Final report

Bathymetry and sediment characterization of Spring Lake
City of Naples, FL

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Introduction

Spring Lake is a small oval shaped detention pond of area (A) 4.9 acres (2 ha) located in the city of Naples and positioned within 5th Avenue South, West Lake Drive, East Lake Dr and 8th avenue South (UTM 17R 420015 E 2891380 N; Fig. 1). The perimeter (P) as determined by aerial photographs from Google Earth is 692m for a low shoreline development index (SDI) of 1.38. The SDI is calculated as $SDI = P/2\sqrt{\pi\ A}$ and reflects the deviation of the shape of the pond from a circle (SDI=1, when the shape is circular).

This pond was sampled by MACTEC on 11/18/2008. Mid-depth water samples and sediment sampled with a Ponar dredge were collected at three locations in the pond. Water was analyzed for chlorides and for the following nutrients: total Kjeldahl Nitrogen (TKN), total nitrogen (TN), Nitrates + nitrites (NOx), ammnonia, orthophosphate (Soluble Reactive Phosphorus SRP) and total phosphorus (TP). Additionally, the water was tested for metals (As, Cd, Cr, Cu, Pb, Hg) and Fecal coliform/enterococci. The sediment was not analyzed for nutrients, but for metals (As, Cd, Cr, Cu, Pb, Hg) as well as polynuclear aromatic hydrocarbons (PAHs) and total recoverable petroleum hydrocarbons (TRPH).

MACTEC compared the results with the Surface Water Standards from the Florida Administrative Code (FAC) 62-302. It was found that dissolved oxygen, conductivity, pH and turbidity were within the water quality standards at the time, location and hour of the sampling. Metals were within the limits with the exception of Cu (> class II standard). Unfortunately, the water hardness was not included in the water analysis making it impossible to check if some metal analyses met the State standards. Furthermore, the detection limit for Hg was higher than the listed class III standard. The sample should thus have ideally been concentrated to lower the detection limit. Nitrogen appeared to be problematic for this pond and phosphorus concentrations were too low to be detected at the laboratory.

Sediment results were compared to the default soil cleanup target levels (SCTLs) contained in FAC 62-777 in the event that the sediment is dredged. There are no State quality standards for sediments developed for ponds at this time. It was found that As and Cu exceeded the SCTLs. TRPH and BaP also exceeded the SCTLs.

Our group conducted a more involved analysis with the nutrients to determine that, at the time of MACTEC sampling in 2008, this pond was eutrophic for nitrogen with a trophic state index (TSI, Carlson 1977) of 54.3 ± S.D. 1.5. The TSI is a dimensionless number ranging from 0 to a 100 (although the scale can go beyond 100) which reflects the trophic status of the water. Water with a TSI<40 reflects oligotrophy (from the Greek oligos “few" and trophikos "feeding") and is thus clear with low TP, TN and phytoplankton. Water with 40<TSI<50 is mesotrophic (meso = middle) and is thus positioned in the middle range of water clarity, phytoplankton, TP and TN. Water with 50<TSI<70 is eutrophic and reflects true (=”eu”) nutrients and phytoplankton rich conditions as well as more turbid waters. Eutrophic conditions in shallow hydrosystems lead to occasional hypoxia (ie. Low DO) or anoxia (ie. no DO) near the hydrosystem’s bed. Finally, when TSI>70, the water is hypereutrophic and water is highly turbid and very rich in nutrients. Anoxia near the hydrosystem’s bed is then always present.

The salinity computed from the chlorides concentration is 0.14 ± S.D. 0.0 ppt and is within normal range (0.001 to 0.5 ppt) for a freshwater pond. The spatial variability for the sediment was high with an average of 74% for the coefficient of variation (CV). Until now, Spring Lake had no bathymetry available.

Objectives

This comprehensive, but snapshot in the time investigation had several objectives:

1. Build an accurate bathymetry of Spring Lake which would help managing the pond and study its ecology
2. Assess the health and trophic status of the pond through its water characteristics
3. Assess the health and trophic status of the pond based upon its sediment characteristics for organic content and nutrients
4. Assess how much sediment and floc has accumulated on the pond bed since its inception
5. Assess how much metals (Al, Cr, Ni, Cu, Zn, As, Se, Ag, Cd, Ba, Hg and Pb) have accumulated since the inception of the pond and compare the concentration to the Soil Cleanup Target Levels (SCTLs)
6. Provide the sponsor with a comprehensive set of interpretations
7. Provide the sponsor with a comprehensive set of recommendations

Methods

Bathymetry data acquisition– The bathymetry of the deepest portion of the pond >0.7m) was initiated in October 2012 with the use of a Garmin GPSMAP 531S sonar/GPS. The GPS was equipped with the Wide Area Augmentation System (WAAS) giving an accuracy of often 3m. Sonar soundings and GPS coordinates were taken at every 3 seconds intervals from a kayak which made a concentric spiral over the pond (Fig. 2). A few sonar soundings were also correlated to actual depths measured by lowering a Secchi disk to the pond's bed. The resulting regression was used to correct the depth given by the sonar (Fig. 3). Shallow soundings were made from a kayak using a meter stick which were georeferenced with a WAAS enhanced Garmin Etrex Vista handheld GPS. The shoreline of the pond was walked with the handheld GPS which logged the track and thus delineated the actual perimeter.

