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Detecting Temporal Change in Land-Surface Altitude Using Robotic Land-Surveying Techniques and Geographic Information System Applications at an Earthen Dam Site in Southern Westchester County, New York

Open-File Report 2017–1028

U.S. Department of the Interior
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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)
foot (ft)	0.3048	meter (m)
square foot (ft^2)	0.09290	square meter (m^2)
cubic foot (ft^3)	0.02832	cubic meter (m^3)

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).

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

Abbreviations

GIS	geographic information system
GNSS	global navigation satellite system
NSSDA	National Standard for Spatial Data Accuracy
NYCDEP	New York City Department of Environmental Protection
RTK	real time kinematic
RMSE	root mean squared error
USGS	U.S. Geological Survey

Detecting Temporal Change in Land-Surface Altitude Using Robotic Land-Surveying Techniques and Geographic Information System Applications at an Earthen Dam Site in Southern Westchester County, New York

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Abstract

In 2005, the U.S. Geological Survey began a cooperative study with New York City Department of Environmental Protection to characterize the local groundwater-flow system and identify potential sources of seeps on the southern embankment at the Hillview Reservoir in southern Westchester County, New York. Monthly site inspections at the reservoir indicated an approximately 90-square-foot depression in the land surface directly upslope from a seep that has episodically flowed since 2007. In July 2008, the U.S. Geological Survey surveyed the topography of land surface in this depression area by collecting high-accuracy (resolution less than 1 inch) measurements. A point of origin was established for the topographic survey by using differentially corrected positional data collected by a global navigation satellite system. Eleven points were surveyed along the edge of the depression area and at arbitrary locations within the depression area by using robotic land-surveying techniques. The points were surveyed again in March 2012 to evaluate temporal changes in land-surface altitude. Survey measurements of the depression area indicated that the land-surface altitude at 8 of the 11 points decreased beyond the accepted measurement uncertainty during the 44 months from July 2008 to March 2012. Two additional control points were established at stable locations along Hillview Avenue, which runs parallel to the embankment. These points were measured during the July 2008 survey and measured again during the March 2012 survey to evaluate the relative accuracy of the altitude measurements. The relative horizontal and vertical (altitude) accuracies of the 11 topographic measurements collected in March 2012 were ±0.098 and ±0.060 feet (ft), respectively. Changes in topography at 8 of the 11 points ranged from 0.09 to 0.63 ft and topography remained constant, or within the measurement uncertainty, for 3 of the 11 points.

Two cross sections were constructed through the depression area by using land-surface altitude data that were interpolated from positional data collected during the two topographic surveys. Cross section *A–A′* was approximately 8.5 ft long and consisted of three surveyed points that trended north to south across the depression. Land-surface altitude change decreased along the entire north-south trending cross section during the 44 months, and ranged from 0.2 to more than 0.6 ft. In general, greater land-surface altitude change was measured north of the midpoint as compared to south of the midpoint of the cross section. Cross section *B–B′* was 18 ft long and consisted of six surveyed points that trended east to west across the depression. Land-surface altitude change generally decreased or remained constant along the east-west trending cross section during the 44 months and ranged from 0.0 to 0.3 ft. Volume change of the depression area was calculated by using a three-dimensional geographic information system utility that subtracts interpolated surfaces. The results indicated a net volume loss of approximately 38 ±5 cubic feet of material from the depression area during the 44 months.

Introduction

Hillview Reservoir in southern Westchester County, New York, was constructed between 1913 and 1916, contains more than 900 million gallons of water, and has been operating continuously since the first water tunnel was constructed in 1917 (Chu and others, 2013). Ninety percent of New York City’s water is piped to the northern end of the reservoir from the Kensico Reservoir, which is fed by the Delaware and Catskill aqueducts in upstate New York. The water is chlorinated at the reservoir and piped from the southern end of the reservoir for distribution to users in the city (fig. 1). Since the late 1990s, several seeps have been observed flowing from the steepest slope (referred to as “southern embankment” in this report) of the earthen embankment at the southern end of the facility. In 2001, the New York City Department of Environmental Protection (NYCDEP) drilled 16 wells at the southern end of the reservoir to identify potential sources

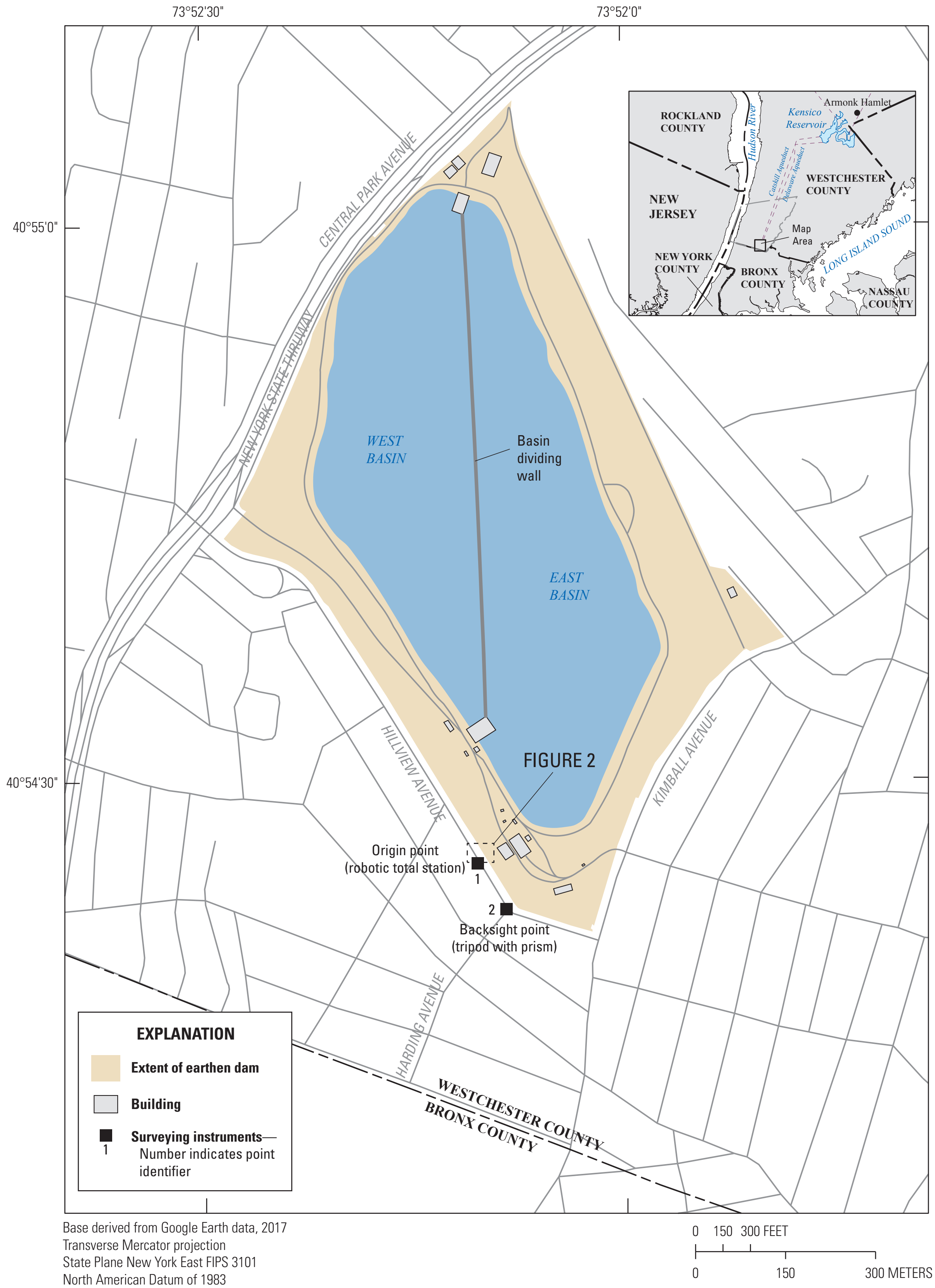

Figure 1. Location of the Hillview Reservoir, Westchester County, New York, and survey points.

of the seeps. An additional nine existing wells were used to supplement the monitoring network (25 wells total) for the seepage investigation.

