Sediment Metals Status in Lake Thonotosassa

Hillsborough County, Florida

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Technical Report

in partial fulfillment of Pollution Recovery Fund Project #06-03A:

"Lake Thonotosassa Muck Removal Feasibility Assessment"

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Introduction

Lake Thonotosassa is the largest natural freshwater lake in Hillsborough County covering an area of 849 acres (3.44 km^2) (Hillsborough County Water Atlas). The lake is fed by Baker Creek at the southeastern end of the lake and water flows out through Flint Creek on the northeastern end to the Hillsborough River (Figure 1). Past studies on fossil diatom assemblages from sediment cores have shown that historically Lake Thonotosassa has been a eutrophic system (Brenner *et al.* 1996). The lake shifted from a eutrophic to a hypereutrophic system at some point in the early 1900's, presumably due to nutrient loading from surrounding agriculture and population growth (Brenner *et al.* 1996). Degradation of the lake's water quality continued through most of the 20^{th} century as the area's population grew (Dye 1972; Cowell *et al.* 1975). Some improvement to Lake Thonotosassa's water quality and biological communities were observed in the early 1970's following improvements to wastewater treatment at several citrus processing plants and at the Plant City sewage treatment plant (Dye 1972; Cowell *et al.* 1975). High nutrient effluents from these facilities ultimately reached the lake through the Pemberton Creek – Baker Creek drainage and contributed to the hypereutrophic conditions in Lake Thonotosassa (Dye 1972; Cowell *et al.* 1975). Despite the reduction from these point sources Lake Thonotosassa still exhibited hypereutrophic conditions due in part to nitrogen inputs from stormwater runoff (U.S. EPA 2005). The reduction in nutrient inputs has been the primary focus for Southwest Florida Water Managements (SWFWMD) Surface Water Improvement and Management (SWIM) plan for the lake (SWFWMD 2003).

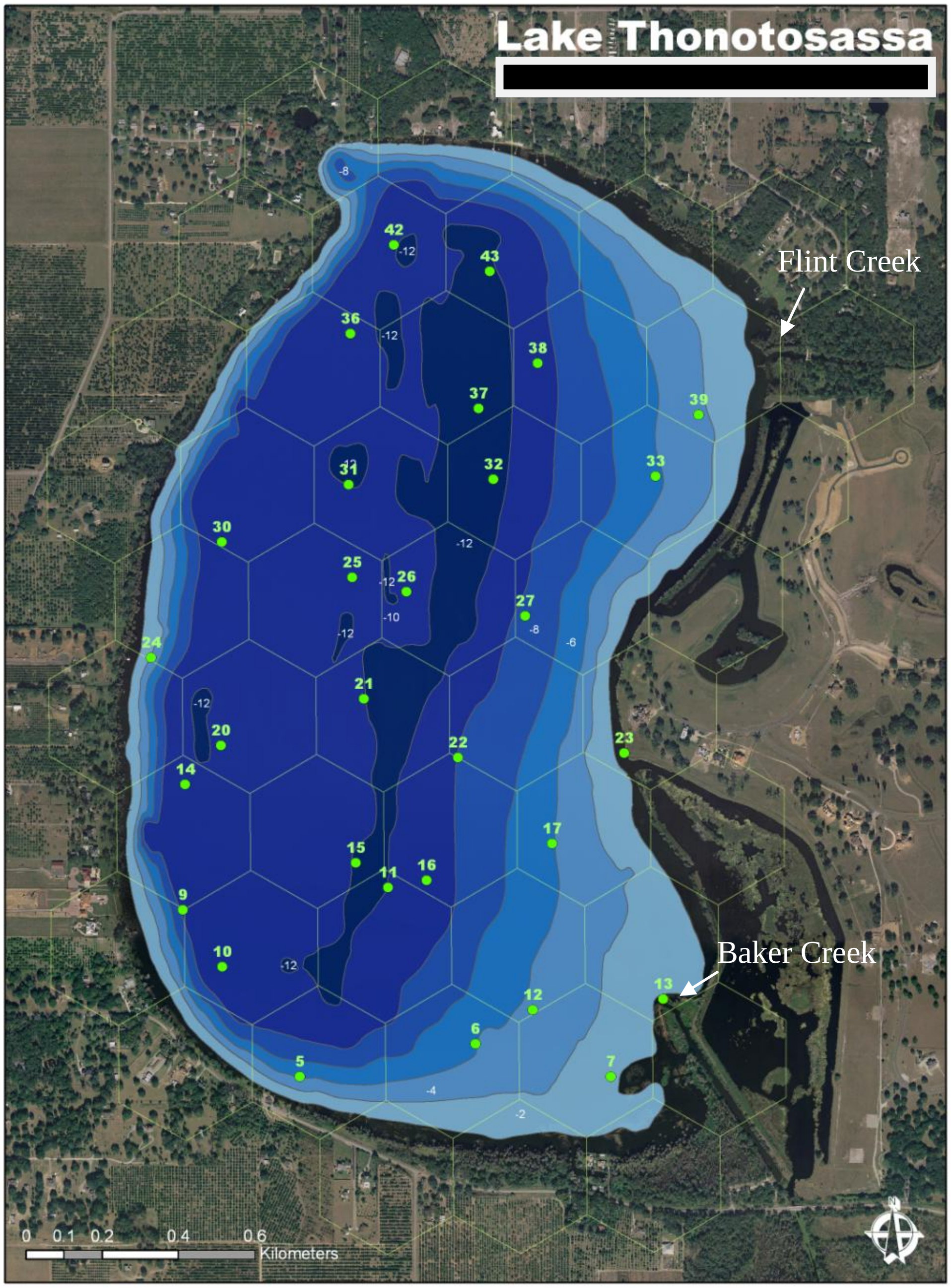

Figure 1 EPCHC Lake Thonotosassa sediment sampling grid and sample locations May 2008. Lake bathymetry indicated in feet at 2 foot (0.61 meter) intervals.

The U.S. Environmental Protection Commission (U.S. EPA) published recommended Total Maximum Daily Loads (TMDLs) for Lake Thonotosassa for unionized ammonia and for lead (U.S. EPA 2005). In the case of the lead impairment, the U.S. EPA recorded three instances of dissolved lead concentrations exceeding their chronic water quality criterion of 2.70 ppb (at a hardness of 88 mg/l $CaCO_3$) during 2002 (U.S. EPA 2005). According to the U.S. EPA criteria, a water body is considered impaired for lead if the chronic water quality criterion is exceeded two or more times during a three year period. Potential sources of lead included storm water runoff and the historic deposition of lead in lake sediments from the combustion of leaded gasoline prior to its ban in the 1980s (U.S. EPA 2005). The U.S. EPA report suggested that the observed lead exceedences may be due to the re-suspension of contaminated sediments from storm events. Therefore the U.S. EPA recommended sampling the lake sediments for lead contamination. This recommendation was the primary reason for the current study.

Material and Methods

Sediment samples were collected at 30 random locations throughout the lake on May 5-6, 2008. Sampling locations were generated by superimposing a hexagonal grid over a GIS map of the lake and generating one set of random GPS coordinates within each hexagon (Figure 1). Sediment samples were collected at each location using a stainless steel Young grab sampler. The grab sampler and all sampling utensils were field cleaned with Liqui-Nox® detergent (Alconox, Inc. White Plains, NY), rinsed with ambient surface water and decontaminated with 99% pesticide grade isopropyl alcohol (2-Propanol, FisherChemicals, Fisher Scientific Fair Lawn, NJ) prior to sampling and all equipment and samples were handled wearing latex gloves. The top 2 cm layer of sediment was removed from each grab using a stainless steel or Teflon®

coated spoon, placed in a stainless steel beaker, and homogenized by stirring. The homogenized sample was then split, with one fraction being placed in a pre-cleaned HDPE sample jar for metals analysis and second fraction being placed in smaller HDPE jar for silt+clay analysis.

The sediment samples were analyzed for a suite of 14 trace metals and processed using a total digestion method with hydrofluoric acid using a CEM MARS Xpress microwave digester. Analysis was performed on a Perkin Elmer Optima 2000 Optical Emission Spectrometer according to EPA Method 200.7.

The sediment metal concentrations were regressed against corresponding *in situ* aluminum values as a reference element in order to detect possible sediment enrichment and graphed using SigmaPlot® 10 software (SYSTAT 2006a). The Florida Department of Environmental Protection's interpretive tool for assessment of metal enrichment in Florida freshwater sediment (Carvalho *et al.* 2002) was used to compare selected metals:aluminum values in Lake Thonotosassa with Florida state reference sites.

The sediment quality assessment guidelines (SQAGs) developed for freshwater ecosystems were used to evaluate the potential levels of sediment toxicity for specific metals (MacDonald *et al.* 2000; Ingersoll *et al.* 2001; MacDonald *et al.* 2003). These are defined as the **Threshold Effect Concentration** (TEC), the value below which toxic effects to aquatic organisms would be unlikely, and the **Probable Effect Concentration** (PEC), the value above which toxic effects to aquatic organisms would be likely to occur (MacDonald *et al.* 2003).

The percent silt + clay was determined following the methods developed for the U.S. EPA Environmental Monitoring and Assessment Program for Estuaries (EMAP-Estuaries) as outlined in Versar (1993). These methods have been shown to be valid for both marine and freshwater sediments.

Summary statistics were calculated using SYSTAT® 11 software (SYSTAT Software, Inc. 2004) or SigmaStat® 3.5 (SYSTAT 2006b). PRIMER® v6 software was used for multivariate statistical analysis including principle components analysis (PCA) and cluster analysis on the sediment metals (PRIMER-E, Ltd. 2006; Clarke and Gorley 2006). Values for aluminum and iron were excluded from analysis since these two metals were measured as background parameters. Where measured values were below the minimum detectable level (MDL) for a given metal, ½ the MDL value was substituted for statistical analysis. The metals data were normalized and log (n+1) transformed prior to analysis and the Euclidian distance was used as the measure of resemblance for the cluster analysis. The spatial distribution of individual metals was mapped using ArcGIS® 9.2 software (ESRI 2006).

Results

The sample depth and percent silt + clay summary statistics for all 30 sampling sites are presented in Table 1. Depths ranged from 0.54 m to 3.78 m with a median sample depth of 3.27 m (Table 1). Over half of the sites (60%) had depths greater than 3 m, while only 10% (3 sites) were shallower than 1 m (Table 1). The silt+clay content ranged from 0.3% to 82.7% with a median value of only 1%. Half of the samples had percent silt+clay values below 1%, while one-third of the samples were greater than 50% (Table 1). Higher silt+clay values tended to be concentrated at the deeper sites on the west and central areas of the lake (Figure 2).

Table 1 Lake Thonotosassa station depth and sediment characteristics.

	Depth (meters)	Silt+Clay (%)
N	29	30
Minimum	0.54	0.30
Maximum	3.78	82.70
Median	3.27	1.00
Mean	2.70	25.26
Standard Deviation	1.03	33.47
< 1 meter	10%	
1-2 meters	20%	
2-3 meters	10%	
>3 meters	60%	
< 1% Silt+Clay		50.00%
1-25% Silt+Clay		16.67%
25-50% Silt+Clay		0.00%
50-75% Silt+Clay		20.00%
>75% Silt+Clay		13.33%

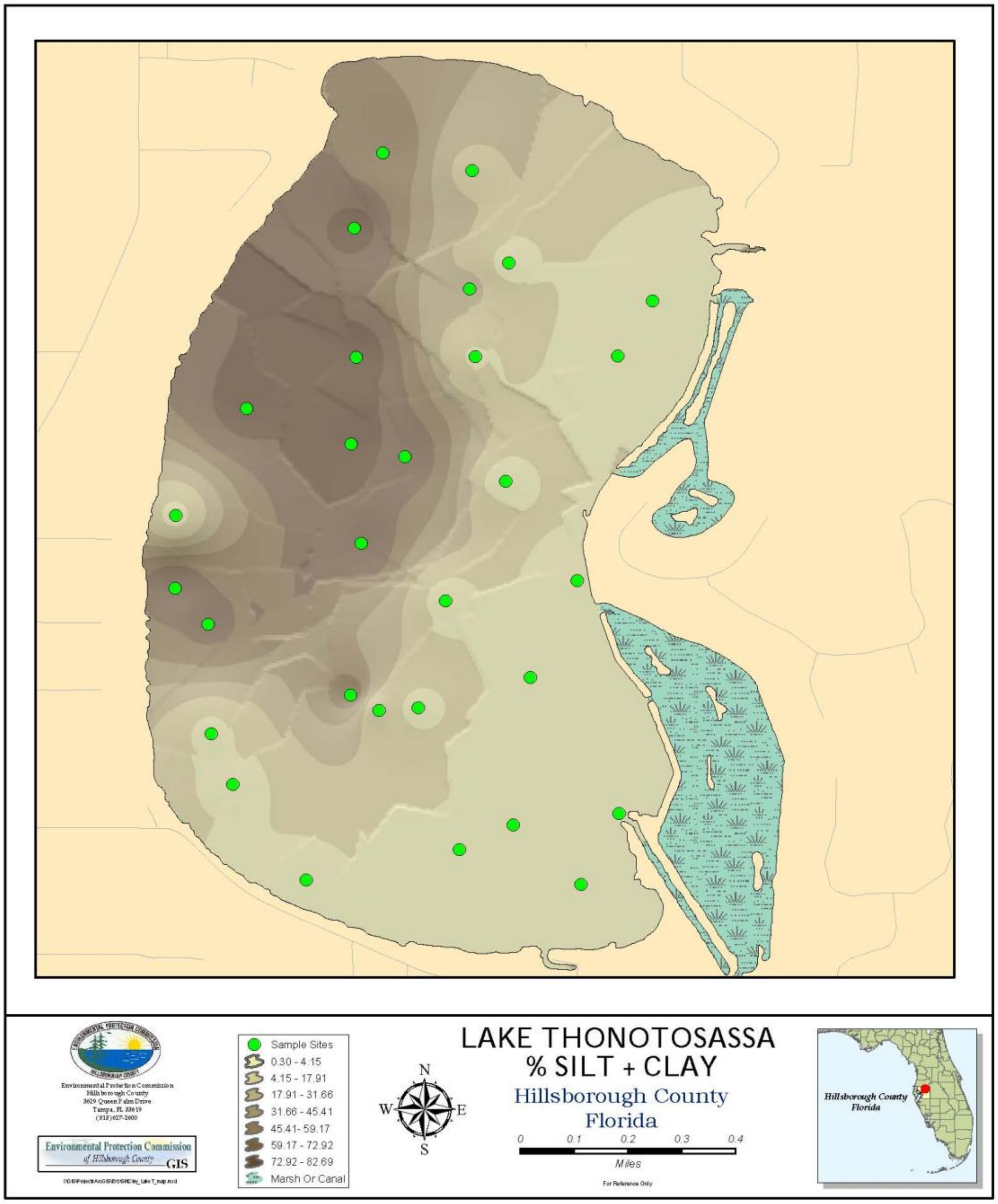

Figure 2 Lake Thonotosassa silt+clay distribution.

The sites clustered into six distinct groups based on their sediment metals composition (Figure 3). The first group designated as “A” split off from the other sites at a Euclidian distance of six and was composed of ten sites. Group “A” sites were generally located in the deeper, western portion of the lake (Figure 4) and were characterized by high (> 50%) silt+clay content (Table 2). The remaining 20 sites (group “B”) were further subdivided into groups “B1” and “B2”. Group “B1” consisted of a single site (08LTH06) on the southern end of the lake at a depth of 2 m (Figure 4; Table 2). This site was characterized by low silt+clay content (0.3%) and had the highest concentrations for antimony, arsenic, cadmium, and tin (Table 2). Group “B2” was further split into four distinct subgroups designated as groups “B2a”, “B2b”, “B2c” and “B2d” (Figure 3). Group “B2a” consisted of two sites located in the north-central portion of the lake (Figure 4). These two sites were among the deepest with a median depth of 3.56 m and had a median silt + clay content of 17% (Table 2). Group “B2b” was composed of nine sites located primarily along the eastern side of the lake with a couple of sites scattered along the southern and western shore lines (Figure 4). The “B2b” sites varied widely in depth but all had very low silt + clay contents (median = 0.5%; Table 2). Group “B2c” consisted of a single site (08LTH39) which was located on the northeastern side of the lake near the Flint Creek outfall (Figure 4). This site was characterized by a relatively shallow depth and low silt + clay content (Table 2). Group “B2d” was composed of seven sites primarily on the eastern side of the lake, however two sites were along the southwestern shore and a single station (08LTH13) was located at the mouth of Baker Creek on the southeastern corner of the lake (Figure 4). The median depth for the “B2d” sites was 3.39 m although station 08LTH13 was only 0.5 m deep (Table 2). These sites were also characterized by their low silt + clay composition (Table 2).

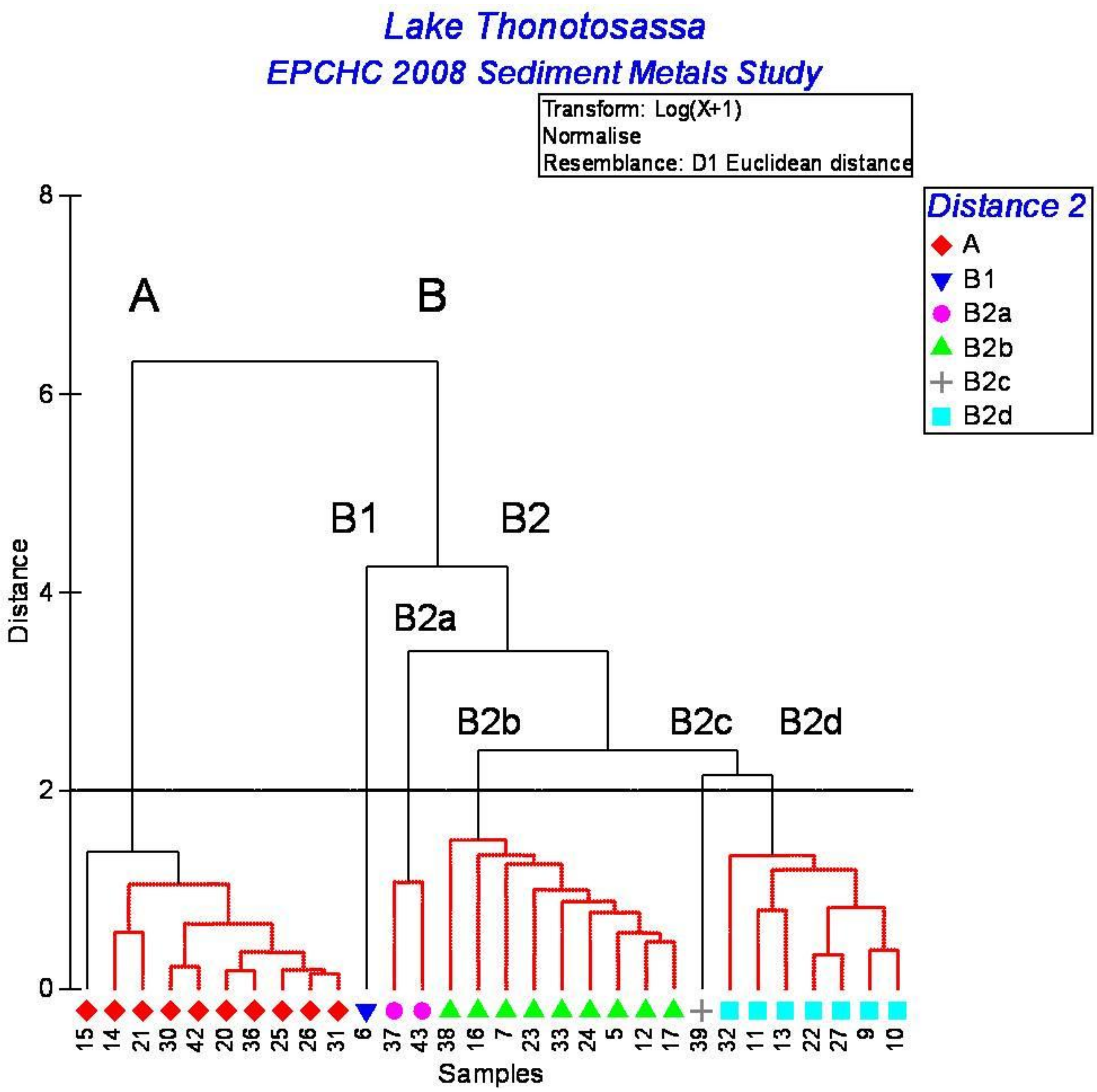

Figure 3 Euclidian distance cluster analysis of Lake Thonotosassa sediment metals (excluding Al & Fe). Data log (n+1) transformed and normalized for analysis.

