United States Department of Agriculture | **Natural Resources Conservation Service** | **11 Campus Boulevard Suite 200 Newtown Square, PA 19073**

Subject: ENG -- Ground-Penetrating Radar (GPR) Assistance **Date:** 31 August 2005

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Purpose:
Ground-penetrating radar (GPR) was used to conduct lake sedimentation surveys on the reservoirs of seven floodwater retarding structures within the Conewango Creek Watershed in western Cattaraugus and eastern Chautauqua Counties, and on the reservoir of the Newtown-Hoffmann structure in Chemung County, New York.

Participants:
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Dave Sullivan, Geologist, USDA-NRCS, Syracuse, NY

Activities:
All field activities were completed during the period of 8 to 10 August 2005.

Survey Area:
Ground-penetrating radar surveys were completed on seven floodwater retarding structures within the Conewango Creek Watershed in western Cattaraugus and eastern Chautauqua counties, New York. These surveys were conducted as part of the National Dam Rehabilitation Program. These watersheds are underlain by Upper Devonian shales, sandstones, and siltstones of the Conewango, Conneaut, and Canadaway formations. Principal soils on the bottomlands include Canadice and Birdsall. Principal soils on the surrounding uplands include Lordstown, Volusia, and Mardin. The taxonomic classifications of these soils are listed in Table 1.

Table 1. Taxonomic Classification of the Principal Soils in the Study Areas

Soil Series	Taxonomic Classification
Birdsall	Coarse-silty, mixed, active, nonacid, mesic Typic Humaquepts
Canadice	Fine, illitic, mesic Typic Endoaqualfs
Lordstown	Coarse-loamy, mixed, active, mesic Typic Dystrudepts
Mardin	Coarse-loamy, mixed, active, mesic Typic Fragiudepts
Volusia	Fine-loamy, mixed, active, mesic Aeric Fragiaquepts

The reservoirs surveyed in Chautauqua County included those behind floodwater retarding structures numbers 3 (Bethany Camp Dam), 6 (Ferrington Hollow), and 9A (Villenova). Floodwater Retarding Structure #3 is located about 1.2 miles southwest of Thornton. Floodwater Retarding Structure #6 is located about 1.4 miles northwest of Cherry Creek. Floodwater Retarding Structure #9A is located about 1.4 miles northeast of Hamlet.

The reservoirs surveyed in Cattaraugus County included those behind floodwater retarding structures numbers 1 (Searles Dam), 13 (New Albion Dam), 16A (Walker Road Dam), and 19 (Battle Creek). Floodwater Retarding Structure #1 is located about 0.8 mile southeast of Waterboro. Multipurpose Structure #13 is located along Highway 5 just northwest of New Albion. Floodwater Retarding Structure #16A is located about 1.3 miles north of East Randolph. Floodwater Retarding Structure #19 is located about 1.7 miles southwest of Randolph.

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000, manufactured by Geophysical Survey Systems, Inc. (North Salem, New Hampshire).[1] Daniels (2004) discusses the use and operation of GPR. The SIR System-3000 weighs about 9 lbs and is backpack portable. With an antenna, this system requires two people to operate. A 70 MHz antenna was used in the surveys. All radar records were processed with the RADAN for Windows (version 5.0) software program (Geophysical Survey Systems, Inc).[1] Processing included setting the initial pulse to time zero, color transformation, marker editing, and range gain adjustments.

An Allegro field computer (Juniper Systems, North Logan, Utah) and a Garmin Global Positioning System Map 76 receiver (with a CSI Radio Beacon receiver, antenna, and accessories that are fitted into a backpack) (Garmin International, Inc., Olathe, Kansas).[1] The Garmin GPS receiver was operated in the manual mode. Geodetic datum was WGS-84 (World Geodetic System of 1984). The Geographic (longitude/latitude) Coordinate system was used with all units of measure expressed in decimal degrees.

To help summarize the results of the GPR survey, SURFER for Windows (version 8.0) software, developed by Golden Software, Inc.(Golden, Colorado), was used to construct the two-dimensional simulations shown in this report.[1] Grids of interpreted water depths and sediment thickness data were created using kriging methods with an octant search.

Background:
Presently, more than fifty percent of the dams constructed by the former USDA-Soil Conservation Service are older than 35 years and more than 1,800 will exceed their 50-year design life within the next 10 years (Caldwell, 2000). Many dams are in need of immediate rehabilitation. One of the primary issues in dam rehabilitation is reservoir sedimentation. Sedimentation is the major cause of reduced reservoir storage capacity. As part of a statewide assessment program, the USDA-NRCS is determining the volume of sediments deposited within selected reservoirs. The primary objectives of lake sedimentation surveys are to determine current reservoir capacity, learn of changes in storage volume, and estimate the volume of accumulated sediments.

Traditional methods used to conduct lake sedimentation surveys are slow and labor intensive. Acoustic equipment (fathometer) has been used to facilitate some reservoir surveys. However, this technology can not resolve gradational contacts nor penetrate layers of aquatic vegetation and organic materials. Recently, ground-penetrating radar (GPR) has been used to survey lakes (Haeni et al., 1987, Izbicki and

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[1] Manufacturer's names are provided for specific information; use does not constitute endorsement.

Parker, 1991; Truman et al., 1991; Sellmann et al., 1992; Mellett, 1995; and Moorman and Michel, 1997) and stream channels (Spicer et al., 1997). The present surveys integrate GPS and GPR technologies to improve the efficiency of bathymetric assessments. The use of GPS is less labor intensive and time consuming than conventional positioning methods.

Survey Procedures:
The SIR System-3000 was mounted in a boat and the 70 MHz antenna was towed alongside in an inflatable raft. The boat and raft made multiple traverses across each reservoir. Locations of traverse lines were arbitrary and were continuously adjusted according to changing lake conditions and geometries. Measurement points for both GPS and GPR were simultaneously recorded at intervals of about 10 to 15 seconds. Intervals varied with the length of traverse and the speed of advance.

