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:** 28 June, 2007

To: Margo L. Wallace
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USDA-NRCS,
344 Merrow Road, Suite A
Tolland, CT 06084-3917

Purpose:
Considerations are being made for the removal of the dam that impounds Hemingway Pond in Watertown, Connecticut. A bathymetric survey was conducted with ground-penetrating radar (GPR) to assess the thickness of recent sediments within Hemingway Pond.

Participants:
Charles Berger, Town Engineer, Public Works Department, Watertown, CT
Rudy Chlanda, Geologist, USDA-NRCS, Amherst, MA
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Joe Kavan, Civil Engineer, USDA-NRCS, Tolland, CT
Lisa Krall, Soil Scientist, USDA-NRCS, Tolland, CT
Shawn McVey, Assistant State Soil Scientist, USDA-NRCS, Tolland, CT
Donald Parizek, Soil Scientist, USDA-NRCS, Windsor, CT
Benjamin Smith, Hydrologist, USDA-NRCS, Tolland, CT

Activities:
All field activities were completed on 18 June 2007.

Background:
The dam that impounds Hemingway Pond is being considered for removal. Bottom sediments from the pond were tested and found to contain metals and Polynuclear Aromatic Hydrocarbons (PAHs) (Traci Lott's interdepartmental memo (Connecticut DEP, Bureau of Water Management) to Christopher Bellucci; dated 11 March 2004). Based on the levels of chemicals within these sediments, their removal is not considered necessary. However, the release of sediments downstream needs to be limited to prevent adverse effects on aquatic life habitats. A ground-penetrating radar (GPR) survey was request by the NRCS Engineering Staff in Tolland, Connecticut, to assess the relative thickness of these bottom sediments. Ground-penetrating radar (GPR) has been used to map the topography and characterize the sediments within lakes (Moorman and Michel, 1997; Mellett, 1995; Sellmann et al., 1992; Izbicki and Parker, 1991; Truman et al., 1991; and Haeni et al., 1987) and stream channels (Spicer et al., 1997).

Summary:

1. A GPR survey was completed at Hemingway Pond. The results of this survey are displayed in Figures 4 & 5.

2. All GPR estimated data on the depth to bottom sediment and coordinates of each observation point have been e-mailed to Rudy Chlanda and Benjamin Smith. This data set is contained in the compendium to this report.

It was my pleasure to be of assistance to you and your staff.

With kind regards,

Jim Doolittle
Research Soil Scientist
National Soil Survey Center

cc:

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Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 ®, manufactured by Geophysical Survey Systems, Inc. (GSSI, Salem, NH).[1] 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 200 MHz antenna was used in this survey. While not the lowest frequency antenna available to USDA-NRCS, the 200 MHz antenna provided the best balance of penetration depth and resolution at Hemingway Pond. This antenna provided adequate depth (greater than 3 m) and acceptable resolution of subsurface features.

Radar records contained in this report were processed with the RADAN for Windows ® (version 5.0) software program developed by GSSI.[1] Processing included setting the initial pulse to time zero, color transformation, header and marker editing, distance normalization, horizontal stacking, migration, filtration, and range gain adjustments.

An Allegro CX ® 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) were used to record the coordinates of the reference stations that were impressed on the radar record.[1] The Garmin GPS receiver was operated in the manual mode. Geodetic datum was WGS-84 (World Geodetic System of 1984). The Geographic Coordinate system (longitude/latitude) was used with units expressed in decimal degrees.

SURFER for Windows ® (version 8.0) (Golden Software, Inc., Golden, CO), was used to construct the images of the estimated water depths and bottom sediment thicknesses displayed in this report.[1] Grids were created using kriging methods with an octant search.

Figure 1. The Web Soil Survey map of the area surrounding Hemingway Pond.

Hemingway Pond Site:
The pond is located off of Echo Lake Road and Porter Street in downtown Watertown, Connecticut (see Figure 1). The pond has formed behind a dam which retards the flow of water along Steele Brook. The pond is irregularly shaped and bounded by dense

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

vegetation, commercial buildings, and public parks. The pond shows evidence of sedimentation. The dominate soil located along the floodplain is Pootatuck. The very deep, moderately well drained Pootatuck soils formed in loamy alluvial sediments. Pootatuck is a member of the coarse-loamy, mixed, active, mesic Fluvaquentic Dystrudepts soil taxonomic family. The names of the soil map units identified in the immediate vicinity of Hemingway pond are listed in Table 1.

