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:** 6 July 2004

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Purpose:
Lake sedimentation surveys were completed on seven flood-control reservoirs in western Cattaraugus and eastern Chautauqua counties, New York, using ground-penetrating radar (GPR).

Participants:
Stan Bishop, Cattaraugus County DPW, Ellicottville, NY
Brian Davis, District Manager, Cattaraugus County Soil & Water Conservation District, Ellicottville, NY
Jim Doolittle, Research Soil Scientist, USDA-NRCS, Newtown Square, PA
Robert Hartrick, Area Conservationists, USDA-NRCS, Batavia, NY
Christopher Henry, Civil Engineer, USDA-NRCS, Syracuse, NY
Steve Perschke, Area Engineer, USDA-NRCS, Batavia, NY
Benjamin Reckahn, Student Trainee Soil Conservationist, USDA-NRCS, Jamestown, NY
Bob Shenk, District Technician, Cattaraugus County Soil & Water Conservation District, Ellicottville, NY
Dave Sullivan, Geologist, USDA-NRCS, Syracuse, NY

Activities:
All field activities were completed during the period of 14 to 16 June 2004.

Survey Area:
Ground-penetrating radar surveys were completed on seven flood-control reservoirs in western Cattaraugus and eastern Chautauqua counties, New York. These surveys were conducted as part of the National Dam Rehabilitation Program. The reservoirs surveyed in Cattaraugus County included floodwater retarding structures numbers 1, 2, 3, 4, 5, and 16. Floodwater retarding structure Number 1 is located on Ischua Creek in Machias Township. Structures numbers 2 and 3 are located on Johnson Creek in Farmersville Township. Structure Number 4 is located on Saunders Creek in Franklinville Township. Structure Number 5 is located on Gates Creek in Lyndon Township. Structure Number 16 is located on Elm Creek in Napoli Township. In addition, structure Number 33, located on a tributary to Cherry Creek in Cherry Creek Township, Chautauqua County, was also surveyed. These watersheds are underlain by Upper Devonian shales, sandstones, and siltstones of the Conewago, Conneaut, and Canadaway formations. Principal soils on the bottomlands include Canadice and Birdsall (see Table 1). Principal soils on the surrounding uplands include Lordstown, Volusia, and Mardin (see 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

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (here after referred to as the SIR System-3000), manufactured by Geophysical Survey Systems, Inc.[1] Morey (1974), Doolittle (1987), and Daniels (1996) have discussed the use and operation of GPR. The SIR System-3000 consists of a digital control unit (DC-3000) with keypad, SVGA video screen, and connector panel. A 10.8-volt lithium-ion rechargeable battery powers the system. The SIR System-3000 weighs about 9 lbs (4.1 kg) and is backpack portable. A 120 MHz antenna was used in sedimentation surveys described in this report. This antenna provided adequate depth (greater than 4 m) and acceptable resolution of subsurface features.

The RADAN for Windows (version 5.0) software program developed by Geophysical Survey Systems, Inc, was used to process the radar records.[1] Processing included setting the initial pulse to time zero, color table and transformation selection, and range gain adjustments.

The position of each radar observation points was measured with a Trimble AG114 GPS Receiver.[1.] The receiver was operated in the manual mode. All coordinates were expressed in terms of latitude and longitude. Coarse outlines of most reservoirs were obtained by walking the perimeter shoreline and manually recording waypoints with a Garmin GPSMAP 76 receiver.[1.]

To help summarize the results of this study, the SURFER for Windows, version 8.0, developed by Golden Software, Inc., was used to construct two-dimensional simulations.[1] Grids 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 34 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 the reduction in 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, ascertain changes in storage volume, and determine the volume of accumulated sediments. Secondary objectives include estimation of lateral and longitudinal deposition of sediments and annual yield rates.

Conventional methods for conducting 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 Parker, 1991; Mellett, 1995; Moorman and Michel, 1997; Sellmann et al., 1992; Truman et al., 1991) and stream channels (Spicer et al., 1997). The present study integrates GPS and GPR technologies for bathymetric surveys. 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 120 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 to lake conditions and geometry, and drift. Observation points for both GPS and GPR were simultaneously recorded at intervals of about 10 or 15 seconds. Intervals varied with the length of traverse and the speed of advance.

In general, surveys were limited to areas with water depths in excess of about 20 inches. The outboard motor would foul and the boat would drag bottom in areas with shallower water depths. As a consequence, large areas of most reservoirs were to shallow to be surveyed.

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

Where possible, shorelines were walked and GPS observations were recorded to document boundaries of the reservoirs. Water depths and thickness of sediments were assumed to be zero at these locations. This method was inaccurate as departures from the shoreline occurred in areas with dense vegetation, debris, saturated soils, and steep escarpments.

Calibration of GPR:

Ground-penetrating radar is a time scaled system. This system measures the time that it takes electromagnetic energy to travel from the 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 (Morey, 1974):

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

The velocity of propagation is principally affected by the dielectric permittivity (E) of the profiled material(s) according to the equation (Morey, 1974):

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

Where C is the velocity of propagation in a vacuum (0.3 m/nanosecond). Velocity is expressed in meters per nanosecond (ns). A nanosecond is one billionth of a second. The amount and physical state of water (temperature dependent) have the greatest effect on the dielectric permittivity of a material. The dielectric permittivity of air and water are 1 and 81, respectively.

Based on previous studies, the water was assumed to have a velocity of propagation of 0.033 m/ns and a dielectric permittivity of 80. The electrical properties of lake bottom sediments are variable. The inaccessibility of lake bottom sediments to multiple direct measurements made determinations of propagation velocities impractical. As a consequence, the propagation velocity was estimated from electrical properties of known, similar sediments. Moorman and Michel (1997) reported that conversions of travel times to depths using this method have a margin of uncertainty of less than 15 percent. Base on a referenced value for saturated silts (Daniels, 1996), the bottom sediments were assumed to have a velocity of propagation of about 0.06 m/ns and a dielectric permittivity of 25.

On radar profiles, reflections from interfaces spaced closer than one half wavelength apart are indistinguishable due to constructive and destructive interference (Daniels, 1996). Daniels (1996) used the following equation to show the relationship between velocity of propagation (v), antenna center frequency (f), and wavelength (λ):

$$\lambda = v/f \qquad [3]$$

Equation [3] shows that the propagated wavelength will decrease with decreasing propagation velocity and increasing antenna frequency. With a 120 MHz antenna, using equation [3] and average velocities of 0.033 and 0.060 m/ns resulted in wavelengths of about 47 and 50 cm through water and saturated silts, respectively. Layers spaced closer than these intervals are difficult to distinguish on radar records.

<u>Interpretations:</u>

All radar records were of good interpretative quality. Figure 1 is a representative radar record from Reservoir #2. The depth scale is expressed in meters and is plotted on the left-hand side of the figure. Although the radar provides a continuous bathymetric profile of the lake, measurements of the water depth were restricted to observation points (white vertical lines at the top of the radar profile). On this radar record, these lines were spaced at a time interval of 10 seconds. The strong 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 bands (colored grey, white, grey) represents the lake bottom. In this radar record, this interface varies in depth from about 0.6 to 1.2 m. The second group of high amplitude (also colored grey, white, grey), closely spaced multiple bands represents the base of the post-impoundment sediments and the contact with the original bottom materials.

