiper maintains a clean optical surface on the turbidity probe. A manually operated come-along winch is used to raise the sliding mount assembly for monitor servicing. Servicing and maintenance procedures include the calculation of fouling and drift corrections and follow USGS standard procedures for continuous monitors (Wagner and others, 2006). Routine visits and maintenance are scheduled for 4-week intervals in the summer, 6-week intervals in the spring and fall, and 8-week intervals during the winter. From November 2014 through December 2016, daily mean turbidity values ranged from 0.6 to 8.2 formazin nephelometric units (FNU).
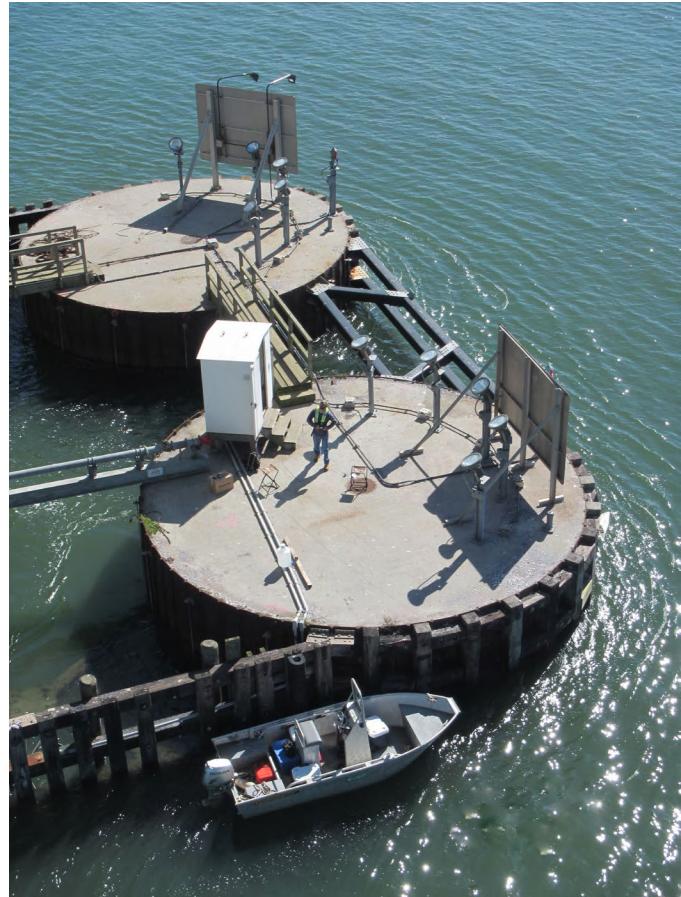
Figure 3. U.S. Geological Survey tide-gaging station 01311875 on bridge protection pier for Marine Parkway-Gil Hodges Memorial Bridge, Rockaway Inlet at Floyd Bennett Field, New York. Photograph by R. Cartwright, U.S. Geological Survey.

Acoustic Doppler Current Profiler Measurements

Prior to installation of the ADVM, 14 reconnaissance discharge measurements were made in April and May 2014 by using a boat-mounted ADCP on a 16-foot aluminum Workskiff (fig. 6) to determine the flow distributions and bathymetry at various locations in Rockaway Inlet. Maximum outgoing (towards ocean) flow when measurements were made was +195,000 cubic feet per second, and maximum incoming (towards bay) flow was −249,000 cubic feet per second. To develop the relation between the index velocity (as measured by the ADVM) and the mean cross-sectional velocity, an additional 58 ADCP measurements were made. All discharge measurements were made following standard quality-assurance protocols outlined in Mueller and Wagner (2009), including water temperature comparison, salinity measurement with a refractometer, moving bed tests, and compass calibration. Discharge measurements were 12 minutes in duration because this timing allowed for slow, steady channel transects

A

B

C

Figure 4.   A stainless-steel sliding mount fastened to the inside of a wooden fender structure *A*, deployed, *B*, raised, and *C*, with acoustic Doppler velocity meter and water-quality monitor raised for servicing. Photographs by R. Cartwright, U.S. Geological Survey.

A

B
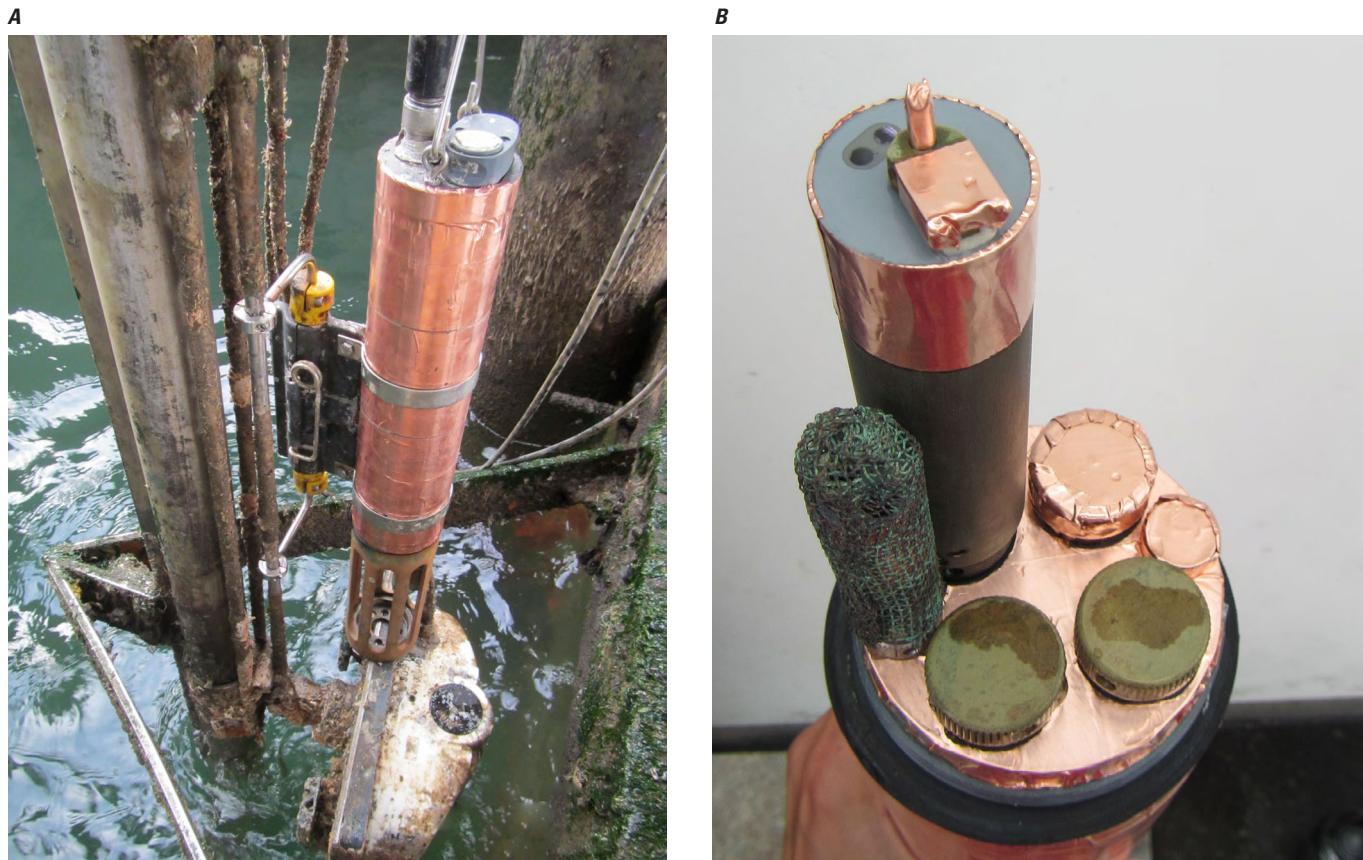
Figure 5.   A water-quality monitor with antifouling measures: *A*, monitor body with copper tape and brass probe guard and *B*, copper-taped monitor bulkhead, brass turbidity probe, and copper mesh over conductivity/temperature probe. Photographs by R. Cartwright, U.S. Geological Survey.

while maintaining a multiple of the 6-minute elevation and velocity data measured at the tide-gaging station. Instead of using the standard protocol of a 1-minute velocity recording interval (Levesque and Oberg, 2012), the 6-minute collection interval was used so that data would remain available online to cooperators and flood forecasters during the 6- to 8-hour-long measurement campaigns.

Index-Velocity Development

The index-velocity method described by Ruhl and Simpson (2005) for computing discharge in tidally influenced environments was used in this study. Discharge was computed as a three-step process: (1) calculating the cross-sectional area based on a stage time-series and bank elevations, (2) calculating the mean cross-sectional velocity based on a measured index-velocity time series, and (3) calculating discharge as the product of the mean velocity and area.

A stage-area rating was developed to relate elevation (stage) and cross-sectional area, using the USGS program AreaComp2 (Levesque and Oberg, 2012; USGS, 2015). A standard cross section was established by surveying the

banks with a global navigation satellite system and choosing a representative ADCP measurement for channel bathymetry (appendix 1, table 1.1). The standard cross section runs parallel to and is about 200 feet east of the bridge, and the cross section extends north and south (landward) above the period-of-record maximum elevation from Hurricane Sandy (Schubert and others, 2015).