Bathymetry interpolation and surface and volume computations – Discrete depth soundings were transformed in feet and referenced against the NGVD elevation determined on top the concrete culvert structure located at the end of the narrow umbilical channel in the uttermost southeastern pond location. This culvert runs under East Lake Dr. and connects to East Lake. The resulting elevations were then interpolated with Surfer 8 (www.goldensoftware.com) using the Kriging method (Matheron, 1963) on a square tight grid (1.5x1.5m). A variogram was generated to assess which model to use with the Kriging method. A "breakline" delineating the perimeter prevented the interpolations from being made outside the perimeter of the pond. Volumes, pond surface area and bed surface area were then calculated by Surfer 8 at every 0.2' intervals from the highest to the lowest elevation equivalent to an empty pond. The mean depth defined as the "volume/pond surface area" was also computed every 0.2 feet. The resulting data was graphed with MS Excel 2010 and each scattergram was fitted a polynomial order 2 or 3. Non-linear regressions were not conducted as, from previous experience, the coefficient of correlation is generally very high and the data are well distributed over the range.

Water column physical characterization –Water profiles were conducted on 10/6/12 around noon in the deepest portion of the pond in its south central section (17R 4200053E, 2891332N, Fig. 4). Temperature, conductivity, dissolved oxygen (DO), pH and ORP were measured every 0.25m until the pond's bed was reached with an YSI (www.YSI.com) multi-parameters 600 XL sonde equipped with the 6560 temperature/conductivity, 6562 Rapid Pulse polarographic DO and the 6565 pH/ORP sensors. Photosynthetically Active Radiation (PAR) was measured with a LI193 4Pi underwater sensor coupled with a LI-1400 meter (www.licor.com) every 0.25m under constant atmospheric lighting and away from the boat's shading. Light decreases exponentially with depth as $I_z=I_0 \exp(-kz)$, where I_z is the light at depth z, I_0 is the light just below the surface and k is the light extinction coefficient (Kirk, 2011). By plotting $Ln(I_0/I_z)=kz$, it was thus possible to determine k graphically and to assess the depth to which algal photosynthesis was possible, z_{eu} and defined as $I_0/100$ (i.e. $z_{eu}=Ln(100)/k$). Light transparency was also determined with a Secchi disk (SD) which was lowered in the water column until it was no longer seen. Secchi disk depth was measured to the nearest cm.

Water nutrients – The water column was sampled in subsurface and 0.5 m above the pond's bed using a vertical 2.2L Beta™ Van Dorn bottle sampler. Once sampled, water was kept in an opaque 1.5L Nalgene bottle which was kept in the dark in a cooler with no ice. Within 4 hours, water for the analysis of total phosphorus (TP, EPA365.1) was transferred to a 125ml Nalgene bottle which was kept refrigerated until being analyzed. A 60ml subsample was then filtered on a Nucleopore 0.22µm pore size filter into an 80ml Nalgene bottle which was immediately frozen until being analyzed for dissolved nutrients: NO_x (EPA353.2), NO_2^- (EPA353.2), NH_4^+ (EPA350.1) and soluble reactive phosphorus (SRP, EPA365.1). NO_3^- was computed as NO_x- NO_2^- . Nutrients were analyzed by the NELAC laboratory of the Southeast Environmental Research Center (SERC) at Florida International University (FIU), Miami, FL on a Technicon Autoanalyzer II System (Pulse Instrument Ltd.).

Total chlorophyll of the various algal groups, photosynthesis capabilities - Three dark adapted 3ml water subsamples were then run through a Phyto-PAM (www.walz.com; Schreiber et al. 1986) to determine the total chlorophyll of the three major algal groups: Chlorophyceae (greens), Bacillaryophyceae (brown diatoms) and Cyanophyceae (blue green or cyanobacteria).. The Phyto-PAM used the factory calibrated standard reference spectra. The photosynthetic capabilities of the three algal groups were also measured using the Pulse Amplitude Modulation method (Schreiber et al. 1986).