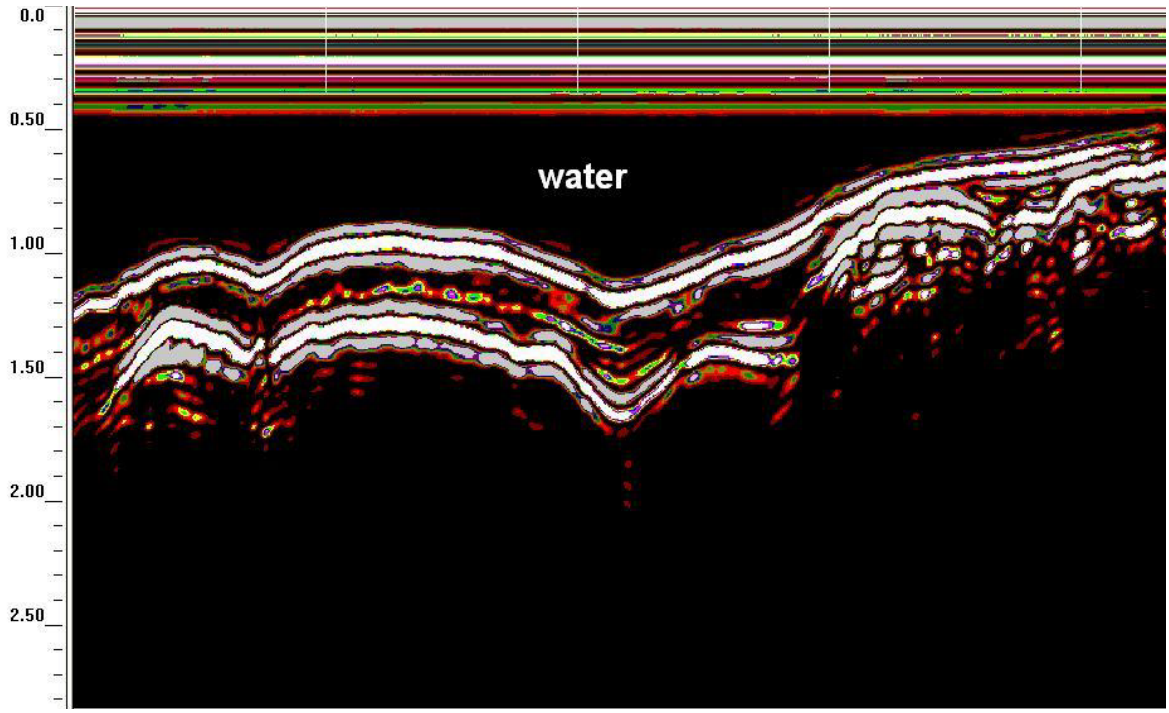

Figure 1. Representative radar record from Reservoir #2 that was collected with a 120 MHz antenna.

With the120 MHz antenna the lake-bottom sediments were penetrated. The sediments consist of recent deposits. As no borings were made through these sediments at the time of this survey, the identity of these layers were not verified and the thickness of lake bottom sediments was estimated, but not measured. These layers were characterized as consisting principally of saturated silty sediments. This is of course 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 E_r that ranges from 10 to 40 (Conyers and Goodman, 1997).

Results:

Seven reservoirs were surveyed in a 2.5 day period. Although GPR provides a continuous record of subsurface lake features, data were interpreted at only the geo-referenced GPR observation points. A total of 773 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 radar interpretations of water depths within each reservoir are listed in Table 2. Within the reservoirs surveyed, interpreted water depths ranged from 0.36 to 3.83 m. These are relatively small and shallow reservoirs. The greatest depths were recorded in Reservoir #16 (3.83 m) and Reservoir #2 (3.47 m). The area surveyed in Reservoir #2 had the greatest averaged water depth (2.41 m). The shallowest averaged water depths were recorded in Reservoir #1 (0.71 m), Reservoir #33 (1.04 m) and Reservoir #5 (1.17 m).

Basic statistics for the radar interpretations of post-impoundment sediment thickness within each reservoir are listed in Table 3. Within the reservoirs surveyed, interpreted sediment thickness ranged from 0.00 to 2.11 m. As mentioned in the *Calibration of GPR* section, the minimum resolution of the 120 MHz antenna is about 50 cm in saturated silty sediments. As a consequence, estimations of sediment layers that are less than 50 cm thick are speculative and subject to error. Both the shallowest (0.00 m) and greatest (2.11 m) thickness of post-impoundment sediments were recorded in Reservoir #1. However, the greatest averaged thickness of post-impoundment sediments (1.08 m) was observed in reservoir # 4. The shallowest averaged thickness (0.56 m) of post-impoundment sediments was observed in reservoir # 3.

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

	#1	#2	#3	#4	#5	#33	#16
NUMBER	87	96	151	113	97	25	204
AVERAGE	0.76	2.41	1.55	1.57	1.17	1.04	1.76
SD	0.15	0.71	0.62	0.62	0.58	0.20	0.95
MIN	0.49	0.55	0.40	0.45	0.36	0.70	0.38
MAX	1.19	3.47	2.75	2.97	2.54	1.29	3.83
25% TILE	0.64	1.88	1.02	1.08	0.74	0.89	0.90
75% TILE	0.87	2.99	2.17	2.05	1.52	1.21	2.41

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

	#1	#2	#3	#4	#5	#33	#16
NUMBER	87	96	151	113	97	25	204
AVERAGE	0.63	0.64	0.56	1.08	0.74	0.88	0.81
SD	0.45	0.38	0.20	0.29	0.37	0.27	0.29
MIN	0.00	0.00	0.11	0.39	0.21	0.45	0.22
MAX	2.11	1.96	1.36	1.70	1.87	1.36	1.66
25% TILE	0.30	0.41	0.45	0.92	0.45	0.69	0.60
75% TILE	0.94	0.75	0.65	1.26	1.00	1.11	1.01

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 0.25 m. The locations of the observation points are also in each plot. With the exception of Dam #1, the approximate outline of each reservoir is shown. These outlines were achieved by walking the perimeter of the reservoir with a GPS receiver. For Dam #1, only the survey limits, defined by accessible navigation depths, are shown. As evident in each of plots, large areas of each reservoir could not be navigated with the survey boat or surveyed with the raft mounted GPR at the time of the survey. In general, areas of thickness post-impoundment sediments are located in the deepest portions of each reservoir and conform to the locations of former stream channels.

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 was abrupt and contrasting. This characteristic provided a most 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 and this interface was identifiable on most radar records. 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.

Recommended Action:

1. If additional reservoirs are to be surveyed with GPR, winter operations should be considered. During winter months, reservoirs would be frozen and shallow areas could be more comprehensibly surveyed with GPR. The use of a snowmobile or snowshoes should be considered.

2. A copy of the spreadsheet of the GPS and GPR data has been forwarded by e-mail to Chris Henry.

It was my pleasure to work in New York and with members of your fine staff.