Initial ADCP measurements were collected in April and May 2014 to help determine ADVM placement and design. By following methods from Levesque and Oberg (2012), the ADVM was programmed to collect multicell data in 10-meter increments from 10 to 110 meters and, to avoid measuring areas of flow disturbance from the bridge protection piers, the ADVM range-averaged the data from 20 to 50 meters. The ADVM was programmed such that cells 2–5 of the multicell data measured the same area as the range-averaged data. These range-averaged data were the index velocities on which the index-to-mean velocity relation was based. The ADVM was programmed with an averaging interval of 180 seconds and a measurement interval of 360 seconds, to match 6-minute data collection at the tide-gaging station, which is centered on the top of the hour and measured every 6 minutes thereafter.
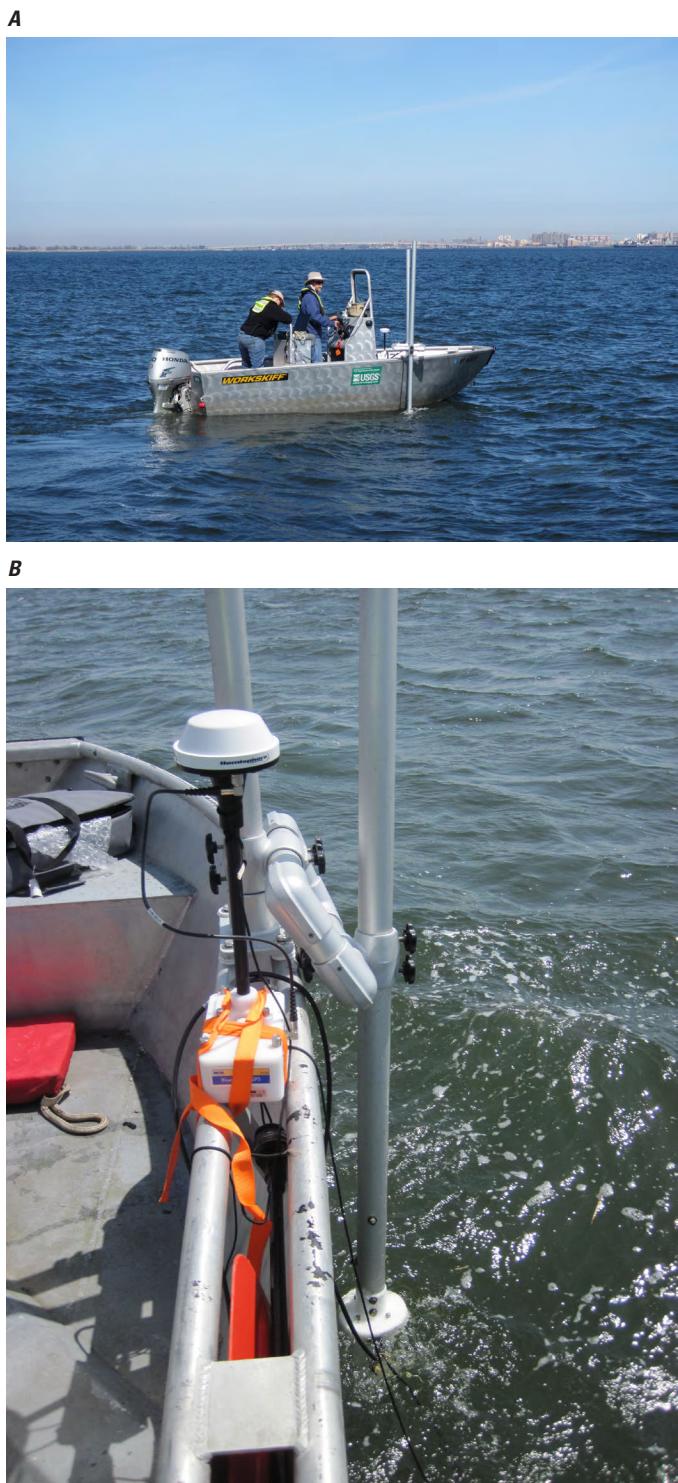
Figure 6. A boat-mounted acoustic Doppler current profiler on *A*, 16-foot aluminum Workskiff with *B*, adjustable aluminum mount. Photographs by U.S. Geological Survey.

Suspended-Sediment Data

Two different sets of SSC data were collected and analyzed: (1) fixed-point samples were collected adjacent to the turbidity probe to develop a relation between turbidity and SSC at the tide-gaging station, and (2) depth-integrated samples were collected at equal discharge increments (EDIs) across Rockaway Inlet and analyzed individually to define cross-sectional variability.

Fixed-point samples were collected concurrently with 6-minute turbidity readings using a Kemmerer sampler (fig. 7) lowered to near midwater depth adjacent to the turbidity probe. A total of 51 fixed-point samples were collected for SSC between 2015 and 2016 (table 1; also in appendix 1, table 1.3). On September 28 and October 6, 2015, 27 fixed-point samples were collected throughout incoming tidal cycles for spring-tide conditions. On May 26, 2016, an additional 24 fixed-point samples were collected throughout a semidiurnal tidal cycle during neap-tide conditions. The October fixed-point samples were collected when storm-related high-turbidity values were being recorded, with the intent of collecting water samples with high SSC values.

Depth-integrated EDI samples were collected across Rockaway Inlet from a boat with a D–96–A1 collapsible-bag sampler for suspended sediment and water quality (USGS, variously dated; fig. 8) to determine the cross-sectional variability of SSC. A discrete sample was collected and analyzed at each of the five EDI sampling locations, from which a mean SSC value was calculated by averaging the concentrations of the individual samples. A total of 43 EDI samples—including 5 at 8 cross sections and several replicate samples—were collected for SSC analysis between 2015 and 2016 (table 2; also in appendix 1, table 1.3). Of these 43 EDI samples, 11 are sequential replicate samples because they were collected at the same location over a short time (USGS, 2004). Twenty EDI samples were collected for SSC analysis in April 2015 during peak ebb and flood conditions of spring tide, when water velocity and turbidity values are typically high. Twenty-three EDI samples were collected for SSC analysis in April 2016 during ebb and flood conditions of neap tide, when maximum water velocity and turbidity values are typically low.

For both collection methods, water samples were transferred from the sampler to pretared, 3-liter polyethylene sample bottles and stored in a refrigerator prior to shipment for laboratory analysis. Samples were analyzed by the USGS Kentucky Water Science Center Sediment Laboratory for SSC and the mass percentage of the sediment less than sand size (62.5 micrometers) (Shreve and Downs, 2005).

Estimation of Sediment Flux

Discharge and SSC were determined by correlating discrete measurements with continuous data, then the sediment flux was calculated by multiplying the two parameters (Rasmussen and others, 2009, p. 22).

Table 2. Dates and tidal notes for equal discharge increment (EDI) sampling of suspended-sediment concentration, in Rockaway Inlet at Jamaica Bay, New York. EDI samples were collected approximately 200 feet east of tide-gaging station.

Date	Number of samples	Tidal conditions
Apr. 18, 2015	20	Spring tide, outgoing and incoming
Apr. 13, 2016	10	Neap tide, outgoing
Apr. 14, 2016	13	Neap tide, incoming
Total	**43**	

A

B
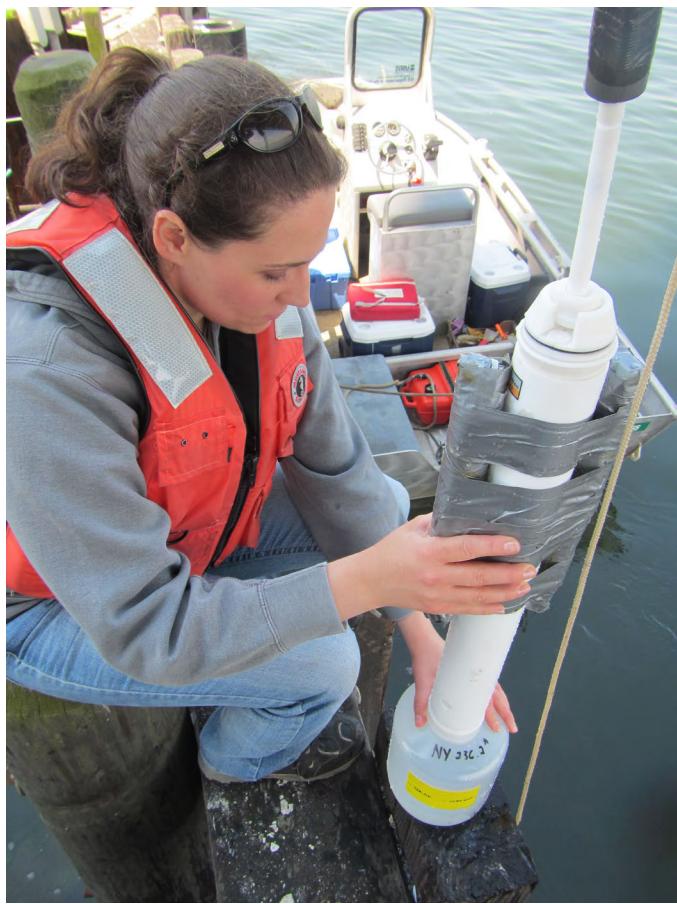
Figure 7. The collection of a fixed-point sample of suspended-sediment concentration by using a Kemmerer sampler adjacent to the turbidity probe at the tide-gaging station. Weights taped to the sampler keep it from swinging in tidal currents. Photograph by R. Cartwright, U.S. Geological Survey.

Table 1. Dates and tidal notes for fixed-point sampling of suspended-sediment concentration, in Rockaway Inlet at Jamaica Bay, New York. Fixed-point samples were collected adjacent to the turbidity probe at the tide-gaging station.