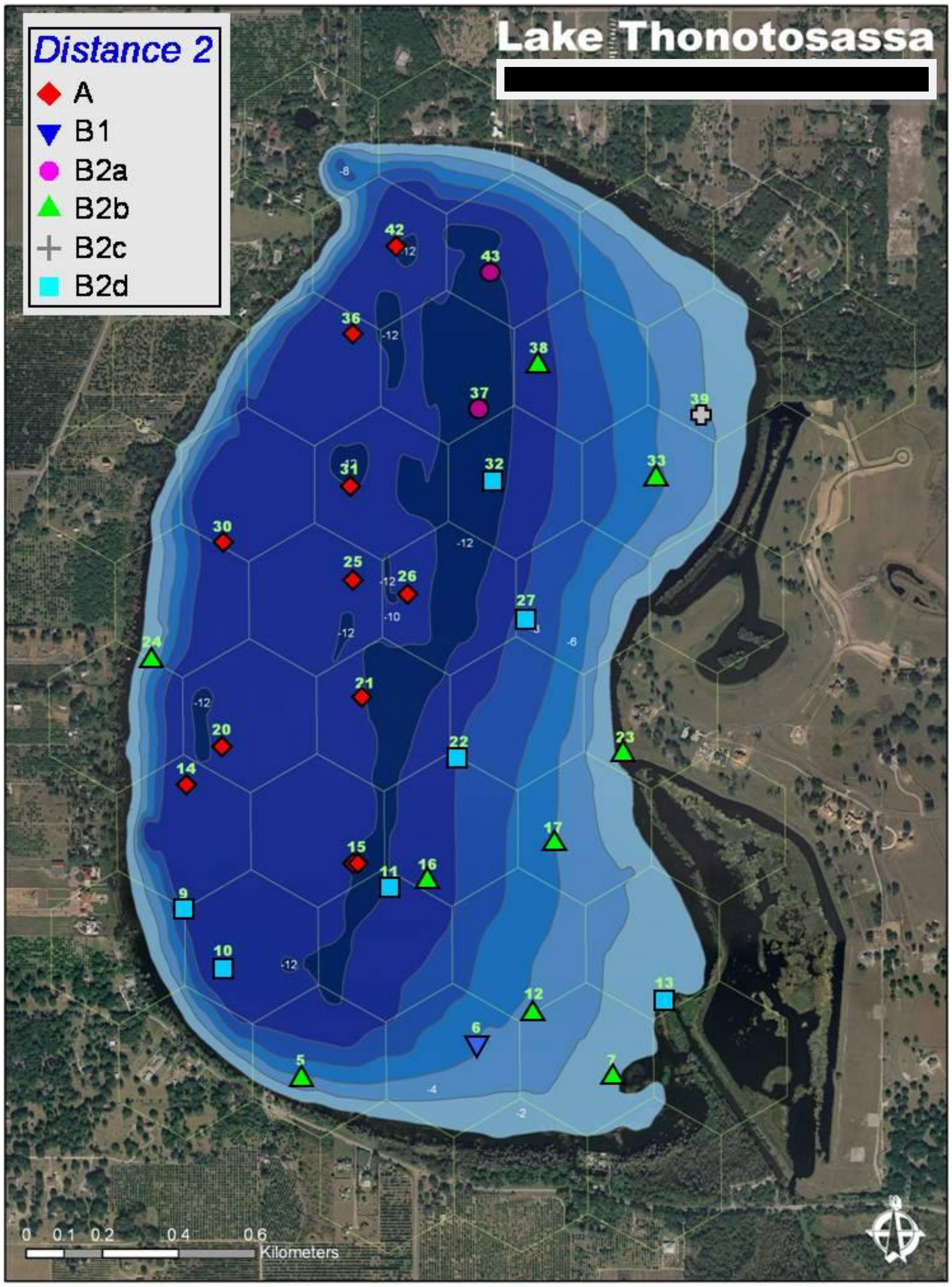

Figure 4 Spatial distributions of metals cluster groups in Lake Thonotosassa.

Table 2 Lake Thonotosassa summary statistics for station depth, sediment silt + clay, and sediment metals by station and Euclidian distance groupings.

Sample	Group	Depth (m)	Silt + Clay (%)	Al (mg/kg)	Sb (mg/kg)	As (mg/kg)	Cd (mg/kg)	Cr (mg/kg)	Cu (mg/kg)
08LTH14	A	3.48	63.5	38648	4.05	<MDL	1.85	42.97	15.03
08LTH15	A	3.45	56.9	32444	3.88	<MDL	1.73	35.89	15.47
08LTH20	A	3.39	71.8	45096	<MDL	<MDL	1.80	49.05	15.90
08LTH21	A	ND	70.6	41116	2.69	<MDL	1.84	46.77	16.86
08LTH25	A	3.48	80.7	43678	<MDL	<MDL	1.71	43.93	15.52
08LTH26	A	3.54	69.2	42013	<MDL	<MDL	1.75	43.36	14.16
08LTH30	A	3.27	77.8	46634	<MDL	<MDL	1.58	42.51	13.10
08LTH31	A	3.42	82.7	41015	<MDL	<MDL	1.75	42.89	15.86
08LTH36	A	3.27	77.2	48906	<MDL	<MDL	1.82	46.88	13.69
08LTH42	A	3.30	58.6	37568	<MDL	<MDL	1.62	38.59	12.10
Distance Group A		**3.42**	**71.2**	**41564**	**<MDL**	**<MDL**	**1.75**	**43.17**	**15.25**
		3.27 3.54	**56.9 82.7**	**32444 48906**	**<MDL 4.05**	**<MDL <MDL**	**1.58 1.85**	**35.89 49.05**	**12.10 16.86**
08LTH06	**B1**	**2.01**	**0.3**	**507**	**14.44**	**7.35**	**2.52**	**3.75**	**0.53**
08LTH37	B2a	3.60	20.6	8367	7.75	<MDL	1.48	17.33	5.68
08LTH43	B2a	3.51	13.5	5921	8.02	<MDL	1.23	12.30	4.25
Distance Group B2a		**3.56**	**17.1**	**7144**	**7.89**	**<MDL**	**1.36**	**14.82**	**4.97**
		3.51 3.60	**13.5 20.6**	**5921 8367**	**7.75 8.02**	**<MDL <MDL**	**1.23 1.48**	**12.30 17.33**	**4.25 5.68**
08LTH05	B2b	1.86	0.7	515	10.91	5.24	1.24	3.02	1.01
08LTH07	B2b	0.81	0.6	834	11.26	5.77	1.57	2.74	0.63
08LTH12	B2b	1.65	0.5	568	10.10	5.78	1.21	2.23	0.50
08LTH16	B2b	3.27	0.7	731	10.52	5.64	1.11	3.99	1.13
08LTH17	B2b	1.77	0.5	611	10.48	5.06	1.26	2.93	0.57
08LTH23	B2b	0.75	0.3	667	10.22	6.98	1.31	2.07	0.37
08LTH24	B2b	1.17	0.3	640	10.24	4.98	1.34	2.75	0.46
08LTH33	B2b	1.95	0.5	570	10.36	5.41	1.07	2.92	0.79
08LTH38	B2b	3.36	0.6	631	9.95	5.02	0.99	3.60	0.52
Distance Group B2b		**1.77**	**0.5**	**631**	**10.36**	**5.41**	**1.24**	**2.92**	**0.57**
		0.75 3.36	**0.3 0.7**	**515 834**	**9.95 11.26**	**4.98 6.98**	**0.99 1.57**	**2.07 3.99**	**0.37 1.13**
08LTH39	**B2c**	**1.41**	**0.3**	**546**	**9.44**	**<MDL**	**1.07**	**2.40**	**<MDL**
08LTH09	B2d	3.48	0.6	891	10.76	<MDL	1.40	3.65	1.24
08LTH10	B2d	3.39	0.7	932	9.79	<MDL	<MDL	3.68	1.10
08LTH11	B2d	3.60	2.9	1575	10.24	<MDL	1.52	5.43	1.55
08LTH13	B2d	0.54	1.3	2248	9.68	<MDL	1.55	6.12	0.81
08LTH22	B2d	2.94	0.3	572	9.46	<MDL	1.48	2.56	0.70
08LTH27	B2d	2.79	0.6	602	10.19	<MDL	1.46	3.08	0.69
08LTH32	B2d	3.78	2.9	1551	10.29	<MDL	1.19	4.64	1.59
Distance Group B2d		**3.39**	**0.7**	**932**	**10.19**	**<MDL**	**1.46**	**3.68**	**1.10**
		0.54 3.78	**0.3 2.9**	**572 2248**	**9.46 10.76**	**<MDL <MDL**	**1.19 1.55**	**2.56 6.12**	**0.69 1.59**

Table 2 Continued.

<table>
<tr><th>Sample</th><th>Group</th><th colspan="2">Fe (mg/kg)</th><th colspan="2">Pb (mg/kg)</th><th colspan="2">Mn (mg/kg)</th><th colspan="2">Ni (mg/kg)</th><th colspan="2">Se (mg/kg)</th><th colspan="2">Ag (mg/kg)</th><th colspan="2">Sn (mg/kg)</th><th colspan="2">Zn (mg/kg)</th></tr>
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<tr><td>289</td><td>654</td><td>8.04</td><td>14.33</td><td><MDL</td><td>14.18</td><td>3.26</td><td>3.87</td><td><MDL</td><td><MDL</td><td><MDL</td><td><MDL</td><td>6.54</td><td>8.73</td><td><MDL</td><td>3.00</td></tr>
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<tr><td>08LTH09</td><td>B2d</td><td colspan="2">631</td><td colspan="2">11.70</td><td colspan="2"><MDL</td><td colspan="2">3.88</td><td colspan="2"><MDL</td><td colspan="2"><MDL</td><td colspan="2">7.53</td><td colspan="2">4.27</td></tr>
<tr><td>08LTH10</td><td>B2d</td><td colspan="2">574</td><td colspan="2">12.62</td><td colspan="2"><MDL</td><td colspan="2">3.85</td><td colspan="2"><MDL</td><td colspan="2"><MDL</td><td colspan="2">6.83</td><td colspan="2">3.21</td></tr>
<tr><td>08LTH11</td><td>B2d</td><td colspan="2">826</td><td colspan="2">13.01</td><td colspan="2">16.44</td><td colspan="2">4.07</td><td colspan="2"><MDL</td><td colspan="2"><MDL</td><td colspan="2">6.60</td><td colspan="2">4.27</td></tr>
<tr><td>08LTH13</td><td>B2d</td><td colspan="2">602</td><td colspan="2">12.59</td><td colspan="2">13.25</td><td colspan="2">3.62</td><td colspan="2"><MDL</td><td colspan="2"><MDL</td><td colspan="2">6.53</td><td colspan="2"><MDL</td></tr>
<tr><td>08LTH22</td><td>B2d</td><td colspan="2">436</td><td colspan="2">14.30</td><td colspan="2"><MDL</td><td colspan="2">3.65</td><td colspan="2"><MDL</td><td colspan="2"><MDL</td><td colspan="2">6.86</td><td colspan="2"><MDL</td></tr>
<tr><td>08LTH27</td><td>B2d</td><td colspan="2">438</td><td colspan="2">12.99</td><td colspan="2"><MDL</td><td colspan="2">3.64</td><td colspan="2"><MDL</td><td colspan="2"><MDL</td><td colspan="2">8.13</td><td colspan="2"><MDL</td></tr>
<tr><td>08LTH32</td><td>B2d</td><td colspan="2">841</td><td colspan="2">11.52</td><td colspan="2">13.32</td><td colspan="2">4.33</td><td colspan="2"><MDL</td><td colspan="2"><MDL</td><td colspan="2">6.70</td><td colspan="2">5.23</td></tr>
<tr><td colspan="2" rowspan="2">Distance Group B2d</td><td colspan="2">602</td><td colspan="2">12.62</td><td colspan="2"><MDL</td><td colspan="2">3.85</td><td colspan="2"><MDL</td><td colspan="2"><MDL</td><td colspan="2">6.83</td><td colspan="2">3.21</td></tr>
<tr><td>436</td><td>841</td><td>11.52</td><td>14.30</td><td><MDL</td><td>16.44</td><td>3.62</td><td>4.33</td><td><MDL</td><td><MDL</td><td><MDL</td><td><MDL</td><td>6.53</td><td>8.13</td><td><MDL</td><td>5.23</td></tr>
</table>

The principle components analysis (PCA) showed the same grouping of sites as the cluster analysis (Figure 5). Figures 6, 7 and 8 display the site depth and percent silt + clay results on the PCA ordination plot and illustrate the influence of the sediment composition on the sites that grouped together. The first two principle components (PC1 and PC2) explained over 92% of the variation among the sites (Table 3). PC1 accounted for 87% of the variation and was nearly equally weighted by all of the metals except arsenic and cadmium while PC2 accounted for 7.2% of the variation and was heavily weighted by arsenic and cadmium (Tables 3 & 4). Since silver was below its MDL at all sites it had a coefficient of 0 across all PC axes (Table 4). Figure 9 shows the concentrations of the individual metals superimposed on the PCA plot. The "group A" sites had the highest concentrations for all of the metals with the notable exception of antimony, arsenic, and tin (Table 2; Figure 9). Cadmium generally was higher at the "group A" sites but the highest value for cadmium was at the "group B1" site (08LTH06), which is represented by the upper left data point on the PCA plots (Figures 6-9).

Sediment metals summary data for all 30 sites are presented in Table 5. All of the metals were below their established threshold effects concentrations with the exception of cadmium and chromium. A large percentage of the sites were below their MDLs for most of the metals (Table 5). Silver (Ag) was below the MDL at all sites (Table 5). Results by individual metal are presented below.

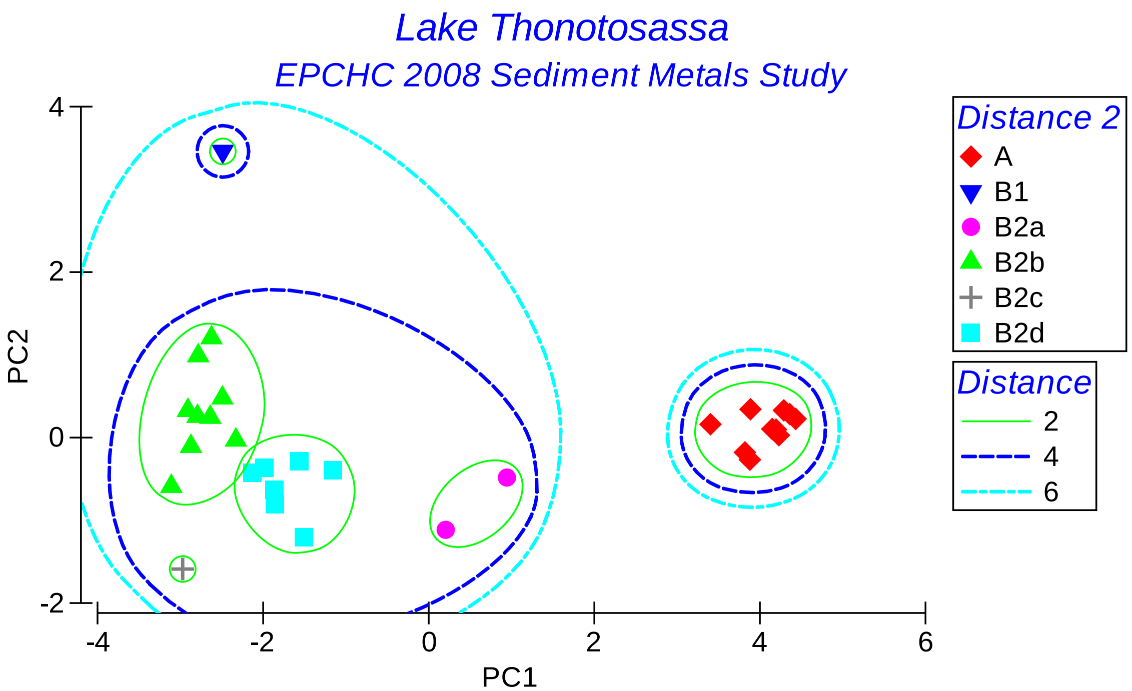

Figure 5 PCA plot of Lake Thonotosassa sediment metals with Euclidian distance groups.

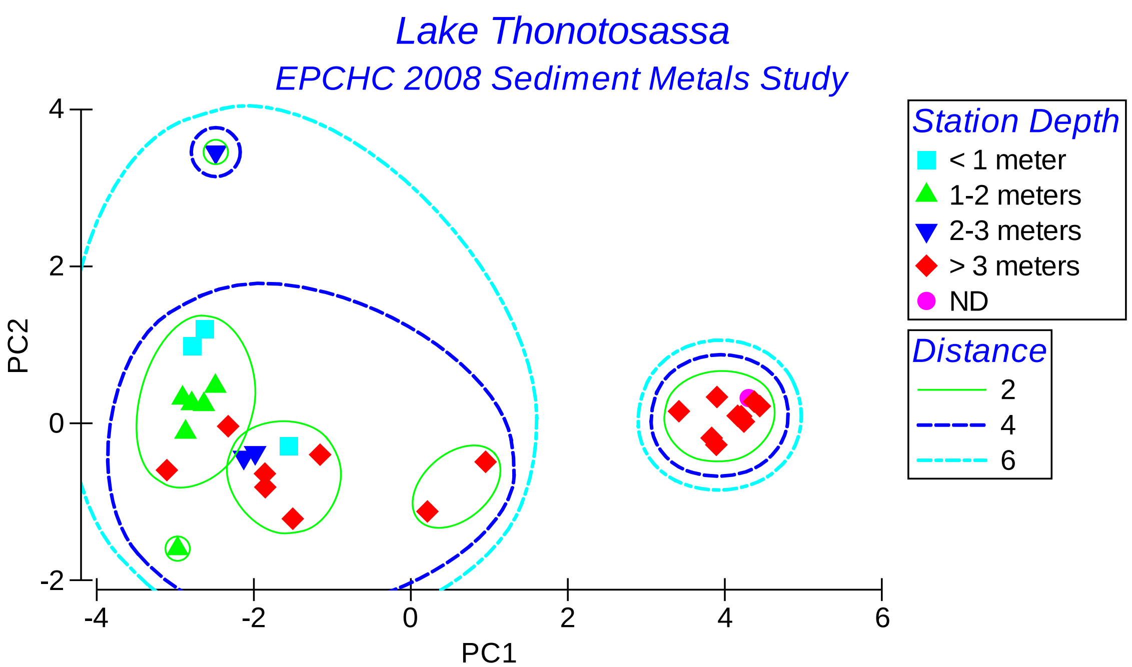

Figure 6 PCA plot of Lake Thonotosassa sediment metals with station depth classification.