Table 1. The names and symbols for the soil map units identified in the study areas.

Soil Map Unit Symbol	Soil Map Unit Name
34C	Merrimac sandy loam, 8 to 15 % slopes
102	Pootatuck fine sandy loam
306	Udorthents-Urban land complex
307	Urban land

Survey Procedures:
The radar system and 200 MHz antenna were mounted in a fiberglass canoe. The canoe was powered by a small trolling motor. The canoe made eight traverses across different portions and arms of Hemingway Pond. Except along the center lines of channels, which formed the two northward extending arms of the pond, traverse lines were serendipity located and were adjusted to avoid grounding on sand bars and entanglement in overlying tree limbs. The canoe frequently bottomed-out on underwater sandbanks. Reference points for both GPS and GPR were recorded simultaneously at intervals of 10 seconds. Because of wave-path masking from dense vegetation, differential GPS was not always available.

Calibration of GPR:
Ground-penetrating radar is a time scaled system. This system measures the time that it takes electromagnetic energy to travel from an antenna to an interface (e.g., soil horizon, bedrock, 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 (0.298 m/ns). Velocity is expressed in meters per nanosecond (ns). For water, the E_r is 80 and the v is 0.033 m/ns.

As the physical properties of the bottom sediments were unknown at the time of this investigation, hyperbola matching techniques were used to estimate the average propagation velocity. When radar waves impinge on a point object of contrasting electrical properties, a diffraction hyperbola is produced on the radar record. The resulting hyperbola is caused by the radar's hemispherical wavefront. The apex of the hyperbola is produced when the GPR is directly over the point object (the shortest travel path). As the antenna move away from the object, the signal travels farther and thus appears later in time or deeper in the record. The slope of the hyperbola asymptotes is related to the propagation velocity thru the material. The asymptotes become steeper as the velocity of the material decreases. During post processing, modeled hyperbolic shapes were fitted to the shapes of point reflectors buried in the bottom sediments. This resulted in the estimation of an average velocity of 0.066 m/ns and an E_r of 25 for the bottom sediments.

On radar records, reflections from interfaces spaced closer than one-half wavelength apart are indistinguishable due to constructive and destructive interference (Daniels, 2004). Daniels (2004) 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. Using equation [3] and the velocity of pulse propagation through the bottom sediments (0.066 m/ns) results in a

wavelength of about 30 cm for the 200 MHz antenna. With the 200 MHz antenna, submerged layers spaced closer (vertically) than ½ a wavelength (or about 15 cm) are indistinguishable on radar records.

With the 200 MHz antenna the lake-bottom sediments were penetrated. Variations in sediments are distinguishable on radar records. However, the compositions of these layers are unknown. As no borings were made through these sediments at the time of this survey, the identity of these layers can not be verified nor their thickness accurately estimated.

Interpretation of GPR Data:
Radar records were of good interpretative quality. Figures 2 and 3 are portions of radar records collected in Hemingway Pond. In both figures, the depth and distance scales are expressed in meters. Although the radar provides a continuous profile, measurements of the water depth were restricted to the reference points (white, vertical lines at the top of the radar records shown in Figures 2 and 3). On these radar records, these lines appear at a distance interval of about 5 meters.

In Figure 2, the horizontal, moderate-amplitude (colored red) reflector at the top of the radar record represents the reflection from the water's surface. Below the surface reflection, the first series of high-amplitude reflections represents the water/ bottom sediment interface. On this portion of the radar record, this interface varies in depth from about 75 to 110 cm. Typically, the bottom sediments consist of a series of weak to moderate amplitude, slightly inclined, parallel, planar reflectors (in Figure 2, see imagery between the 5 and 25 m distance marks). However, in some portions of the pond, reflectors were higher in amplitude, and were more irregular or segmented in appearance (in Figure 2, see imagery between the 0 and 5 m distance marks), or consisted of multiple interfaces that were difficult to discriminate from the original bottom sediments. In these portions of the pond, the distinction of bottom sediments from original bottom materials was unclear and more ambiguous. In general, the contact between bottom sediments and original bottom materials was abrupt and highly contrasting, indicating substantial differences in moisture content and density. As a consequence, this interface provided a high amplitude continuous planar reflection that could be traced laterally across most portions of the radar records. As seen in Figure 2, the original bottom materials have a unique graphic signature or appearance that enables their distinction from the overlying, more recent bottom sediments. Compared with the bottom sediments, the original bottom materials generally consisted of segmented, irregular and wavy, high amplitude reflectors.