Date	Number of samples	Tidal conditions
Sept. 28, 2015	12	Spring tide, incoming
Oct. 6, 2015	15	Spring tide, incoming
May 26, 2016	24	Neap tide, incoming and outgoing
Total	**51**	

Figure 8. The collection of depth-integrated, equal discharge increment samples of suspended-sediment concentration: *A*, D–96–A1 sampler, and *B*, transferring water from sample bag into polyethylene bottle. Photographs by U.S. Geological Survey.

Water Velocity and Discharge

In March 2015, 58 ADCP measurements were made during spring tides with the intent of measuring the full range of water velocity (table 3). These measurements (numbers 15–72; USGS, 2017b) were correlated with ADVM-observed data to develop an index-velocity rating (fig. 9) by using methods described in Levesque and Oberg (2012) and the Surrogate Analysis and Index Developer (SAID) tool (Domanski and others, 2015). A simple linear regression was developed by correlating mean channel velocity for measurements made on March 21 and 23, 2015, with the range-averaged measured velocity at the ADVM (fig. 9; appendix 1, table 1.2):

$$Vmean = 0.923 \times Vi + 0.024, \tag{1}$$

where

$Vmean$ is the mean cross-sectional velocity, in feet per second, and

Vi is the average index velocity measured by the ADVM, in feet per second.

This regression produced a strong coefficient of determination (R^2 of 0.981), and the residual plots were normally distributed and of equal variance (Riggs, 1968, p. 7). An additional 43 ADCP measurements were made from 2015 to 2016 and plot well within the 95-percent prediction interval (USGS, 2017a) of the initial March 2015 measurements (fig. 10). Therefore, a more complex index-velocity relation—such as a quadratic, loop, or bimodal rating—that is more commonly used for a tidal environment (Ruhl and Simpson, 2005) was not necessary to compute discharge.

Discharge was computed by multiplying the output from the stage-area and index-velocity relations. Because this gaging station is in a tidal environment, and because of the difference between the solar period (24 hours) and the lunar period (24 hours and 50 minutes), an unbiased daily discharge cannot be determined by averaging all values collected in a 24-hour period. To account for this difference in solar and lunar periodicity, a low-pass Godin filter (Godin, 1972; Ruhl and Simpson, 2005), which removes frequencies that have periods less than 30 hours and effectively removes variations due to astronomical tides, was used. Without a filter, there would be an apparent oscillation, or tidal aliasing, within the computed daily value time series that would be unrelated to physical conditions (USGS, 2011). The daily mean discharge was computed as the daily average of the low-pass-filtered discharge.

Sediment Concentration and Flux

As previously described in the section "Suspended-Sediment Data," results from analyses of suspended-sediment concentration were used for two purposes: (1) fixed-point samples collected near the turbidity probe were used to develop a relation between turbidity and SSC at the tide-gaging station;

Table 3. Acoustic Doppler current profiler discharge measurement dates, numbers, and remarks, in Rockaway Inlet at Jamaica Bay, New York.

Date	Measurement number	Remark
Apr. 25, 2014	1–8	Reconnaissance
May 13, 2014	9–14	Reconnaissance
Mar. 21, 2015	15–46	Index-velocity rating
Mar. 23, 2015	47–72	Index-velocity rating
May 7, 2015	73–78	Rating validation
Oct. 27, 2015	79–103	Rating validation
Apr. 14, 2016	104–109	Rating validation
Dec. 14, 2016	110–115	Rating validation

and (2) cross-sectional, depth-integrated samples were used to define cross-sectional variability of SSC.

Forty-three cross-sectional, depth-integrated EDI samples were collected in April 2015 and April 2016 during peak flood and ebb tides. Overall, SSCs ranged from 2 to 8 milligrams per liter (mg/L) (1.2 to 1.6 formazin nephelometric units [FNU]) during ebb tide and from 4 to 11 mg/L (2.0 to 2.7 FNU) during flood tide. Physical limitations of sample collection prevented sampling across the channel during high-turbidity events (usually storms). To supplement these data, an additional 51 fixed-point samples were collected in September and October 2015 and May 2016, with SSC values ranging from 3 to 20 mg/L and corresponding turbidity values ranging from 1.7 to 12 FNU. Figure 11 shows the simple linear regression (R^2 of 0.75; appendix 1, table 1.3) between fixed-point SSC and turbidity and the 90-percent prediction interval (Rasmussen and others, 2009), plotted with the mean EDI SSC data:

$$SSC = 1.29 \times Turb + 2.52, \tag{2}$$

where

SSC is suspended-sediment concentration, in mg/L; and

$Turb$ is turbidity, in FNU.

The mean EDI SSCs plot within the prediction interval of the SSCs determined by the fixed-point-SSC to turbidity regression relation (although they are clustered around the lower end because of practicality of sampling during storms), which supports the assumption that the fixed-point SSCs are representative of the mean SSC across the entire cross section and thereby validates the fixed-point-SSC to turbidity relation as a means to estimate sediment loads in this reach, particularly at lower turbidities and SSCs. During the November 2014 to December 2016 study period, daily mean suspended-sediment concentrations ranged from 3 to 13 mg/L.
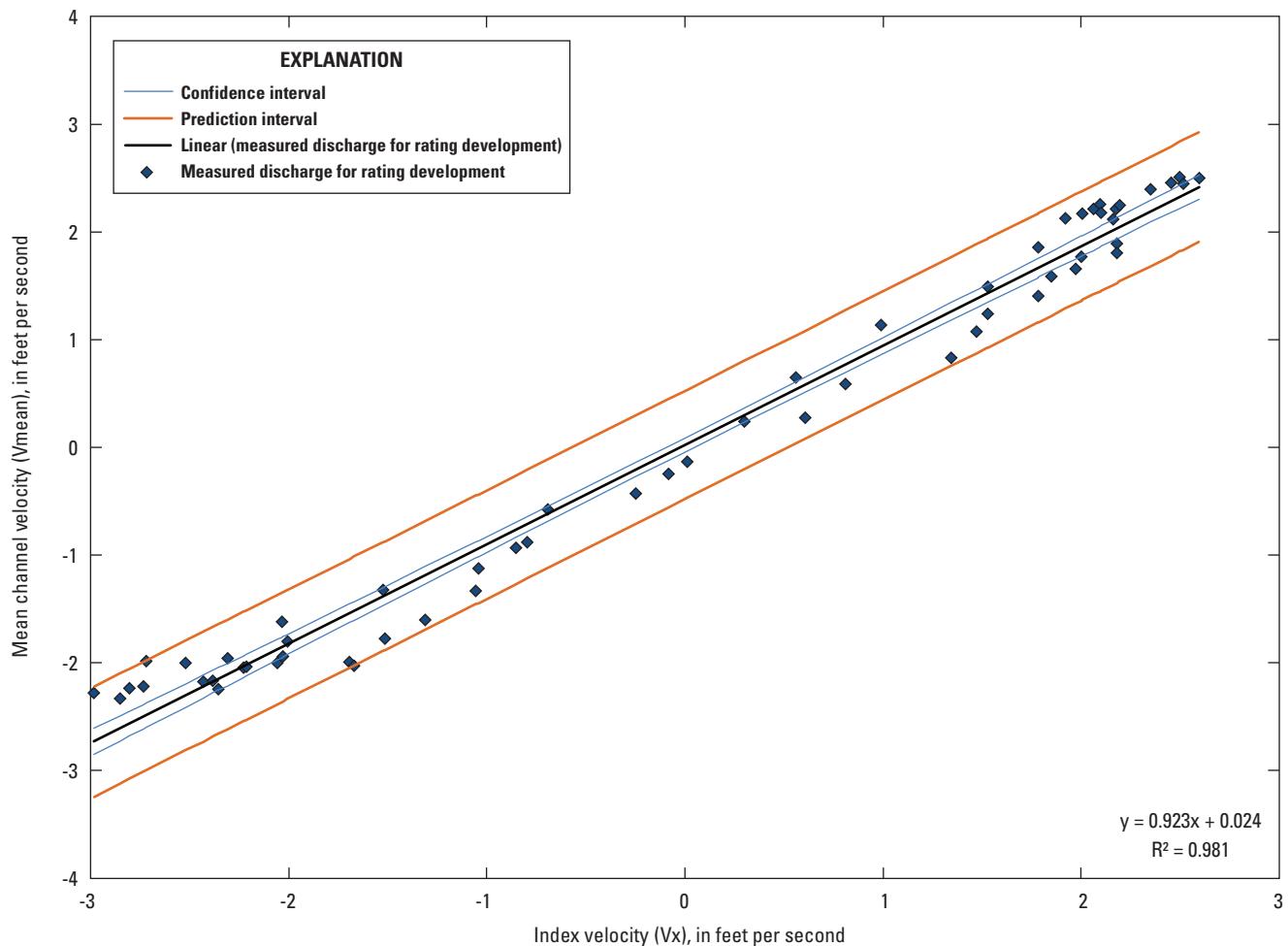
Figure 9.   Index-velocity rating, determined by using simple linear regression, based on 58 discharge measurements made during March 2015 in Rockaway Inlet at Jamaica Bay, New York. R^2 is 0.981.