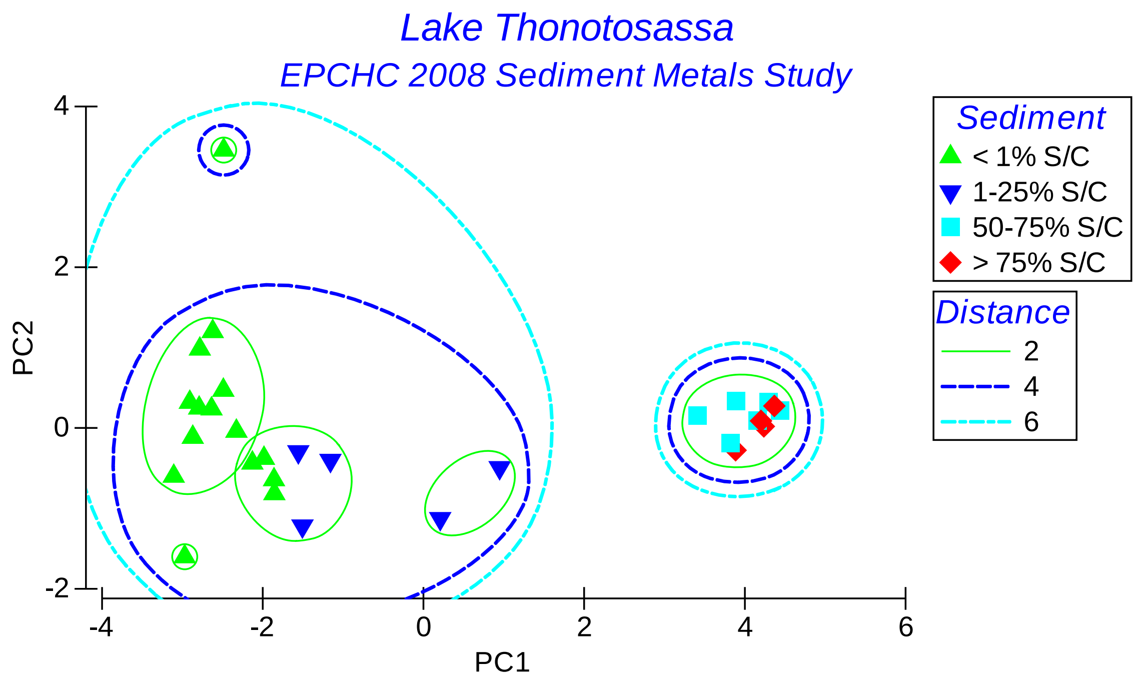

Figure 7 PCA plot of Lake Thonotosassa sediment metals with sediment classification.

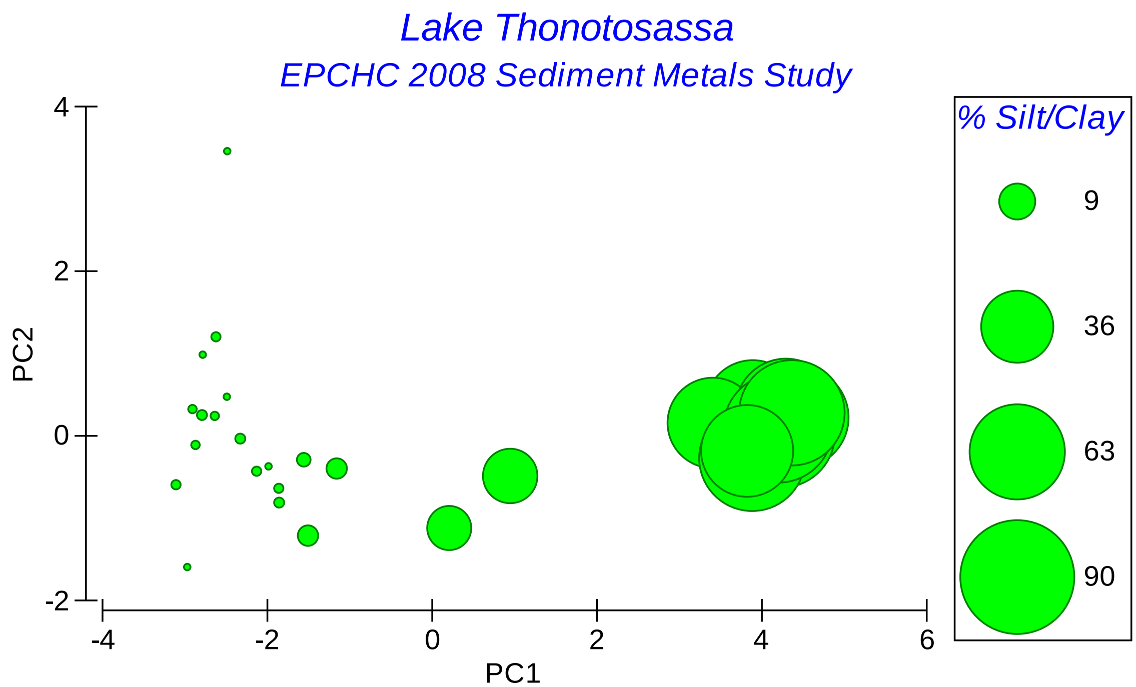

Figure 8 PCA plot of Lake Thonotosassa sediment metals with % silt+clay value bubbles superimposed.

Table 3 Lake Thonotosassa sediment metals Principle Components eigenvalues.

Eigenvalues			
PC	Eigenvalues	%Variation	Cum.%Variation
1	9.35	85.0	85.0
2	0.79	7.2	92.2
3	0.53	4.8	97.0
4	0.15	1.4	98.3
5	0.09	0.8	99.2

Table 4 Lake Thonotosassa sediment metals Principle Components eigenvectors.

Eigenvectors (Coefficients in the linear combinations of variables making up PC's)					
Variable	PC1	PC2	PC3	PC4	PC5
Antimony (Sb)	-0.310	0.035	0.224	-0.644	-0.200
Arsenic (As)	-0.203	0.684	-0.683	-0.130	0.030
Cadmium (Cd)	0.202	0.710	0.645	0.093	0.149
Chromium (Cr)	0.325	0.000	-0.033	-0.193	0.167
Copper (Cu)	0.324	-0.015	-0.064	-0.262	-0.105
Lead (Pb)	0.312	0.113	-0.031	0.114	-0.903
Manganese (Mn)	0.318	-0.059	-0.052	-0.402	0.188
Nickel (Ni)	0.325	0.065	-0.090	-0.001	0.016
Selenium (Se)	0.322	0.019	-0.126	-0.128	0.096
Silver (Ag)	0.000	0.000	0.000	0.000	0.000
Tin (Sn)	-0.317	0.033	0.179	-0.418	-0.183
Zinc (Zn)	0.322	-0.071	-0.046	-0.297	0.067

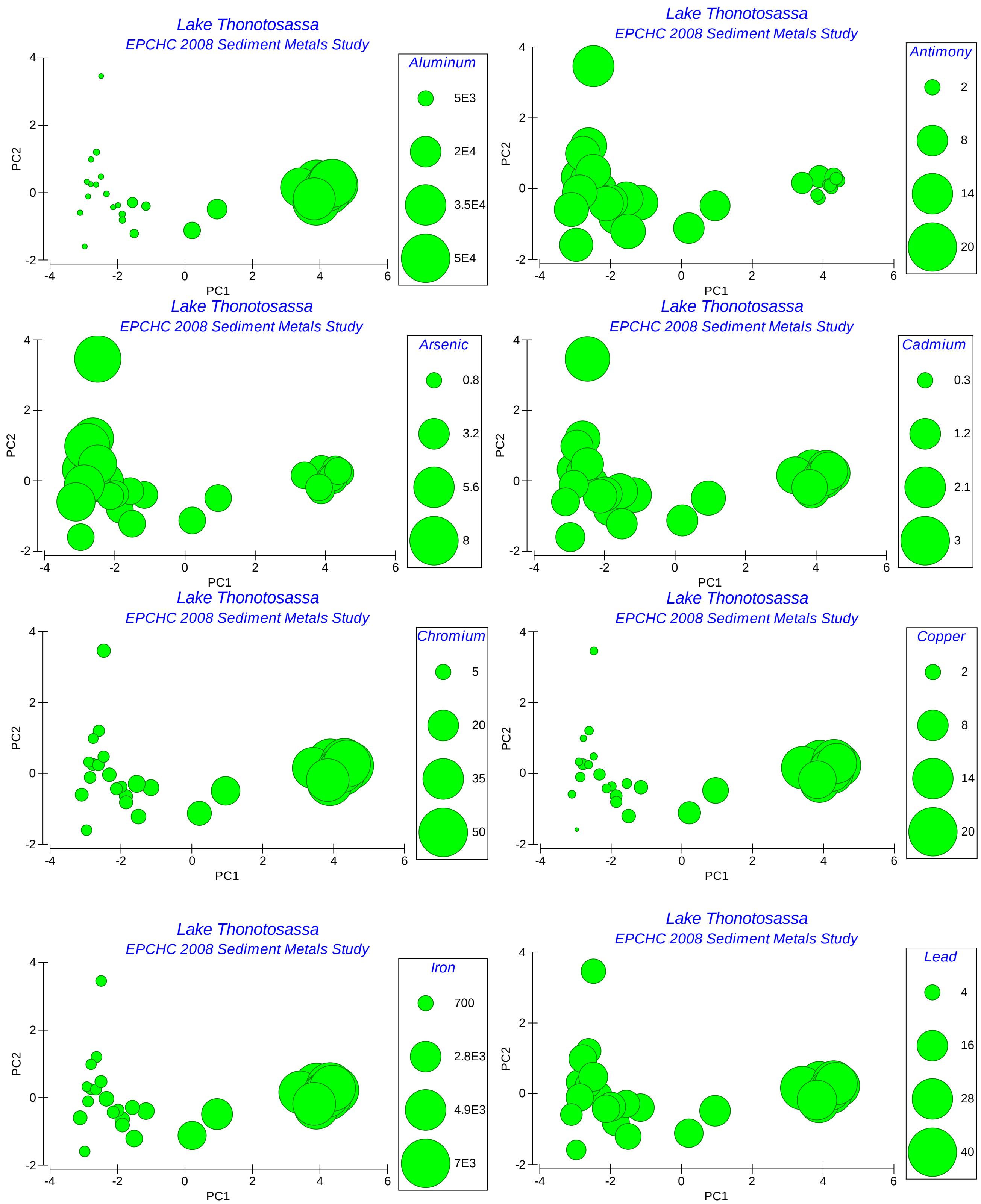

Figure 9 PCA bubble plots for individual metals. Values in mg/kg.

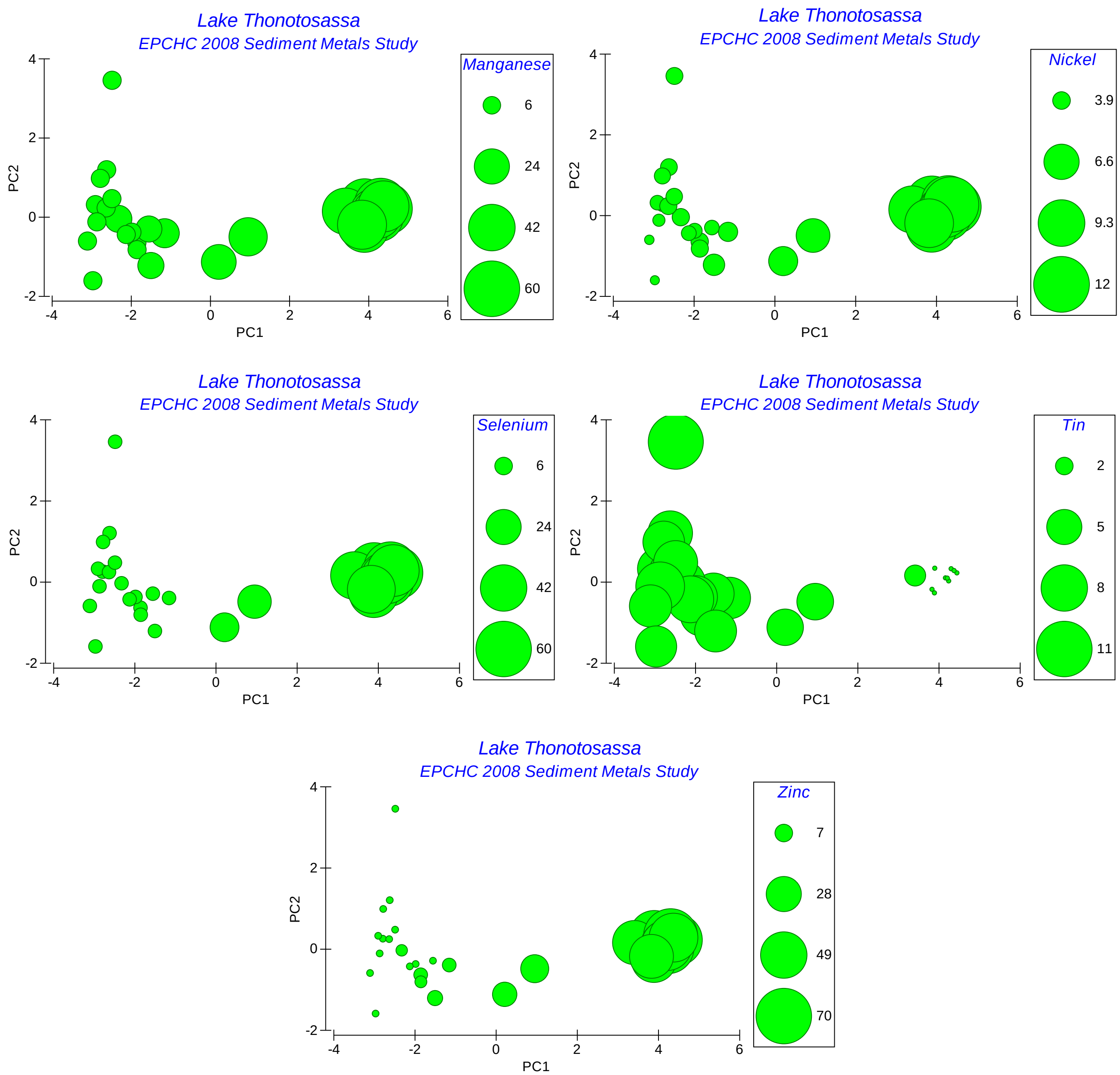

Figure 9 Continued.

Table 5 Lake Thonotosassa summary statistics for sediment metals; values in mg/kg. **MDL** = Minimum Detection Limit; **TEC** = Threshold Effect Concentration; **PEC** = Potential Effect Concentration; **N** = number of samples.

	Al	**Sb**	**As**	**Cd**	**Cr**	**Cu**	**Fe**
MDL	120.35	2.63	4.87	0.43	0.42	0.21	58.93
TEC			9.79	0.99	43.40	31.60	
PEC			33.00	4.98	111.00	149.00	
N	30	30	30	30	30	30	30
Minimum	507	<MDL	<MDL	0.99	2.07	<MDL	289
Maximum	48906	14.44	7.35	2.52	49.05	16.86	6,810
Median	1242	9.735	2.44	1.48	4.315	1.185	642
Mean	14887	7.47	3.53	1.49	17.47	5.73	2,520
Standard Deviation	19544	4.13	1.64	0.32	18.94	6.64	2,692
% < MDL	0%	23.33%	66.67%	0%	0%	3.33%	0%
% < TEC			33.33%	0%	86.67%	96.67%	
% >TEC, < PEC			0%	100%	13.33%	0%	
% > PEC			0%	0%	0%	0%	

	Pb	**Mn**	**Ni**	**Se**	**Ag**	**Sn**	**Zn**
MDL	3.69	12.89	0.45	7.21	0.39	2.11	2.09
TEC	35.80		22.70				121.00
PEC	128.00		48.60				459.00
N	30	30	30	30	30	30	30
Minimum	6.56	<MDL	3.24	<MDL	<MDL	<MDL	<MDL
Maximum	32.14	53.79	11.91	56.15	<MDL	10.85	66.38
Median	13.155	13.285	3.875	3.61	<MDL	6.57	3.74
Mean	17.58	22.90	6.21	20.26	<MDL	5.21	20.28
Standard Deviation	8.39	19.41	3.35	22.19	0.00	3.06	25.14
% < MDL	0%	46.67%	0%	60%	100%	30%	43.33%
% < TEC	100%		100%				56.67%
% >TEC, < PEC	0%		0%				0%
% > PEC	0%		0%				0%

Aluminum (Al): Aluminum concentrations were measured as a background element to detect possible metal enrichment relative to local levels and for comparing the metal:aluminum ratios from these sites to the FDEP reference sites (Carvalho *et al.* 2002). Aluminum values ranged between 507 – 48,906 mg/kg and had a positive correlation with the percent silt + clay (Table 5). The highest concentrations were found at the deepest sites, which were on the western half of the lake (Figure 10).

Antimony (Sb): MacDonald *et al.* (2003) did not establish SQAGs for antimony. This metal was not among the metals that were analyzed for the FDEP interpretive tool (Carvalho *et al.* 2002). The Sb:Al ratio indicated that Sb levels in Lake Thonotosassa were not elevated above background levels (Figure 11). The Sb:Al regression also showed an inverse relationship between Sb and Al sediment concentrations. Higher levels of Sb were typically found at the shallower sites that had lower silt + clay values (Figure 12).

Arsenic (As): Two-thirds of the sites had values that were below the MDL and all sites were below the TEC for arsenic (Table 5). The highest concentration was recorded at the "B1" group which had one site (08LTH06) and was also present at all 9 sites within the "B2b" group (Table 5). The As:Al ratio indicated that arsenic levels were not above local background levels (Figure 13), but sites with the highest concentrations were elevated relative to the FDEP state reference sites (Figure 14). Arsenic also showed an inverse relationship with aluminum in the Lake Thonotosassa sediments (Figure 13). Highest Arsenic values were at sites with low % silt+clay (Figure 15).