For each reservoir, coordinates outlining the shoreline of each reservoir were obtained by engineers in the New York State Office off of digitized maps. Locations of GPR measurement points were determined with GPS. For many point, GPS measurements were obtained in the differential mode. Differential correction requires data from four satellites. Often fewer than four satellites were visible (do to restricted mast angle and the negative influence of nearby slopes and vegetation), and, as a consequence, locations were recorded in the autonomous mode.

A warm and comparatively dry summer has resulted in a noticeable draw-down of water and the prolific growth of aquatic vegetation within the reservoirs. Areas of impenetrable aquatic vegetation fouled the outboard motor and arrested advance. Accordingly, these areas were avoided. As a consequence, large areas of most reservoirs could not be surveyed.

Calibration of GPR:
Ground-penetrating radar is a time scaled system. This system measures the time taken by electromagnetic energy to travel from an antenna to an interface (e.g., lake bottom, stratigraphic layer) and back. To convert the travel time into a depth scale, either the velocity of pulse propagation or the depth to a reflector must be known. The relationships among depth (D), two-way pulse travel time (T), and velocity of propagation (V) are described in the following equation (Daniels, 2004):

$$V = 2D/T \qquad [1]$$

The velocity of propagation is principally affected by the relative dielectric permittivity (E_r) of the profiled material(s) according to the equation (Daniels, 2004):

$$E_r = (C/V)^2 \qquad [2]$$

Where C is the velocity of propagation in a vacuum (0.3 m/nanosecond). Velocity is expressed in meters per nanosecond (ns). The amount and physical state of water (temperature dependent) have the greatest effect on the relative dielectric permittivity of a material. The E_r of air and water are 1 and 80, respectively.

Water is assumed to have an E_r of 80 and a velocity of propagation of 0.033 m/ns. The electrical properties of lake bottom sediments are variable. Base on a referenced value for saturated silts (Daniels, 2004), the bottom sediments were assumed to have an E_r of 25 and a velocity of propagation of about 0.06 m/ns

<u>Interpretations:</u>

Radar records were of good interpretative quality. Figure 1 is a representative radar record from the reservoir at Multipurpose Structure # 13 (New Albion Dam) in the Conewango Creek Watershed. The vertical scale is a time scale expressed in nanoseconds. The horizontal scale is a distance scale expressed in scans. Although the radar provides a continuous bathymetric profile of the reservoir, measurements of water depths and sediment thicknesses were restricted to geo-referenced observation points (white vertical lines at the top of the radar profile). On this radar record, these lines are spaced at an interval of 200 scans.

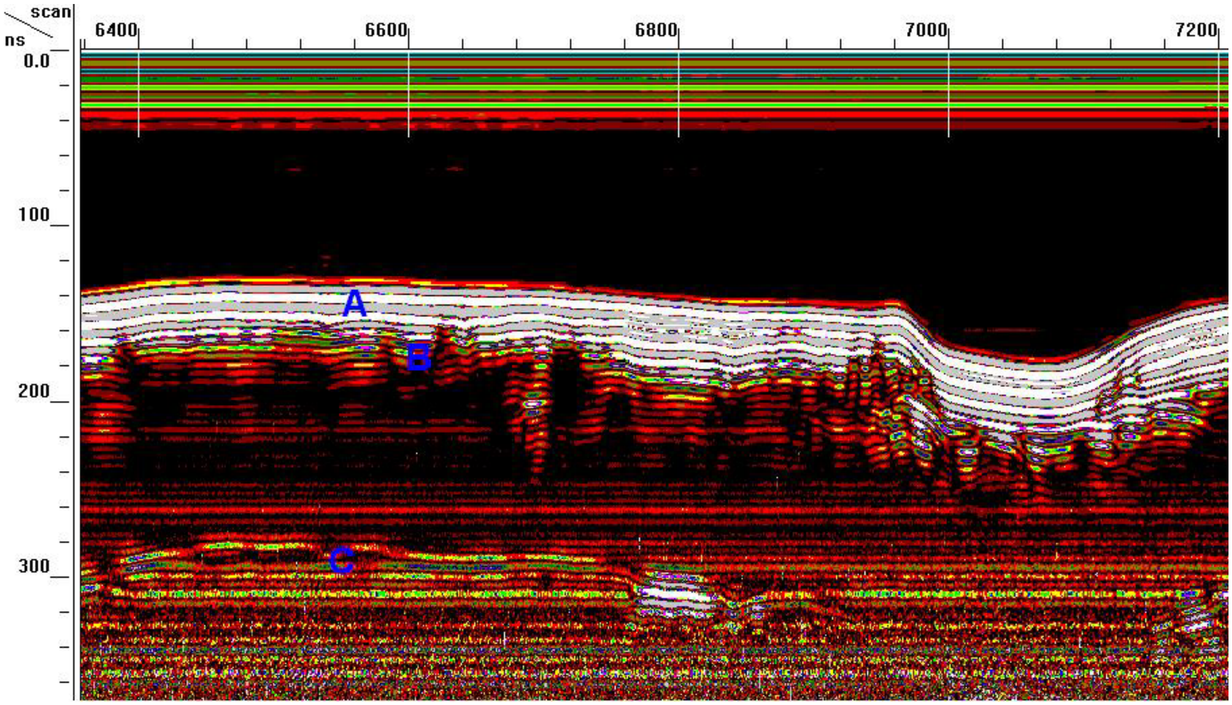

Figure 1. A representative radar record collected with 70 MHz antenna.