In 2005, the U.S. Geological Survey (USGS) began a cooperative study with NYCDEP to characterize the local groundwater-flow system at the reservoir and identify potential sources of seeps. Monthly site inspections at the reservoir revealed a depression of approximately 90 square feet (ft^2) in the land surface. The depression was directly upslope from a seep at the toe of the southern embankment (fig. 2). Qualitative observations during regular site visits from 2005 through 2008 indicated that the depression area upslope of the primary seep seemed to be increasing in areal extent (area) and depth (volume). In an attempt to detect topographic change within the depression area, the USGS measured land-surface altitudes during two topographic surveys—the first in July 2008 and the second in March 2012—with a robotic total station (described in the “Robotic Surveying” section). A third topographic survey was planned for the spring of 2016; however, the depression area near the seep was covered with large stones, gravel, and construction debris in the summer of 2012 so representative land-surface altitudes could no longer be measured.

Purpose and Scope

Positional data collected during the two topographic surveys are presented in this report to determine if land-surface altitude changed near a seep at the toe of the southern embankment at Hillview Reservoir during the 44 months between July 2008 and March 2012. Volume change estimates that are presented in this report were made with a geographic information system (GIS) to quantify potential volume loss of sediment from the depression area. Contour maps of land-surface altitudes and temporal land-surface altitude change are shown in illustrations.

Hydrogeologic Setting

The embankment at the southern end of the Hillview Reservoir is part of the earthen dam that surrounds and contains water in the east and west basins of the reservoir. It is comprised of reworked Pleistocene material consisting of clays, silts, and fine sands; artificial fill consisting of modified glacial clays; and unmodified glacial till (New York City Department of Environmental Protection, 1909; Chu and others, 2013). During the construction of the Hillview Reservoir, these reworked materials were placed on an underlying layer of low-permeability Pleistocene-age glacial till and drift that unconformably lie on top of metamorphic bedrock. The hydrogeology of the southern embankment (and the earthen dam site) is detailed in Chu and others (2013).

Study Area

The depression area is at the toe of the southern embankment of Hillview Reservoir adjacent to the seep, and southwest and downslope of the east basin and reservoir operations buildings (fig. 1). A chain link fence, a stone retaining wall, and residential housing units along Hillview Avenue are to the west and downslope of the depression area. The areas to the north, northwest, and southeast of the depression area are part of the southern embankment and are characterized by a steep land-surface gradient, episodic groundwater seeps, and vegetation (trees, bushes, and grasses). Variable diameter trees and brush grew from the depression area until a recent effort by the NYCDEP to remove vegetation from the southern embankment and the earthen dam site as a whole. The southern embankment has the steepest land-surface altitude gradient (approximately 53 percent) at the Hillview Reservoir that is indicated by recently collected topographic data. Land-surface altitude ranges from approximately 300 feet (ft) above the North American Vertical Datum of 1988 (NAVD 88) at the top (crest) of the embankment, to 225 ft above NAVD 88 behind the wall (toe) parallel to Hillview Avenue that retains part of the southern embankment. The downslope angle of the embankment is approximately 62 degrees (°).

Methods of Investigation

A robotic total station (described in the “Robotic Surveying” section) was used to precisely determine the altitude of the depression area on the southern slope of Hillview Reservoir in July 2008 and March 2012. The results of these surveys were analyzed by using a GIS to determine the distribution of altitude change within the depression area and estimate volume change during the 44 months between topographic surveys. The positional data presented in this report are referenced to a global navigation satellite system (GNSS) measurement of the origin point where the total station was positioned (fig. 1, point 1) approximately 100 ft west of the depression area on the western side of Hillview Avenue (figs. 1 and 2; table 1). A GNSS measurement was also used to establish a horizontal position of the backsight location and trigonometric leveling (total-station-based levels) were used to establish the altitude. The locations of the point of origin and the backsight were selected because the baseline distance between the two points is long relative to the distance from the origin point to the depression area (increases angular accuracy of the total station); the locations were relatively stable, so the surveying equipment could be placed at the control point positions at a later date (repeatability); and the points were suitable for GNSS observations.