With kind regards,

Jim Doolittle
Research Soil Scientist
National Soil Survey Center

cc:
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References

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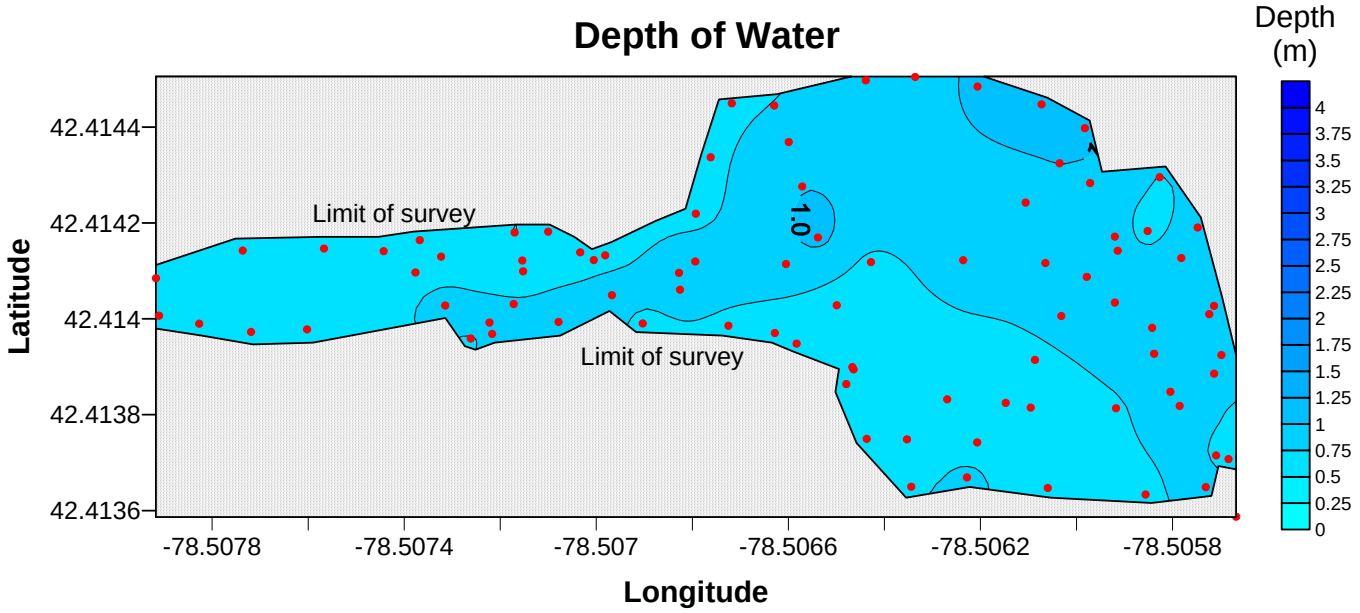
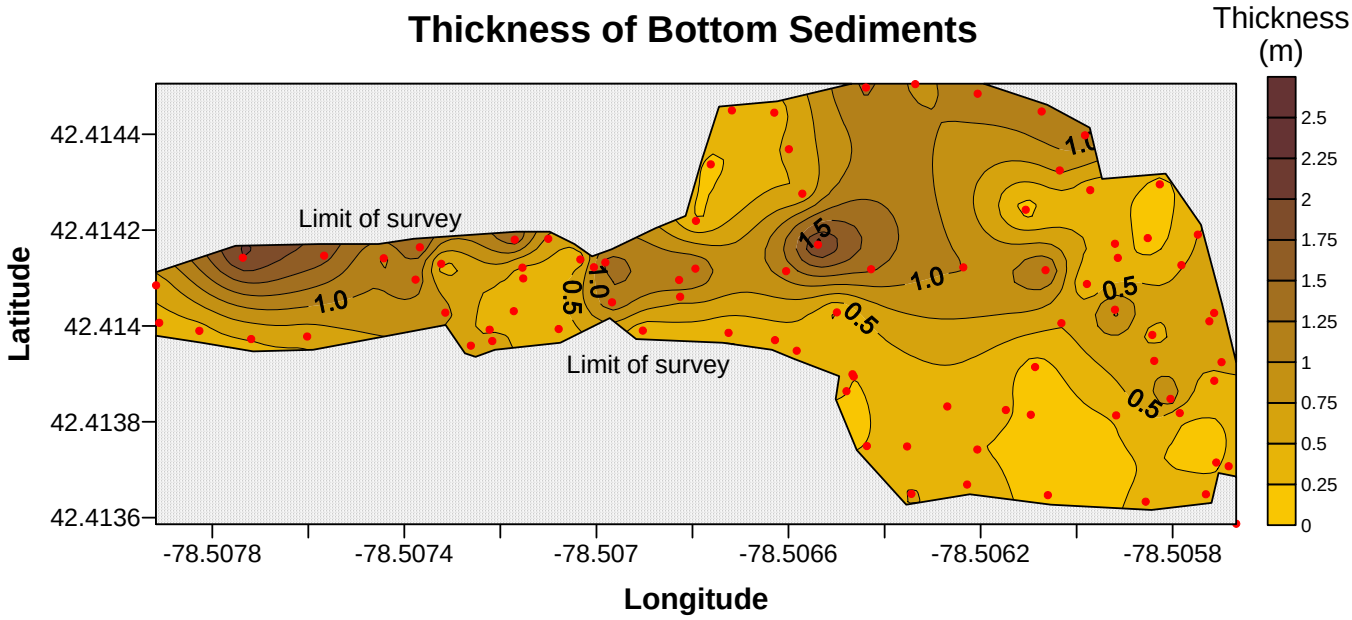
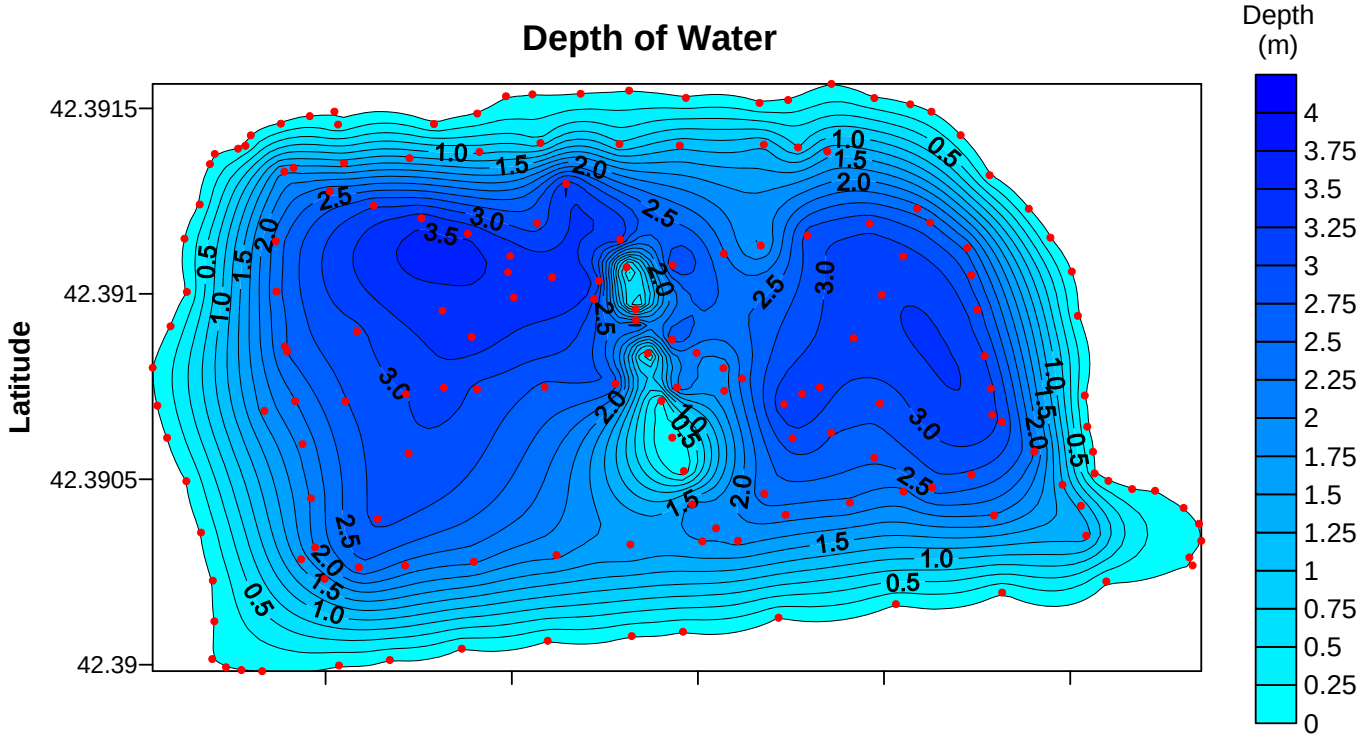
DAM #1
CATTARAUGUS COUNTY, NEW YORK