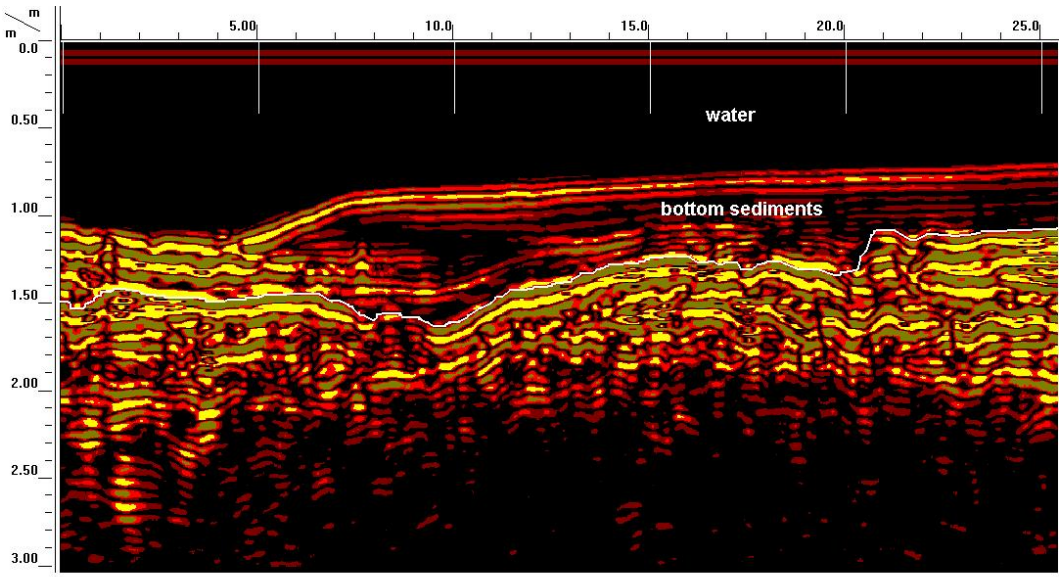

Figure 2. Each material has dissimilar dielectric properties and unique graphic signatures on this portion of a radar record from Hemingway Pond.

In shallower portions (< 30 cm) of Hemingway Pond the surface pulse and the water/ bottom sediment interface were superimposed and difficult to differentiate (see Figure 3 between the 15 and 25 m distance marks). In some portions of the pond, because of slight differences in particle sizes and densities, or the occurrence of gradational boundaries, the contact between the bottom sediments and the original bottom materials was ambiguous. The interface separating the recent bottom sediments and the original bottom sediments provides a high amplitude reflection in the left-hand portion of the radar record shown in Figure 3. Here the materials are assumed to have abrupt and highly contrasting dielectric properties. However, in the right-hand portion of the radar record shown in Figure 3, the materials have gradational and/or less contrasting dielectric properties and the interface is less obvious and more interpretative.