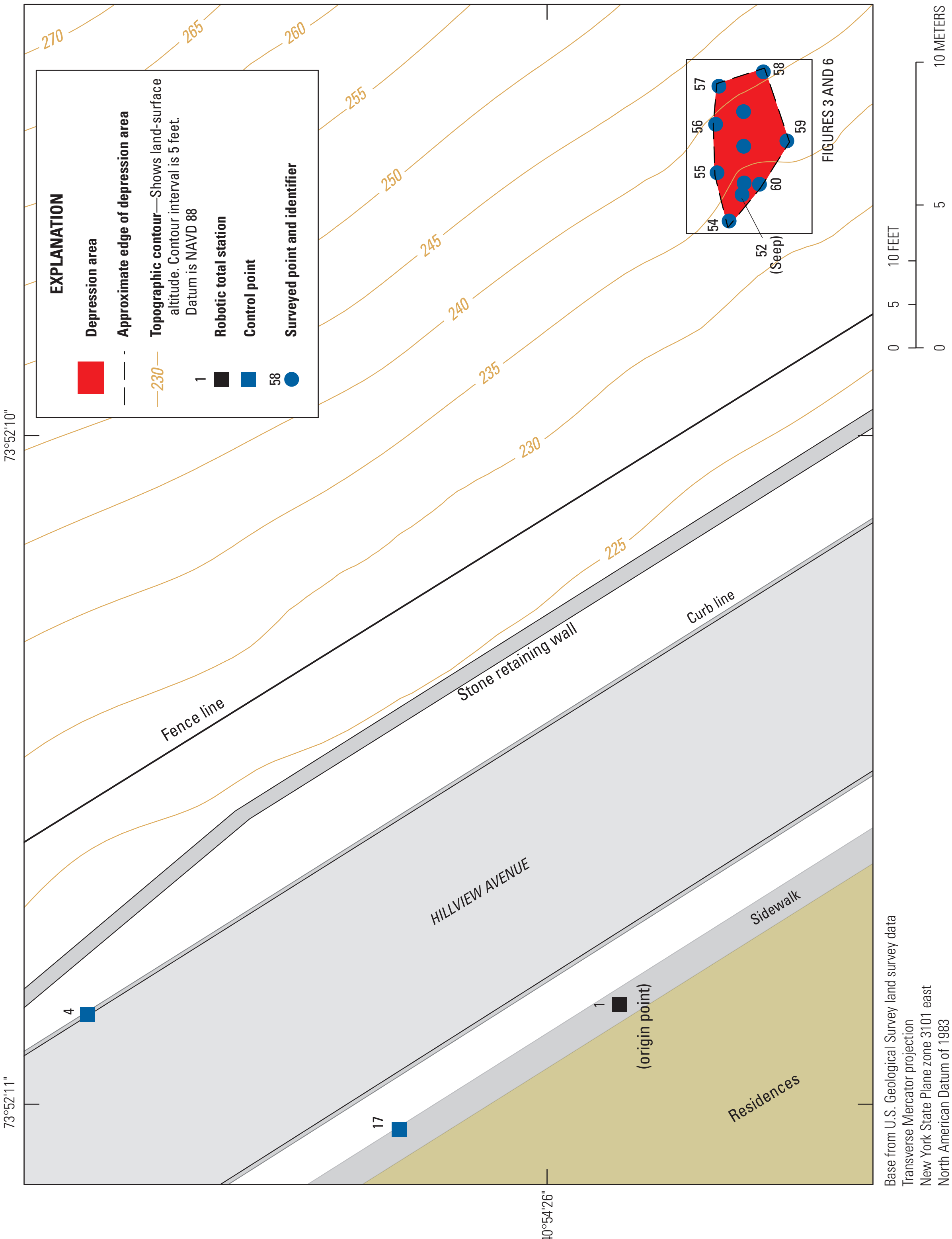

Figure 2. Location of survey points and extent of depression area on the southern hillside of the Hillview Reservoir, Westchester County, New York. Location is shown in figure 1.

Table 1. Coordinates of surveyed points near the southern embankment at the Hillview Reservoir, Westchester County, New York, in 2008 and 2012.

[Altitude is referenced to the North American Vertical Datum of 1988. Horizontal coordinates (northing and easting) are New York State Plane, zone 3101 east, referenced to the North American Datum of 1983. Altitude difference was calculated by subtracting surveyed altitudes derived from the 2008 topographic survey from altitude derived from the 2012 topographic survey. Locations of points are shown on figures 1 and 2. —, no data]

Point number	Northing, in feet	Easting, in feet	Altitude, in feet		Altitude difference, in feet	Altitude uncertainty, in feet	Description
			July 2008	March 2012			
1	756,015.7	666,334.5	219.052	—	—	—	Origin point
2	755,752.0	666,501.6	205.293	—	—	—	Backsight point
4	756,076.7	666,333.5	220.067	220.063	-0.004	±0.008	Control point
17	756,040.9	666,320.3	220.066	220.063	-0.003	±0.008	Control point
52	756,001.5	666,427.6	232.53	232.53	0.00	±0.060	Topography measurement
54	756,003.0	666,424.5	234.41	234.32	-0.09	±0.060	Topography measurement
55	756,004.4	666,430.0	237.29	237.12	-0.17	±0.060	Topography measurement
56	756,004.6	666,435.7	239.75	239.12	-0.63	±0.060	Topography measurement
57	756,004.2	666,440.0	242.08	242.11	0.03	±0.060	Topography measurement
58	755,999.1	666,441.7	241.01	240.98	-0.03	±0.060	Topography measurement
59	755,996.4	666,433.7	236.09	235.93	-0.16	±0.060	Topography measurement
60	755,999.6	666,428.8	234.60	234.44	-0.16	±0.060	Topography measurement
61	756,001.3	666,428.9	234.30	234.05	-0.25	±0.060	Topography measurement
62	756,001.4	666,433.2	236.24	235.90	-0.34	±0.060	Topography measurement
63	756,001.4	666,437.0	238.33	238.22	-0.11	±0.060	Topography measurement

Real-Time Kinematic Surveying

The point of origin for the topographic surveys was a masonry nail set in a sidewalk along the western side of Hillview Avenue approximately 100 ft west of the depression area (figs. 1 and 2). The geographic coordinates of this point were determined in July 2008 with a GNSS by using a single-base real-time kinematic (RTK) surveying method. This method is more commonly referred to as “rover-base” global positioning and requires a base station composed of a dual-frequency receiver mounted over a high-accuracy (resolution less than 1 inch) benchmark of known altitude. The base-station receiver, located near Armonk, N.Y., broadcasts a positional correction to the rover receiver (at the reservoir site) in real time that is used to derive a corrected altitude at the rover’s position (fig. 1; Rydlund and Densmore, 2012). The single-base RTK method assumes similar satellite geometry and atmospheric conditions (and other sources of positional error) at the locations of the rover and the base station because of the relatively small baseline distance between stations.

RTK was also used to determine the horizontal position of the backsight location (fig. 1, point 2), which was a masonry nail set in the top of a concrete curb at the northwestern corner of Harding Avenue and Hillview Avenue and is where the stationary reflective prism was placed. The altitude of the backsight point was determined with a trigonometric leveling method by using a total station; the vertical difference between the point of origin and the backsight can be calculated if the distance between the points and the vertical (zenith) angle are known, both of which can be precisely measured by the total station. Measurements taken by the total station at the point of origin indicate that the altitude of the backsight point did not change during the 44 months between topographic surveys. This altitude check of the backsight is done before, during, and after each topographic survey for quality assurance and was used to identify potential movement of the instruments during the topographic surveys and movement of the physical markers between topographic surveys.

Robotic Surveying

Robotic land-surveying techniques (robotics) were used to measure land-surface altitudes along the edge and within the depression area. A total station is an electronic digital theodolite with a built-in electronic distance measurement tool (Kavanagh, 2004). The robotic total station functions much like a conventional total station except the operator commands the robotic total station remotely from a target location by transmitting instructions using a radio signal. Instructions are transmitted from a radio that is connected to a data-collection device and are received by a second radio that is connected to the total station. For some instruments, the data collection device is a removable faceplate that can be disconnected from the robotic total station and mounted to a telescoping aluminum prism pole. The total station tracks the position of the target (prism) by processing a broadcasted signal from an omni-directional prism that is mounted to the top of the prism pole. Instrument tracking is done with an internal motor that is able to precisely point the instrument at the center of the omni-directional prism. The operator commands the total station to make a measurement when the instrument is locked on the prism. After the measurement is made, and the data have been collected, the operator moves to the next target location and continues the land survey. Distances to targets are measured by the total station with a laser-based long-range distance meter and a phase-comparison method. The phase difference between the transmitted light and the reflected received light is detected and represents distance to the target (Trimble Inc., 2016).

The first of the two topographic surveys was conducted on July 17, 2008. To prepare for the topographic survey, the total station was mounted to a tripod and set up above the origin point (figs. 1 and 2). A stationary reflective prism (backsight) was mounted to a tripod above the backsight point south along Hillview Avenue approximately 315 ft south of the origin point (fig. 1). In total, 13 points were surveyed along the edge of the depression area, at arbitrary locations within the depression area, and at two locations along Hillview Avenue (figs. 2 and 3; table 1). A flat-bottom topographic shoe was attached to the bottom of the prism pole to make sure the pole did not sink into the soil during the topographic surveys conducted near the depression area.

The two points along Hillview Avenue—a fire hydrant bolt (point 4) and a cross cut on a curb (point 17)—were measured for horizontal and vertical (altitude) control because the locations were considered stable (fig. 2). The two control points were resurveyed on March 30, 2012, for quality assurance. The relative positional errors—the difference between the positional data collected during the July 2008 and March 2012 surveys—of control points 4 and 17 are less than 0.1 ft in the horizontal direction (northing and easting) and less than 0.01 ft in the vertical direction (altitude). The relatively small positional errors for both points validated the stability of the physical markers and the area near the curb and the fire hydrant along Hillview Avenue during the 44 months between topographic surveys. The error associated with these measurements is discussed in detail in the “Measurement Uncertainty” section.