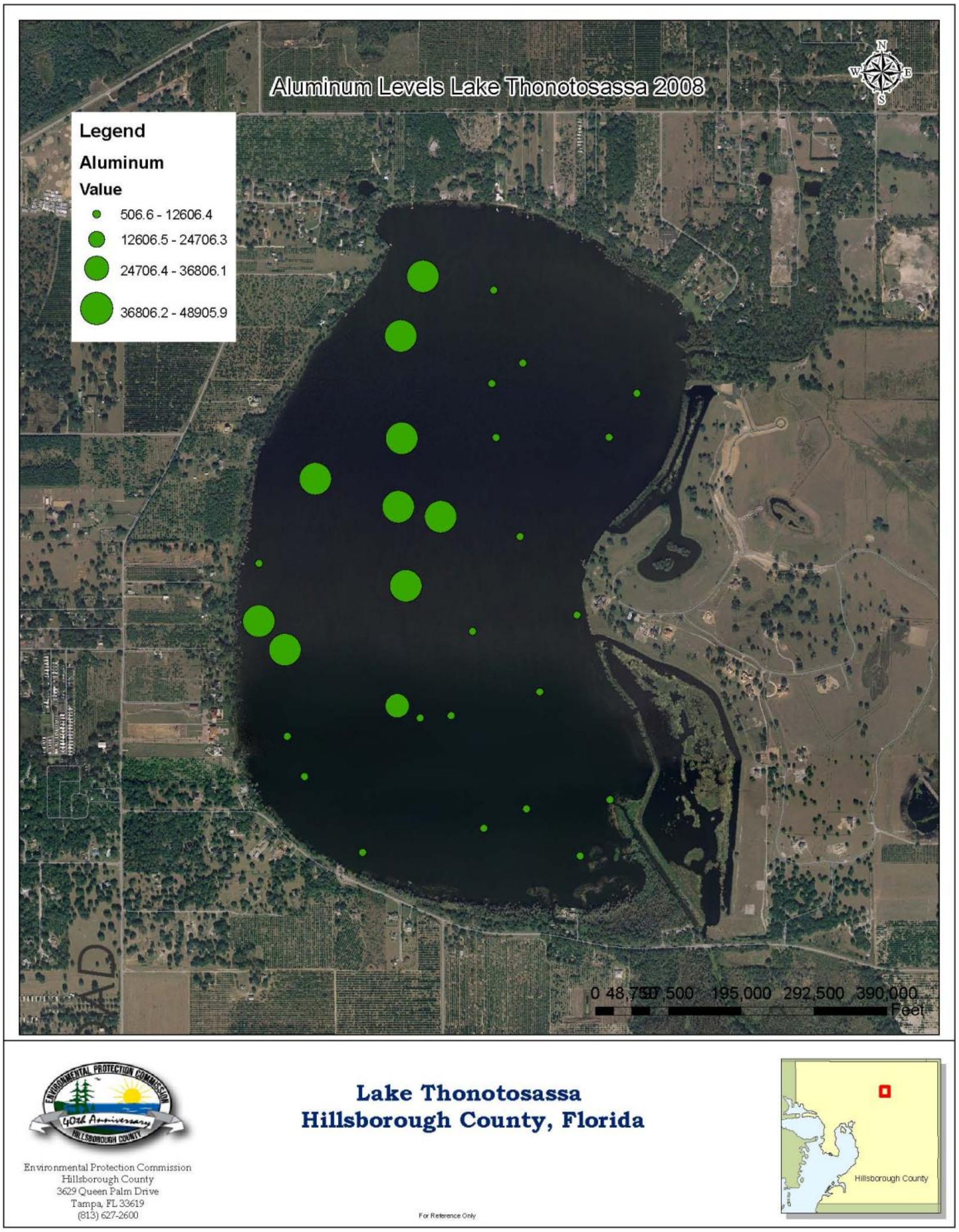

Figure 10 Spatial distribution of aluminum in Lake Thonotosassa sediments. Values in mg/kg.

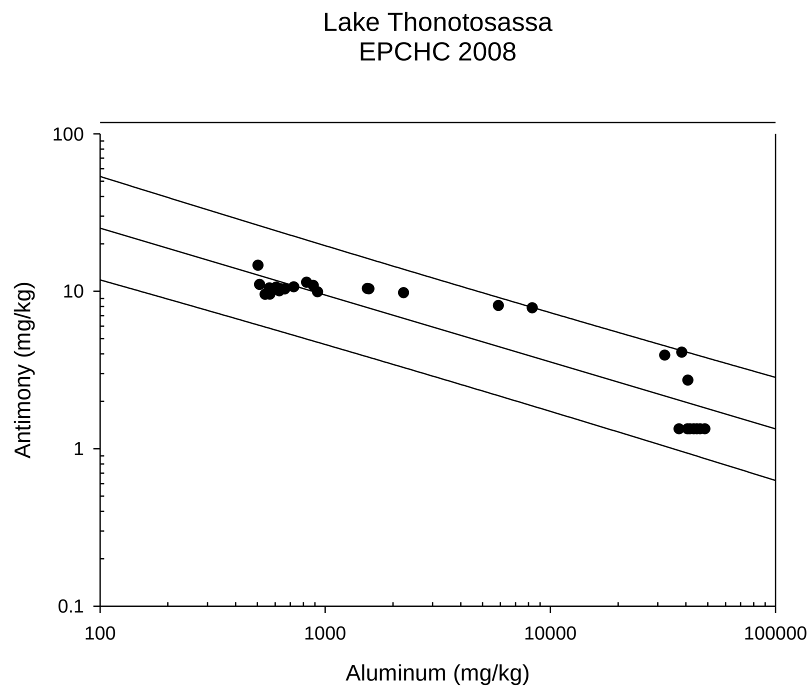

Figure 11 Sb:Al regression for Lake Thonotosassa sediments.

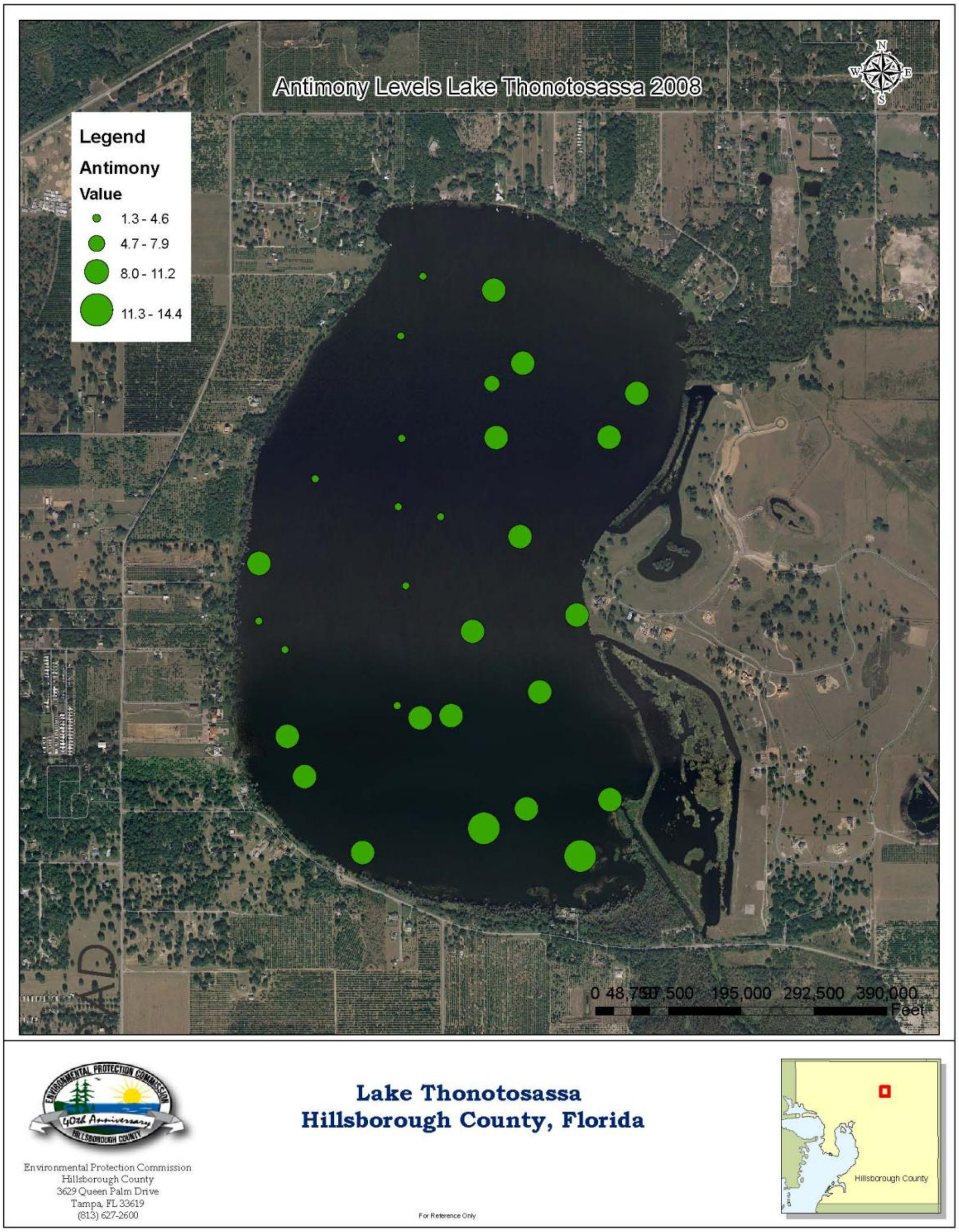

Figure 12 Spatial distribution of antimony in Lake Thonotosassa sediments. Values in mg/kg.

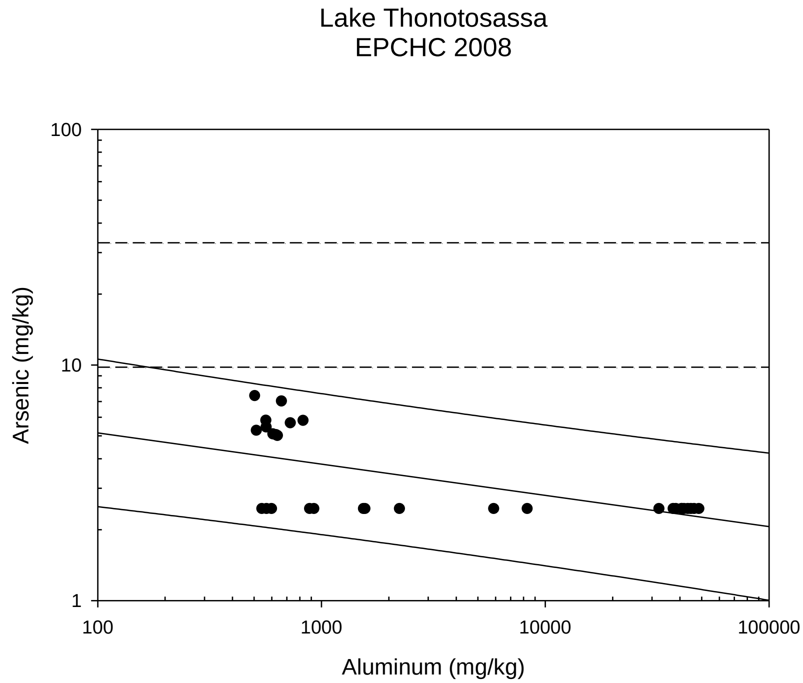

Figure 13 As:Al regression for Lake Thonotosassa sediments. Regression line with 95% prediction intervals. Dashed lines indicate TEC and PEC threshold concentrations.

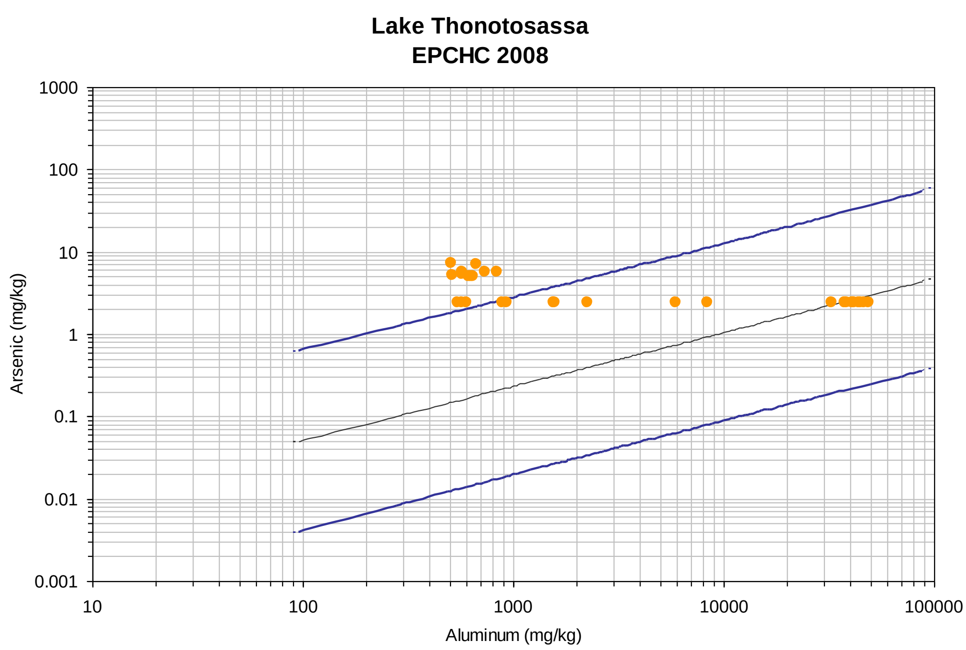

Figure 14 As:Al regression for Lake Thonotosassa sediments plotted against FDEP reference site regression line with 95% prediction intervals (from Carvalho *et al.* 2002).

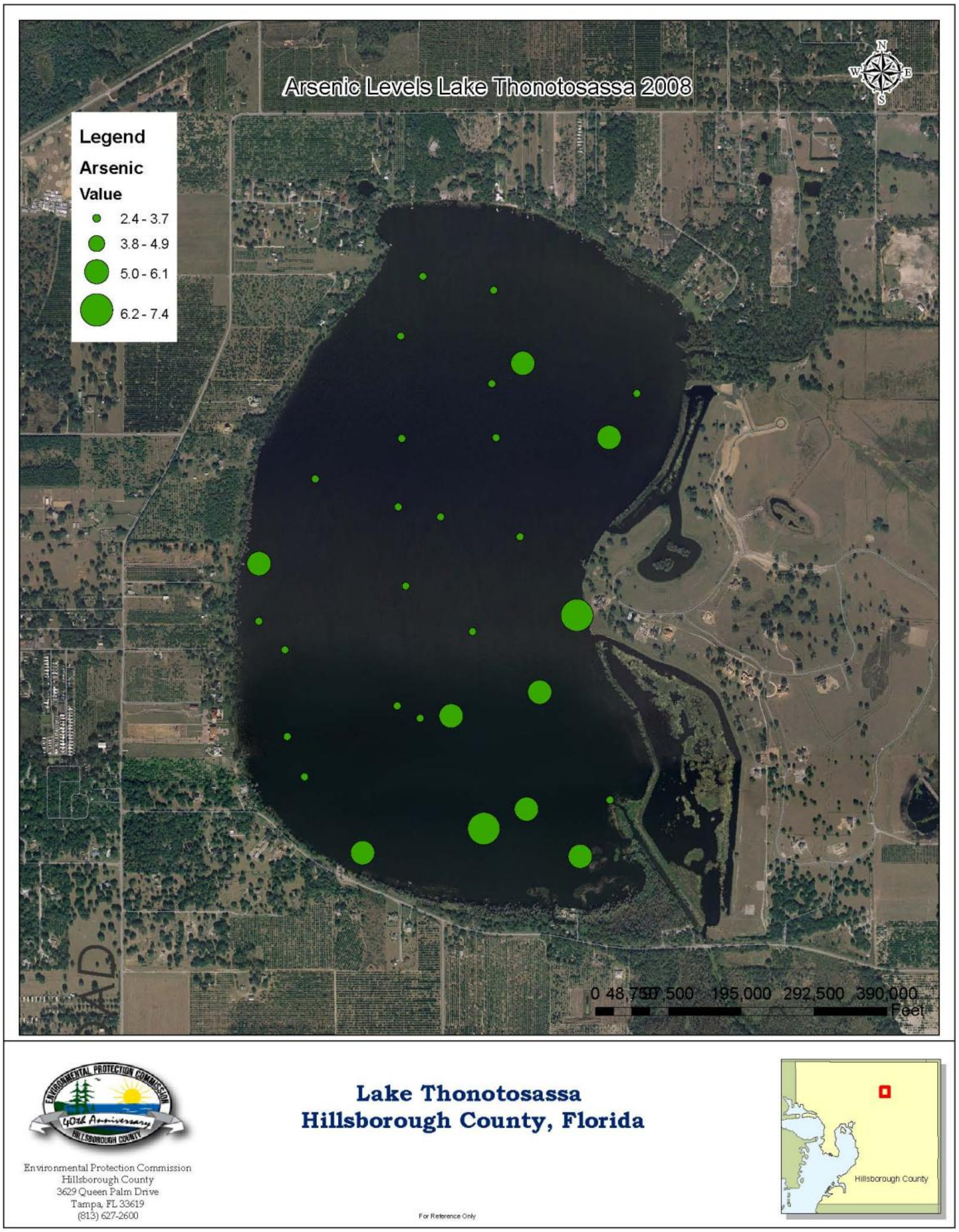

Figure 15 Spatial distribution of arsenic in Lake Thonotosassa sediments. Values in mg/kg.

Cadmium (Cd): All sites had values that were above the established TEC for cadmium but there were no PEC exceedences (Table 5). The highest Cd concentration was recorded at “B1” group (single site 08LTH06). The Cd:Al ratio within the Lake Thonotosassa sediments suggests that the cadmium level is not enriched above local background levels with the possible exception of site 08LTH06 (Figure 16). The cadmium levels were however enriched compared to the reference sites in the FDEP database, particularly at sites with lower aluminum concentrations (Figure 17). Cadmium levels were generally higher at the deeper sites on the western portion of the lake with the exception of station 08LTH06 which was near the south shore (Figure 18).

Chromium (Cr): Eighty-seven percent of the sites had values that were below the established TEC for chromium, while four sites (13%) were above the TEC. These four sites were all within the group “A” (Table 5). The Cr:Al ratio within the Lake Thonotosassa sediments indicates that chromium levels are not elevated above local background levels or enriched relative to the FDEP reference sites (Figure 19 & 20). The highest concentrations of chromium were found at the deeper sites on the western half of the lake (Figure 21).

Copper (Cu): All of the sites had values that were below the established TEC for copper and 08LTB39 was below the MDL (Table 2). Copper levels were highest at the Group A sites, with a median concentration of 15.25 mg/kg (Table 5). The Cu:Al ratio indicates that copper concentrations are not elevated above local background levels or enriched relative to the FDEP reference sites (Figure 22 & 23). The highest concentrations of copper were located at the deeper sites on the western side of the lake (Figure 24).