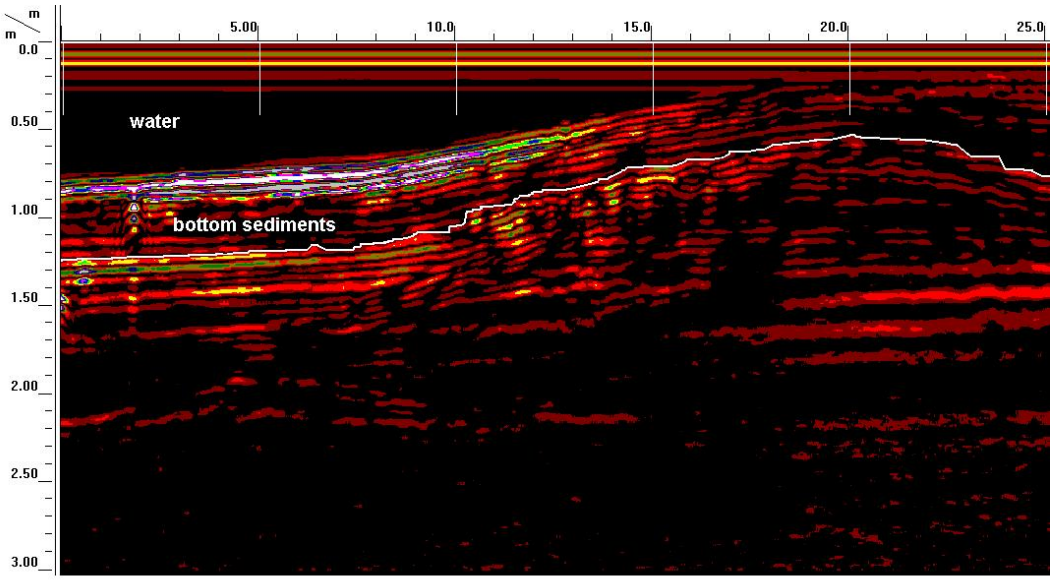

Figure 3. In some portions of Hemingway Pond interfaces are too closely spaced, gradational, or separate less dissimilar materials and are difficult to interpret.

Depth Estimates and Contouring:
The radar survey was completed in 1/2 day. The depths to bottom sediments were recorded at 202 points using GPR and GPS. Based on GPR interpretations, the average water depth was 40 cm with a range of 10 to 134 cm. At one half of the reference points, the water depth was between 24 and 54 cm. Based on GPR interpretations, the thickness of the recent bottom sediments averaged 134 cm with a range of 49 to 270 cm. At one half of the reference points, the thickness of the bottom sediments was between 101 and 165 cm.

While these statistics are useful, two-dimensional plots of these estimates provide more coherent pictures of spatial variations within Hemingway Pond. In Figures 4 and 5, the outline of Hemingway Pond was digitized off of recent photographs. In these plots, it must be emphasized that data were collected only in areas covered with sufficient water and where the canoe's steerageway could be maintained. Because of sedimentation, large areas of Hemingway Pond are covered by sand bars, or are too shallow or overgrown with vegetation to be surveyed. These areas are colored green in the accompanying plots.

Figure 4 is a two-dimensional contour map of water depths. In this plot, the contour interval is 25 cm. Figure 5 is a two-dimensional contour map of sediment thicknesses. In this plot, the contour interval is 50 cm. In each plot, colors have been used to help express differences in estimated depths or thicknesses.