To resurvey the points that were evaluated in July 2008 for the March 2012 survey, a robotic total station was used to determine the correct point locations. To accomplish this, the horizontal coordinates (northing and easting) documented during the original survey were loaded into a data collector, which was paired with the total station. The total station was then programmed to direct the operator to the original surveyed locations. Surveyed locations from the July 2008 survey were surveyed again in March 2012 within ±0.1 ft. This technique is traditionally referred to as a stake out, which is the industry standard for accurately determining locations that were previously surveyed.

Measurement Uncertainty

A numerical approach was used to assess the relative accuracy of the altitude measurements made by the total station, and to validate the stake-out approach used to survey the points within the depression area for the March 2012 survey. For numerical accuracy of spatial data, the national standard for spatial data accuracy (NSSDA) method that computes the root mean squared error (RMSE) at the 95-percent confidence level of the survey data is acceptable (Wilson and Richards, 2006; Rydlund and Densmore, 2012).

Validation of Stake-Out Method

The differences in the measured horizontal coordinates between the July 2008 and March 2012 topographic surveys (residuals) were used to evaluate the relative accuracy of the stake-out method. The term “relative” is used in this report to describe how well the horizontal measurements from the March 2012 survey match the horizontal measurements from the July 2008 survey at the 13 surveyed locations. The July 2008 horizontal coordinates are considered to be the control points for the surveys because the actual values for these locations are unknown. The relative root mean squared error was calculated in the northing direction (table 2) by using the following equation:

$$RMSE_y = \sqrt{\sum_{i=1}^{n} \frac{\left(y2008_i - y2012_i\right)^2}{n}}, \qquad (1)$$

where

$RMSE_y$ is the relative root mean squared error for northing,

$y2008$ are the northing coordinates from July 2008 land survey,

$y2012$ are the northing coordinates from March 2012 land survey,

i is an integer from 1 to n, and

n is the number points being checked.

The relative root mean squared error was calculated the same way for the easting coordinates (table 2), by using the following equation:

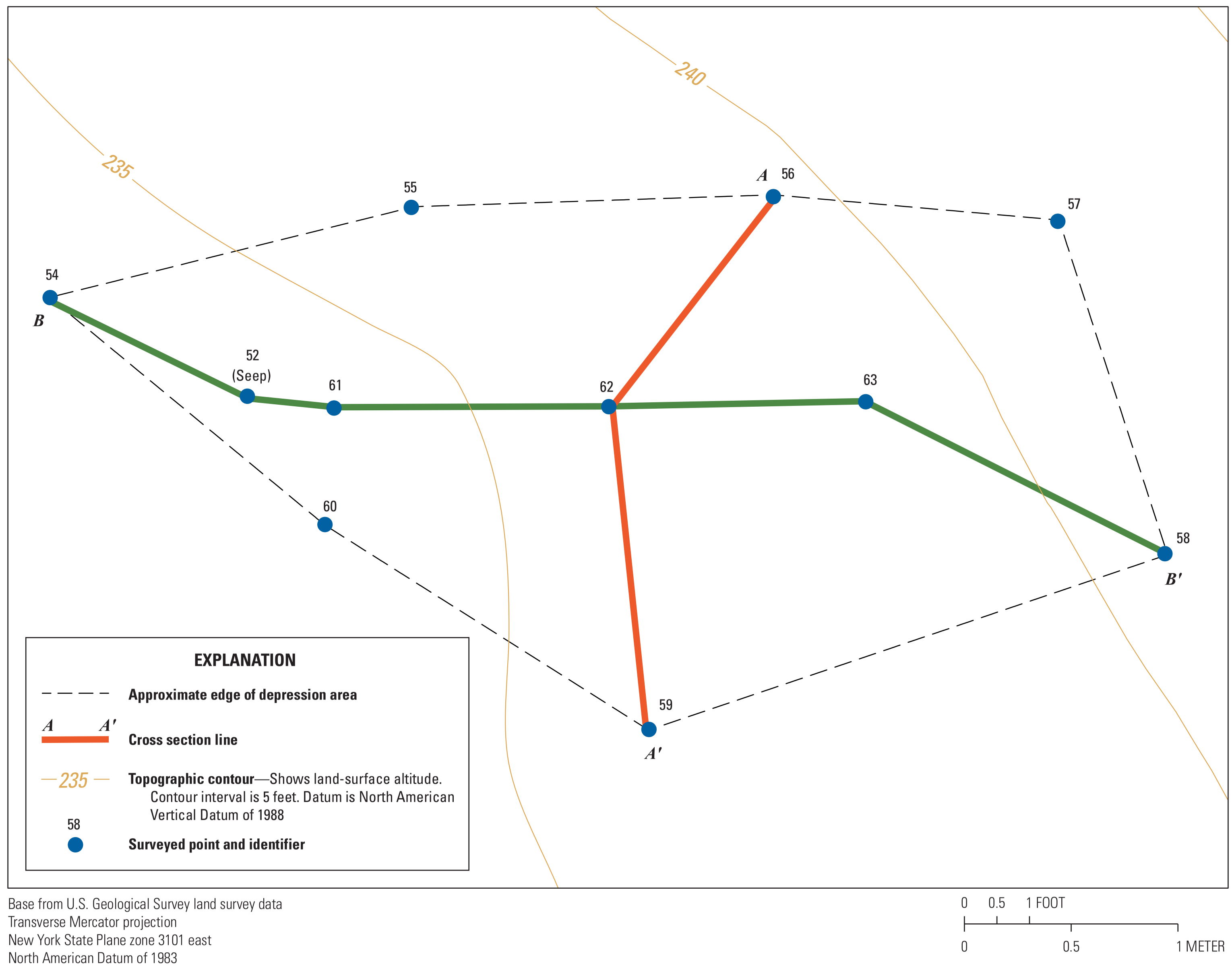

Figure 3. Location of survey points and cross section lines from the topographic surveys in 2008 and 2012 of the southern embankment at the Hillview Reservoir, Westchester County, New York. Location of points are shown in figure 2.

Table 2. Relative horizontal root mean square error for surveyed points on the southern embankment at the Hillview Reservoir, Westchester County, New York, in 2008 and 2012.

[Horizontal coordinates (northing and easting) are New York State Plane, zone 3101 east, referenced to the North American Datum of 1983. Locations of points are shown on figures 1 and 2. NA, not applicable]

Point number	Northing, in feet			Easting, in feet		
	July 2008	March 2012	Residuals	July 2008	March 2012	Residuals
4	756,076.653	756,076.714	-0.061	666,333.479	666,333.420	0.059
17	756,040.859	756,040.908	-0.049	666,320.264	666,320.207	0.057
52	756,001.482	756,001.546	-0.064	666,427.577	666,427.561	0.016
54	756,002.983	756,003.031	-0.048	666,424.521	666,424.532	-0.011
55	756,004.401	756,004.417	-0.016	666,430.020	666,430.079	-0.059
56	756,004.563	756,004.582	-0.019	666,435.663	666,435.643	0.020
57	756,004.172	756,004.204	-0.032	666,440.030	666,440.012	0.018
58	755,999.102	755,999.097	0.005	666,441.671	666,441.658	0.013
59	755,996.352	755,996.397	-0.045	666,433.692	666,433.731	-0.039
60	755,999.551	755,999.546	0.005	666,428.772	666,428.753	0.019
61	756,001.348	756,001.306	0.042	666,428.917	666,428.893	0.024
62	756,001.362	756,001.356	0.006	666,433.168	666,433.115	0.053
63	756,001.439	756,001.373	0.066	666,437.044	666,437.090	-0.046
Root mean squared error						
Northing			0.042	NA	NA	NA
Easting			NA	NA	NA	0.038

$$RMSE_x = \sqrt{\sum_{i=1}^{n} \frac{\left(x2008_i - x2012_i\right)^2}{n}}, \tag{2}$$

where

$RMSE_x$ is the relative root mean squared error for easting,

$x2008$ are the easting coordinates from July 2008 land survey, and

$x2012$ are the easting coordinates from March 2012 land survey.