The horizontal reflector at the top of the radar record represents the reflection from the lake's surface and its multiples. The first series of high amplitude, subsurface bands (see "A"; bands are colored grey, white, grey) represents the lake bottom. On this radar record, this interface varies in depth from about 140 to 180 ns (about 2.5 to 3.0 m, respectively). The lowest group (see above "B") of high amplitude (also colored grey, white, grey), bands represents the base of the post-impoundment sediments and the contact with the original bottom materials. These reflectors are more segmented an uneven than the overlying reflectors from the more recently deposited, lacustrine sediments. A "double-return echo" from the lake bottom is evident at "C." This multiple reflection is a form of noise and should be ignored.

With the 70 MHz antenna the lake-bottom sediments were penetrated. These sediments represent recent deposits. As no borings were made through these sediments at the time of the surveys, the identity of these layers were not verified and the thickness of lake bottom sediments was estimated, but not measured. These recent deposits are assumed to consist principally of saturated silty sediments. This is an oversimplification, but is useful to approximate the relative thickness of the post-impoundment sediments.

A task of this investigation was to identify the lake bottom and the base of the post-impoundment sediments on each radar record. The interface separating water from saturated sediments was easily identified and trace laterally on all radar records. The interpreted base of the post-impoundment sediments was identified as the deepest continuous high amplitude reflection. Although an E_r of 25 and an average velocity of 0.060 m/ns were used to determine the general thickness of the underlying saturated post-impoundment silty sediments, saturated silts are known to have an E_r that ranges from 10 to 40 (Conyers and Goodman, 1997).

Results:

Conewango Creek Watersheds:

Seven reservoirs within the Conewango Creek Watershed were surveyed in a 2.5 day period. A total of 620 GPR observation points were recorded. For each reservoir, the number of observation points varied with the size of the reservoir and the area accessible to the boat. Basic statistics for the interpretations of water depths within each reservoir are listed in Table 2. At the recorded observation points, interpreted water depths ranged from 0.32 to 4.02 m. These reservoirs are relatively small and shallow. The greatest depth was recorded in the reservoir of flood retarding structure #13 (4.02 m). This reservoir also had the greatest averaged water depth (2.32 m). The shallowest averaged water depths were recorded at flood retarding structure #6 and #9A (about 1.1m).

Table 2. Basic Statistics for Water Depths in each of the Conewango Creek Watershed Reservoirs.
(With the exception of number of observations, all data are in m).

STRUCTURE	#1	#3	#6	#9A	#13	#16A	#19
Number	43	50	52	97	209	83	86
Mean	2.16	1.32	1.11	1.12	2.32	1.54	1.41
SD	0.55	0.63	0.29	0.56	0.70	0.43	0.76
Minimum	0.60	0.32	0.54	0.33	0.66	0.45	0.35
Maximum	3.25	2.37	1.65	2.29	4.02	2.21	3.37
25% Tile	1.93	0.86	0.97	0.69	1.96	1.22	0.77
75% Tile	2.42	1.86	1.33	1.51	2.74	1.90	2.02

Table 3. Basic Statistics for Sediment Thickness in each of the Conewango Creek Watershed Reservoirs.
(With the exception of number of observations, all data are in m).

STRUCTURE	#1	#3	#6	#9A	#13	#16A	#19
Number	43	50	52	97	209	83	86
Mean	0.77	0.94	0.89	0.89	0.79	0.92	0.67
SD	0.15	0.15	0.24	0.29	0.17	0.22	0.11
Minimum	0.52	0.56	0.44	0.16	0.34	0.47	0.45
Maximum	1.18	1.23	1.46	1.83	1.27	1.46	0.99
25% Tile	0.66	0.84	0.70	0.73	0.67	0.76	0.60
75% Tile	0.86	1.0323	1.04	1.03	0.90	1.08	0.73

Basic statistics for the interpretations of the post-impoundment sediment thickness within each reservoir are listed in Table 3. For the recorded observation points, based on radar interpretations, sediment thicknesses ranged from about 0.2 to 1.8 m. The greatest (1.83 m) thickness of post-impoundment sediments was obtained in the reservoir of flood retarding structure #9A. For all reservoirs, the averaged thicknesses of post-impoundment sediments were similar and ranged from about 0.7 to 0.9 m. The shallowest averaged thickness (0.67 m) of post-impoundment sediments was obtained in the reservoir of flood retarding structure #19.

Newtown-Hoffmann (Site 12E); Chemung County, New York:
Sullivan Dam is located along the east side of New York Highway 13 about 2.7 miles northeast of Horseheads. Based on radar interpretations made at 226 observation points, the averaged depth of water within this reservoir is 1.87 m with a range of about 0.3 to 4.6 m. At one-half of the observations points, the depth of water was between about 1.2 and 2.3 m. Also based on radar interpretations, recent sediments averaged 0.69 m thick with a range of about 0.4 to 1.1 m. At one-half of the observations points, the thickness of recent sediments was between about 0.6 and 0.7 m.

Two-Dimensional Plots:
Plots of the interpreted radar data can be found at the end of this report. In each plot, a gradational spectrum between two colors has been assigned to individual water depth or sediment thickness levels. In each plot, the color bar interval is 0.50 for water depths and 0.25 m for sediment thicknesses. For each structure, the approximate outline of the reservoir is shown. These outlines were achieved by digitizing data points off of base maps. As evident in each of the plots, large areas within each reservoir could not be navigated because of dense vegetation that fouled the motor and restricted the movement of the survey boat.

Discussion:
Major sources of measurement error are variations in the velocity of propagation through water and post-impoundment sediments. In addition, errors in identifying the base of the post-impoundment sediments may have occurred in areas with alluvial sediments that predated the impoundment of water. The dielectric contrast between water and the post-impoundment sediments is abrupt and contrasting. This characteristic provided a clear and easily identifiable interface on radar records. Though less contrasting the contrast between the saturated low-density, post-impoundment sediments and the higher-density pre-impoundment materials is substantial. As a consequence, this interface was identifiable at most observation points. However, misidentification of the base of the post-impoundment sediments could result in significant error in the estimation of sedimentation. Some reservoirs are situated on areas formerly occupied by alluvial soils. These soils have layers of sediment that may be confused with post-impoundment sediments. As the textural composition and moisture content of the post-impoundment sediments is unknown, the sediments were presumed to be saturated silts with an estimated dielectric permittivity of 25. Ancillary coring data would have greatly increased our knowledge of the composition, dielectric properties, and thickness of the post-impoundment sediments. In the absence of this data, estimations of the sediment thickness are constrained and subject to error.