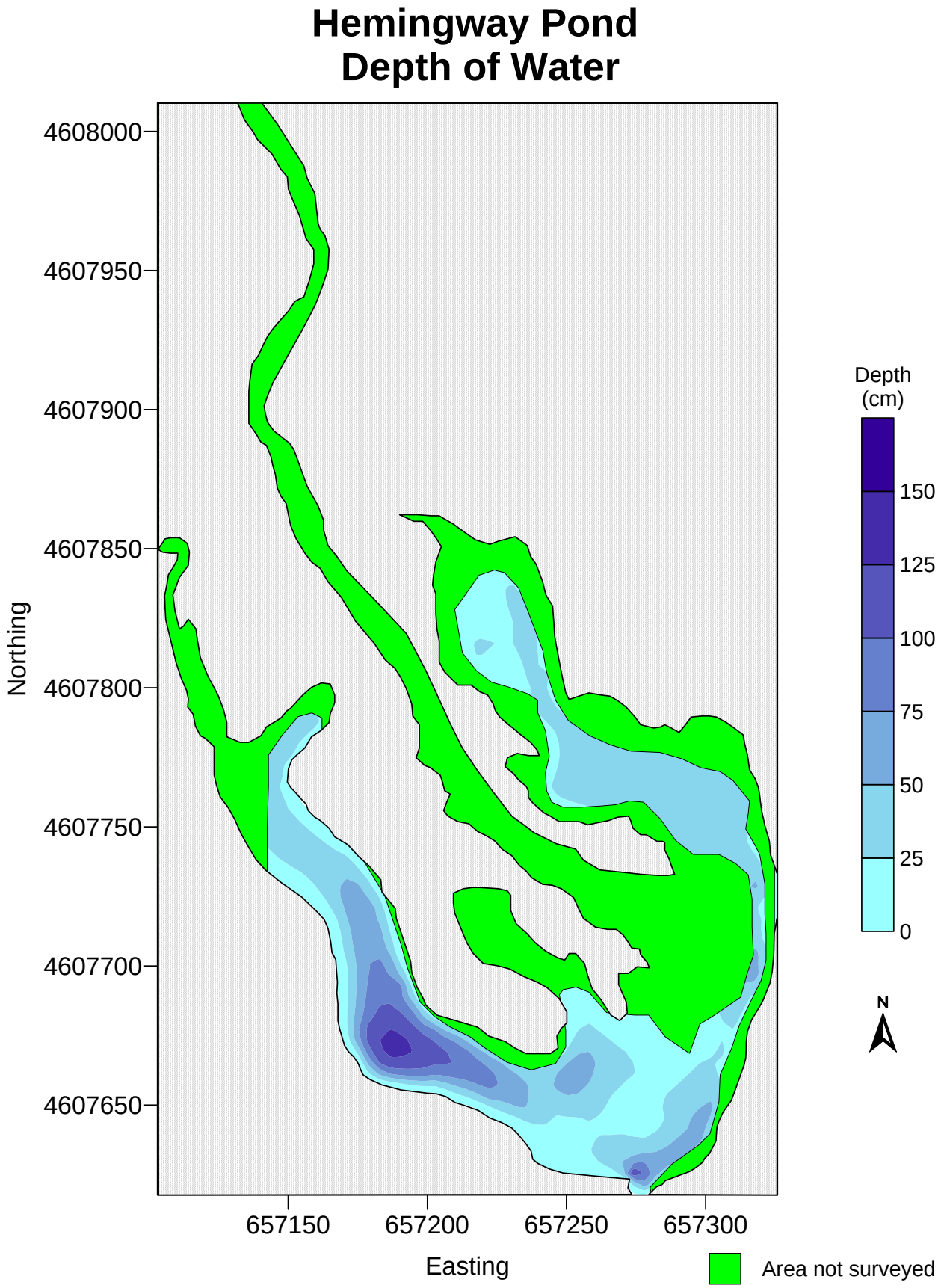

Figure 4. GPR interpreted depths of water within Hemingway Pond. The extensive areas shown in green were not surveyed because they were too shallow or too overgrown with vegetation.