Error distribution is circular for horizontal (northing and easting) measurements and linear for vertical (altitude) measurements. For approximating circular error when $RMSE_x$ is not equal to $RMSE_y$, the NSSDA level (Greenwalt and Schultz, 1968; Federal Geographic Data Committee, 1998) recommends using the following equation to estimate measurement accuracy at the 95-percent confidence:

$$Accuracy_h \sim 2.4477 \times 0.5 \times (RMSE_x + RMSE_y), \tag{3}$$

where

$Accuracy_h$ is the relative horizontal accuracy at the 95-percent confidence level.

The relative accuracy of the horizontal coordinates collected during the March 2012 survey at the 95-percent confidence level is ±0.098 ft. This indicates that the horizontal (northing and easting) measurements of the 13 locations resurveyed during March 2012 were measured within a 0.098-ft radius of the original surveyed location. This uncertainty can be attributed to random errors, such as the prism and rod not being completely orthogonal (plumb) to the land surface at the time of the measurement, or a systematic uncertainty, such as the manufacturer-specified distance-weighted error of the total station described in appendix 1.

Altitude Accuracy

The relative root mean squared error of the altitude measurements collected by the total station at the 13 locations surveyed during the March 2012 topographic survey was calculated (Greenwalt and Schultz, 1968; Federal Geographic Data Committee, 1998) by using the following equation:

$$RMSE_a = \sqrt{\sum_{i=1}^{n} \frac{\left(a2008_i - a2012_i\right)^2}{n}}, \tag{4}$$

where

$RMSE_a$ is the relative root mean squared error for altitude,

a2008 is the altitude of a point from the July 2008 topographic survey, and

a2012 is the altitude of a point from the March 2012 topographic survey.

To evaluate the relative accuracy of the altitude measurements ($Accuracy_a$) at the 95-percent confidence level, the following equation may be used:

$$Accuracy_a = 1.96 \times RMSE_a . \quad (5)$$

The two stable control points (fig. 2, points 4 and 17; table 3) were selected to evaluate the accuracy of the altitude dataset from the March 2012 survey. No altitudes are known or published for points 4 and 17 so the altitude accuracy of the March 2012 survey is relative to the July 2008 survey and is not considered absolute. The remaining 11 points on the southern embankment near or within the depression area may have been affected by land-surface altitude change during the 44 months between topographic surveys and are not considered stable. The relative accuracy for the altitude measurements collected during the March 2012 land survey is ±0.008 ft, which outperformed the expected manufacturer specification of ±0.027 ft at the 95-percent confidence level (appendix 1; Trimble Inc., 2015).

Additional relative altitude uncertainty associated with the horizontal accuracy needs to be considered for the 11 measurements that bound or are within the depression area on the southern embankment. A downslope angle of approximately 62° and a horizontal positioning error ($Accuracy_h$) of ±0.098 ft could result in an additional altitude error of ±0.052 ft (fig. 4). The altitude uncertainty due to the horizontal positioning error (±0.052 ft) plus the altitude accuracy calculated from the root mean squared error at the 95-percent confidence level (±0.008 ft) indicates that the total potential relative uncertainty for the 11 measurements could be ±0.060 ft. The altitude measurements of control points 4 and 17 should be unaffected by the altitude uncertainty resulting from the horizontal positioning error because the land surface is essentially flat at these locations.

Modeled Surfaces

A natural-neighbors interpolation (Sibson, 1981) was used to create continuous land-surface models of the depression area for July 2008 and March 2012 using the measured altitude values from the topographic surveys. The natural-neighbors method does not infer anomalies in the interpolated surface but rather requires that interpolated values are within the range of the known (measured) values. The method assigns values to unknown points by creating Theissen polygons around the known points that are closest to the unknown point. Another polygon is then constructed around the unknown point and the percentage of overlap between the polygons surrounding the known points, and the polygon surrounding the unknown point, determines the interpolated value of the unknown point. The sections that are shown in this report were constructed using the interpolated altitude data from the modeled surfaces, and are described in the “Land-Surface Altitude Change” section. These interpolated data are reported to 0.1 ft in this report.

Land-Surface Altitude Change

Eleven points along the edge and within the depression area were measured during the July 2008 topographic survey and were measured again during the March 2012 survey to evaluate potential land-surface altitude change during the 44 months between the two surveys (figs. 2 and 3; table 1). Apparent land-surface altitude (topography) decreased at 8 of the 11 surveyed points from July 2008 to March 2012 (table 1). Altitude remained constant or within measurement uncertainty, as discussed in the “Measurement Uncertainty”

Table 3. Relative vertical root mean square error for surveyed points on the southern embankment at the Hillview Reservoir, Westchester County, New York, in 2008 and 2012.

[Vertical coordinates are referenced to the North American Vertical Datum of 1988. Locations of points are shown on figure 2. NA, not applicable]

Point number	Altitude, in feet		Residuals, in feet
	July 2008	March 2012	
4	220.067	220.062	0.005
17	220.066	220.063	0.003
Relative root mean squared error for altitude	NA	NA	0.008