It was my pleasure to work in New York. The surveys were well organized and the boat crews were very efficient. I deeply appreciated the assistance and counsel of David Sullivan.

With kind regards,

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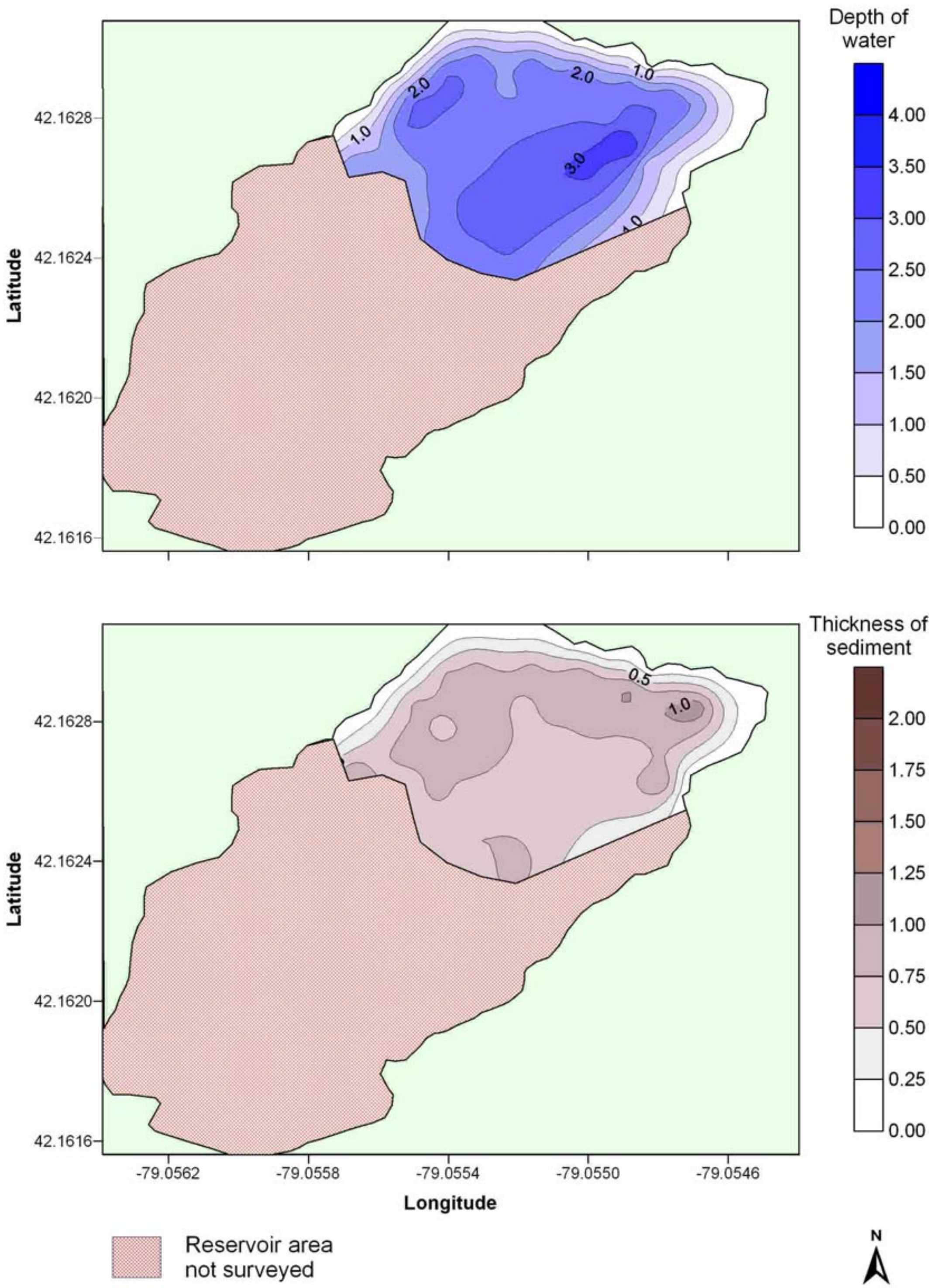