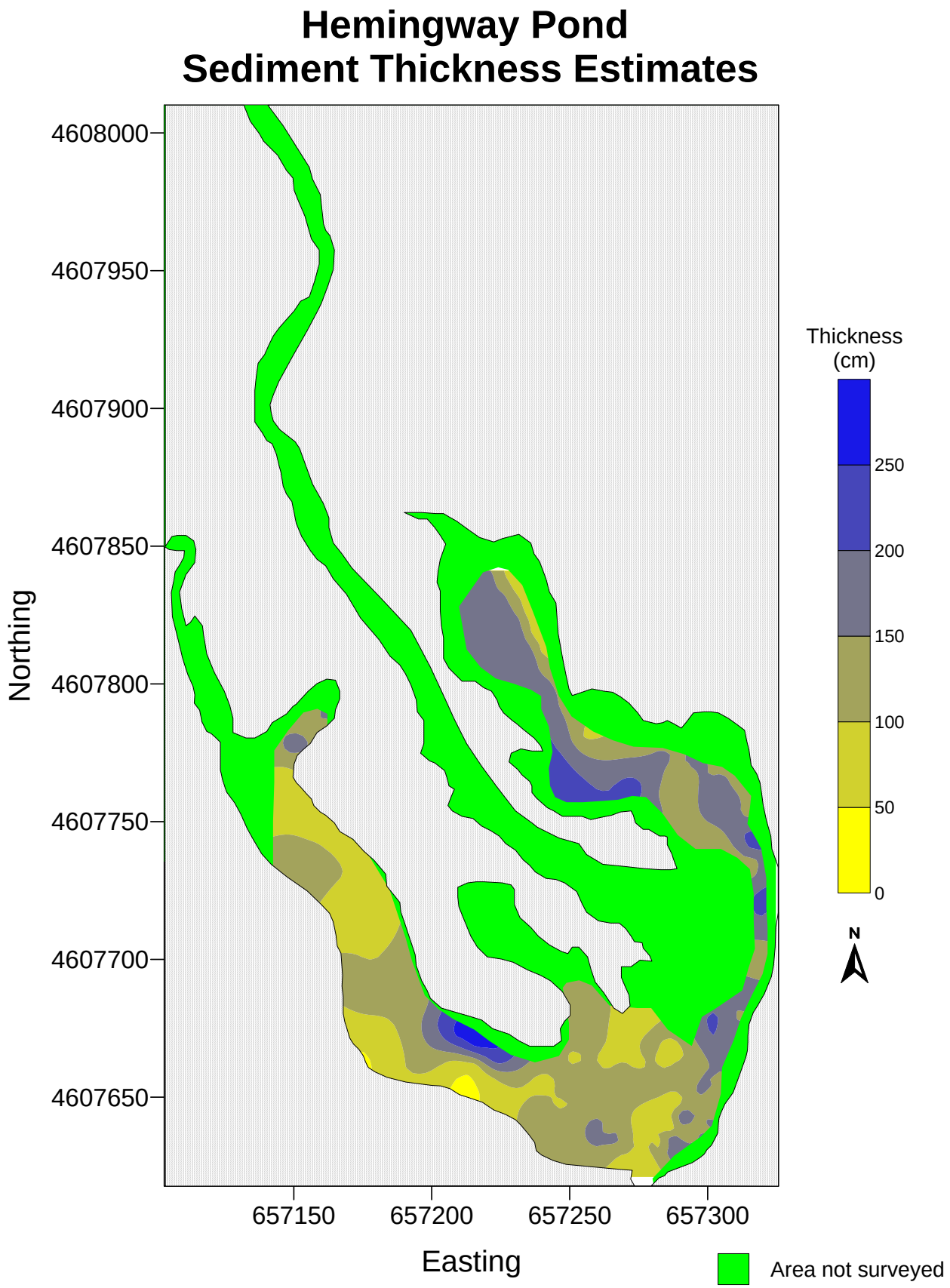

Figure 5. GPR interpreted thickness of bottom sediments within Hemingway Pond. The extensive areas shown in green were not surveyed because they were too shallow or too overgrown with vegetation.

References:

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Data Collected on Hemingway pond with GPR and GPS

Observation	Easting	Northing	Water Depth (cm)	Thickness of Bottom Sediments
1	657280	4607621	70	66
2	657274	4607625	134	49
3	657267	4607631	58	112
4	657260	4607633	28	155
5	657252	4607637	24	132
6	657246	4607642	23	157
7	657240	4607647	41	147
8	657233	4607650	59	92
9	657222	4607655	79	75
10	657215	4607661	91	62
11	657208	4607662	95	76
12	657198	4607661	89	114
13	657192	4607661	87	110
14	657185	4607663	106	62
15	657180	4607668	100	57
16	657177	4607675	103	58
17	657177	4607682	79	119
18	657178	4607691	77	154
19	657178	4607700	72	96
20	657176	4607708	68	92
21	657174	4607716	65	84
22	657169	4607724	53	82
23	657165	4607732	44	111
24	657158	4607737	37	122
25	657149	4607740	36	120
26	657142	4607746	35	97
27	657159	4607788	50	152
28	657155	4607785	54	80
29	657152	4607780	50	177
30	657148	4607775	52	152
31	657147	4607768	37	83
32	657148	4607760	32	63
33	657151	4607752	35	82
34	657156	4607747	37	85
35	657163	4607742	40	89
36	657170	4607737	44	86
37	657175	4607729	54	89
38	657180	4607721	64	75
39	657183	4607711	64	92
40	657186	4607702	73	106
41	657191	4607693	75	105
42	657195	4607684	78	120
43	657202	4607677	82	200
44	657209	4607673	82	261
45	657216	4607669	75	271
46	657224	4607664	70	238
47	657233	4607659	58	136
48	657240	4607654	38	66
49	657247	4607648	21	57
50	657255	4607643	17	115
51	657263	4607638	30	127
52	657271	4607634	40	104
53	657279	4607632	67	114
54	657287	4607630	66	178