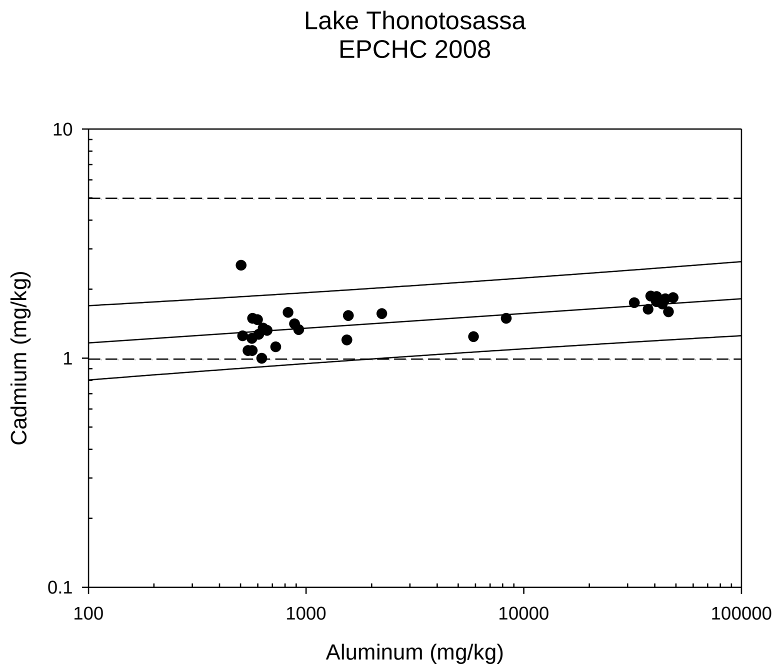

Figure 16 Cd:Al regression for Lake Thonotosassa sediments. Regression line with 95% prediction intervals. Dashed lines indicate TEC and PEC threshold concentrations.

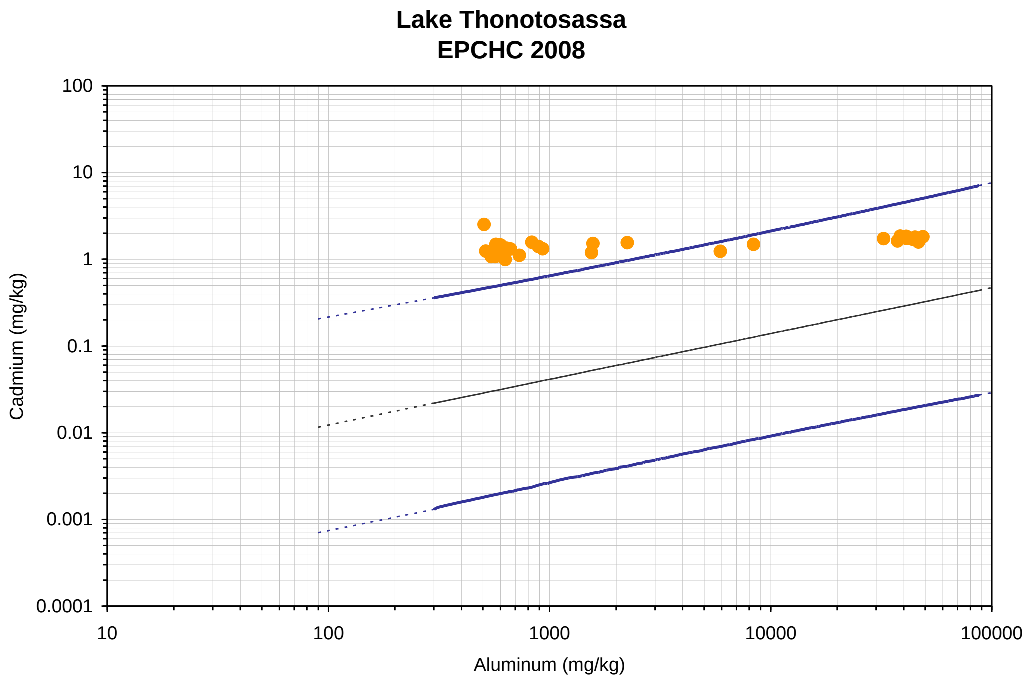

Figure 17 Cd:Al regression for Lake Thonotosassa sediments plotted against FDEP reference site regression line with 95% prediction intervals (from Carvalho *et al.* 2002).

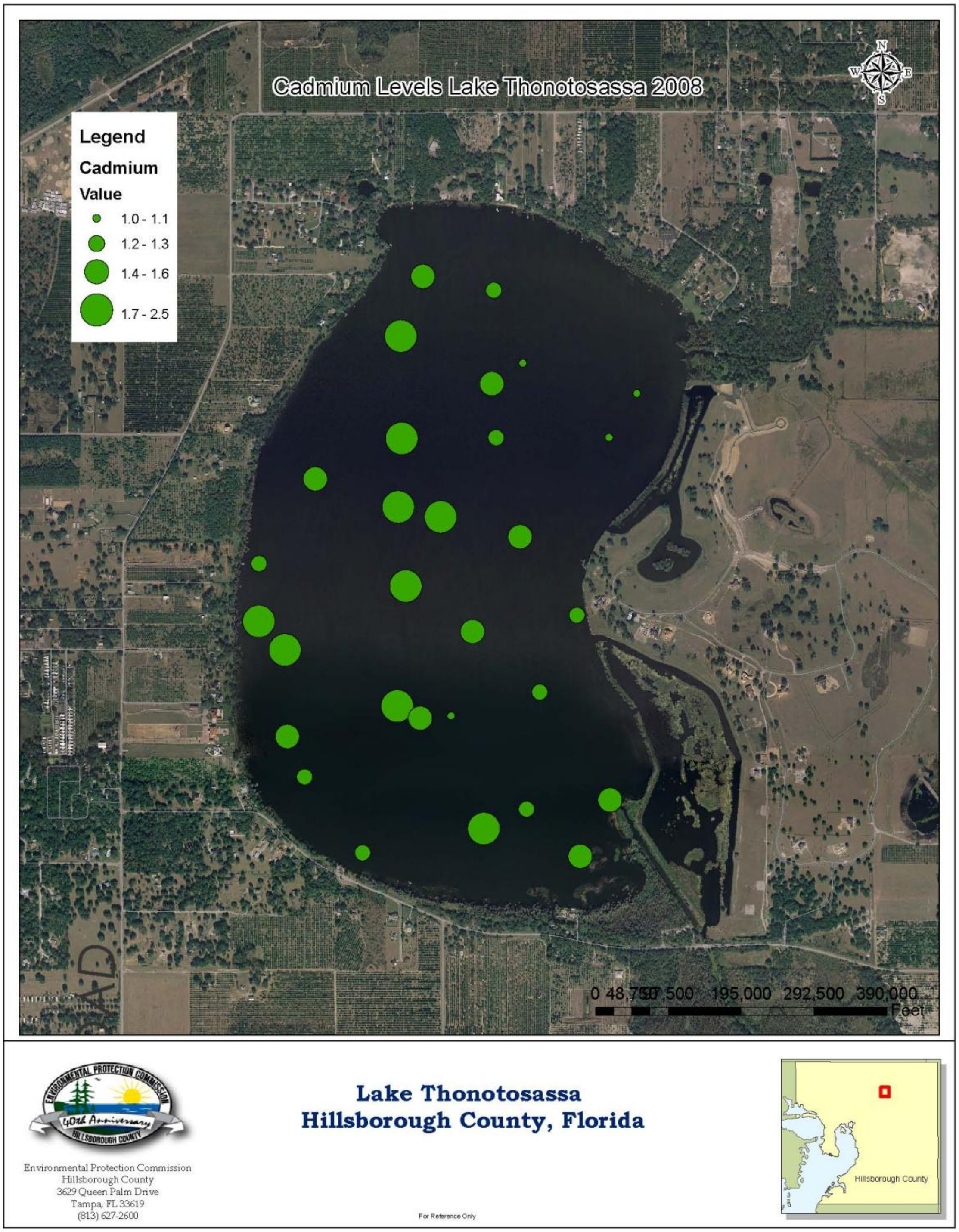

Figure 18 Spatial distribution of cadmium in Lake Thonotosassa sediments. Values in mg/kg.

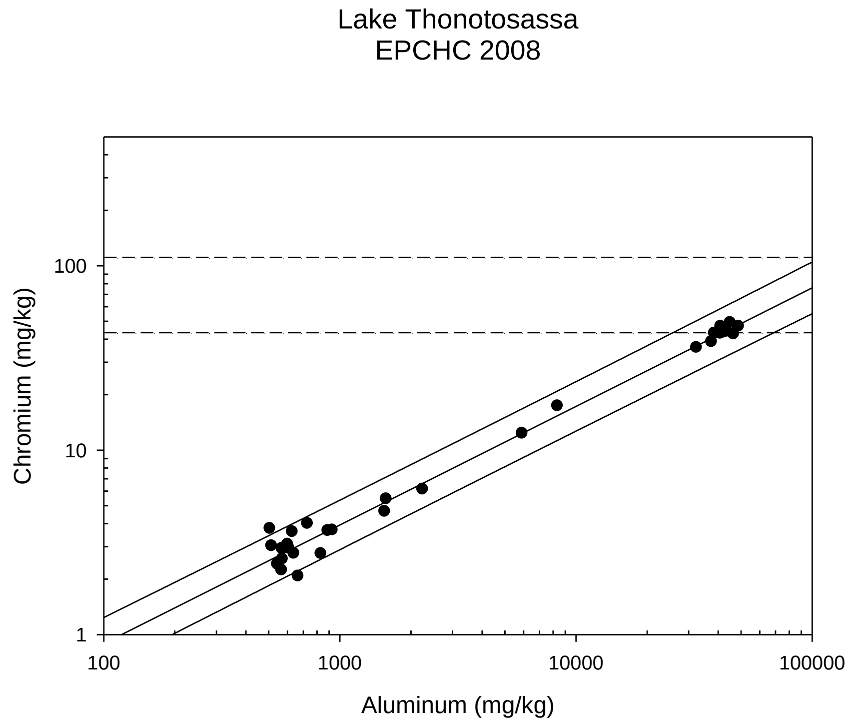

Figure 19 Cr:Al regression for Lake Thonotosassa sediments. Regression line with 95% prediction intervals. Dashed lines indicate TEC and PEC threshold concentrations.

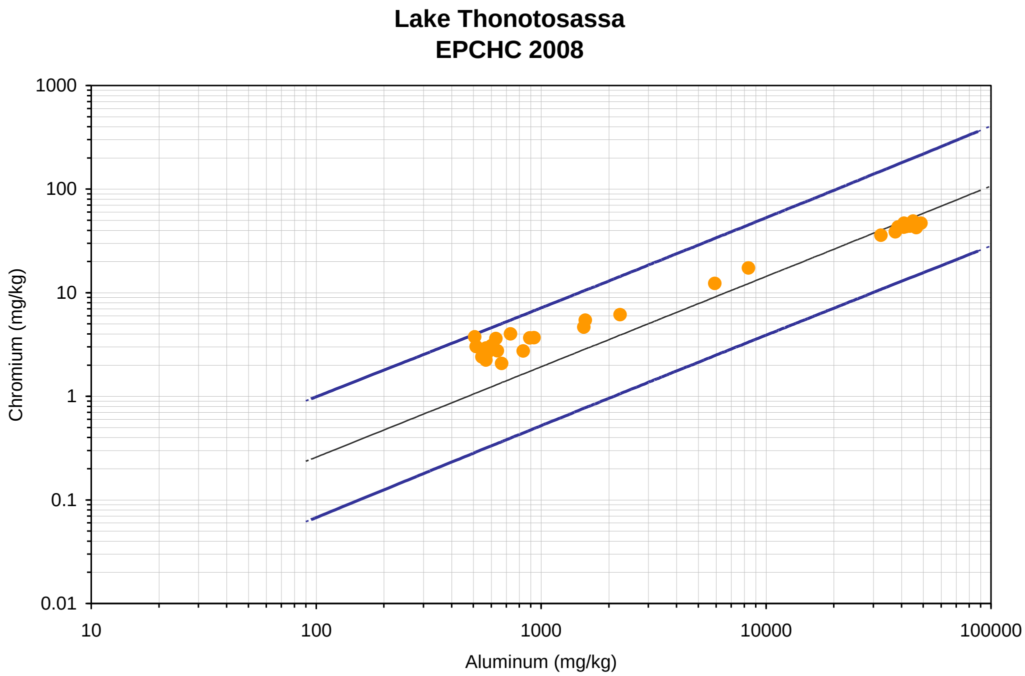

Figure 20 Cr:Al regression for Lake Thonotosassa sediments plotted against FDEP reference site regression line with 95% prediction intervals (from Carvalho *et al.* 2002).

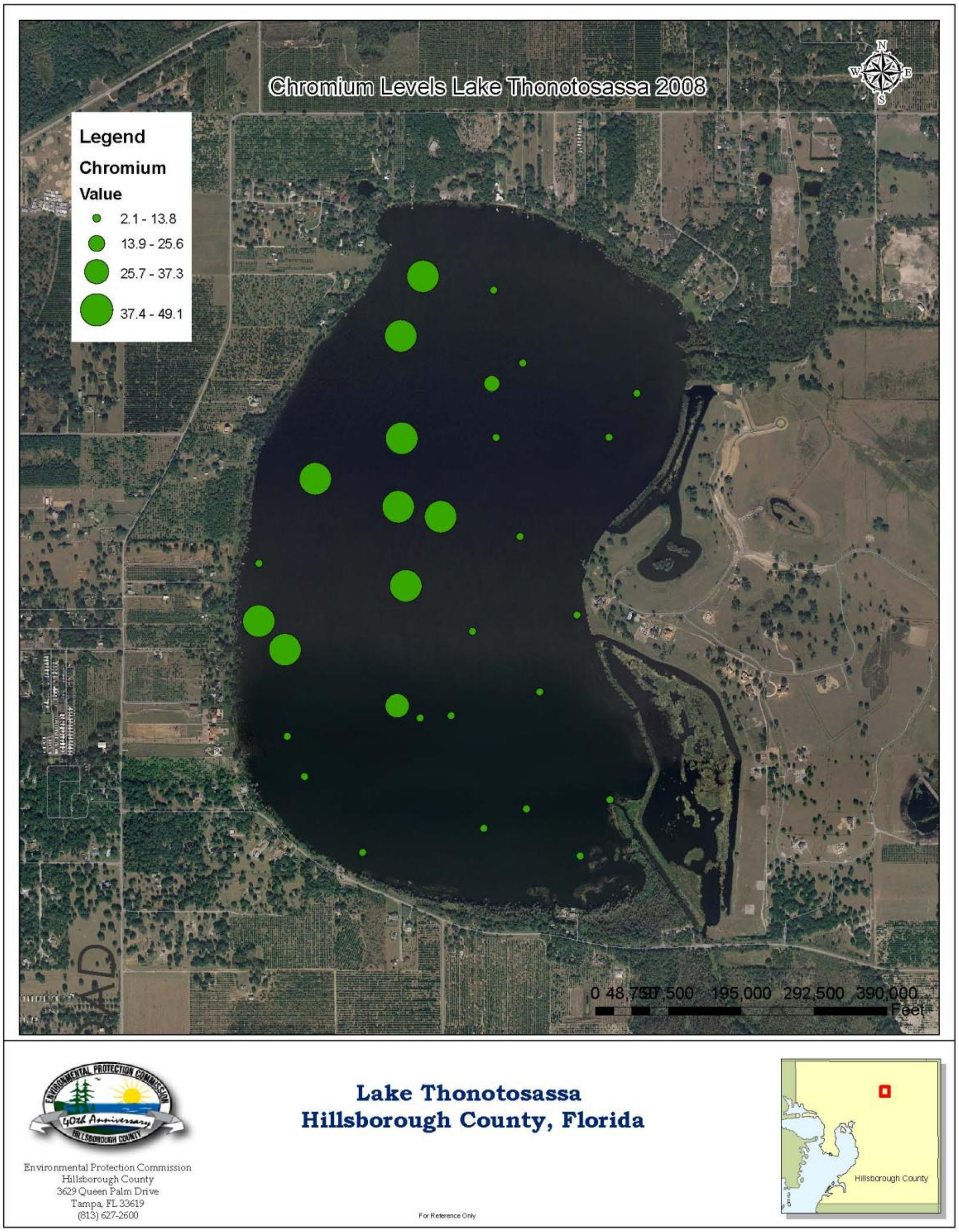

Figure 21 Spatial distribution of chromium in Lake Thonotosassa sediments. Values in mg/kg.

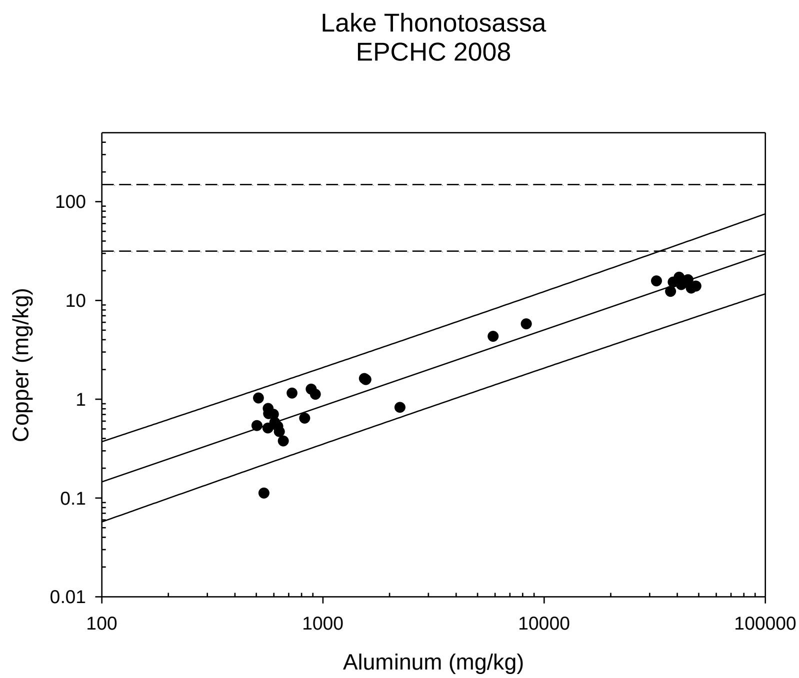

Figure 22 Cu:Al regression for Lake Thonotosassa sediments. Regression line with 95% prediction intervals. Dashed lines indicate TEC and PEC threshold concentrations.