Figure 2. Conewango Structure #1

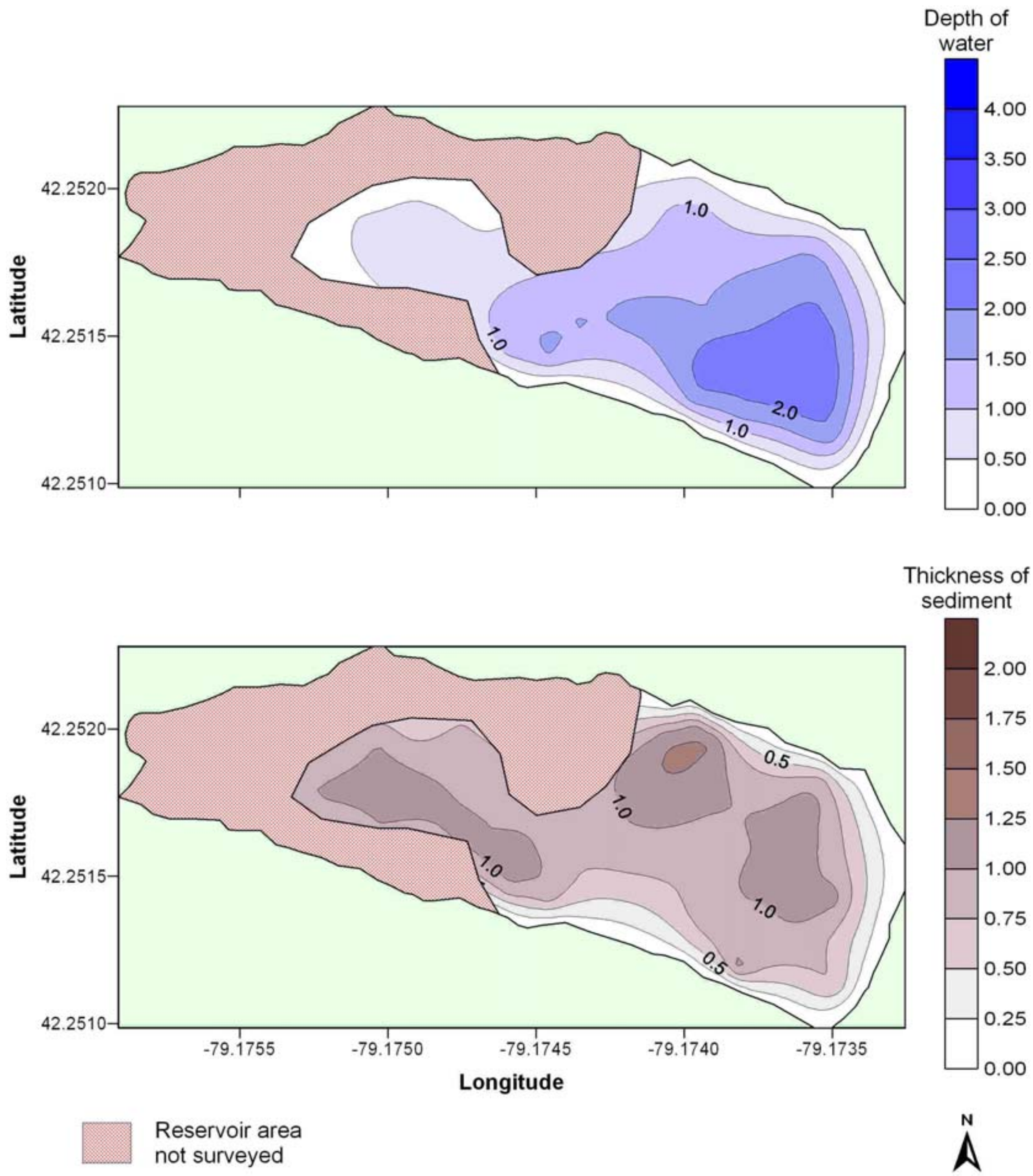


Figure 3. Conewango Structure #3

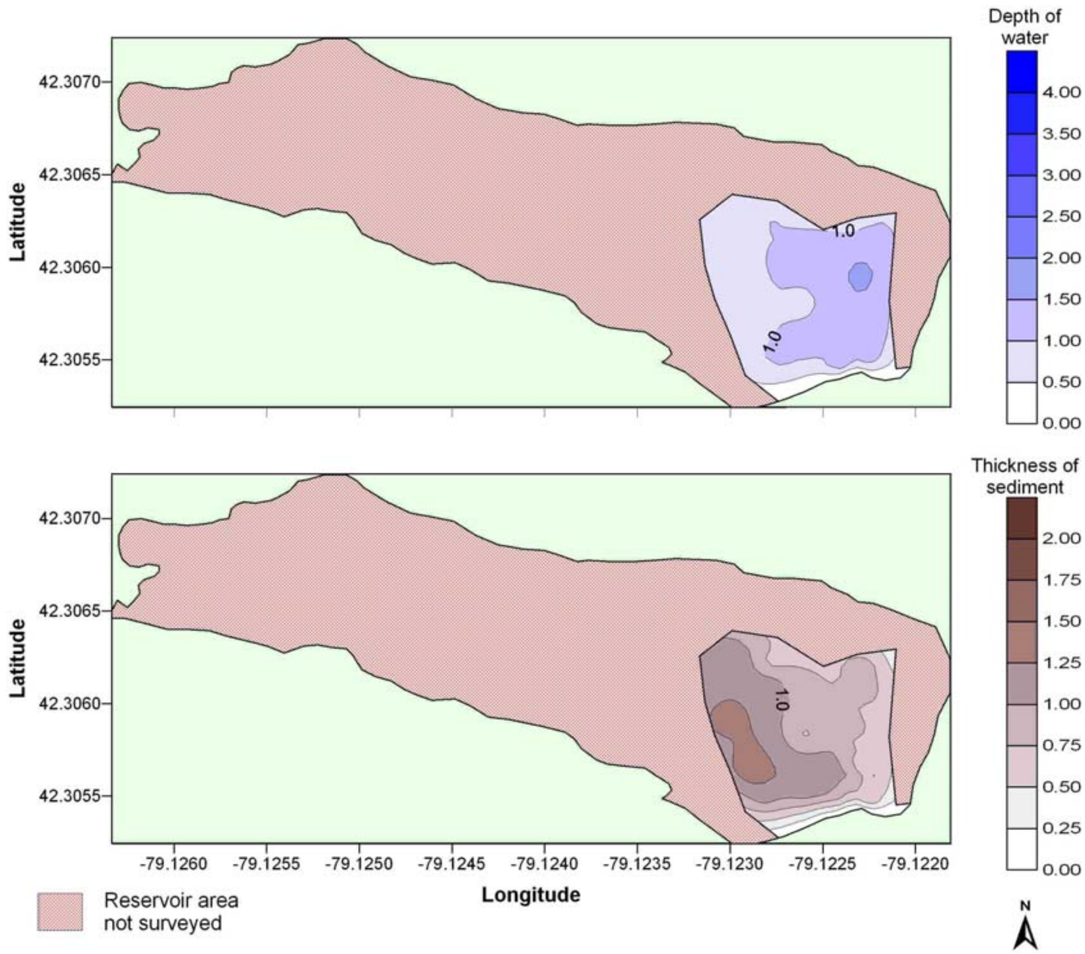