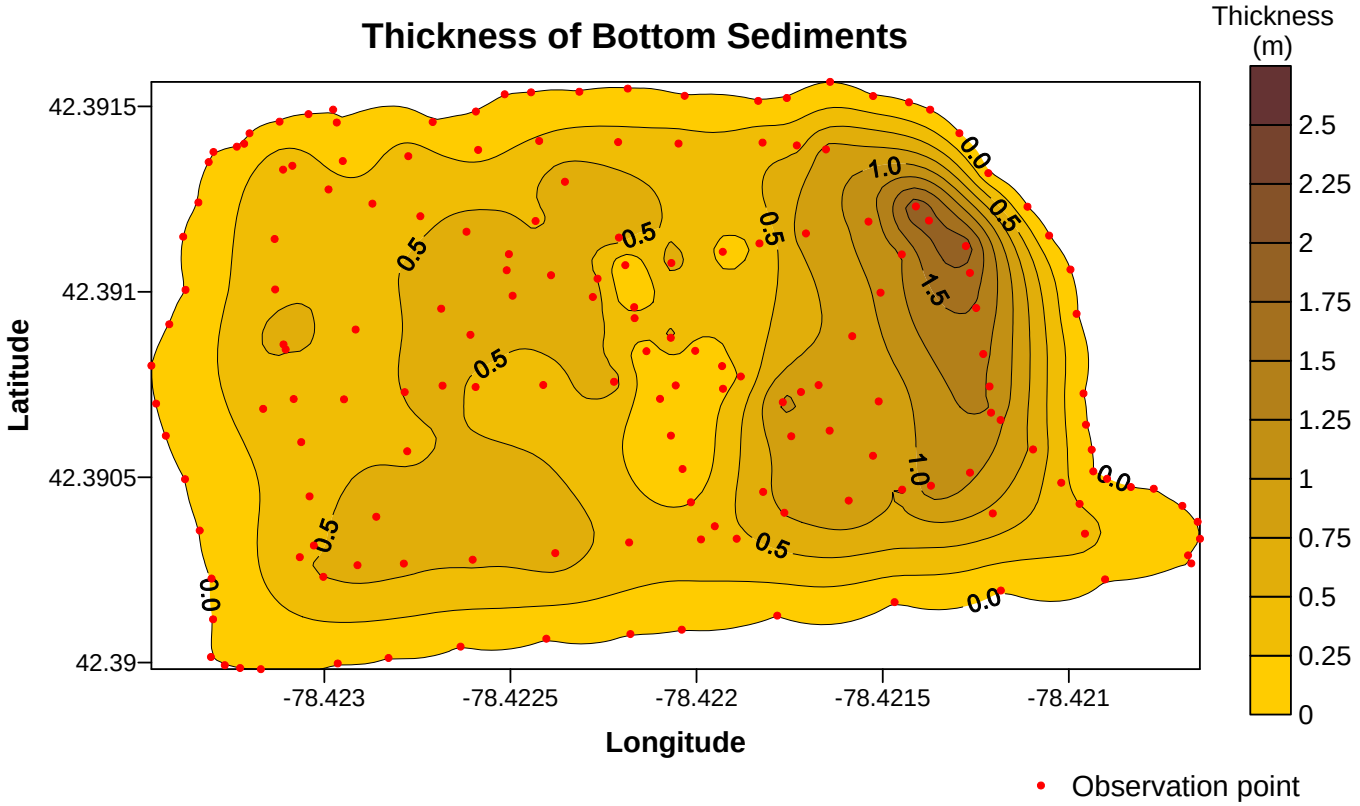




• Observation point

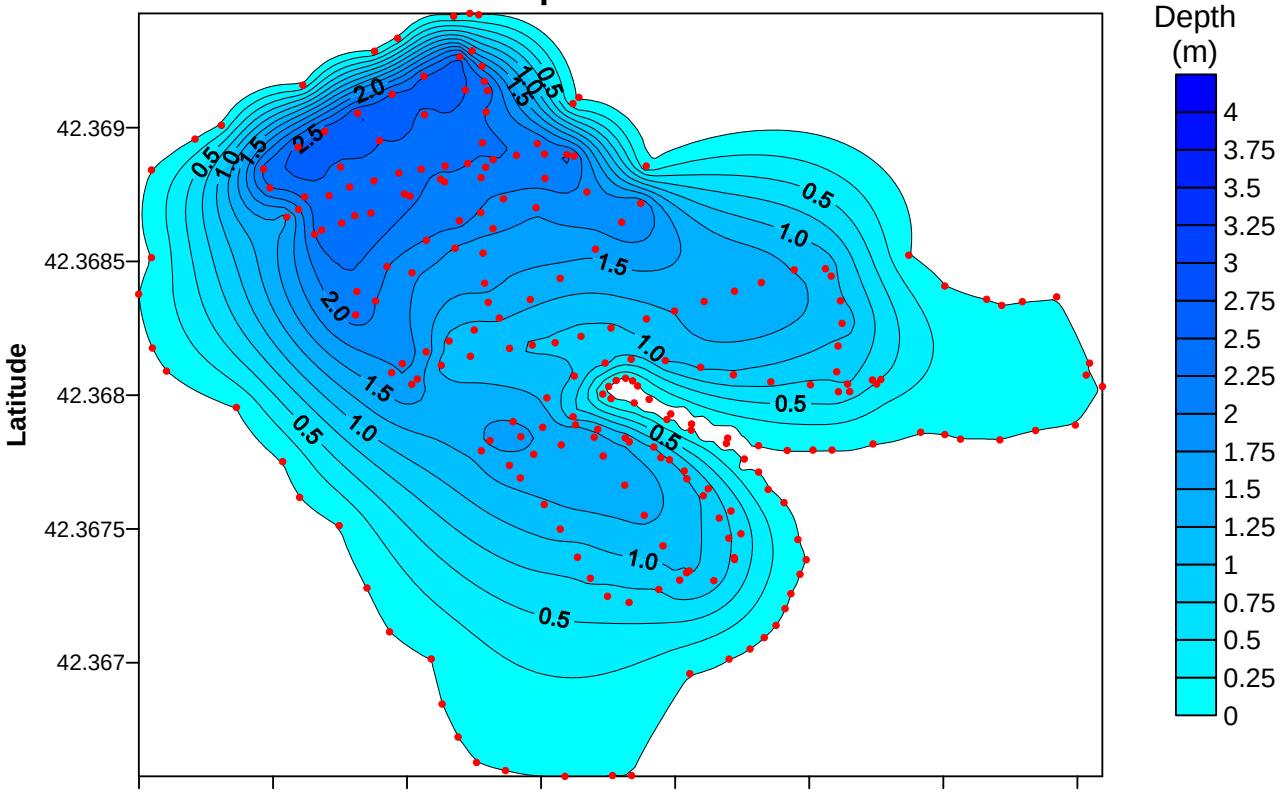
DAM #2
CATTARAUGUS COUNTY, NEW YORK



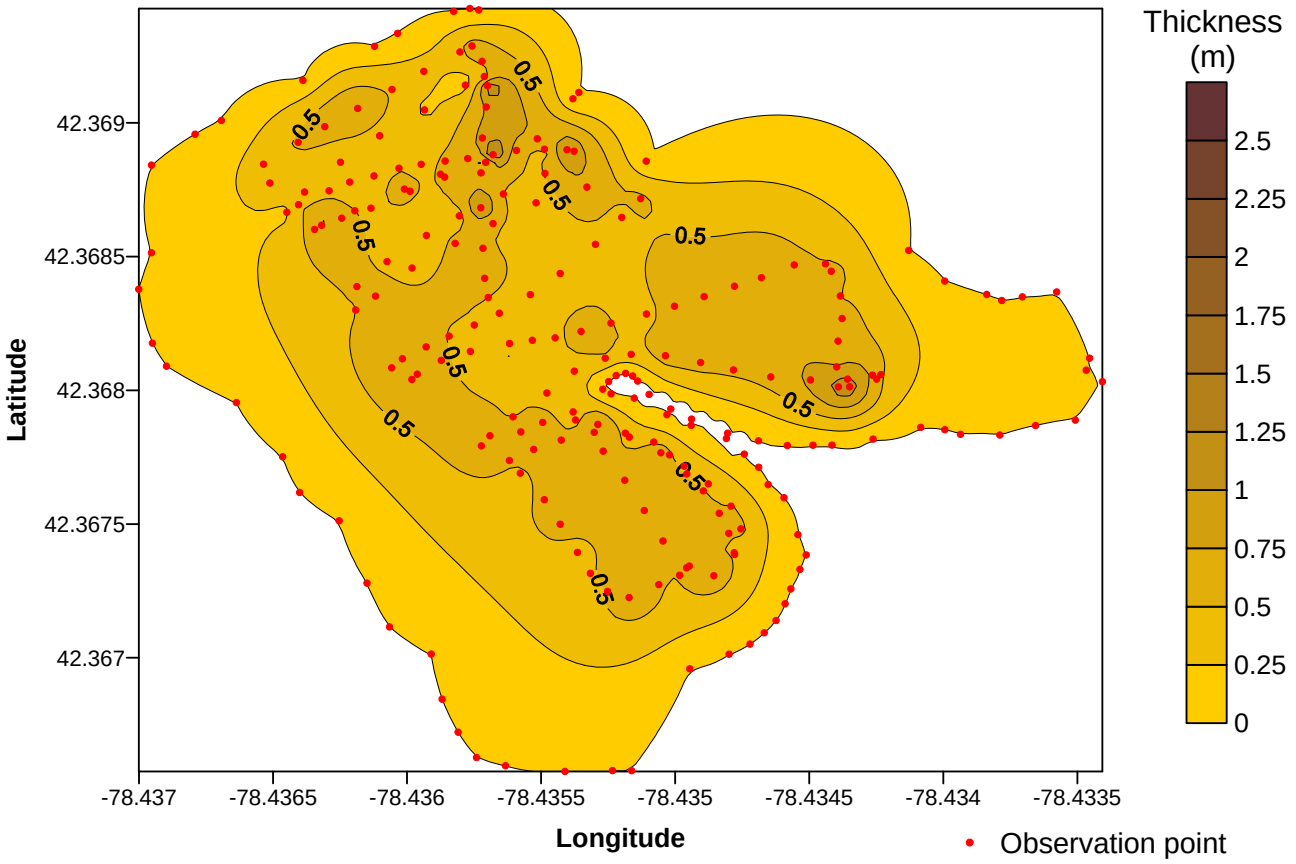