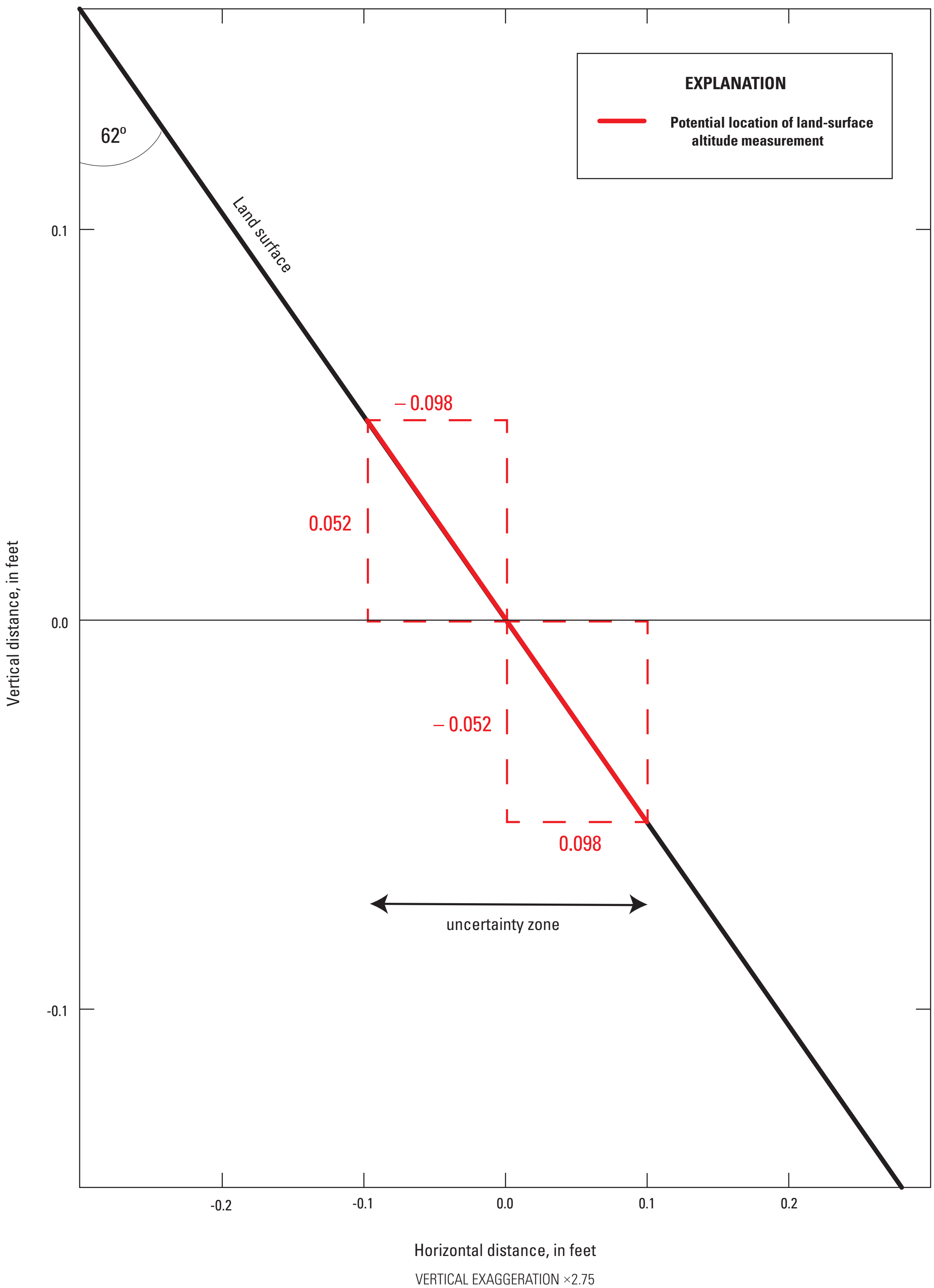

Figure 4. Potential altitude error resulting from a horizontal positional error of plus or minus (±) 0.098 foot on a slope that has a downslope angle of approximately 62 degrees at the Hillview Reservoir, Westchester County, New York, between 2008 and 2012. Vertical exaggeration is approximately 2.75 times.

section, at 3 of the 11 points. Changes in altitude ranged from 0.00 to 0.63 ft at points 52 and 56, respectively, and the median and mean of the absolute differences were 0.16 and 0.18 ft, respectively. Point 56 is 8.6 ft east-northeast of the surface expression of the seep (point 52) that was measured in July 2008.

Two-dimensional (cross section) and 3-dimensional (contour map) models based on positional data collected by the total station were constructed to visualize temporal land-surface altitude change during the 44 months between July 2008 and March 2012.

Cross Section *A–A′*

Cross section *A–A′* generally trends north-south, is 8.5 ft long, and intersects survey points 56, 59, and 62, which is approximately 0.3 ft north of the midpoint of the line (figs. 3 and 5). A temporal comparison of cross section *A–A′* indicates that land-surface altitude decreased along the entire cross section from July 2008 to March 2012 with indicated movement decreasing from north to south. In general, greater land-surface altitude change was detected northeast of the seep (point 52) as compared to southeast, and north of the midpoint of the section (near point 62) as compared to south. Interpolated land-surface altitudes along cross section *A–A′* range from 236.1 to 239.8 ft above NAVD 88 during the July 2008 survey and from 235.9 to 239.1 ft above NAVD 88 during the March 2012 survey. Land-surface altitude changes along cross section *A–A′* ranged from 0.2 ft near point 59 to more than 0.6 ft near survey point 56 (fig. 5; table 1).

Cross Section *B–B′*

Cross section *B–B′* generally trends east-west and intersects survey points 52, 54, 58, 61, 62, and 63 (figs. 3 and 5). Interpolated land-surface altitudes along the approximately 18-ft cross section range from 232.5 to 241.0 ft above NAVD 88 for both the July 2008 and March 2012 surveys. Altitude changes during the 44 months between topographic surveys along cross section *B–B′* were not uniform, ranging from 0.0 ft near points 52 and 58 to more than 0.3 ft near survey point 62 (fig. 5; table 1). The largest altitude change along cross section *B–B′* occurred near points 61, 62, and 63, which are approximately 1.3, 5.3, and 9.5 ft east of the seep (point 52), respectively. Land-surface altitude near the seep apparently did not change during the 44 months.

Contour Maps

Topographic contour lines were generated from the interpolated surfaces (fig. 5) of cross sections *A–A′* and *B–B′* for the July 2008 and March 2012 surveys. The contour lines ranged from 233 to 242 ft above NAVD 88 and are depicted at an interval of 1 ft (fig. 6). The contour map created from the 2012 survey data is characterized by greater contour spacing compared with the map from the 2008 survey data, indicating a reduced land-surface gradient during the 44 months. The land-surface gradient between points 56 and 60 was 60 percent (or a downslope angle of 59°) in 2008 and 55 percent (61°) in 2012. Points 56 and 60 were selected to evaluate the gradient and downslope angle because they are generally oriented parallel to the direction of the slope, or in an approximately northeast-trending line.

A contour interval less than 1 ft could have been used considering the 0.060-ft relative accuracy of the altitude dataset according to the NSSDA requirement for selecting contour intervals that are generated from digital elevation models (National Digital Elevation Program, 2004). For this reason, altitude differences are reported in the following section to 0.1 ft.

A third contour map (fig. 6*C*) was created based on a third surface that was generated by subtracting the interpolated surfaces of the July 2008 survey from those of the March 2012 survey. This map indicates the spatial distribution of temporal land-surface altitude change from July 2008 to March 2012. In general, the greatest land-surface altitude change occurred in the center of the depression area, in contrast to little or no change in topography near the eastern and western edges of the depression area. Contour values for altitude difference range from -0.6 to 0.0 ft, and are mapped at an interval of 0.2 ft. Negative values indicate that land-surface altitude decreased during the 44 months between surveys.

Volume Change

A GIS tool that identifies regions of surface material removal, surface material addition, and areas where the surface has not changed (Esri, Inc., 2012) was used to estimate volume change between the interpolated surfaces that were created from the July 2008 and March 2012 topographic surveys. The tool divided the interpolated surfaces into 83,378 cells that have an equal area of approximately 0.00108 square foot (1 square centimeter). The interpolated altitude from the July 2008 survey was subtracted from that of the March 2012 survey at each cell location. The altitude difference was multiplied by the area of the cell to calculate the change in volume. The operation was performed at each of the 83,378 cells that constitute the interpolated surfaces. The apparent volume change at each cell was then summed to estimate a net volume loss or gain within the depression area. Estimated net volume loss from the depression area on the southern embankment of the reservoir for the 44 months from July 2008 to March 2012 was 38 cubic feet. The expected relative accuracy of the volume loss estimate is approximately 5 cubic feet, which was calculated by multiplying the area of the depression zone by the relative accuracy of the altitude dataset (0.060 ft) at the 95-percent confidence level (Gesch, 2014).