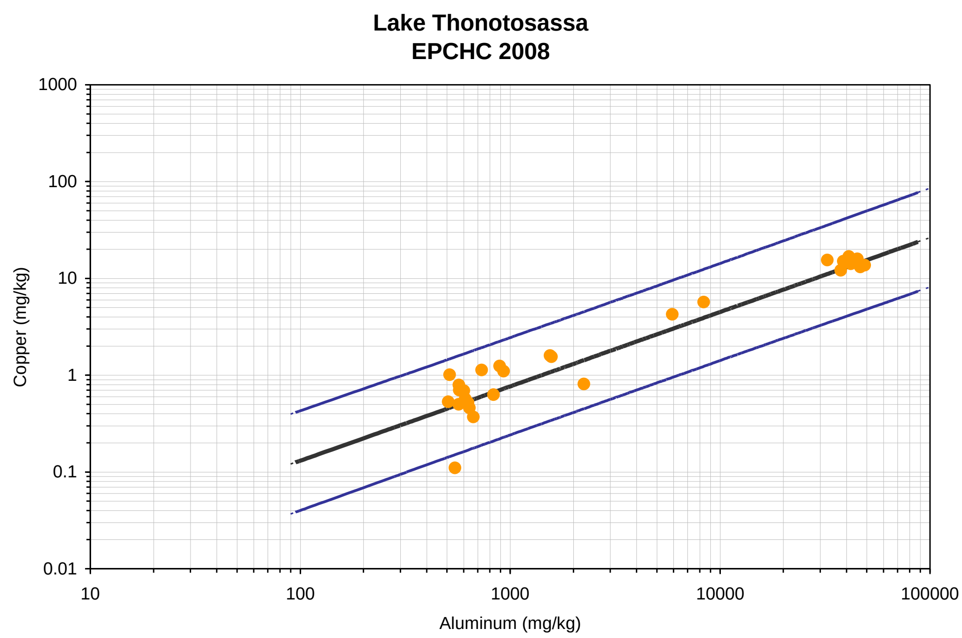

Figure 23 Cu:Al regression for Lake Thonotosassa sediments plotted against FDEP reference site regression line with 95% prediction intervals (from Carvalho *et al.* 2002).

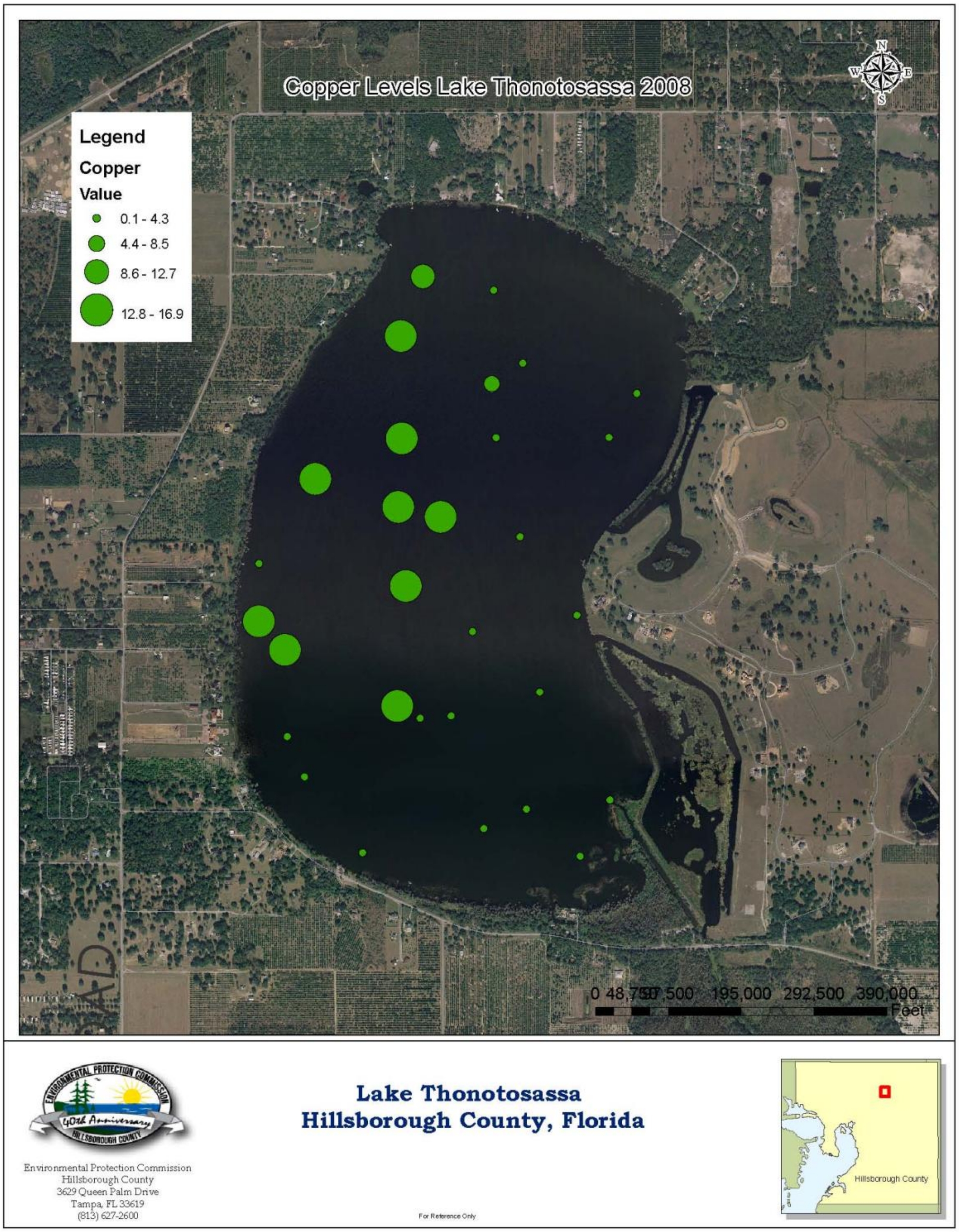

Figure 24 Spatial distribution of copper in Lake Thonotosassa sediments. Values in mg/kg.

Iron (Fe). Iron, like aluminum, is also a common element in crustal soils and is used to normalize other metals (Carvalho *et al.* 2002). Iron levels in the lake Thonotosassa sediments showed similar trends as aluminum. Iron values were highest in areas with higher percent silt + clay values; particularly at the group "A" sites in the western half of the lake (Table 5; Figure 25).

Lead (Pb): Lead was below its established TEC at all sites with the highest concentrations occurring at the Group A sites (Table 5). The Pb:Al ratio suggests that the sediment lead concentrations were not elevated above local background levels, but were higher relative to the FDEP reference sites (Figure 26 & 27). Highest lead concentrations corresponded with the deeper sites on the western half of the lake which had the higher percent silt + clay values (Figure 28).

Manganese (Mn): MacDonald *et al.* (2003) did not establish SQAGs for manganese. It was not one of the trace metals evaluated for the FDEP interpretive tool (Carvalho *et al.* 2002). Manganese concentrations in Lake Thonotosassa were below the MDL in nearly half of the sites (Table 5). The Mn:Al ratio indicate that two sites were potentially enriched above background levels (Figure 29). Highest levels were at the Group A sites located on the west side of the lake and these sites had high percent silt + clay values (Table 5; Figure 30).

Nickel (Ni): Nickel was below its established TEC at all sites with the highest levels at the Group A sites (Table 5). The Ni:Al ratio indicated that nickel concentrations were not above local background levels but several sites were higher than the FDEP reference

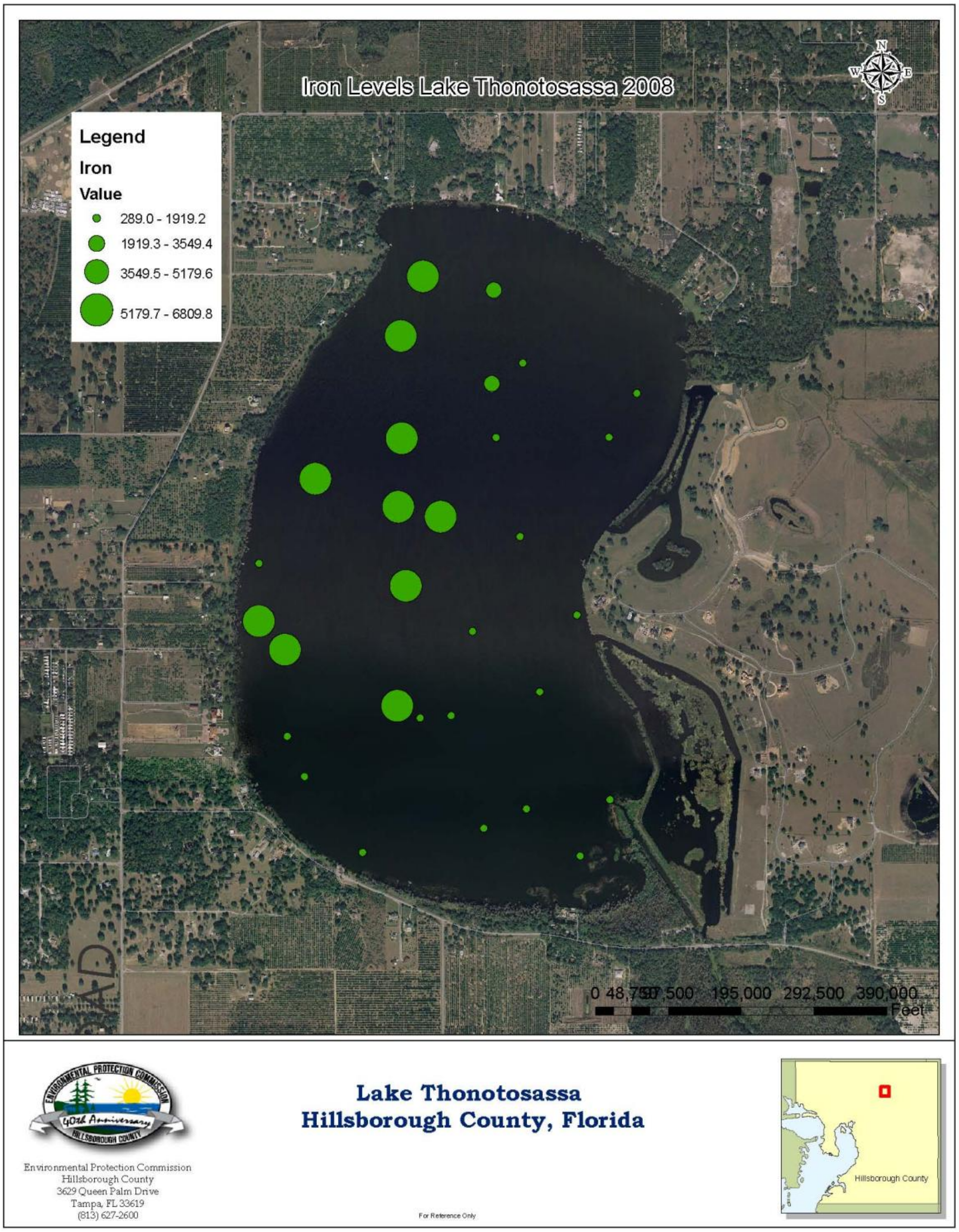

Figure 25 Spatial distribution of iron in Lake Thonotosassa sediments. Values in mg/kg.

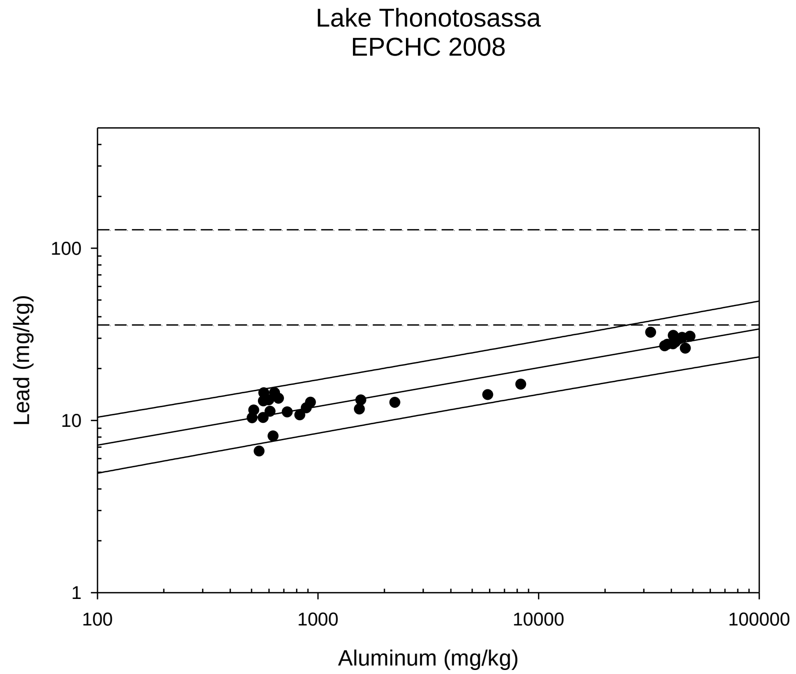

Figure 26 Pb:Al regression for Lake Thonotosassa sediments. Regression line with 95% prediction intervals. Dashed lines indicate TEC and PEC threshold concentrations.

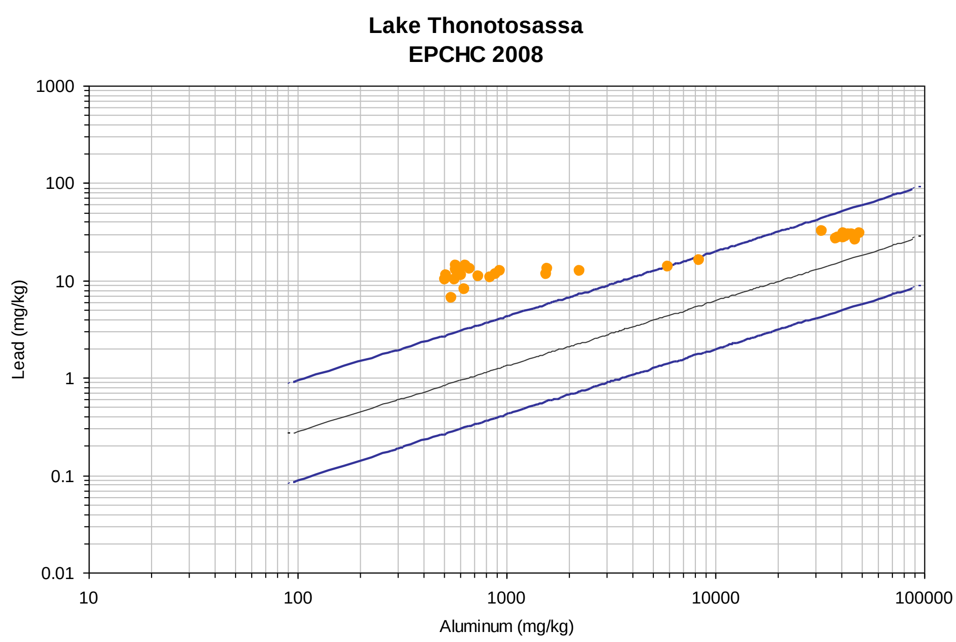

Figure 27 Pb:Al regression for Lake Thonotosassa sediments plotted against FDEP reference site regression line with 95% prediction intervals (from Carvalho *et al.* 2002).

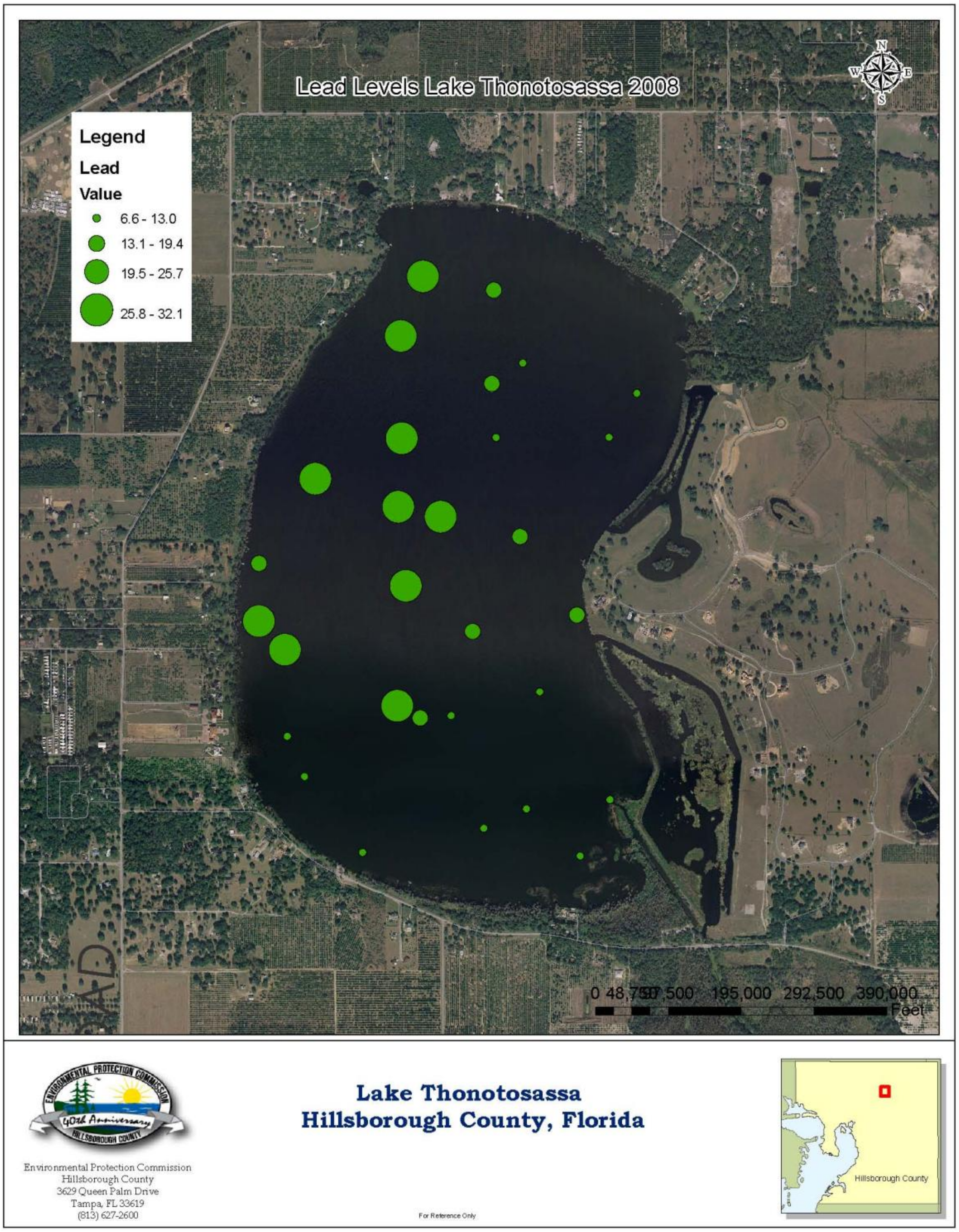

Figure 28 Spatial distribution of lead in Lake Thonotosassa sediments. Values in mg/kg.