$$y = 0.923x + 0.024$$
$$R^2 = 0.981$$
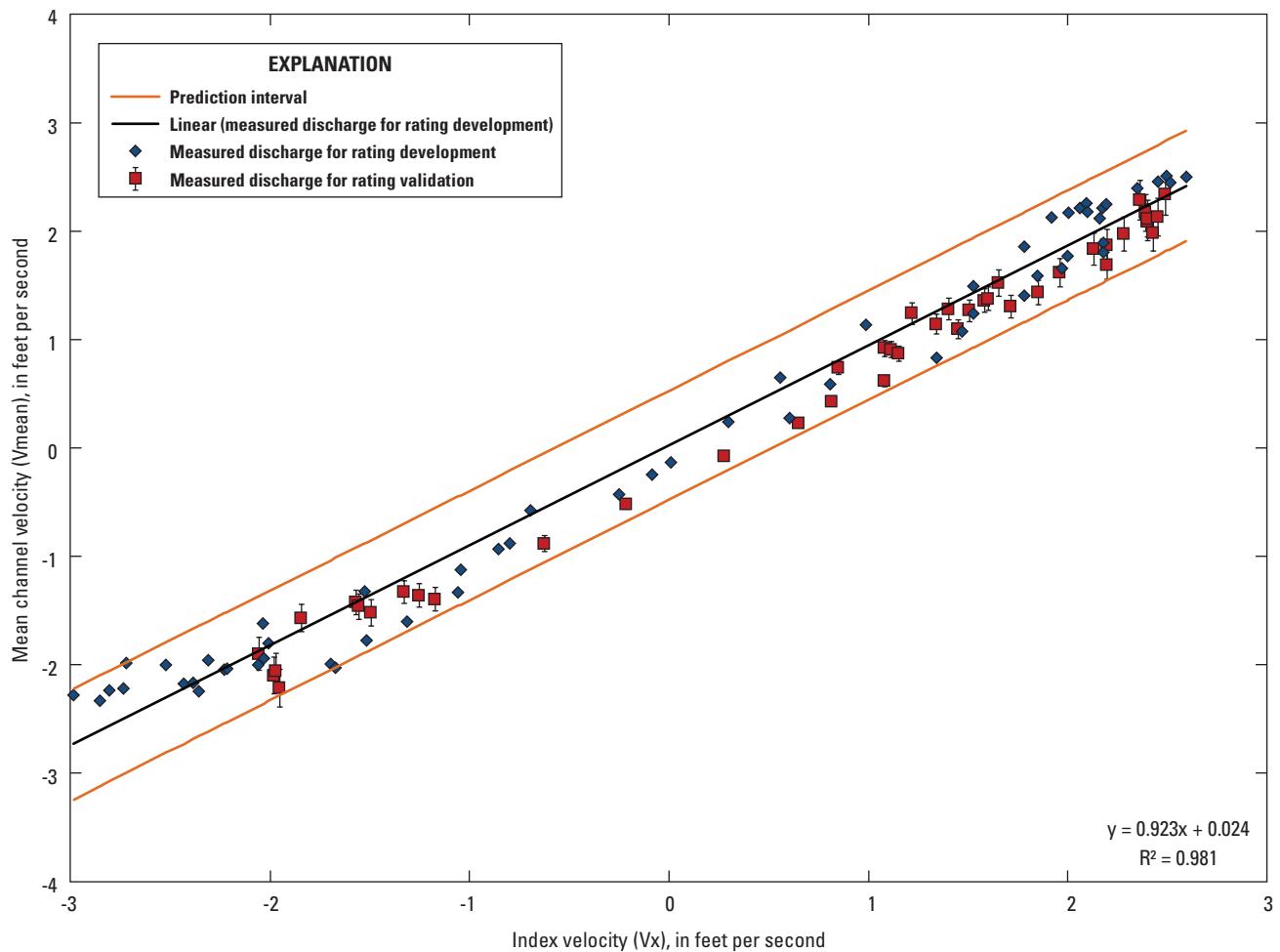
Figure 10. Validation of the index-velocity rating based on March 2015 measurements (fig. 9) by 43 validation discharge measurements made during 2015–16 in Rockaway Inlet at Jamaica Bay, New York.
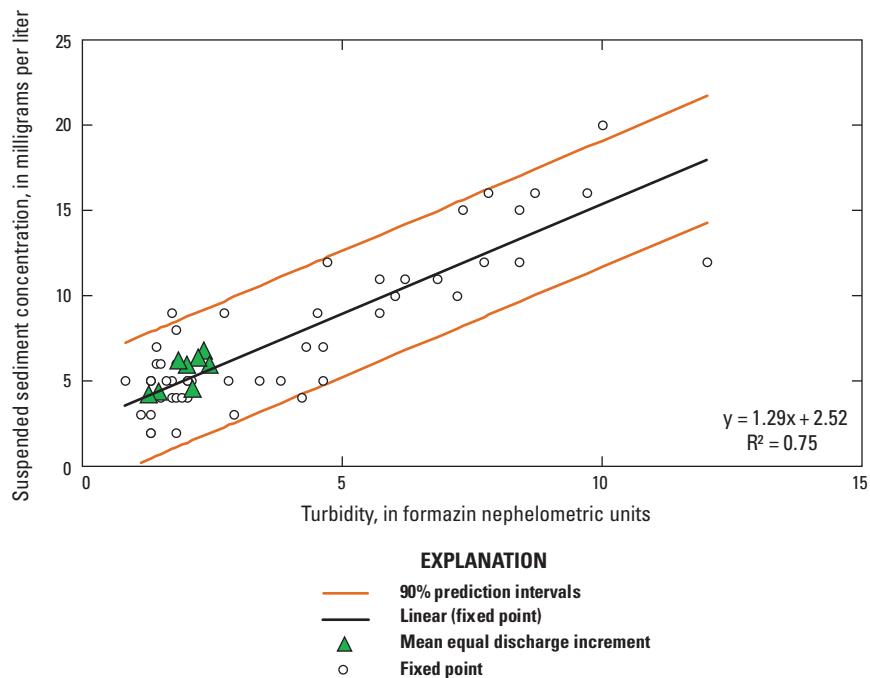
Figure 11.   Relation between suspended-sediment concentration and turbidity derived from fixed-point data and compared to equal discharge increment data, 2015–16, at Rockaway Inlet at Jamaica Bay, New York.

Once the SSC and discharge were determined, the sediment flux was calculated by multiplication of the two parameters (Rasmussen and others, 2009, p. 22) and by conversion of units using AQUARIUS data management software (Aquatic Informatics Inc., 2018). Data from November 2014 to December 2016 of suspended-sediment flux in pounds per second (lb/s) are plotted as suspended-sediment load in figure 12. Sediment loads during this period ranged from about −450 lb/s (towards bay) to about +350 lb/s (towards ocean).

Discussion of Sediment Flux to Jamaica Bay: Role of Storms and Other Factors

Although coastal storms are more commonly known as destructive, under certain conditions they can sustain or expand tidal marshes. Sediment resuspended by wind-driven waves can be transported onto marsh surfaces, especially to the high marsh during storm-surge conditions, thereby providing sediment needed for marsh health and possible accretion. Drivers include, but are not limited to, storm intensity, track, duration and seasonal timing, and marsh morphology.

Spring freshets (high-river-discharge events typically associated with icemelt or snowmelt and spring rains) can also supply sediment to a marsh system that is at or near the river's mouth. In the case of Jamaica Bay, the Hudson River is a potential source of sediment. The Hudson River discharges to the New York Harbor (and New York Bight) area (figs. 1 and 13) and can potentially deliver large volumes of sediment, especially during the spring freshet and during rain events farther to the north in the Hudson River drainage basin.

Under normal flow conditions, the Hudson River estuary tends to import sediment from the seaward direction, but sediment export is expected when spring tides coincide with strong river outflow, for example, during a freshet (Geyer and others, 2001). Under certain conditions, sediment provided by the Hudson River can also be transported towards Rockaway Inlet, at the northeast corner of the bight, and can be made available for transport into Jamaica Bay on incoming tides. Even if a strong freshet coincides with spring tide conditions, wind conditions can strongly affect the movement of the sediment-laden water and prevent it from moving into Jamaica Bay. Modeling results from Choi and Wilkin (2007) suggest that during steady river flow of relatively low volume, a sediment plume advances from the Hudson River estuary into the coastal ocean; upon entering the open shelf, the plume turns westward and flows predominantly along the New Jersey coast. However, northward winds tend to keep fresher (and potentially sediment-laden) water flowing toward the east from the New York Harbor. This eventually leads to a broad, low-salinity area offshore from Long Island, which could potentially be available for transport into Jamaica Bay on flooding tides. For the November 2014 to December 2016 study period,
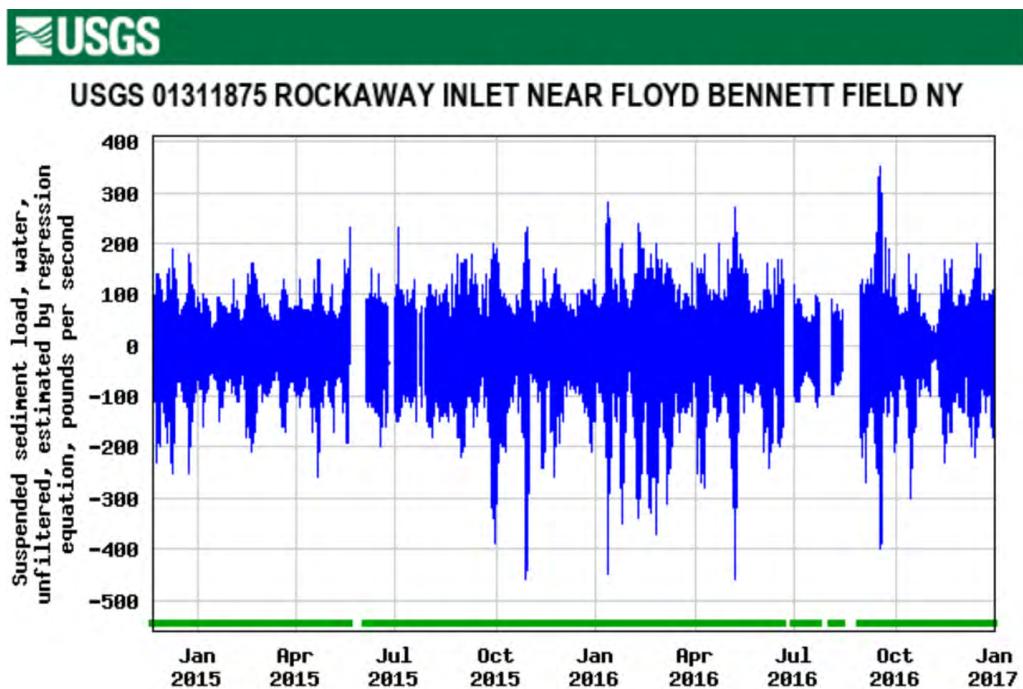
Figure 12.   Suspended-sediment load at Rockaway Inlet at Jamaica Bay, New York, from November 2014 to December 2016. The graph is a screen capture of U.S. Geological Survey (USGS, 2017b) data output.