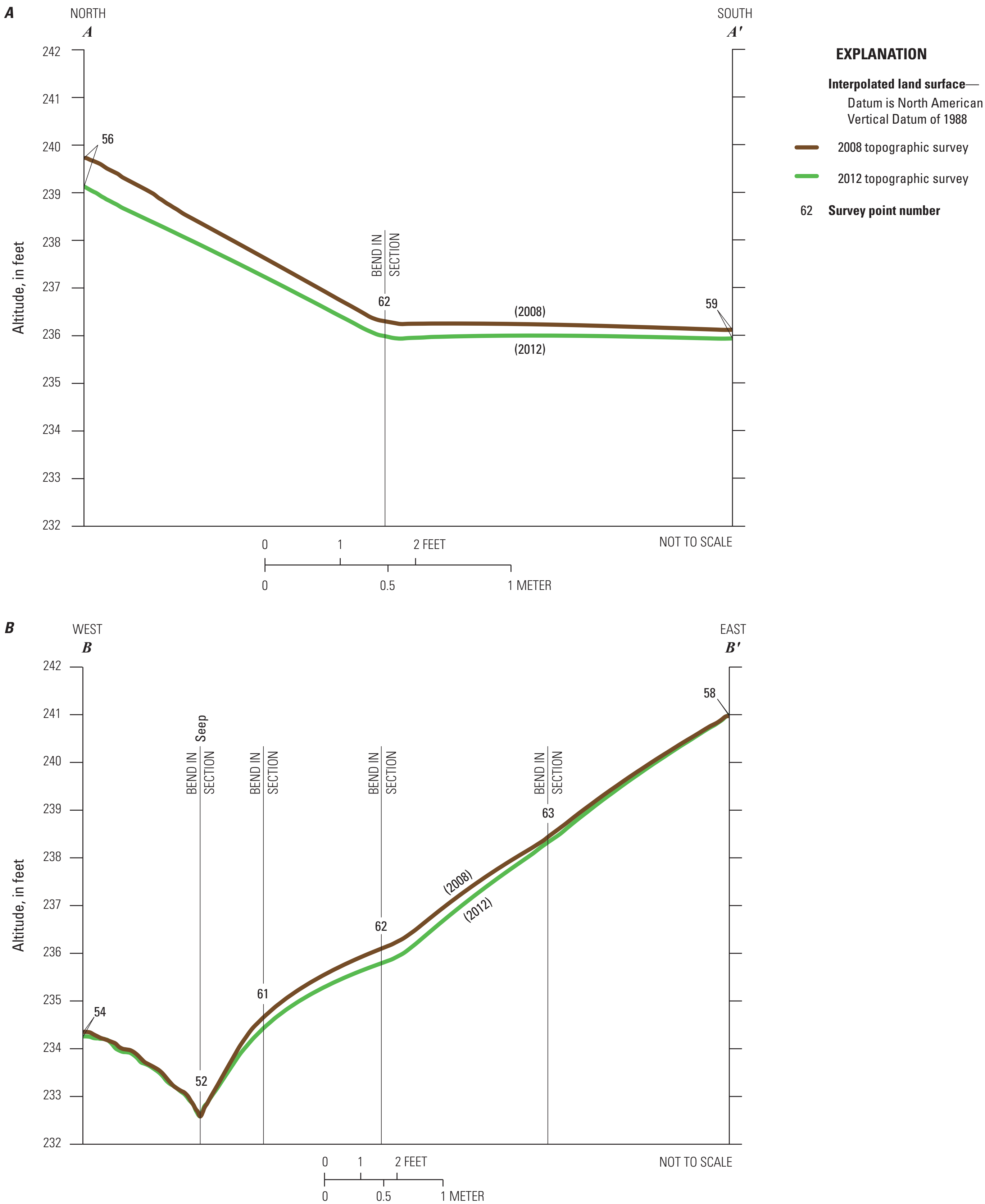

Figure 5. Interpolated land-surface altitude along cross sections *A*, *A*–*A′* and *B*, *B*–*B′* from the topographic surveys of the southern embankment at the Hillview Reservoir, Westchester County, New York, in 2008 and 2012. Locations of cross sections are shown in figure 3. Datum is North American Vertical Datum of 1988.

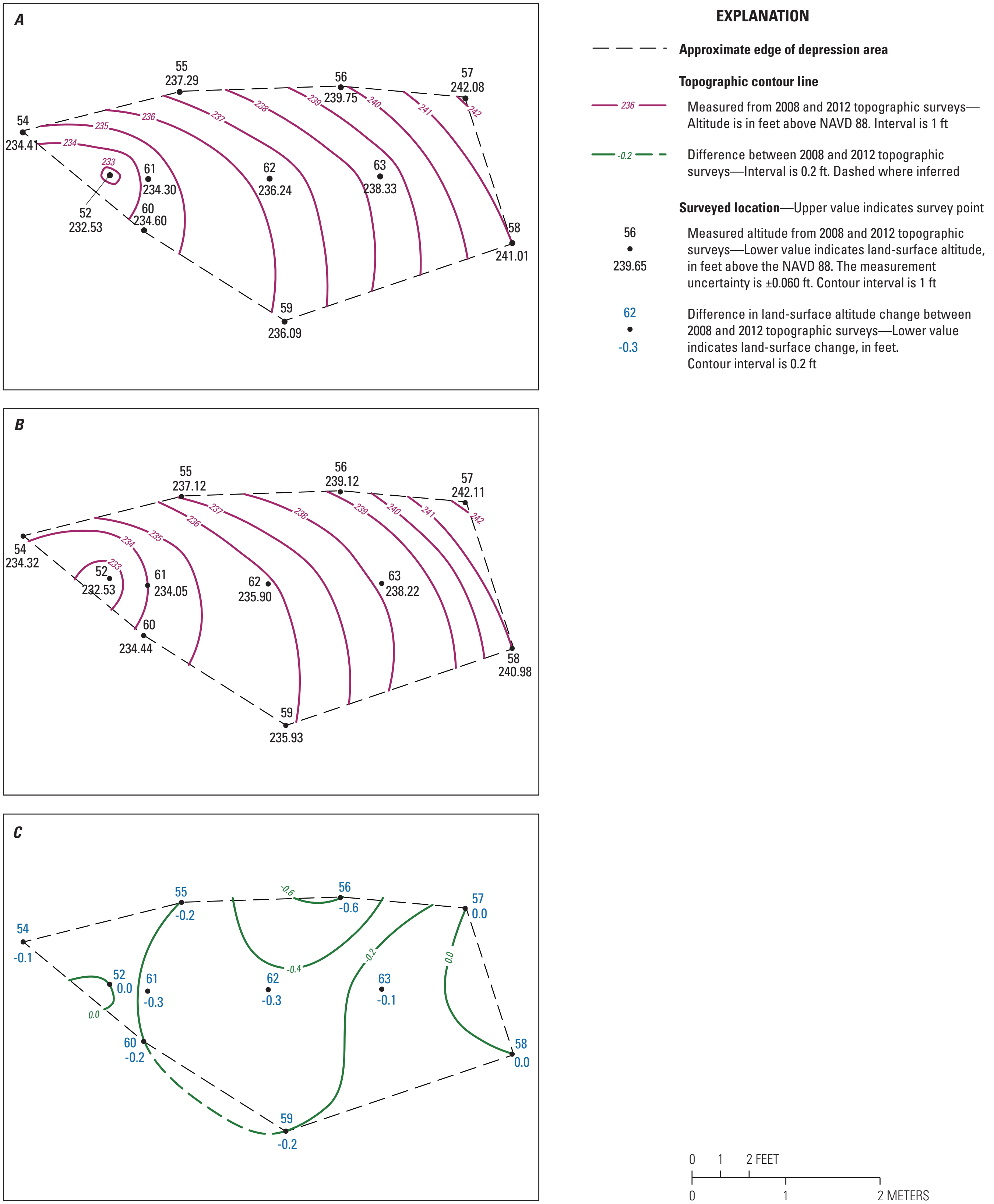

Figure 6. Altitudes at locations and contours from the topographic surveys of *A*, July 2008 and *B*, March 2012 near the southern embankment at the Hillview Reservoir, Westchester County, New York, and *C*, calculated altitude difference and altitude difference contours for the two topographic surveys. Negative values indicate that land-surface altitude decreased during the 44 months between surveys. Location of points are shown on figure 2 and cross section are shown on figure 3. NAVD 88, North American Vertical Datum of 1988; ft, foot.