DAM #3
CATTARAUGUS COUNTY, NEW YORK

Depth of Water

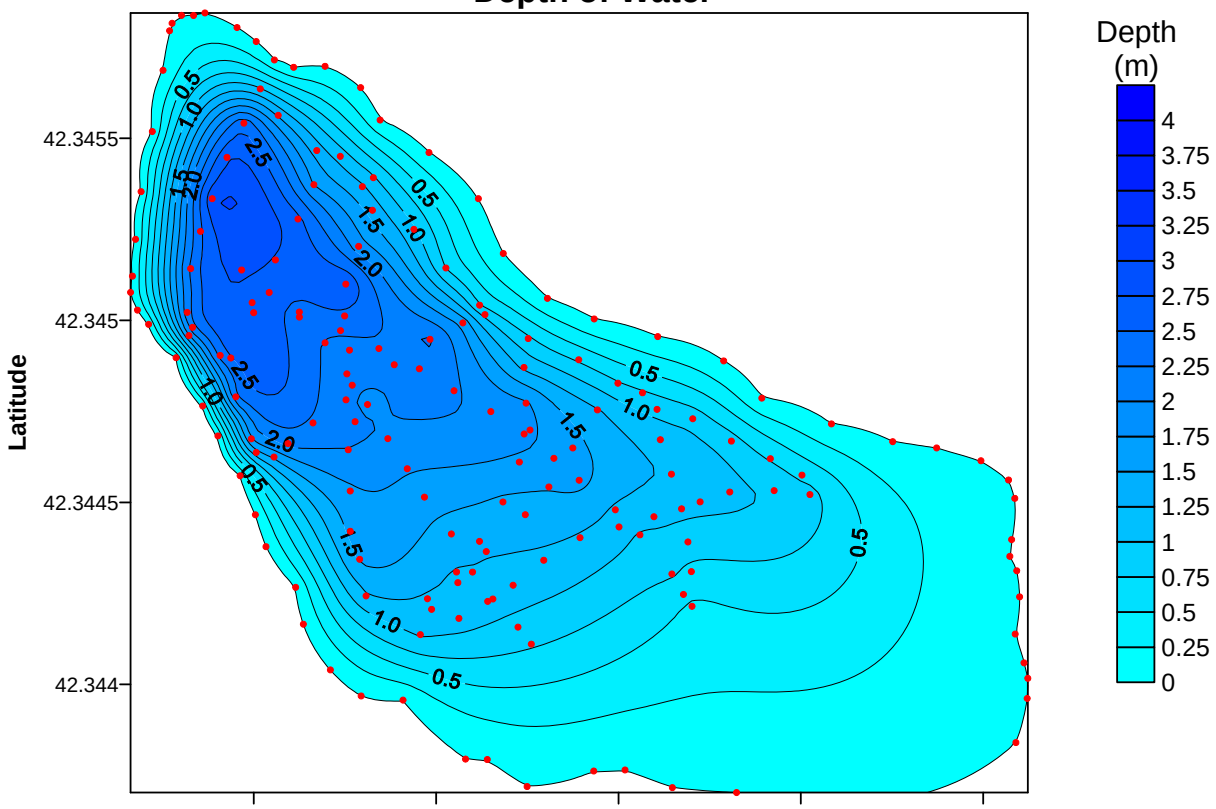


Thickness of Bottom Sediments

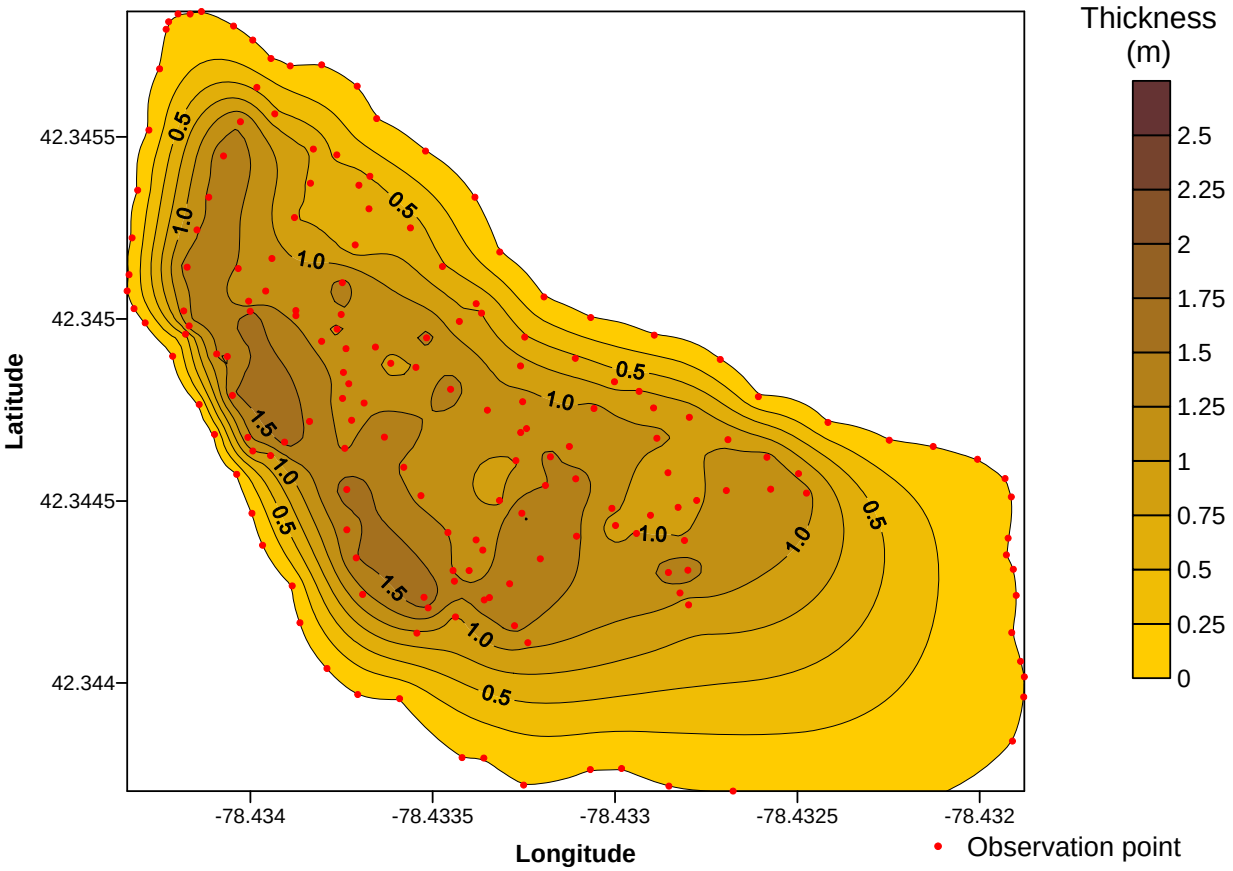


DAM #4