the highest turbidity event associated with a spring freshet at the USGS Hudson River station (01372058; USGS, 2019) did not cause a discernible increase of sediment flux at the Rockaway station (01311875). Other factors that may affect sediment redistribution in the tidal marsh are the many human activities in the marsh, including inlet and channel dredging, marsh-island restoration efforts, historical mosquito ditching, and boat wakes, to name a few. Dredging in the study area is generally focused on keeping navigable channels open but may be done in concert with marsh-island restoration efforts, whereby sediment from channels is pumped onto existing or artificial marsh islands. The effects of dredging and marsh restoration efforts on sediment flux in Jamaica Bay were not a focus of this investigation and cannot be evaluated without additional data collection.

Examples of Sediment Flux from a Coastal Storm

High winds, waves, and tidal surge associated with coastal storms typically cause resuspension of sediment. Figure 14 shows the increase in turbidity recorded at Rockaway Inlet associated with storm surge and winds from Hurricane Joaquin's track off the eastern seaboard during September and October 2015. Storm tide at Rockaway Inlet exceeded the National Weather Service minor coastal flood elevation (fig 14A) with a storm surge about 2 feet above predicted tidal elevations. Turbidity increased from a mean of about 2 FNU during September 22–24 (prior to Joaquin's approach) to a

mean of about 7 FNU during highest winds and storm surge from October 1 to 3 (fig. 14B). Turbidity remained elevated for several tidal cycles as the storm passed and wind velocity diminished. The small gap in the turbidity record on September 24 represents a routine servicing when the monitor was out of the water for cleaning and calibration. This timely servicing provided a high level of confidence in the turbidity record during the following 2 weeks when water samples were collected for SSC analyses. Suspended-sediment concentrations from fixed-point water samples collected on September 28, 2015, and October 6, 2015, ranged from 3 to 16 mg/L and from 4 to 20 mg/L, respectively, and correlate with the higher recorded turbidity values.

The suspended-sediment load through Rockaway Inlet (fig. 15) reflects the higher turbidities recorded at the tide-gaging station during Hurricane Joaquin. Prestorm loads approached about 100 lb/s, whereas loads were nearly 400 lb/s during and immediately after the storm. Sediment loads are often higher during incoming tides (negative loads on the y-axis) than during outgoing tides. Maximum suspended-sediment loads during the storm exceeded 400 lb/s during incoming tides but were only about 200 lb/s during outgoing tides. Figure 16 demonstrates this trend on a 2-day plot displaying tidal elevation and turbidity. The highest turbidities recorded were during the fastest velocities, which were typically during the later stages of the incoming tide. Higher sediment loads during incoming tides were also observed during nonstorm conditions.
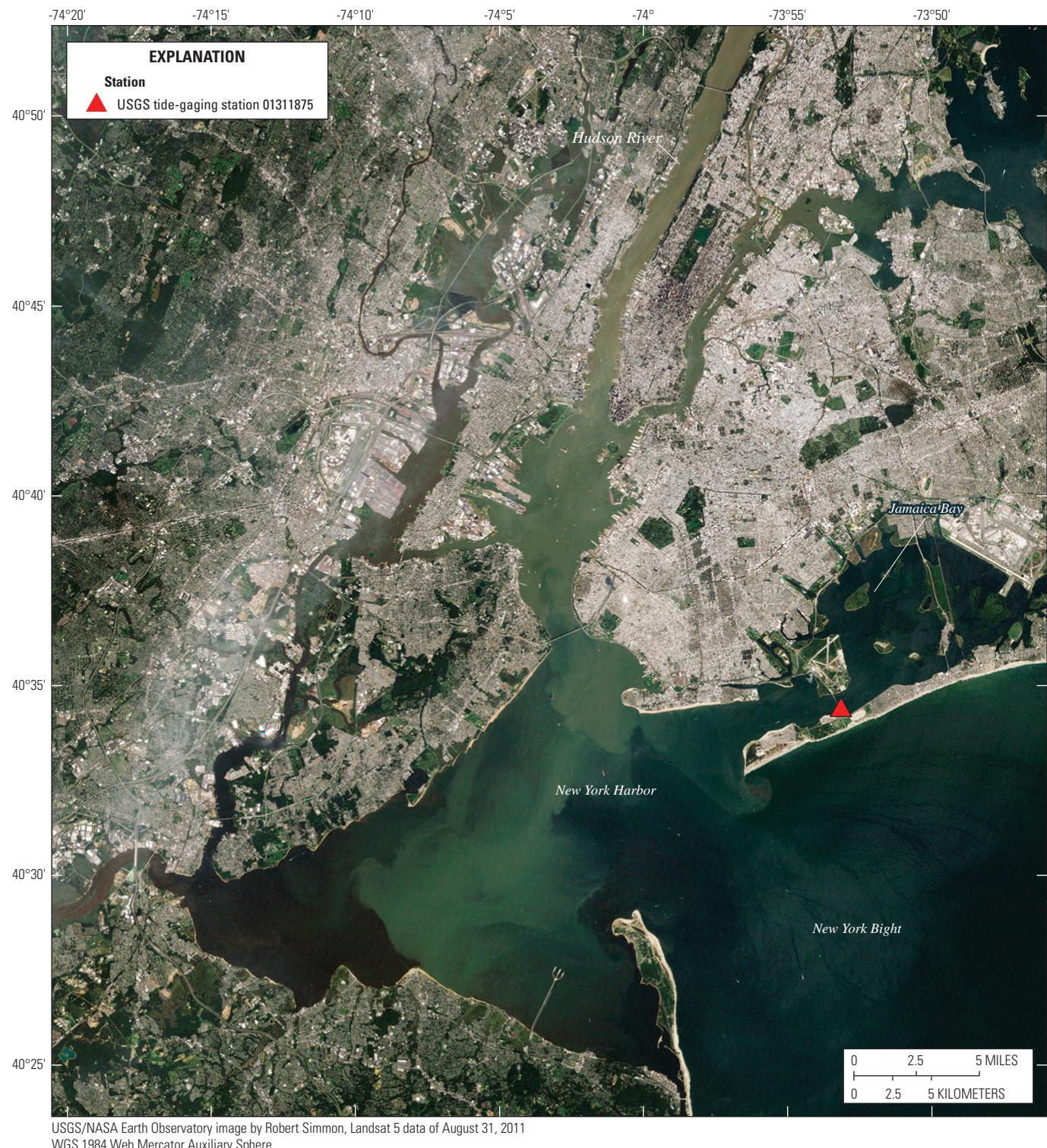
Figure 13. New York metropolitan area and sediment-laden Hudson River discharging to New York Harbor (and New York Bight) after heavy rain associated with Hurricane Irene, August 31, 2011. U.S. Geological Survey (USGS)/National Aeronautics and Space Administration (NASA) Earth Observatory image by Robert Simmon, NASA.