Summary

In 2005, the U.S. Geological Survey and the New York City Department of Environmental Protection began a cooperative study to characterize the groundwater-flow system and identify potential sources of seeps within the southern embankment at the Hillview Reservoir in Westchester County, New York. During monthly site inspections at the reservoir, a depression in the land surface of about 90 square feet was observed directly upslope from a seep that has episodically flowed since 2007. The U.S. Geological Survey used a robotic land-surveying technique (total station) to measure topography of the depression area at the southern embankment at the Hillview Reservoir and collected high-accuracy (resolution of less than 1 inch) measurements to monitor change in land-surface altitude for the 44 months between July 2008 and March 2012. A numerical approach was used to assess the relative accuracy of the altitude measurements of the total station and to validate the stake-out approach used to resurvey the points within the depression area. The relative horizontal and vertical accuracies of the dataset from the March 2012 topographic survey were ±0.098 and ±0.060 ft, respectively. Small positional (horizontal and vertical) errors for two control points validated the stability of the physical markers in the area of the survey during the period between the topographic surveys. Data from the topographic surveys indicate that land-surface altitude decreased at 8 of the 11 points and remained essentially unchanged (or within the accepted measurement uncertainty) at 3 of the 11 points. Changes in altitude at the 8 points ranged from 0.09 ft (point 54) to 0.63 ft (point 56), with a median of 0.16 ft.

Two cross sections were constructed along an approximately 8.5-ft-long north-south trending line (*A–A′*) and an 18-ft-long east-west trending line (*B–B′*). Altitudes for both cross sections exhibited stability near the edges and indicated increased movement near the center of each cross section. Land-surface altitude change along cross section *A–A′* ranged from 0.2 to more than 0.6 ft and generally decreased from north to south. Altitude change generally decreased or remained constant along cross section *B–B′* and ranged from 0.0 to 0.3 ft. A geographic information system utility was used to estimate volume change of the depression area by differencing two modeled land surfaces that were interpolated from high accuracy topography measurements collected by the total station. These data indicated a net volume loss of 38 ±5 cubic feet within the depression area during the 44 months from July 2008 to March 2012.

References Cited

Chu, Anthony, Stumm, Frederick, Joesten, P.K., and Noll, M.L., 2013, Geophysical and hydrologic analysis of an earthen dam site in southern Westchester County, New York: U.S. Geological Survey Scientific Investigations Report 2012–5247, 64 p. [Also available at https://pubs.er.usgs.gov/publication/sir20125247.]

Esri, Inc., 2012, How cut fill works: Esri, Inc., ArcGIS 10.1 desktop help, accessed January 4, 2016, at http://resources.arcgis.com/en/help/main/10.1/index.html#//00q90000003s000000.

Federal Geographic Data Committee, 1998, National standard for spatial data accuracy. pt. 3 of Geospatial positioning accuracy standards: Federal Geographic Data Committee, 25 p. (Also available at https://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/chapter3.)

Gesch, D.B., 2014, An inventory of topographic surface changes—The value of multi-temporal altitude data for change analysis and monitoring, *in* International Society for Photogrammetry and Remote Sensing Technical Commission IV Symposium, May 14–16, 2014, Suzhou, China: The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, v. XL–4, p. 59–63. [Also available at https://doi.org/10.5194/isprsarchives-XL-4-59-2014.]

Greenwalt, C.R., and Schultz, M.E., 1968, Principles and error theory and cartographic applications: St. Louis, Mo., U.S. Air Force Aeronautical Chart and Information Center Technical Report 96, 89 p. [Also available at http://earth-info.nga.mil/GandG/publications/tr96.pdf.]

Kavanagh, B.F., 2004, Surveying with construction applications (5th ed.): Pearson Prentice Hall, Technology and Engineering, 658 p.

National Digital Elevation Program, 2004, Guidelines for digital elevation data: U.S. Geological Survey, 93 p.

New York City Department of Environmental Protection, 1909, Hillview Reservoir: New York City Department of Environmental Protection Contract 30, [n.p.], 27 pls.

Rydlund, P.H., Jr., and Densmore, B.K., 2012, Methods of practice and guidelines for using survey-grade global navigation satellite systems (GNSS) to establish vertical datum in the United States Geological Survey: U.S. Geological Survey Techniques and Methods, book 11, chap. D1, 120 p. [Also available at https://pubs.er.usgs.gov/publication/tm11D1.]

Sibson, Robin, 1981, A brief description of natural neighbor interpolation, chap. 2 *of* Barnett, Vic, ed., Interpreting multivariate data: John Wiley & Sons Ltd., p. 21–36.

Trimble Inc., 2015, Trimble S–6 total station: Trimble Inc. product web page, accessed January 4, 2016, at http://www.trimble.com/Survey/trimbles6.aspx/.

Trimble Inc., 2016, Trimble R8 GNSS system: Trimble Inc. product web page, accessed January 4, 2016, at http://www.trimble.com/Survey/trimbler8gnss.aspx/.

Wilson, G.L., and Richards, J.M., 2006, Procedural documentation and accuracy assessment of bathymetric maps and area/capacity tables for small reservoirs: U.S. Geological Survey Scientific Investigations Report 2006–5208, 24 p. [Also available at https://pubs.er.usgs.gov/publication/sir20065208.]

Appendix 1. Manufacturer Specifications for Uncertainty of Robotic Total Station Measurements

At the 68-percent confidence level, the horizontal and vertical accuracy of the total station can be calculated from the following equations (Trimble Inc., 2015):

$$Accuracy_h = 4\text{mm} + \left[\frac{2}{1{,}000{,}000} \times |x - y|\right], \text{ and} \quad (1–1)$$

$$Accuracy_a = 4\text{mm} + \left[\frac{2}{1{,}000{,}000} \times |x - y|\right], \quad (1–2)$$

where

$Accuracy_h$ is the relative horizontal accuracy,

$Accuracy_a$ is the relative altitude (vertical) accuracy, and

$|x - y|$ is the baseline distance between the point of origin and the foresight.

The distance between the total station (point of origin) and the foresight (prism) locations averaged approximately 107 feet (33 meters) and did not exceed 315 feet (96 meters) (baseline distance), therefore the associated horizontal and vertical accuracy of the positional data measured with the total station during each survey is approximately less than or equal to 0.014 feet at the 68-percent confidence level, and 0.027 feet at the 95-percent confidence level.

Reference Cited

Trimble Inc., 2015, Trimble S–6 total station: Trimble Inc. product web page, accessed January 4, 2016, at http://www.trimble.com/Survey/trimbles6.aspx/.

For more information about this report, contact:
Director, New York Water Science Center
U.S. Geological Survey
2045 Route 112, Building 4
Coram, NY 11727
dc_ny@usgs.gov
(518) 285–5602
or visit our website at
https://ny.water.usgs.gov

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