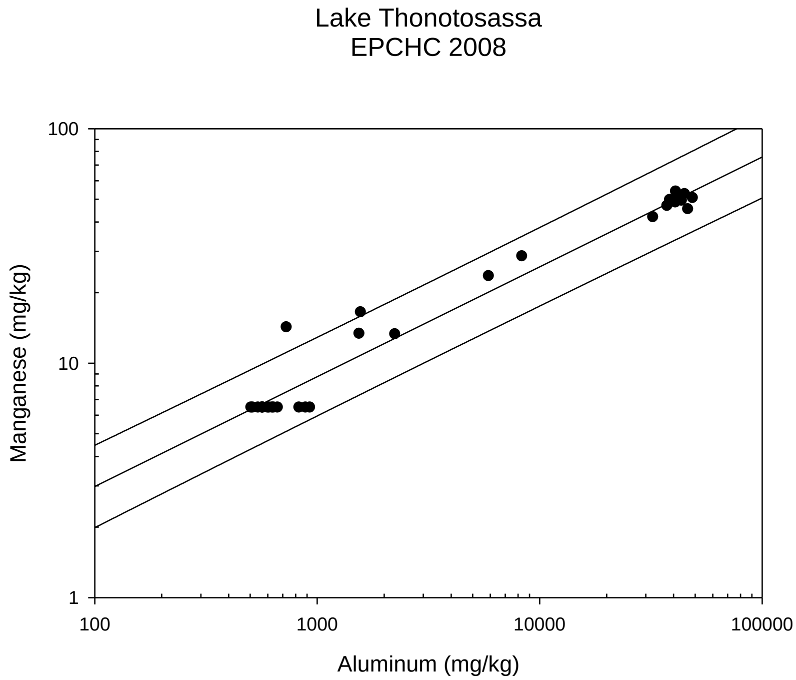

Figure 29 Mn:Al regression for Lake Thonotosassa sediments. Regression line with 95% prediction intervals.

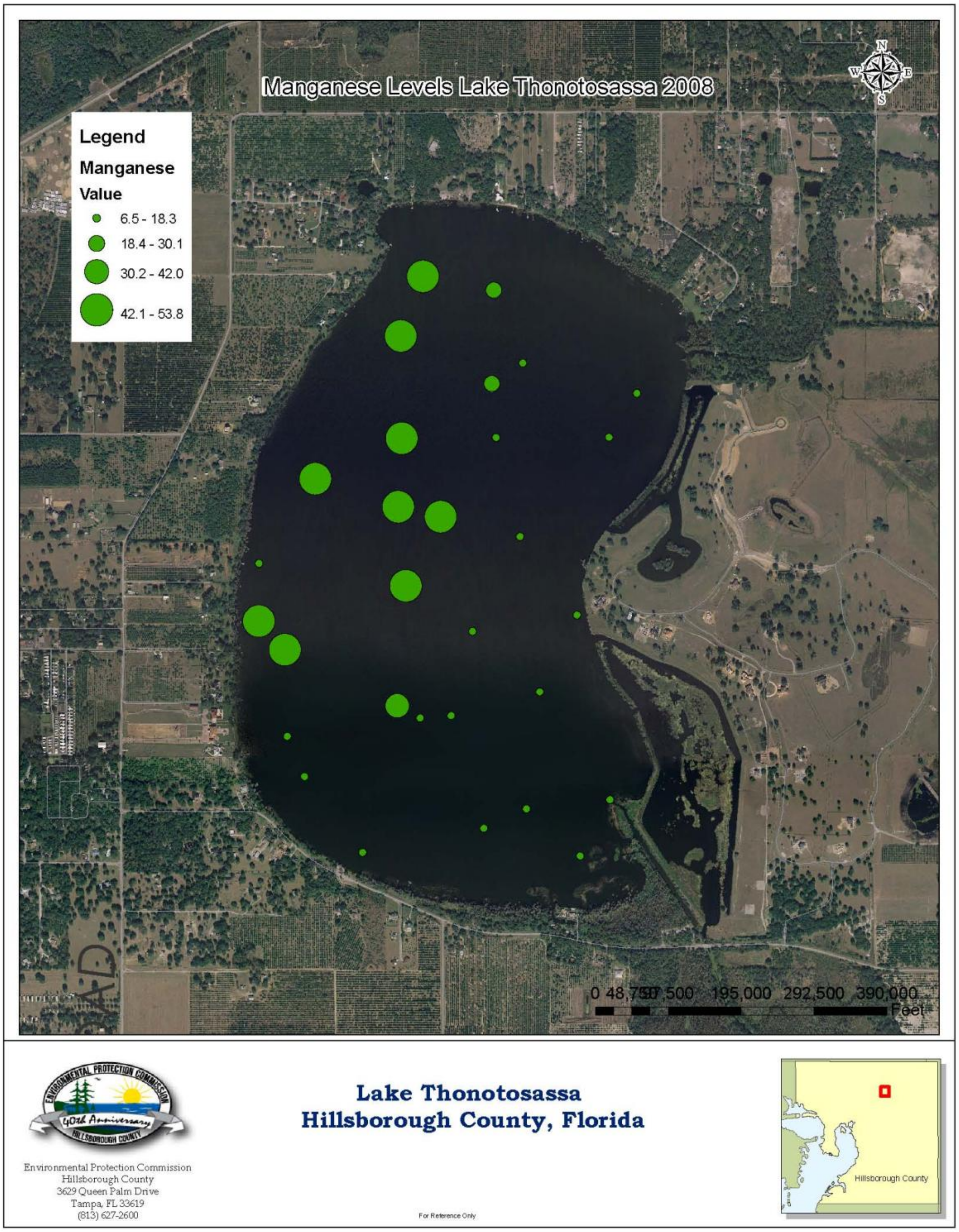

Figure 30 Spatial distribution of manganese in Lake Thonotosassa sediments. Values in mg/kg.

sites (Figure 31 & 32). The sites with the highest nickel levels were on the west side of the lake (Figure 33). These sites correspond to greater depths and higher percent silt + clay values compare to rest of lake sites (Figure 33).

Selenium (Se): MacDonald *et al.* (2003) did not establish SQAGs for selenium. Selenium was not among the metals evaluated for the FDEP interpretive tool (Carvalho *et al.* 2002). Selenium was below the MDL in 60% of the samples (Table 5). The Se:Al ratio suggested that selenium concentrations in Lake Thonotosassa were within local background levels (Figure 34). Highest concentrations tended to be associated with the Group A sites on the west side of the lake (Table 5; Figure 35).

Silver (Ag): Silver was below the MDL in all of the Lake Thonotosassa samples and was not a significant factor in the analysis.

Tin (Sn): MacDonald *et al.* (2003) did not establish SQAGs for tin. Tin it was also not evaluated for the FDEP interpretive tool (Carvalho *et al.* 2002). Tin was below its MDL at 30% of the sites (Table 5). The Sn:Al regression analysis showed that tin levels were not enriched above local background conditions and there was an inverse relationship with sediment aluminum concentrations (Figure 36). The highest concentration of tin was found at station 08LTH06 (Group B1). Overall higher levels were found at sites characterized by shallower depths and lower silt + clay content compare to other lake sites (Table 2; Figure 37).

Zinc (Zn): Zinc was below its TEC for all sites and was below the MDL at 43% of the sites (Table 5). The Zn:Al ratio indicated that zinc concentrations in Lake Thonotosassa sediments were not elevated above local background levels (Figure 38). They were not greater than zinc concentrations found at the FDEP reference sites (Figure 39). The highest zinc concentrations were on the western side of the lake at the deeper sites (Figure 40).

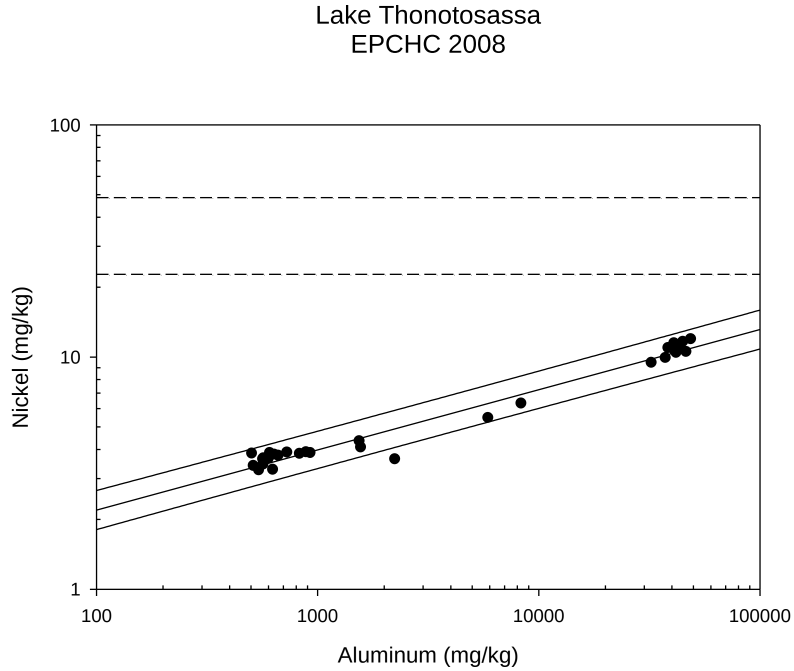

Figure 31 Ni:Al regression for Lake Thonotosassa sediments. Regression line with 95% prediction intervals. Dashed lines indicate TEC and PEC threshold concentrations.

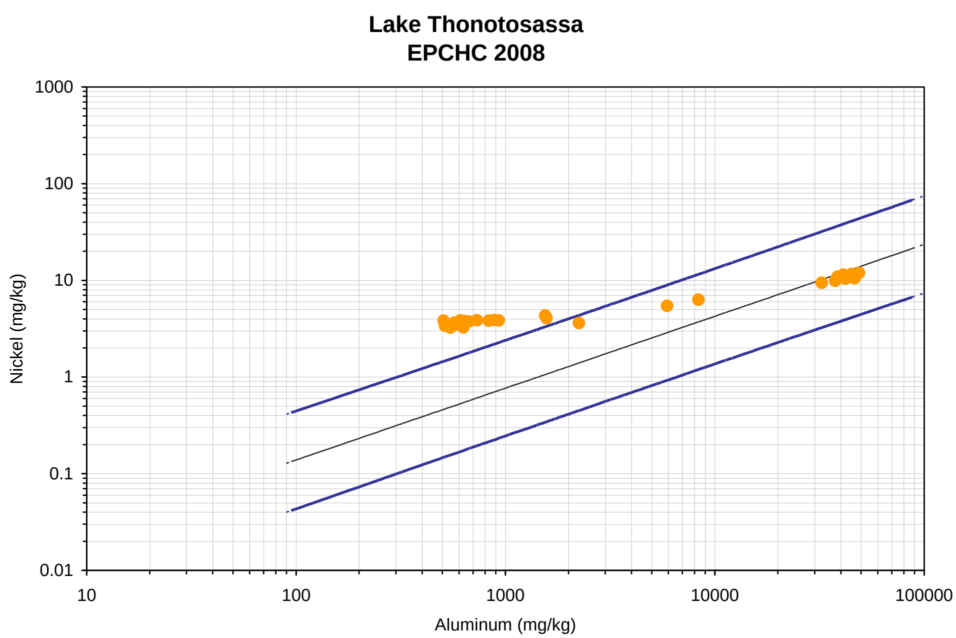

Figure 32 Ni:Al regression for Lake Thonotosassa sediments plotted against FDEP reference site regression line with 95% prediction intervals (from Carvalho *et al.* 2002).

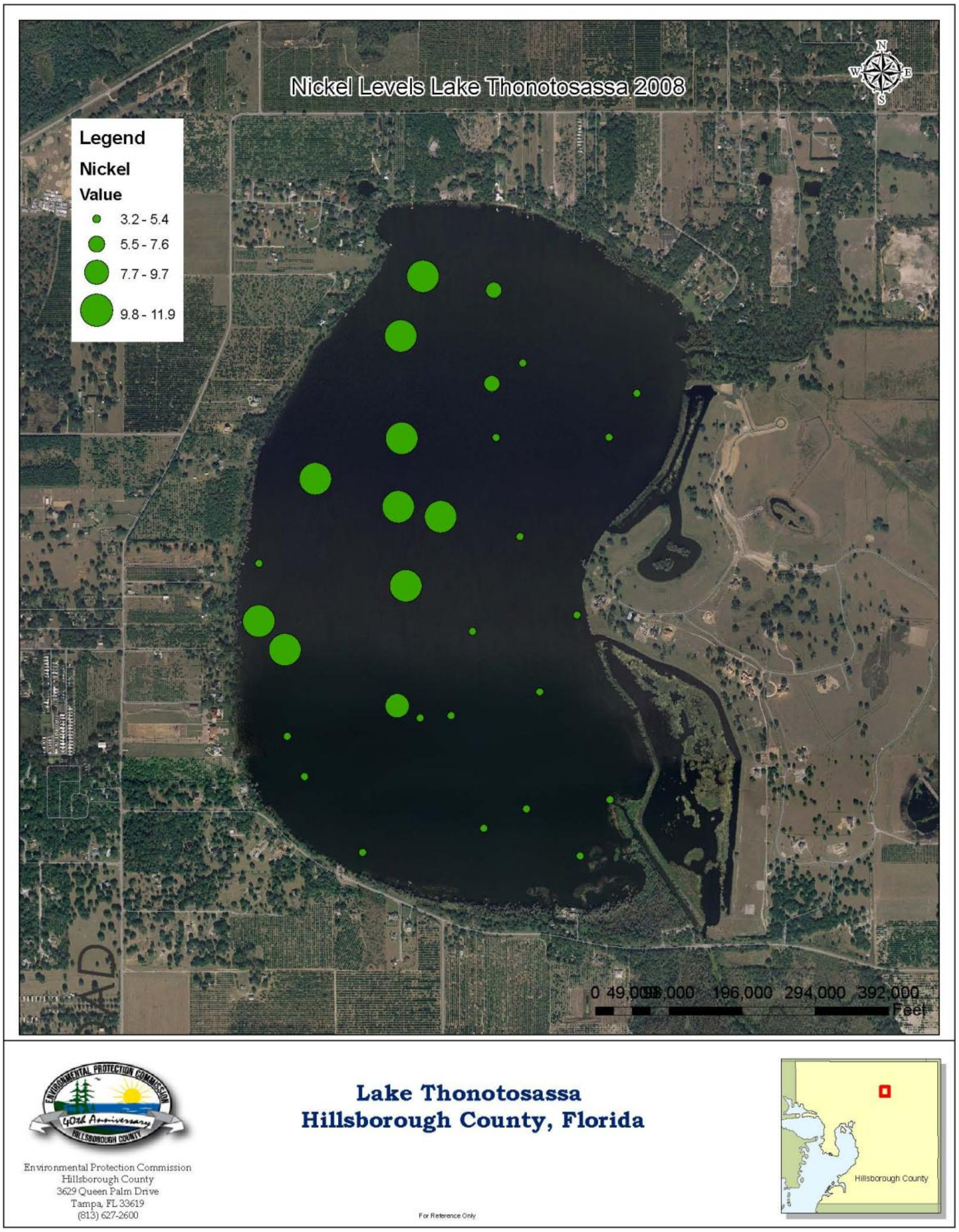

Figure 33 Spatial distribution of nickel in Lake Thonotosassa sediments. Values in mg/kg.

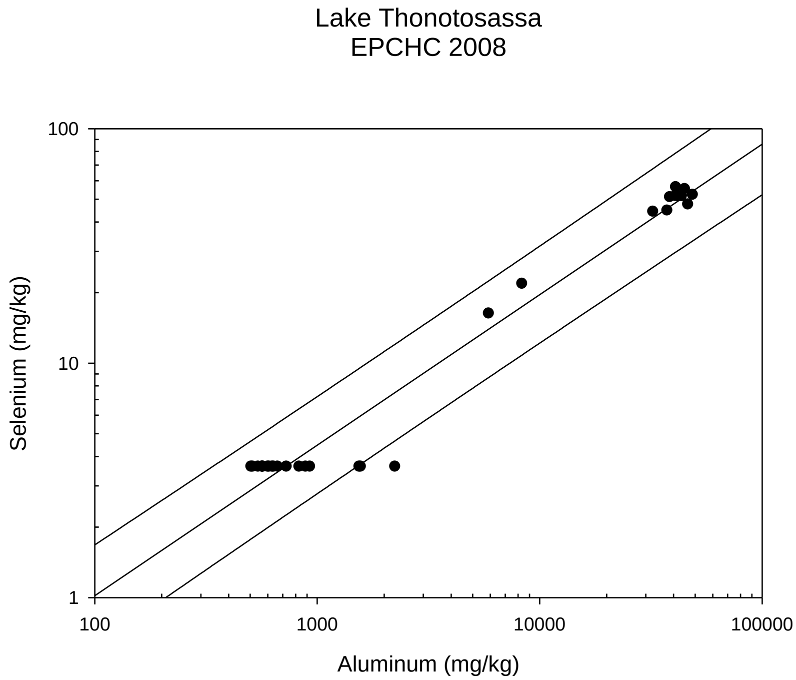

Figure 34 Se:Al regression for Lake Thonotosassa sediments. Regression line with 95% prediction intervals.

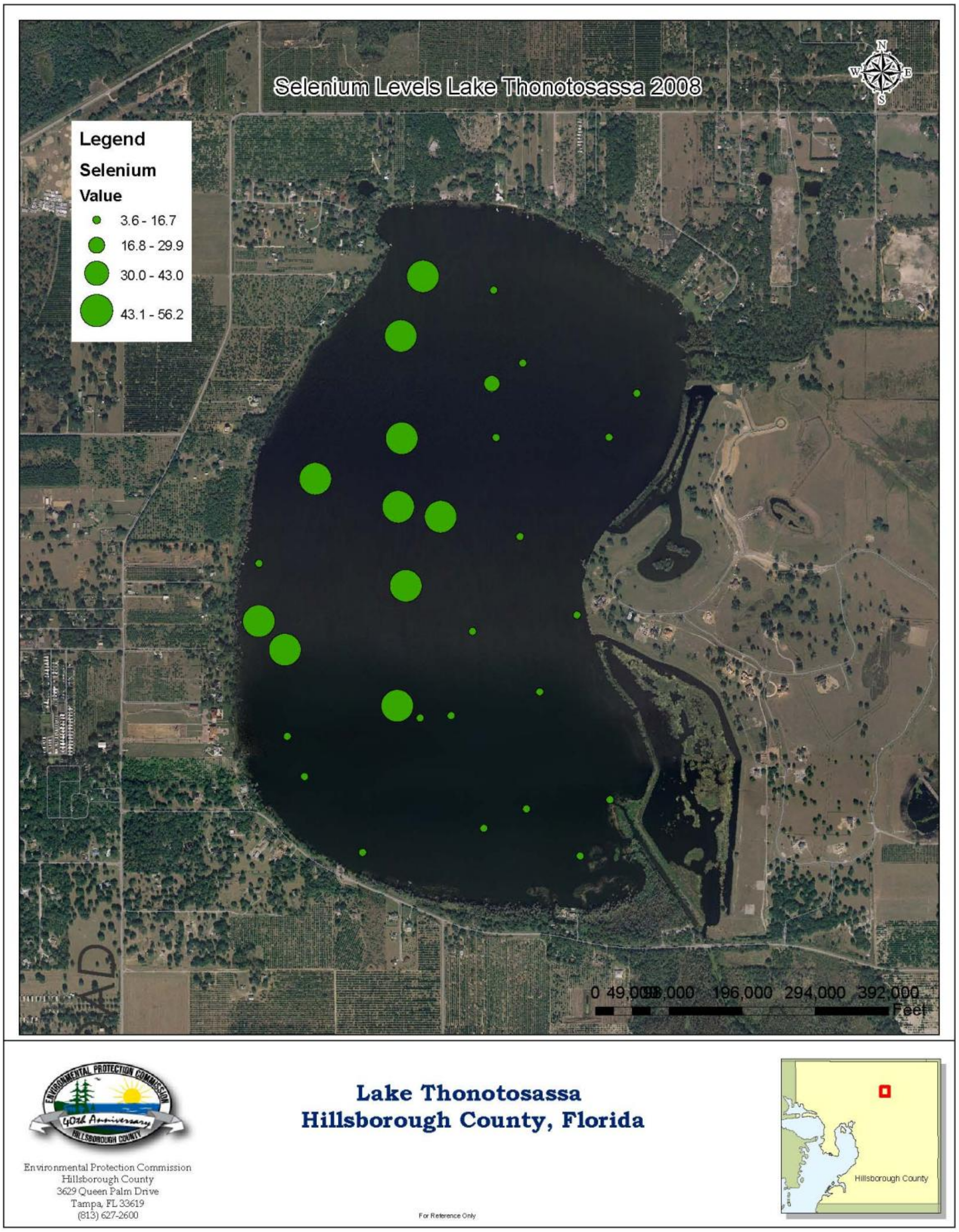

Figure 35 Spatial distribution of selenium in Lake Thonotosassa sediments. Values in mg/kg.