A

B
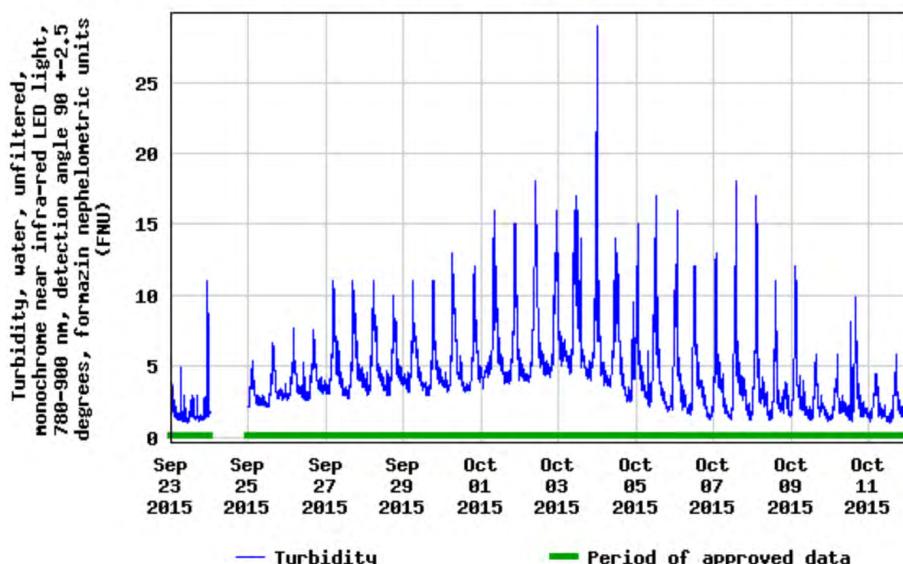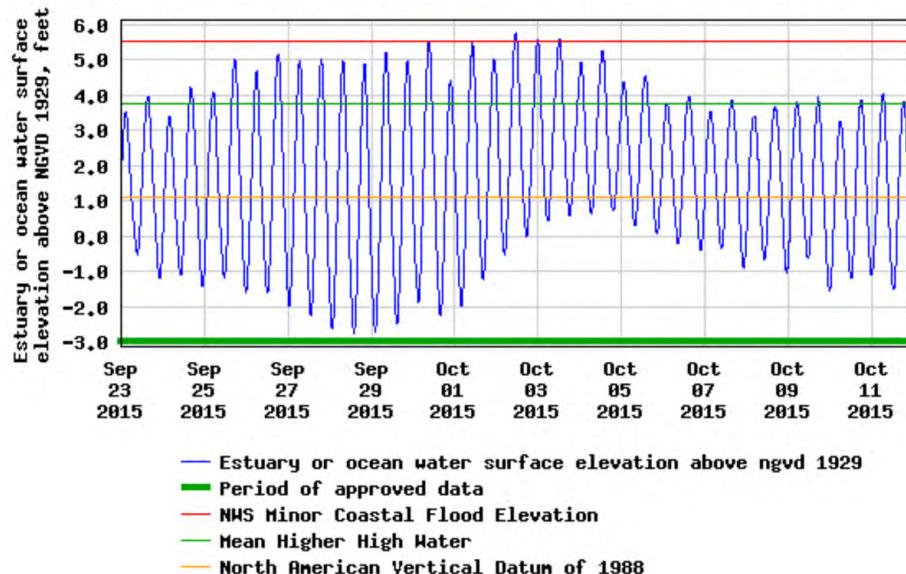
Figure 14.   *A*, Estuary or ocean water-surface elevation and *B*, turbidity at Rockaway Inlet at Jamaica Bay, New York (U.S. Geological Survey [USGS] tide-gaging station 01311875) from September 23 to October 11, 2015, during a period of high winds and minor coastal flooding associated with Hurricane Joaquin. The graphs are screen captures of USGS (2017b) data output. LED, light-emitting diode; NGVD, National Geodetic Vertical Datum; nm, nanometer; NWS, National Weather Service.
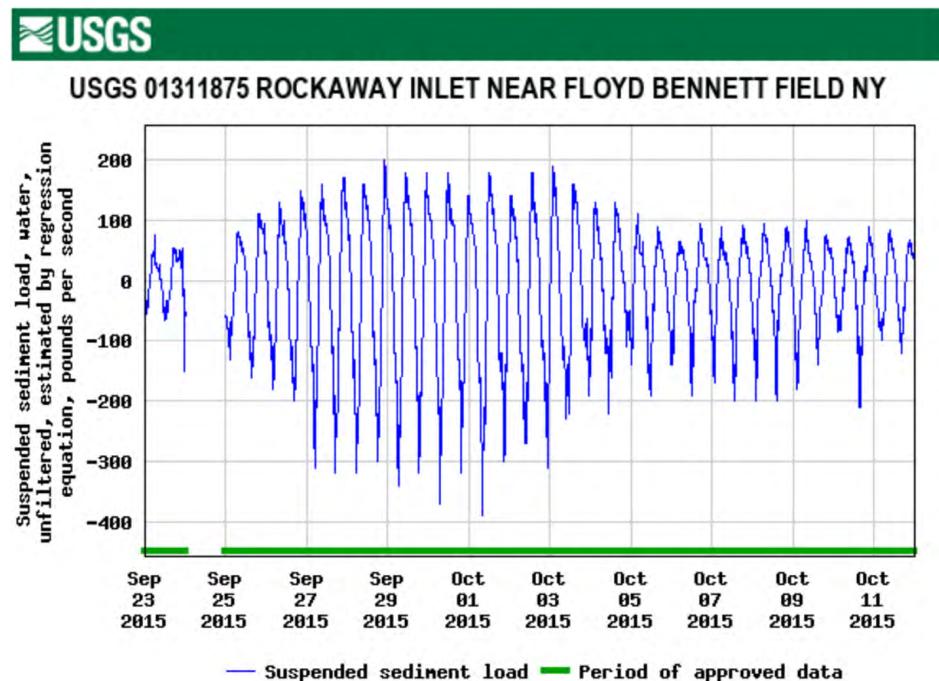
Figure 15.   Suspended-sediment load at Rockaway Inlet at Jamaica Bay, New York
(U.S. Geological Survey [USGS] tide-gaging station 01311875), from September 23 to October
11, 2015, spanning the period October 1–2, when Hurricane Joaquin passed off the eastern
U.S. seaboard. The graph is a screen capture of USGS (2017b) data output.

A
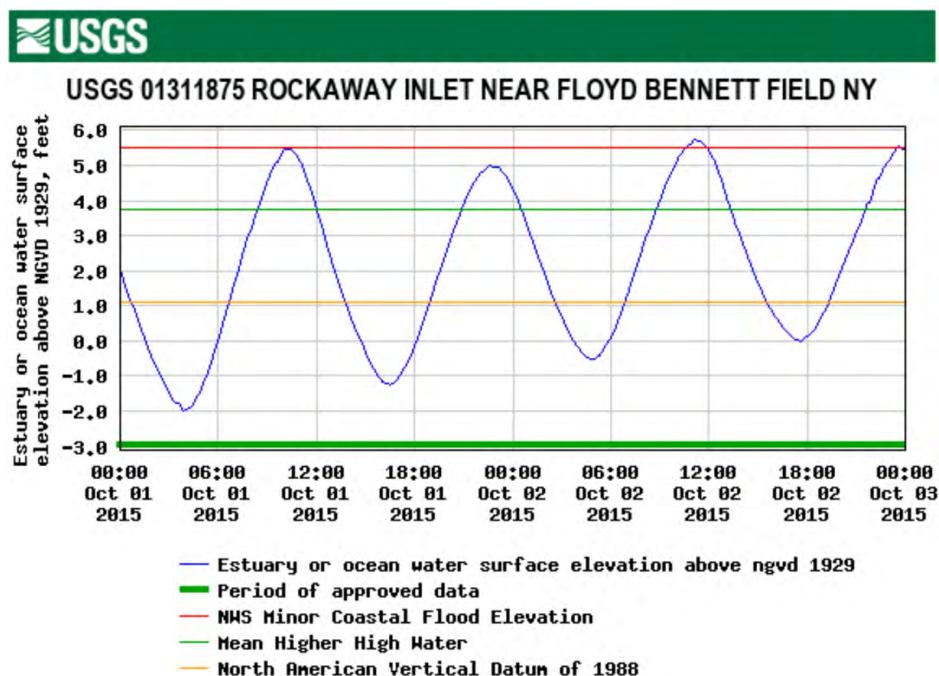
B
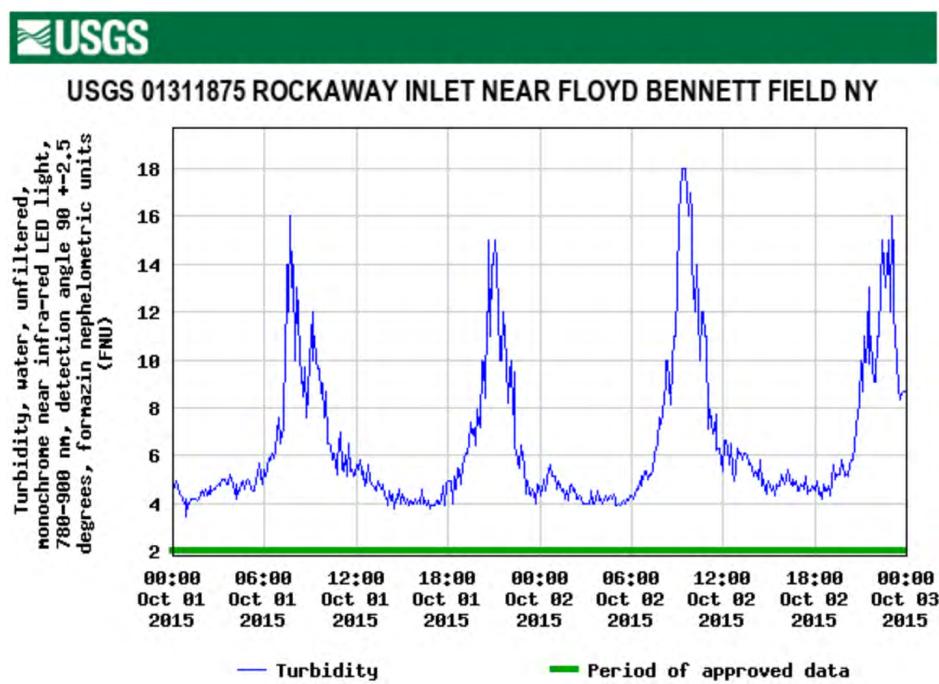
Figure 16. *A*, Tidal elevation and *B*, turbidity at Rockaway Inlet at Jamaica Bay, New York (U.S. Geological Survey [USGS] tide-gaging station 01311875), during October 1–2, 2015, while Hurricane Joaquin passed off the eastern U.S. seaboard. The graphs are screen captures of USGS (2017b) data output. LED, light-emitting diode; NGVD, National Geodetic Vertical Datum; nm, nanometer; NWS, National Weather Service.