Figure 4. Conewango Structure #6

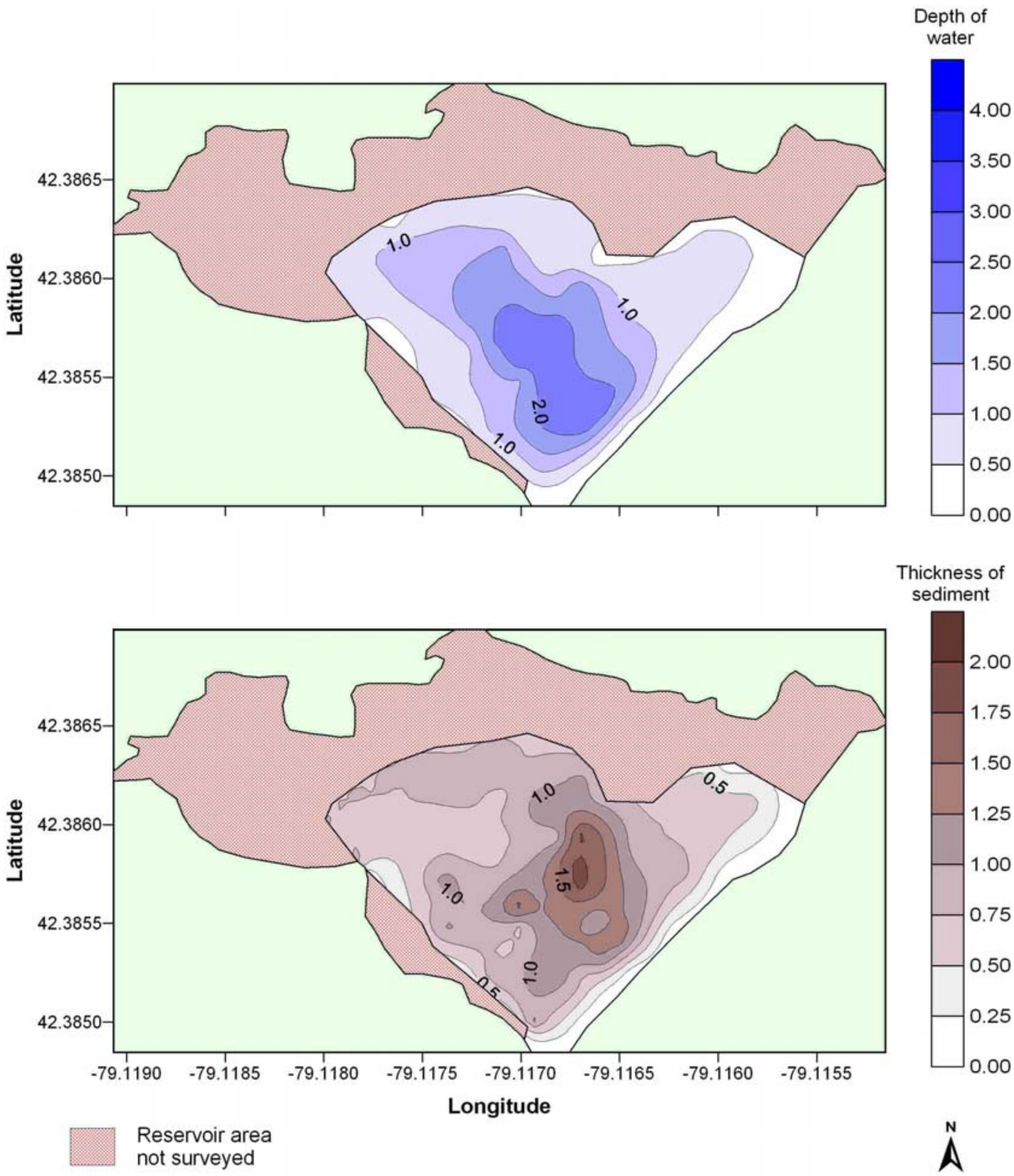


Figure 5. Conewango Structure #9A

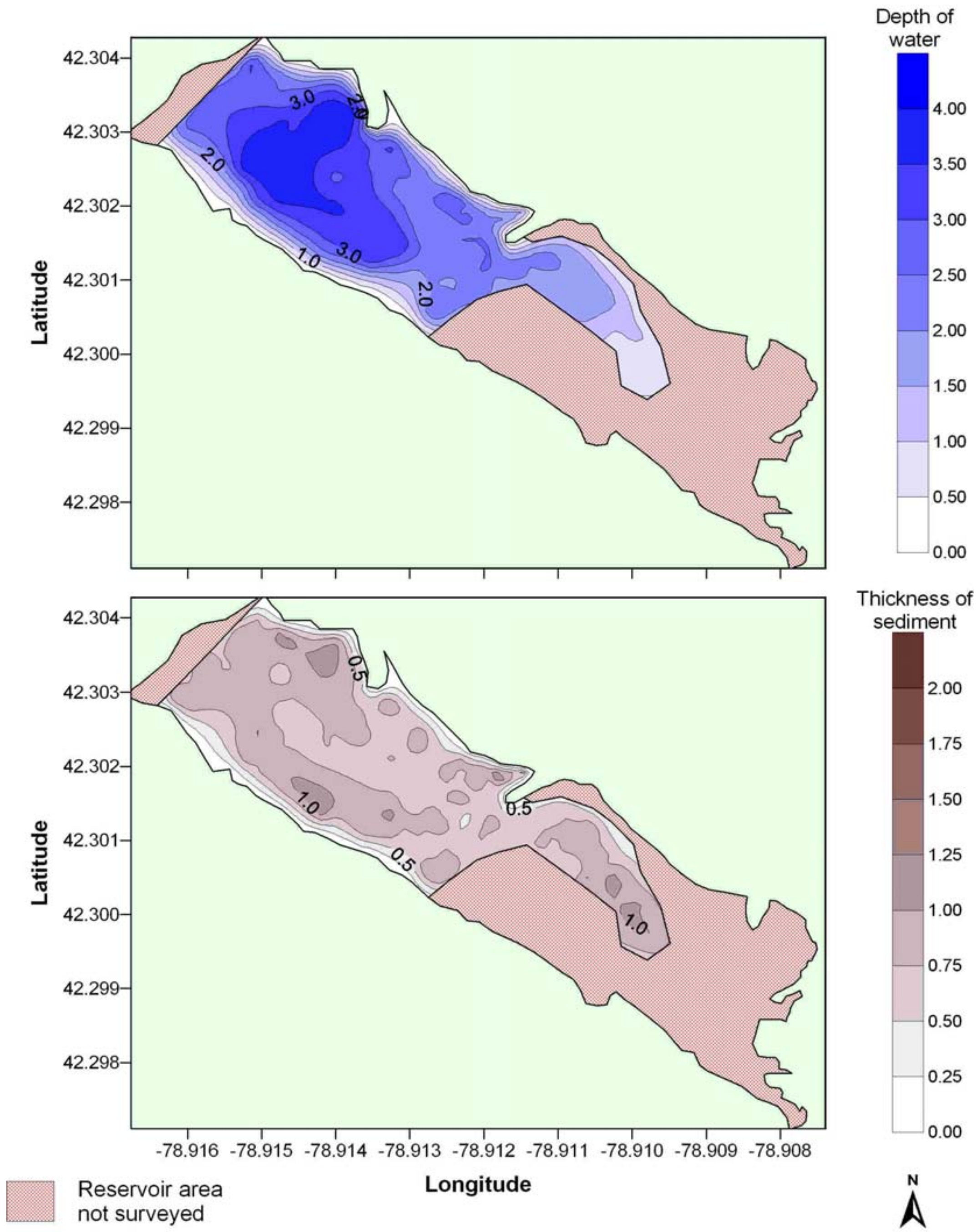