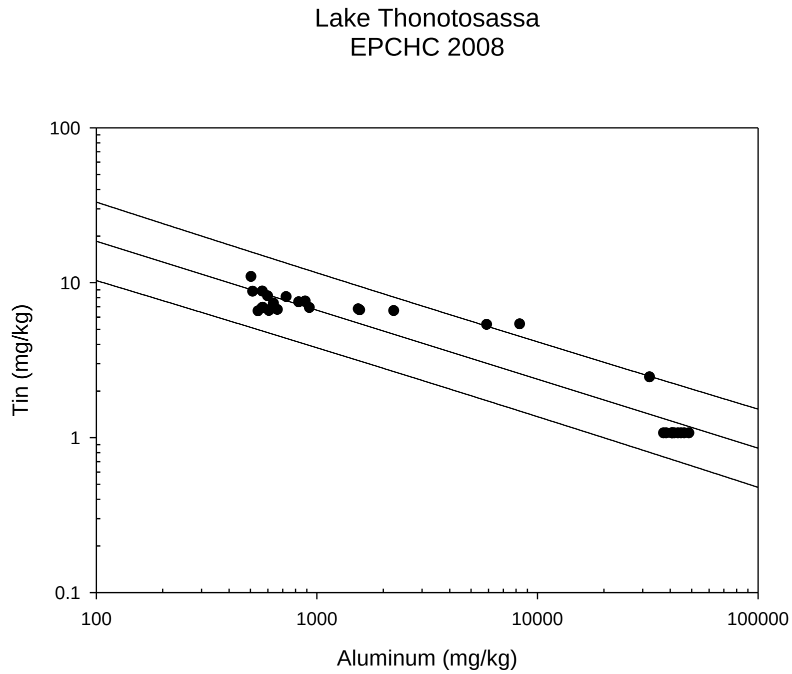

Figure 36 Sn:Al regression for Lake Thonotosassa sediments. Regression line with 95% prediction intervals.

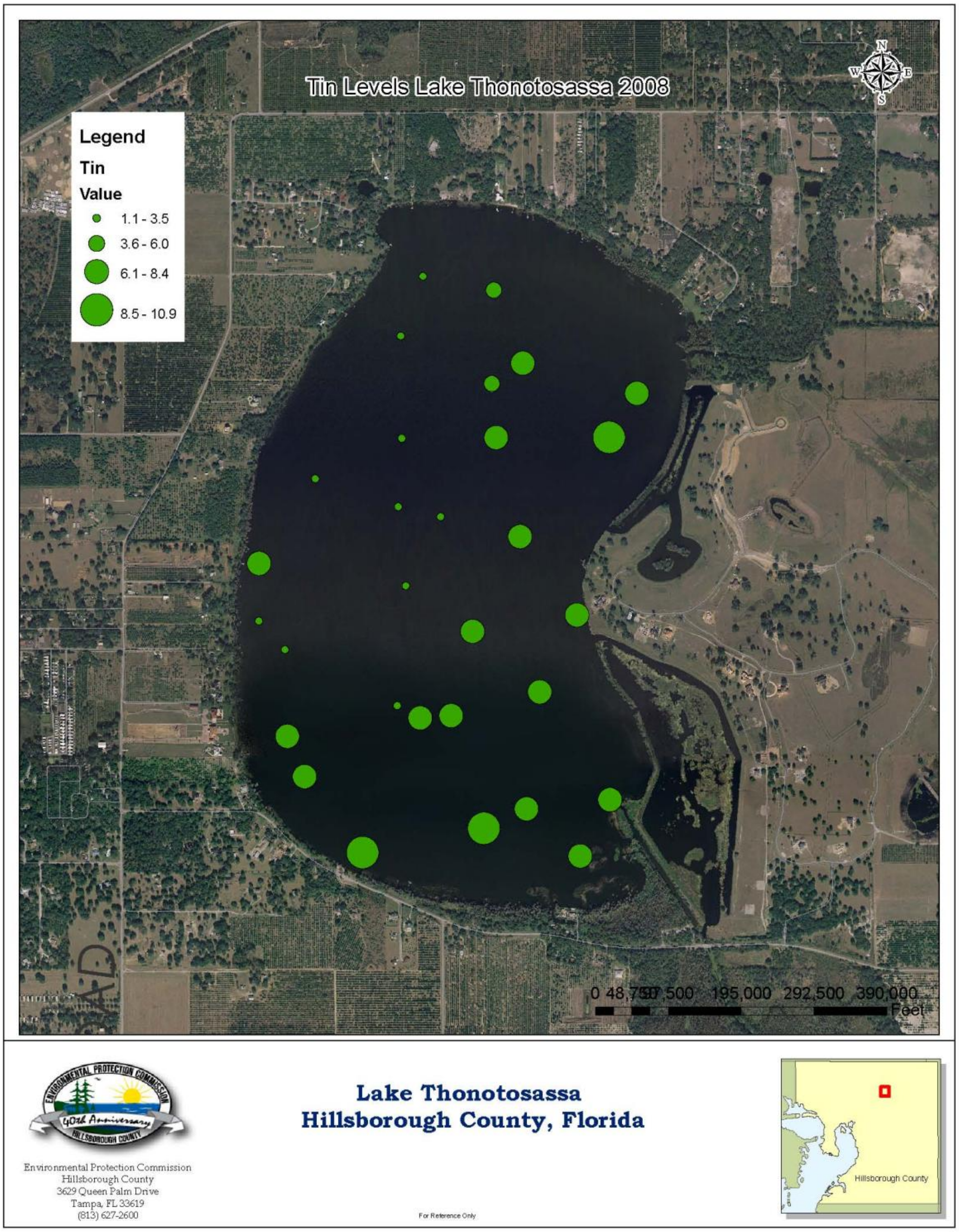

Figure 37 Spatial distribution of tin in Lake Thonotosassa sediments. Values in mg/kg.

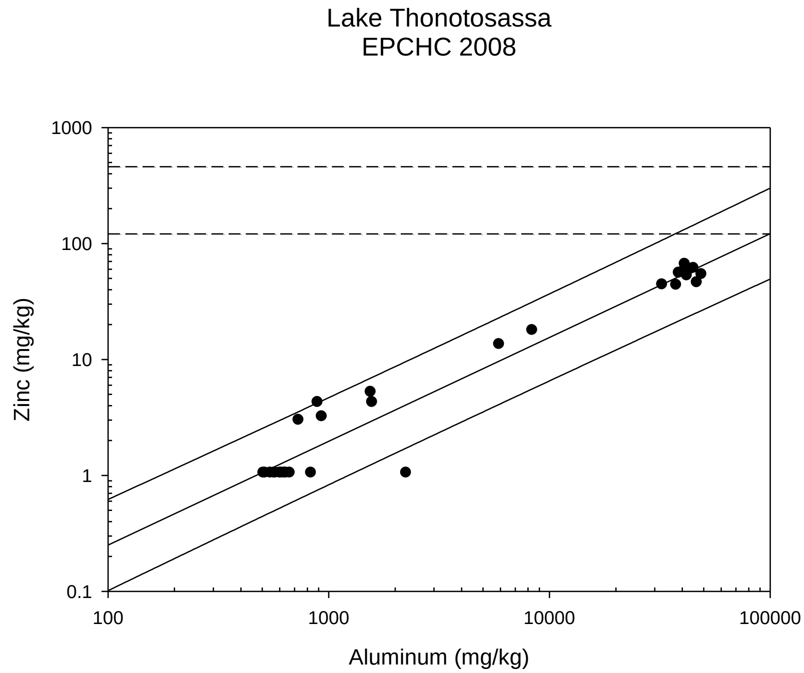

Figure 38 Zn:Al regression for Lake Thonotosassa sediments. Regression line with 95% prediction intervals. Dashed lines indicate TEC and PEC threshold concentrations.

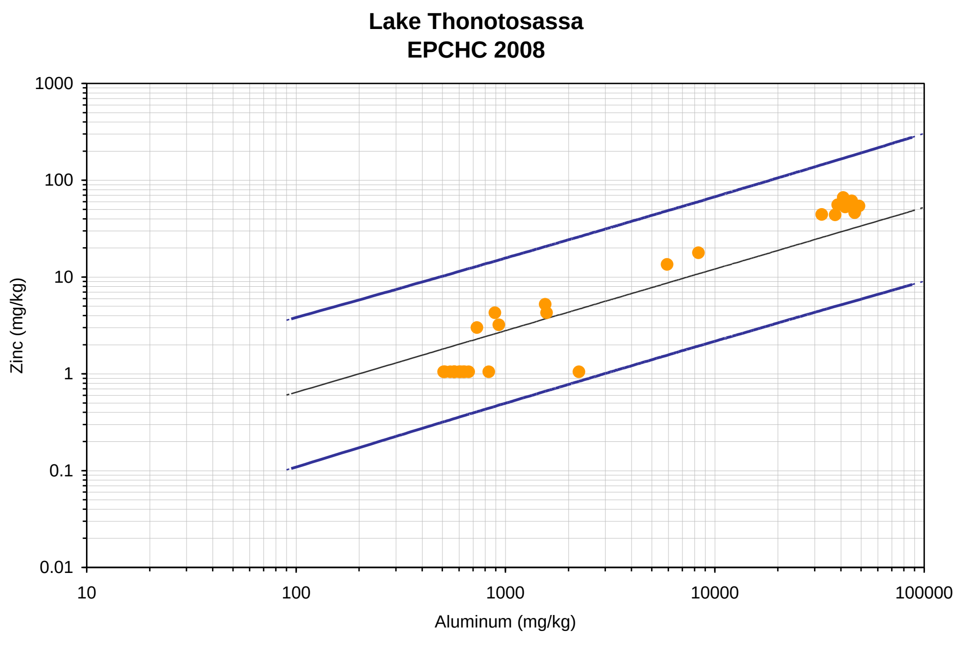

Figure 39 Zn:Al regression for Lake Thonotosassa sediments plotted against FDEP reference site regression line with 95% prediction intervals (from Carvalho *et al.* 2002).

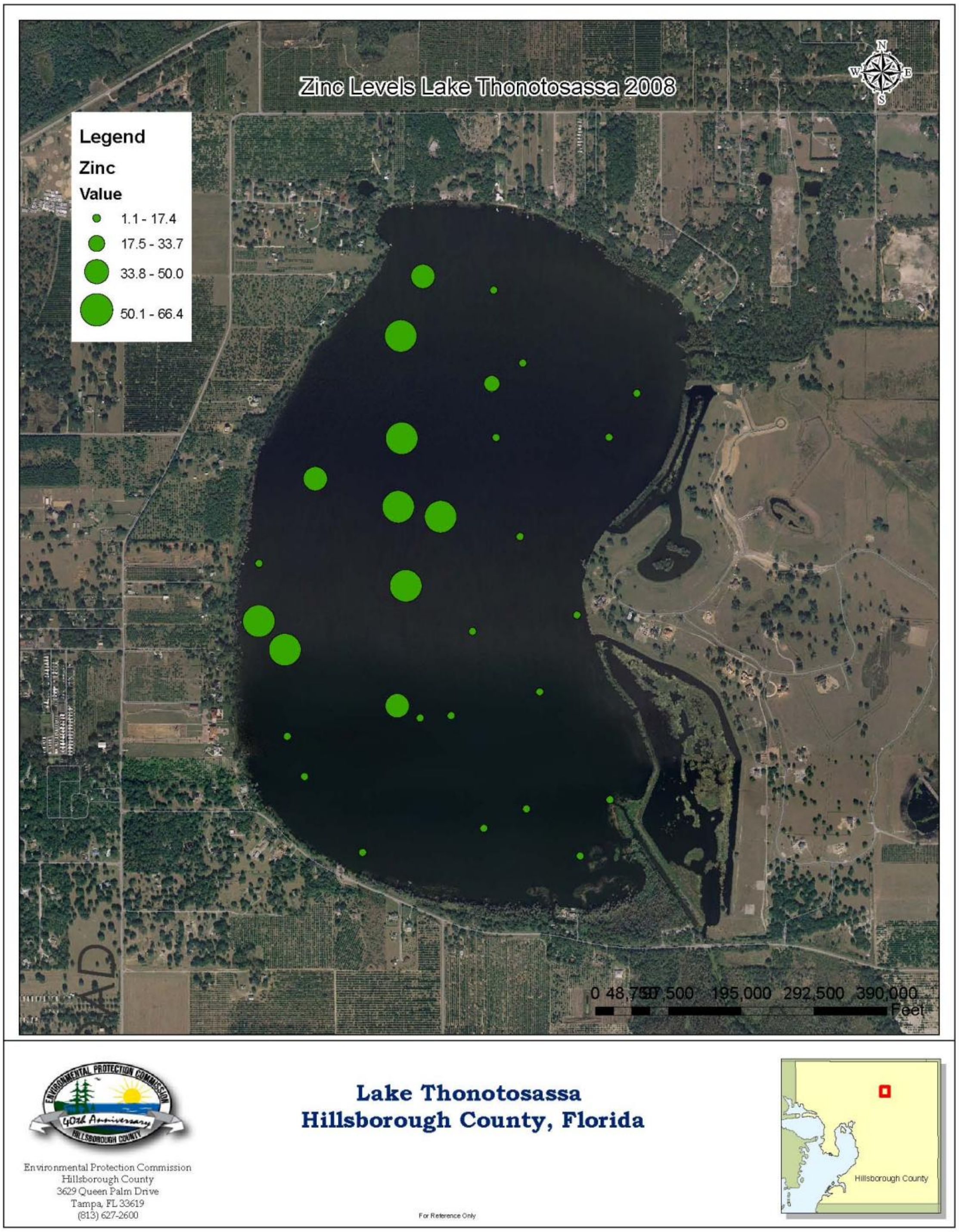

Figure 40 Spatial distribution of zinc in Lake Thonotosassa sediments. Values in mg/kg.

Discussion and Conclusions

Several physical and chemical factors influence the flux of metals between aquatic sediments and the overlying water column. These include the grain size, organic content of the sediments, pH, oxidation-reduction (redox) potential, dissolved oxygen conditions, and the salinity/conductivity of the surrounding waters (de Groot 1995). Of the physical factors mentioned, sediment grain size and corresponding surface area are the most important in affecting trace metal concentrations (Horowitz 1991). In general, smaller grain sized sediments provide larger surface area per mass for the adsorption of trace metals and for chemical reactions (Horowitz 1991). The redox potential and pH are among the most important factors in influencing the chemical speciation and solubility of metals in aquatic environments (Pardue and Patrick 1995; Miao *et al.* 2006).

Lake Thonotosassa's bathymetry strongly influences the distribution of fine sediments on the lake bottom. Previously published maps of the lake's bathymetry indicate a broad, gradual slope on the eastern side of the lake ending in a deep trough of around 4.5 meters near the west side of the lake and with a steep slope along the western shoreline that borders the trough (Kenner 1964; Hillsborough County Water Atlas 2008). Whitmore *et al.* (1996) surveyed the distribution of soft sediments in Lake Thonotosassa and found little or no deposition on the eastern side of the lake while the deeper western sites had soft sediment deposits as thick as 1.5 meters. The percent silt + clay results from this study corroborate the results from Whitmore et al. (1996). Most of the shallow eastern sites had silt + clay values <1% while the deeper western sites all had values in excess of 50%. Whitmore *et al.* (1996) hypothesized that the sediment distribution in Lake

Thonotosassa was due to resuspension of the sediments from the shallow areas by wind mixing the overlying water column. These suspended sediments then would be deposited into the deeper parts of the lake. The steep slope along the western shoreline also causes slumping of the fine sediments focusing their deposition into the deep trough on the western side of the lake (Whitmore *et al.* 1996). The warm shallow areas of the lake and well mixed water column results in the rapid breakdown of organic material which also prevents the accumulation of fine sediments (Whitmore *et al.* 1996).

Metals tend to adsorb onto finer grained sediments and the distribution of most of the metals in Lake Thonotosassa closely followed the distribution of fine sediments. The concentrations of antimony, arsenic and tin however were highest in the shallow areas of the lake, which were characterized by sandy sediments with low % silt + clay values. These shallower sites tend to have better mixing of the overlying water column and higher dissolved oxygen levels which results in an oxidizing environment. One possible explanation for this distribution is that the oxidized states of these three metals are less soluble than their reduced forms (Chen *et al.* 2003; Whitmore *et al.* 2008) and therefore they precipitate into the sediments in the shallow oxygenated areas of the lake. Arsenic and antimony bind and precipitate with iron and manganese compounds under oxic conditions while under anoxic conditions are released into their dissolved state (Chen *et al.* 2003; Whitmore *et al.* 2008). Conversely, the heavier metals are more soluble in their oxidized form while in their reduced states they precipitate out. The deeper areas of the lake are more anoxic forming reducing environments and hence these metals were found in higher concentrations at the deeper sites. (Miao *et al*. 2006).

Overall, the sediment metals concentrations in Lake Thonotosassa were better than the established Florida state sediment quality guidelines (MacDonald *et al.* 2003). Exceptions were cadmium, which exceeded its TEC level at all 30 sites; and chromium which was above its TEC level at four sites. The chromium concentrations were not enriched relative to the FDEP reference sites (Carvalho *et al.* 2002) although cadmium levels were. The metal:aluminum ratios for both of these metals however suggest that they were not elevated above local background levels.

Lead was of particular interest in this study due to the establishment of the TMDL for lead in Lake Thonotosassa surface waters (U.S. EPA 2005). The TMDL report for Lake Thonotosassa suggested that the observed lead exceedences may have been due to the resuspension of contaminated sediments during storm events (U.S. EPA 2005). Lead levels in the lake sediments were highest at the deeper sites and associated with fine sediments. All the sites were below the established TEC for lead (35.8 mg/kg; MacDonald *et al.* 2003) although several sites did approach this threshold. These results suggest that lead contamination is currently not an issue in the lake sediments and that the deeper areas of the lake act as a sink for lead entering the lake system.

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