Summary and Conclusions

To estimate sediment flux in and out of Jamaica Bay, New York, through Rockaway Inlet, an index-velocity station and turbidity sensor were operated at the Marine Parkway-Gil Hodges Memorial Bridge from November 2014 to December 2016 and suspended-sediment samples were collected and analyzed between April 2015 and May 2016. Daily mean turbidity ranged from 0.6 to 8.2 formazin nephelometric units, and computed daily mean suspended-sediment concentrations ranged from 3 to 13 milligrams per liter. Two regressions were computed based on these data. First, continuous (6-minute) discharge was estimated by generating a simple linear regression (R^2 of 0.981) between mean channel velocity measured from a boat-operated acoustic Doppler current profiler and range-averaged velocity measured at the acoustic Doppler velocity meter, and by then multiplying output from the stage-area and index-velocity relations. Second, suspended-sediment concentration was calculated from a simple linear regression (R^2 of 0.75) of measured suspended-sediment concentration and turbidity at the index-velocity station.

These continuous data can be used in model design and calibration to help determine net sediment fluxes to the wetland complex and to evaluate depositional patterns as well as vulnerability of salt marsh shorelines to wave attack. During the study period from November 2014 to December 2016, calculated sediment fluxes in Rockaway Inlet at Jamaica Bay, N.Y., ranged from about −450 pounds per second (towards bay) to about +350 pounds per second (towards ocean). Sediment fluxes observed during this investigation varied with changing velocities associated with daily tidal cycles, as well as to spring and neap tides, but were generally higher during incoming tides than during outgoing tides. A major coastal storm hitting the Jamaica Bay area would likely have a major effect (export or import) on the sediment budget, so continued sediment monitoring is important.

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Appendix 1.   Data Tables and Statistics for Stage-Area, Index-Velocity, and Turbidity-Suspended-Sediment-Concentration Ratings for U.S. Geological Survey Tide-Gaging Station 01311875, Rockaway Inlet at Floyd Bennett Field, New York

Table 1.1.   Stage-area rating data for U.S. Geological Survey tide-gaging station 01311875, Rockaway Inlet at Floyd Bennett Field, New York.

[Rating developed using the U.S. Geological Survey program AreaComp2, version 1.06. Approximate location of standard cross section is 200 feet east of gage; latitude 40°34'25", longitude 73°53'08" North American Datum of 1927; datum of gage: 0 feet above National Geodetic Vertical Datum of 1929]

Stage (feet)	Area (square feet)
-6.0	97,134.8
-5.5	98,947.4
-5.0	100,763.4
-4.5	102,582.7
-4.0	104,405.4
-3.5	106,231.5
-3.0	108,060.9
-2.5	109,893.8
-2.0	111,730.0
-1.5	113,569.6
-1.0	115,412.5
-0.5	117,258.0
0.0	119,106.0
0.5	120,956.2
1.0	122,808.7
1.5	124,663.6
2.0	126,520.7
2.5	128,380.2
3.0	130,242.0

Stage (feet)	Area (square feet)
3.5	132,106.1
4.0	133,972.5
4.5	135,841.2
5.0	137,718.1
5.5	139,599.0
6.0	141,483.8
6.5	143,376.8
7.0	145,343.6
7.5	147,327.1
8.0	149,326.7
8.5	151,342.2
9.0	153,371.8
9.5	155,414.4
10.0	157,469.8
10.5	159,538.0
11.0	161,619.1
11.5	163,713.1
12.0	165,819.2

Table 1.2.   Index-velocity rating data for U.S. Geological Survey tide-gaging station 01311875, Rockaway Inlet at Floyd Bennett Field, New York.

[Discharge measurements used for rating analysis and correlated with acoustic Doppler velocity meter (ADVM)-observed data to develop an index-velocity rating (fig. 9). mm/dd/yyyy hh:mm:ss, month/date, year, hour, minute, second, in Eastern Standard Time; Q, discharge; A, area; Vi, average index velocity measured by the ADVM, in feet per second; Vx, velocity in the x direction (perpendicular to the instrument)]

Measure-ment number	Date/time of measurement (mm/dd/yyyy hh:mm:ss)	Measured discharge (cubic feet per second)	Mean channel ve-locity (Q/rated A) (feet per second)	Stage (feet)	Vi (feet per second)	Vi × Stage (square feet per second)	Range aver-aged cell (Vx) (feet per second)
15	03/21/2015 10:04:09	317,000	2.400	3.51	2.35	8.25	2.35
16	03/21/2015 10:30:18	324,000	2.506	2.76	2.59	7.15	2.59
17	03/21/2015 10:42:41	322,000	2.516	2.39	2.49	5.96	2.49
18	03/21/2015 11:05:52	307,000	2.450	1.67	2.51	4.20	2.51
19	03/21/2015 11:18:21	305,000	2.464	1.28	2.45	3.14	2.45
20	03/21/2015 12:18:24	260,000	2.217	-0.36	2.17	-0.78	2.17
21	03/21/2015 12:36:25	246,000	2.124	-0.81	2.16	-1.75	2.16
22	03/21/2015 13:06:33	201,000	1.769	-1.43	2.00	-2.86	2.00
23	03/21/2015 13:30:27	186,000	1.664	-1.91	1.97	-3.76	1.97
24	03/21/2015 13:42:18	177,000	1.595	-2.12	1.85	-3.92	1.85
25	03/21/2015 13:54:12	156,000	1.409	-2.28	1.78	-4.06	1.78
26	03/21/2015 14:06:28	137,000	1.247	-2.43	1.53	-3.71	1.53
27	03/21/2015 14:18:28	118,000	1.077	-2.54	1.47	-3.74	1.47
28	03/21/2015 14:30:36	91,600	0.839	-2.62	1.34	-3.52	1.34
29	03/21/2015 14:42:08	64,500	0.591	-2.65	0.81	-2.14	0.81
30	03/21/2015 14:54:09	30,000	0.275	-2.61	0.61	-1.58	0.61
31	03/21/2015 15:05:60	-14,000	-0.128	-2.55	0.01	-0.03	0.01
32	03/21/2015 15:17:54	-46,800	-0.426	-2.42	-0.25	0.60	-0.25
33	03/21/2015 15:30:06	-103,000	-0.930	-2.25	-0.85	1.92	-0.85
34	03/21/2015 15:42:53	-147,000	-1.320	-2.05	-1.53	3.13	-1.53
35	03/21/2015 15:54:50	-181,000	-1.615	-1.83	-2.04	3.73	-2.04
36	03/21/2015 16:06:17	-203,000	-1.798	-1.57	-2.01	3.15	-2.01
37	03/21/2015 16:17:56	-221,000	-1.937	-1.36	-2.03	2.76	-2.03
38	03/21/2015 16:29:47	-234,000	-2.040	-1.06	-2.23	2.36	-2.23
39	03/21/2015 16:42:15	-237,000	-2.036	-0.74	-2.22	1.64	-2.22
40	03/21/2015 16:54:41	-254,000	-2.165	-0.42	-2.38	1.00	-2.38
41	03/21/2015 17:06:06	-257,000	-2.171	-0.09	-2.43	0.22	-2.43
42	03/21/2015 17:18:37	-266,000	-2.219	0.22	-2.74	-0.60	-2.74
43	03/21/2015 17:35:34	-272,000	-2.235	0.70	-2.80	-1.96	-2.80
44	03/21/2015 17:48:16	-276,000	-2.244	1.05	-2.36	-2.47	-2.36
45	03/21/2015 18:00:23	-289,000	-2.327	1.38	-2.85	-3.94	-2.85
46	03/21/2015 18:12:21	-285,000	-2.273	1.69	-2.98	-5.04	-2.98
47	03/23/2015 07:42:04	-235,000	-1.953	0.31	-2.31	-0.72	-2.31
48	03/23/2015 07:54:26	-242,000	-1.995	0.59	-2.52	-1.49	-2.52
49	03/23/2015 08:06:26	-242,000	-1.979	0.86	-2.72	-2.34	-2.72
50	03/23/2015 08:18:51	-247,000	-2.000	1.19	-2.06	-2.45	-2.06
51	03/23/2015 08:30:22	-252,000	-2.024	1.47	-1.67	-2.46	-1.67
52	03/23/2015 08:42:27	-250,000	-1.990	1.75	-1.69	-2.97	-1.69

Table 1.2.   Index-velocity rating data for U.S. Geological Survey tide-gaging station 01311875, Rockaway Inlet at Floyd Bennett Field, New York.—Continued

[Discharge measurements used for rating analysis and correlated with acoustic Doppler velocity meter (ADVM)-observed data to develop an index-velocity rating (fig. 9). mm/dd/yyyy hh:mm:ss, month/date, year, hour, minute, second, in Eastern Standard Time; Q, discharge; A, area; Vi, average index velocity measured by the ADVM, in feet per second; Vx, velocity in the x direction (perpendicular to the instrument)]