Figure 6. Conewango Structure #13

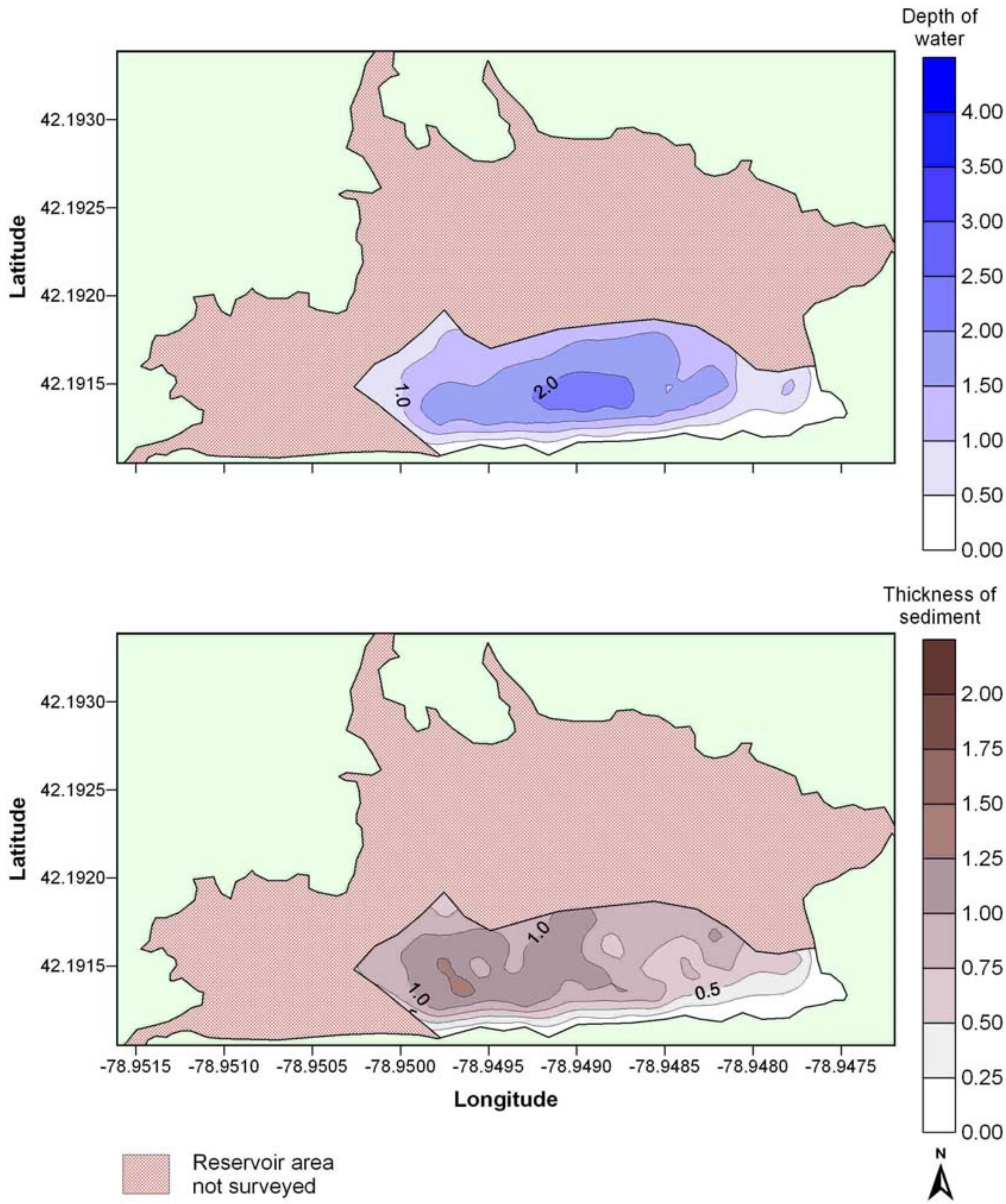


Figure 7. Conewango Structure #16A