55	657297	4607639	70	111
56	657292	4607637	48	106
57	657285	4607637	29	96
58	657278	4607638	24	92
59	657269	4607642	22	115
60	657262	4607644	20	110
61	657254	4607647	29	129
62	657248	4607650	41	137
63	657247	4607656	54	112
64	657248	4607662	56	115
65	657251	4607664	58	84
66	657255	4607664	59	97
67	657262	4607663	47	88
68	657268	4607660	30	108
69	657275	4607658	10	127
70	657282	4607653	21	113
71	657287	4607650	30	100
72	657294	4607649	43	96
73	657301	4607649	60	122
74	657304	4607652	56	125
75	657303	4607657	32	119
76	657299	4607662	31	101
77	657294	4607665	20	109
78	657286	4607667	14	62
79	657289	4607661	22	113
80	657287	4607655	25	96
81	657288	4607647	28	71
82	657286	4607639	35	52
83	657283	4607634	43	67
84	657277	4607632	39	87
85	657271	4607632	33	123
86	657266	4607635	27	180
87	657260	4607640	17	195
88	657258	4607647	35	102
89	657256	4607654	49	123
90	657256	4607661	55	128
91	657256	4607668	57	122
92	657256	4607676	35	110
93	657257	4607684	22	127
94	657255	4607689	16	100
95	657280	4607680	21	63
96	657281	4607677	21	99
97	657283	4607673	18	113
98	657282	4607671	18	108
99	657281	4607668	14	110
100	657279	4607665	20	106
101	657275	4607661	26	89
102	657273	4607657	22	122
103	657271	4607653	17	115
104	657269	4607651	14	114
105	657269	4607645	16	109
106	657272	4607641	21	98
107	657277	4607639	23	86
108	657281	4607637	32	108
109	657285	4607636	43	192
110	657289	4607636	67	157
111	657292	4607636	74	128
112	657297	4607637	56	152
113	657300	4607641	57	155

114	657301	4607645	60	140
115	657301	4607648	64	122
116	657301	4607652	45	134
117	657301	4607655	40	165
118	657301	4607659	32	175
119	657301	4607663	26	182
120	657301	4607667	26	182
121	657301	4607673	16	204
122	657302	4607679	10	212
123	657318	4607698	66	113
124	657320	4607704	59	125
125	657321	4607712	24	198
126	657320	4607719	24	222
127	657319	4607727	55	169
128	657319	4607735	41	189
129	657316	4607742	26	226
130	657312	4607750	36	196
131	657309	4607757	40	185
132	657304	4607765	40	192
133	657298	4607770	33	187
134	657291	4607773	40	149
135	657283	4607775	37	154
136	657274	4607776	41	135
137	657266	4607777	40	120
138	657256	4607781	45	89
139	657249	4607787	43	145
140	657244	4607795	36	160
141	657242	4607804	34	131
142	657239	4607811	31	102
143	657237	4607819	35	78
144	657234	4607826	40	92
145	657231	4607835	29	79
146	657227	4607840	25	86
147	657224	4607841	23	132
148	657225	4607838	20	132
149	657226	4607832	24	156
150	657229	4607826	22	160
151	657232	4607819	26	166
152	657236	4607811	26	174
153	657236	4607801	21	169
154	657230	4607801	19	172
155	657224	4607804	16	188
156	657219	4607807	17	179
157	657215	4607813	28	158
158	657212	4607819	17	158
159	657211	4607826	14	195
160	657219	4607839	16	171
161	657224	4607835	20	146
162	657228	4607830	21	147
163	657231	4607823	24	164
164	657234	4607815	25	161
165	657237	4607809	26	165
166	657240	4607800	30	177
167	657242	4607792	33	158
168	657245	4607784	19	191
169	657246	4607774	21	207
170	657244	4607768	21	238
171	657244	4607763	28	216
172	657246	4607760	21	240

173	657251	4607758	22	240
174	657257	4607759	33	208
175	657266	4607760	45	202
176	657273	4607762	34	233
177	657280	4607760	32	159
178	657286	4607754	41	143
179	657290	4607747	39	134
180	657297	4607743	35	142
181	657304	4607743	32	111
182	657310	4607746	33	186
183	657314	4607753	35	124
184	657314	4607760	35	126
185	657310	4607765	30	122
186	657302	4607769	37	111
187	657295	4607768	32	139
188	657290	4607762	34	118
189	657311	4607739	29	146
190	657318	4607735	40	121
191	657321	4607730	47	177
192	657320	4607724	21	228
193	657322	4607716	24	189
194	657321	4607704	54	127
195	657319	4607696	58	131
196	657315	4607688	30	183
197	657311	4607680	36	140
198	657308	4607671	30	172
199	657303	4607662	27	180
200	657297	4607652	28	170
201	657291	4607643	30	216
202	657288	4607634	63	160