CATTARAUGUS COUNTY, NEW YORK

Depth of Water

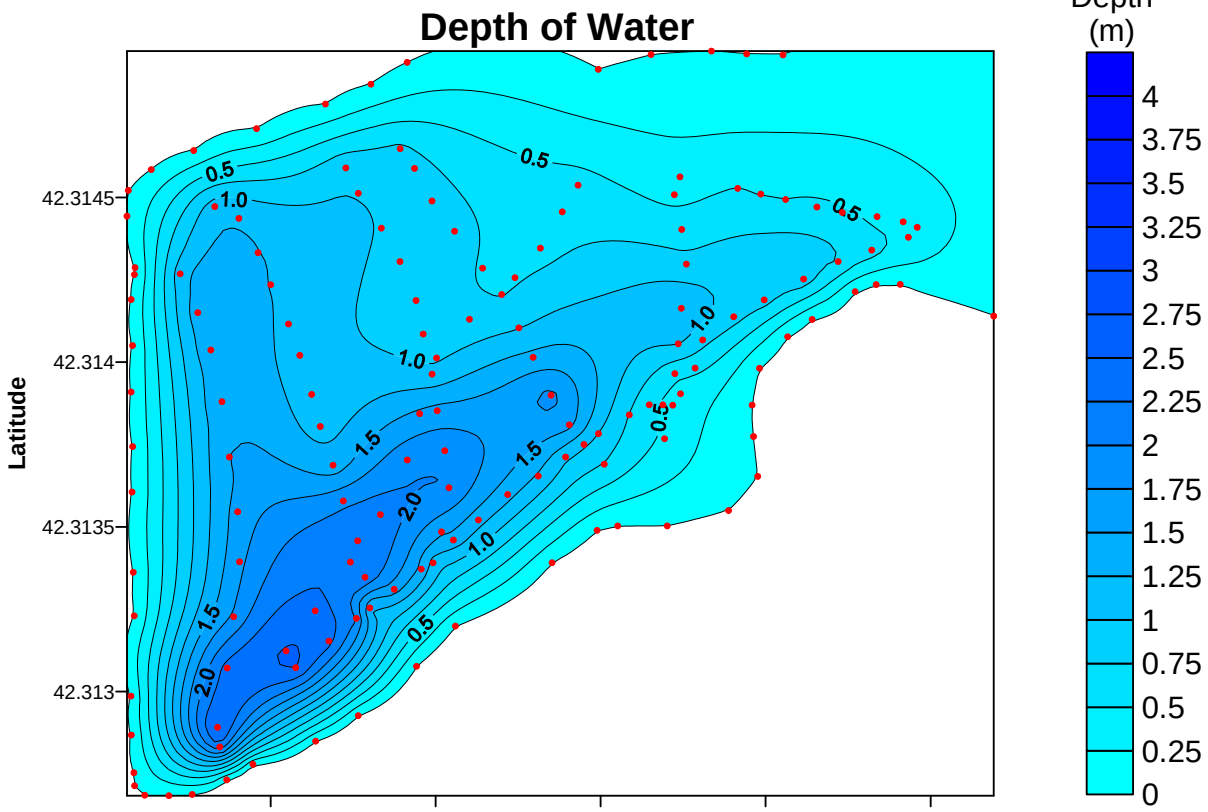


Thickness of Bottom Sediments

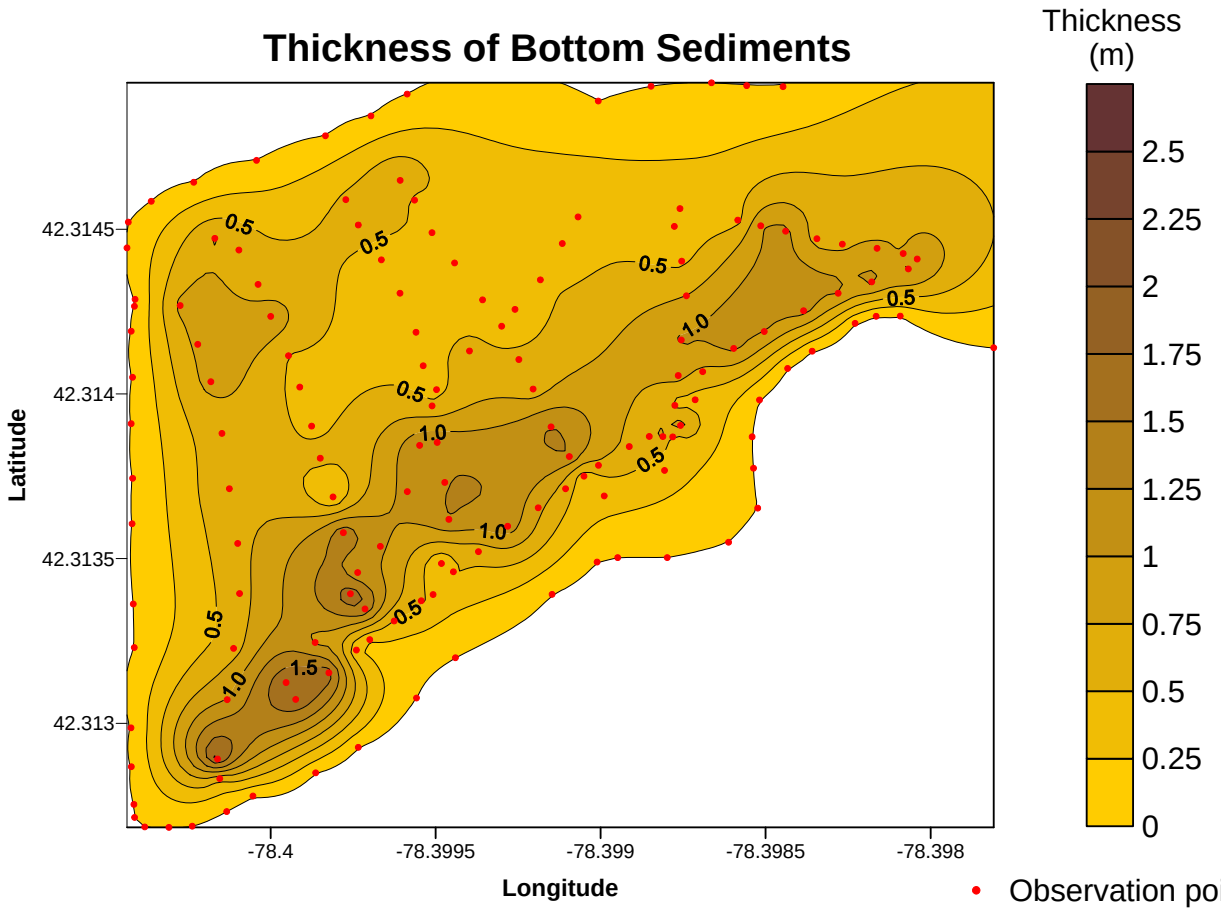


DAM #5
CATTARAUGUS COUNTY, NEW YORK