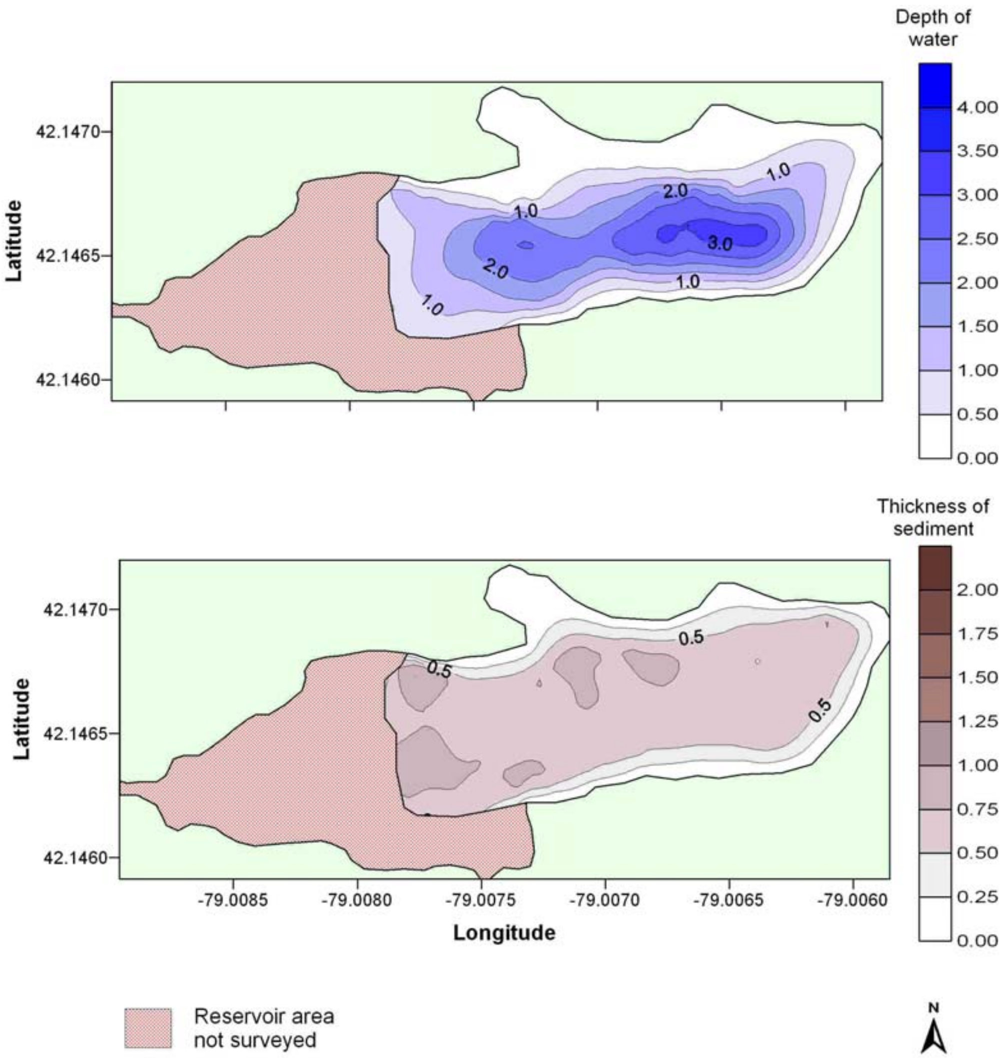
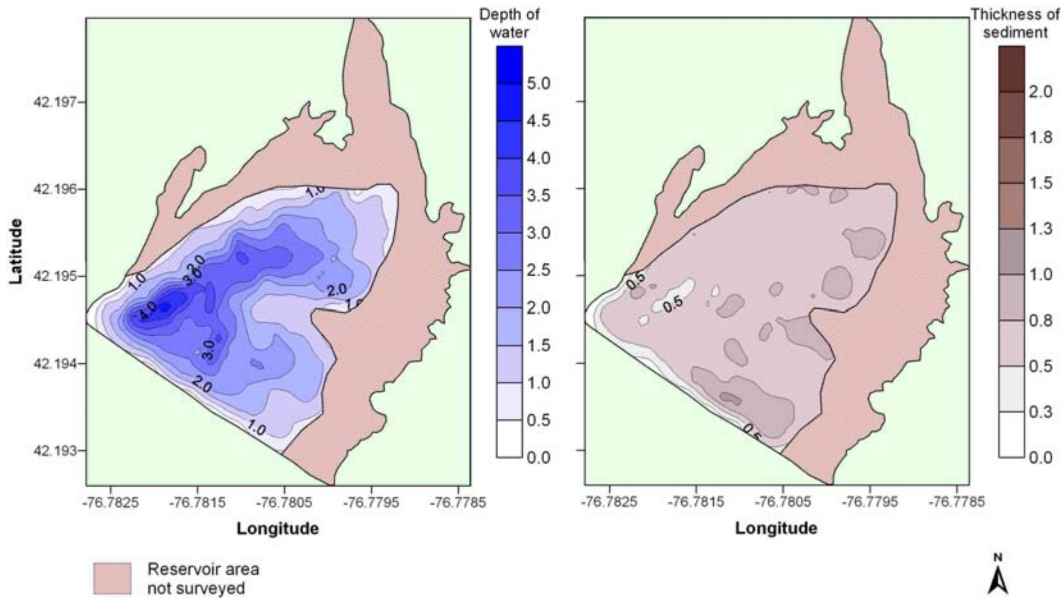


Figure 8. Conewango Structure #19



9. Sullivanville Structure; Chemung County