Measure-ment number	Date/time of measurement (mm/dd/yyyy hh:mm:ss)	Measured discharge (cubic feet per second)	Mean channel ve-locity (Q/rated A) (feet per second)	Stage (feet)	Vi (feet per second)	Vi × Stage (square feet per second)	Range aver-aged cell (Vx) (feet per second)
53	03/23/2015 09:06:16	-226,000	-1.773	2.26	-1.52	-3.43	-1.52
54	03/23/2015 09:18:22	-205,000	-1.598	2.48	-1.31	-3.25	-1.31
55	03/23/2015 09:36:07	-172,000	-1.330	2.76	-1.06	-2.93	-1.06
56	03/23/2015 09:48:24	-146,000	-1.124	2.90	-1.04	-3.03	-1.04
57	03/23/2015 10:00:25	-114,000	-0.876	3.00	-0.80	-2.39	-0.80
58	03/23/2015 10:12:17	-75,100	-0.575	3.07	-0.69	-2.12	-0.69
59	03/23/2015 10:24:48	-31,200	-0.239	3.07	-0.09	-0.27	-0.09
60	03/23/2015 10:37:04	31,800	0.244	2.98	0.30	0.88	0.30
61	03/23/2015 10:48:35	84,500	0.651	2.87	0.56	1.60	0.56
62	03/23/2015 11:00:08	147,000	1.140	2.68	0.99	2.65	0.99
63	03/23/2015 11:11:43	192,000	1.496	2.49	1.53	3.80	1.53
64	03/23/2015 11:23:58	237,000	1.863	2.18	1.78	3.88	1.78
65	03/23/2015 11:36:17	269,000	2.133	1.89	1.92	3.62	1.92
66	03/23/2015 11:47:59	273,000	2.182	1.62	2.10	3.40	2.10
67	03/23/2015 12:00:09	279,000	2.252	1.30	2.19	2.85	2.19
68	03/23/2015 12:12:31	278,000	2.264	1.00	2.09	2.09	2.09
69	03/23/2015 12:24:05	270,000	2.219	0.71	2.06	1.46	2.06
70	03/23/2015 12:36:27	262,000	2.172	0.41	2.00	0.82	2.00
71	03/23/2015 13:53:47	215,000	1.899	-1.49	2.18	-3.25	2.18
72	03/23/2015 14:06:33	203,000	1.804	-1.75	2.18	-3.81	2.18

Table 1.3.   Suspended-sediment concentrations and turbidity rating data for U.S. Geological Survey tide-gaging station 01311875, Rockaway Inlet at Floyd Bennett Field, New York.

[Suspended-sediment concentrations (SSC) used for simple linear regression (fig. 11) between fixed-point SSC and turbidity and the 90-percent prediction interval, and the mean equal discharge increment (EDI) SSC data. mm/dd/yyyy hh:mm:ss, month/date, year, hour, minute, second, in Eastern Standard Time; Q, discharge; SSC, suspended-sediment concentration; SSL, suspended-sediment load; NA, not applicable]

Sample type	Date and time (mm/dd/yyyy hh:mm:ss)	Turbidity (formazin nephelomet-ric units)	Q (cubic feet per second)	SSC (milli-grams per liter)	SSL (pounds per second)	Regression-computed SSC (milligrams per liter)	Residual SSC	Normal quantiles
Fixed point	9/28/2015 15:00	2.9	853,000	3	159.7	6.262	-3.262	-1.473
Fixed point	9/28/2015 15:30	3.4	791,000	5	246.8	6.908	-1.908	-0.962
Fixed point	9/28/2015 16:00	4.3	748,000	7	326.7	8.07	-1.07	-0.511
Fixed point	9/28/2015 16:30	4.7	727,000	12	544.4	8.586	3.414	1.637
Fixed point	9/28/2015 17:00	6.2	707,000	11	485.3	10.52	0.477	0.247
Fixed point	9/28/2015 17:30	8.7	707,000	16	705.9	13.75	2.249	0.962
Fixed point	9/28/2015 18:00	7.2	697,000	10	434.9	11.81	-1.814	-0.887
Fixed point	9/28/2015 18:12	6.8	681,000	11	467.4	11.3	-0.298	-0.098
Fixed point	9/28/2015 18:30	7.8	687,000	16	685.9	12.59	3.411	1.473
Fixed point	9/28/2015 19:00	8.4	715,000	12	535.4	13.36	-1.364	-0.750
Fixed point	9/28/2015 19:30	5.7	778,000	9	436.9	9.877	-0.878	-0.350
Fixed point	9/28/2015 20:00	4.5	883,000	9	495.9	8.328	0.672	0.298
Fixed point	10/6/2015 9:30	1.7	945,700	4	236	4.713	-0.713	-0.247
Fixed point	10/6/2015 10:00	2	844,000	4	210.7	5.1	-1.1	-0.568
Fixed point	10/6/2015 10:30	2.8	815,000	5	254.3	6.133	-1.133	-0.626
Fixed point	10/6/2015 11:00	5.7	787,000	11	540.2	9.877	1.123	0.568
Fixed point	10/6/2015 11:12	7.3	778,000	15	728.2	11.94	3.057	1.23
Fixed point	10/6/2015 11:30	8.4	818,000	15	765.6	13.36	1.636	0.817
Fixed point	10/6/2015 11:42	9.7	816,000	16	814.7	15.04	0.958	0.511
Fixed point	10/6/2015 12:00	10	857,000	20	1070	15.43	4.571	2.266
Fixed point	10/6/2015 12:30	12	844,000	12	632	18.01	-6.012	-2.266
Fixed point	10/6/2015 12:36	7.7	847,000	12	634.2	12.46	-0.460	-0.197
Fixed point	10/6/2015 13:00	6	886,000	10	552.9	10.26	-0.265	-0.049
Fixed point	10/6/2015 13:30	4.6	936,000	7	408.8	8.457	-1.457	-0.817
Fixed point	10/6/2015 14:00	4.6	945,400	5	295	8.457	-3.457	-1.637
Fixed point	10/6/2015 14:30	3.8	965,000	5	301.1	7.424	-2.424	-1.23
Fixed point	10/6/2015 15:00	4.2	986,900	4	246.3	7.941	-3.941	-1.863
Fixed point	5/26/2016 6:30	1.7	844,000	5	263.3	4.713	0.287	0.147
Fixed point	5/26/2016 7:00	1.8	846,000	8	422.3	4.842	3.158	1.342
Fixed point	5/26/2016 7:30	1.8	823,000	4	205.4	4.842	-0.842	-0.298
Fixed point	5/26/2016 8:00	1.9	846,000	4	211.2	4.971	-0.971	-0.456
Fixed point	5/26/2016 8:42	2.1	835,000	5	260.5	5.229	-0.229	NA
Fixed point	5/26/2016 9:00	2.7	874,000	9	490.8	6.004	2.996	1.132
Fixed point	5/26/2016 9:30	1.7	867,000	9	486.9	4.713	4.287	1.863
Fixed point	5/26/2016 10:00	1.8	890,000	6	333.2	4.842	1.158	0.626
Fixed point	5/26/2016 10:30	1.4	932,300	6	349.1	4.326	1.674	0.887
Fixed point	5/26/2016 11:00	1.4	975,500	7	426.1	4.326	2.674	1.043

Table 1.3.   Suspended-sediment concentrations and turbidity rating data for U.S. Geological Survey tide-gaging station 01311875, Rockaway Inlet at Floyd Bennett Field, New York.—Continued

[Suspended-sediment concentrations (SSC) used for simple linear regression (fig. 11) between fixed-point SSC and turbidity and the 90-percent prediction interval, and the mean equal discharge increment (EDI) SSC data. mm/dd/yyyy hh:mm:ss, month/date, year, hour, minute, second, in Eastern Standard Time; Q, discharge; SSC, suspended-sediment concentration; SSL, suspended-sediment load; NA, not applicable]

Sample type	Date and time (mm/dd/yyyy hh:mm:ss)	Turbidity (formazin nephelometric units)	Q (cubic feet per second)	SSC (milligrams per liter)	SSL (pounds per second)	Regression-computed SSC (milligrams per liter)	Residual SSC	Normal quantiles
Fixed point	5/26/2016 11:30	2	1,051,100	5	327.9	5.1	-0.100	0.049
Fixed point	5/26/2016 12:00	2	1,104,000	5	344.4	5.1	-0.100	0.098
Fixed point	5/26/2016 12:30	1.1	1,182,000	3	221.3	3.938	-0.938	-0.402
Fixed point	5/26/2016 13:00	1.3	1,225,000	5	382.2	4.196	0.804	0.350
Fixed point	5/26/2016 13:54	1.3	1,175,000	5	366.6	4.196	0.804	0.402
Fixed point	5/26/2016 14:30	1.8	1,150,000	2	143.5	4.842	-2.842	-1.342
Fixed point	5/26/2016 15:00	1.3	1,124,000	2	140.3	4.196	-2.196	-1.132
Fixed point	5/26/2016 15:30	1.3	1,116,000	3	208.9	4.196	-1.196	-0.687
Fixed point	5/26/2016 16:00	1.3	1,094,500	5	341.5	4.196	0.804	0.456
Fixed point	5/26/2016 16:30	1.3	1,041,000	2	129.9	4.196	-2.196	-1.043
Fixed point	5/26/2016 17:00	0.8	980,500	5	305.9	3.551	1.449	0.687
Fixed point	5/26/2016 17:30	1.5	937,600	4	234	4.455	-0.455	-0.147
Fixed point	5/26/2016 18:00	1.6	867,000	5	270.5	4.584	0.416	0.197
Fixed point	5/26/2016 18:30	1.5	835,000	6	312.6	4.455	1.545	0.750
Equal discharge increment	4/18/2015 9:30	1.4	NA	4.4	NA	NA	NA	NA
Equal discharge increment	4/18/2015 10:10	1.3	NA	4.2	NA	NA	NA	NA
Equal discharge increment	4/18/2015 16:00	2.3	NA	6.8	NA	NA	NA	NA
Equal discharge increment	4/18/2015 16:05	2.4	NA	6.0	NA	NA	NA	NA
Equal discharge increment	4/13/2016 15:12	2	NA	6.0	NA	NA	NA	NA
Equal discharge increment	4/13/2016 15:54	1.8	NA	6.2	NA	NA	NA	NA
Equal discharge increment	4/14/2016 10:54	2.1	NA	4.6	NA	NA	NA	NA
Equal discharge increment	4/14/2016 11:24	2.2	NA	6.4	NA	NA	NA	NA

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