Depth of Water

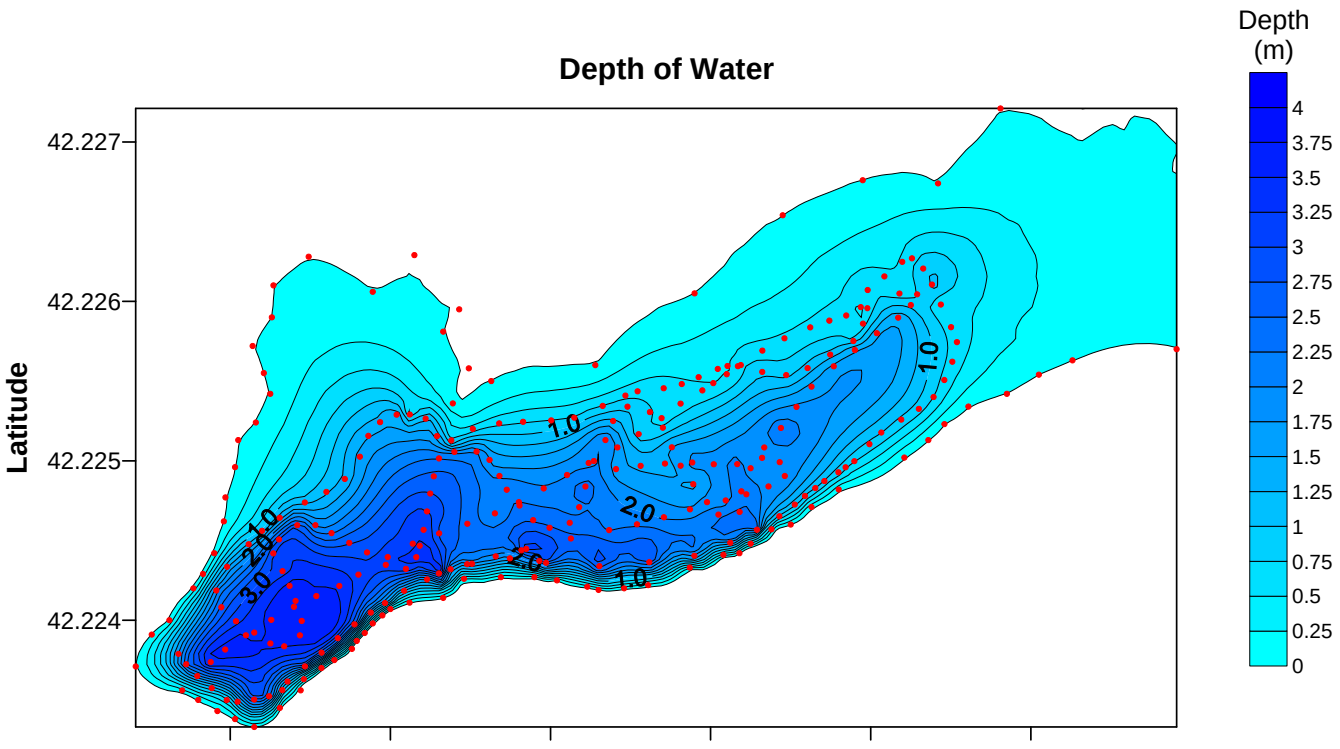


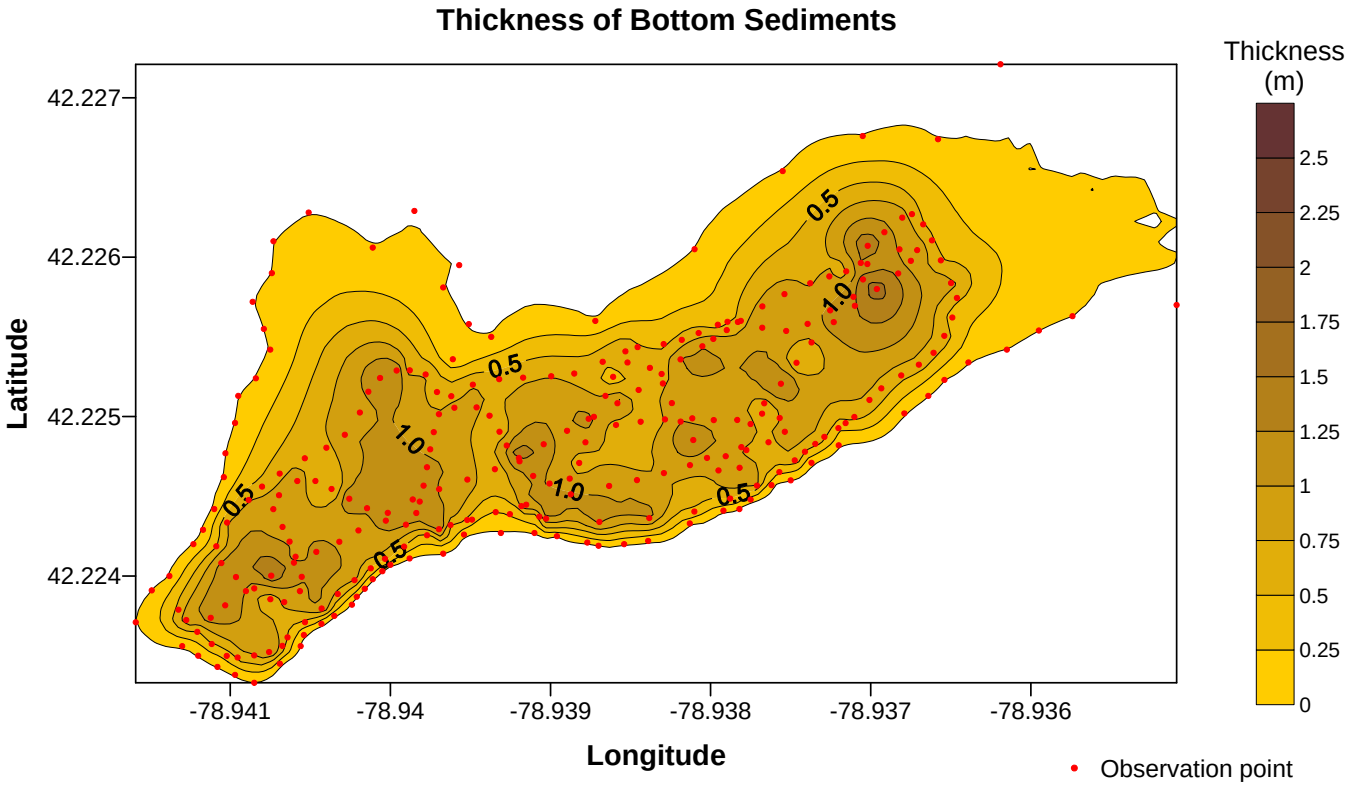
Thickness of Bottom Sediments



• Observation point

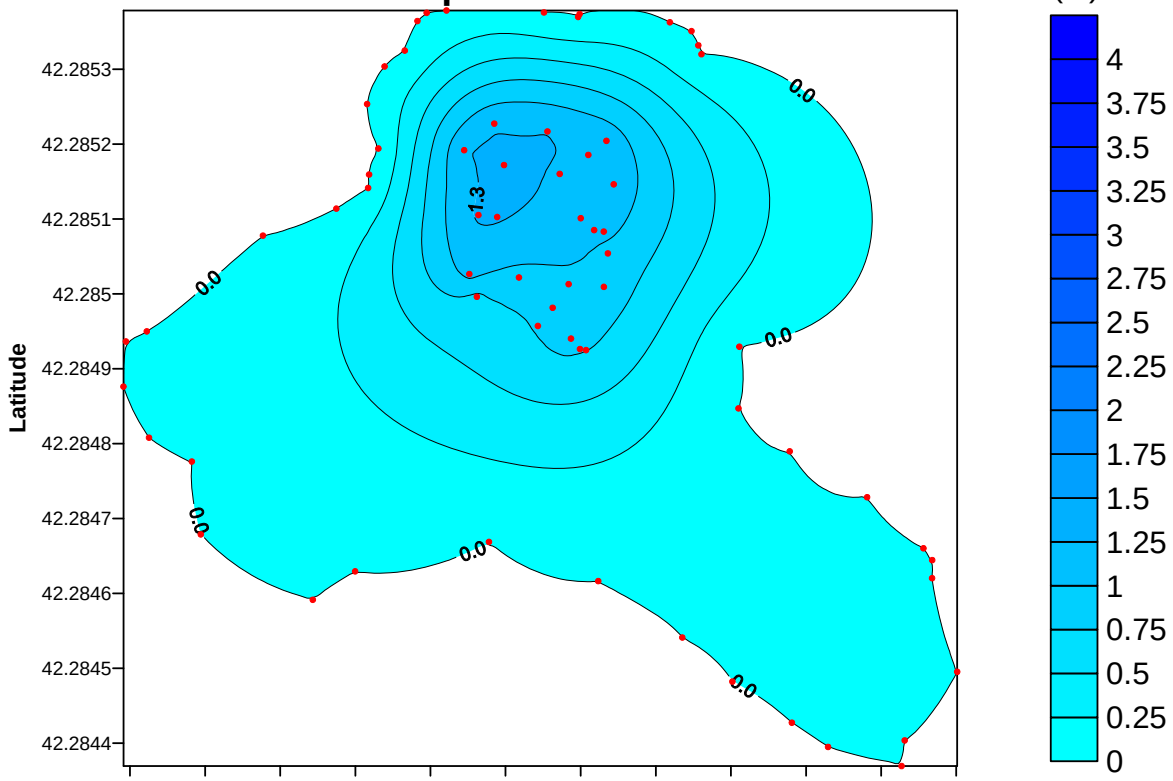
DAM #16
CATTARAUGUS COUNTY, NEW YORK



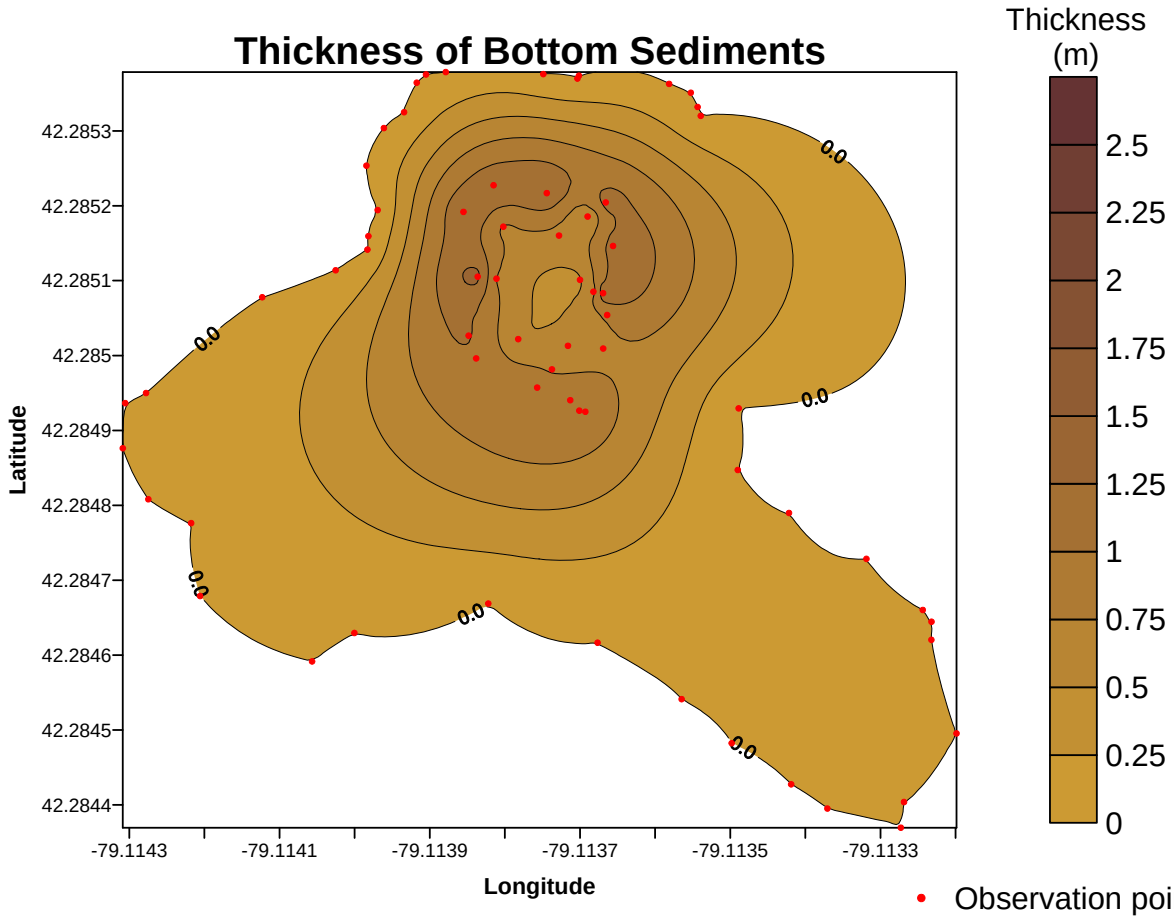


DAM #33
CHAUTAUQUA COUNTY, NEW YORK

Depth of Water



Thickness of Bottom Sediments



• Observation point