Sediment coring – Corings were performed from a 13' aluminum Jon boat. A total of 28 sediment cores were pulled from the pond. All 28 cores had their sediment and flocculent layers thicknesses assessed but only a subset of 17 cores (Fig. 4) had their sediment layer (and sometimes their floc layer) sampled for further analyses in the laboratory (cf. sediment analyses section below). Sediment cores were sampled using a handheld push corer made of interlocking 2" PVC sections which held a clear acrylic tube of inner diameter 6.35cm on top of which a one-way valve was mounted. The one-way valve allowed the water to flow one way as the corer was lowered to the water column and the acrylic core pushed through the sediment. The acrylic core was pushed in the pond's bed until rebuttal and then brought to the surface. The one-way valve, creating a strong suction seal, would hold the sediment material in the acrylic tube up to the surface. At the surface, the acrylic tube's bottom was capped with a rubber stopper #13 to create a second seal. Once on the boat deck, the corer was uncoupled from the acrylic tube and the tube's apex was capped with another rubber #13 stopper. A 10MP picture of the core was then taken against a white erase board after the total sediment core thickness was recorded. The sediment material was then extruded upward by pushing upward a piston inserted at the bottom of the tube (placed there *in lieu* of the rubber stopper). Once the top of the lake bed material was flushed to the opening of the acrylic tube, the depth of the floc layer was measured to the nearest ½ cm by letting a plastic ruler sink through it under its own weight. The flocculent layer was then sampled and kept in a Ziploc bag chilled in a cooler packed with crushed ice. Then, the sediment was pushed upward and its thickness measured to the nearest ½ cm until either sand, peat, clay or limestone was reached. The sediment was collected in a bucket then homogenized and stored in a Ziploc bag chilled in the cooler. All of the other layers underneath the sediment were characterized and measured to the nearest cm then discarded.

Determination of sediment or floc volume and average thickness – Two methods were used to compute the volumes of sediment+floc, sediment and floc and assess their respective average thicknesses.

The first method consisted in interpolating the data with Surfer 8 using the inverse distance to power method. It was assumed that no sediment was found at the perimeter of the pond and the interpolation outside the perimeter was prevented through the use of a break line in Surfer 8. The average thickness of the material over the pond bed was then computed by dividing the volume of material by the surface area of pond.

The second method consisted of averaging all thicknesses for a given material lying over the pond's bed and to multiply the average thickness with the surface area of pond.

Sediment analyzes – Once in the laboratory, part of the sediment or floc was dried until constant weight in a drying oven set at 80 ºC (DW) and then combusted at 550ºC for one hour. The ash weight was then determined (AW) and the ash free dry weight deducted (AFDW). The organic content was finally computed as AFDW/DW (ASTM D2974-87). About 100ml of the sediment was frozen in a plastic cup and sent to the NELAC certified Bioinorganic and Environmental Analytical Facility (BEAF) at FIU, Miami for the analyses of Ag, Al, As, Ba, Cd, Cr, Cu, Hg, Ni, Pb, Se and Zn.

For Hg analysis, the preparation of the sediment samples was done outside the mercury-free room, due to their relative high Hg concentrations. The sediment was homogenized, and 1 ml of the homogenate was transferred to a 10 ml ampoule with 2 ml of concentrated nitric acid (total volume in the ampoule was 3 ml) and left to sit for 20 minutes. The ampoule was sealed and autoclaved for 1 hour at 105ºC. The ampoules were allowed to cool completely to room temperature, and then an aliquot of the ampoule solution was diluted with 1% HCl to 40 ml in a polypropylene centrifuge tube for cold vapor atomic fluorescence spectroscopy (CV-AFS) analysis of Hg.

For the rest of the metal analysis, sediment samples (about 10 g wet weight) were placed in digestion vessels. After adding 10mL of concentrated HNO_3, the vessels were placed onto a hot plate and the samples were digested for 1h at 95ºC following the standard operating procedure (EPA-6020). After cooling off the samples to room temperature, 1mL of hydrogen peroxide was added to each sample. The samples were then re-digested for 20min at 95 ºC. After digestion, the samples were diluted to 50mL with deionized water and left decanted. After the particulates settled, an aliquot of the supernatant was placed in a 10-ml plastic test tube and diluted to 10mL with water or 2% nitric acid. After running standards, the samples were analyzed on inductively coupled plasma mass spectrometry (ICP-MS) for metals which concentrations were reported in mg/kg DW.

Another fraction of the sediment or floc was dried in the oven until constant weight, then grinded to a fine powder with a Belart MICRO-MILL® grinder. A few grams of powdered sample were then sent to the SERC laboratory for the analyses of total phosphorus (TP), total carbon (TC) and total nitrogen (TN, ASTM D5176) which were reported in g/g DW or % DW. Total phosphorus in sediments was determined using the ashing/acid hydrolysis method of Solorzano and Sharp (1980) with the resulting soluble reactive phosphorus (SRP) being measured as SRP in water (EPA365.1). Sediment TC and TN were analyzed using a Perkin Elmer Series II 2400 CHNS/O Analyzer (Nelson and Sommers 1996).

Pond trophic status index (TSI) and determination of the limiting macro-nutrient for phytoplankton growth- The index developed by Brezonik (1984) using the TP, TN, Chlorophyll *a* concentrations and the Secchi disk depths data from 313 Florida lakes was used to assess the pond's trophic status. Three formulas are available depending on the limiting nutrient in the pond water. This limiting nutrient was determined subsequent to the calculation of the water TN/TP concentrations ratio.

- Phosphorus-Limited (mass TN/TP>30): TSI=1/3 [TSI(chla)+TSI(SD)+TSI(TP)]

where TSI(chl *a*)= 16.8+14.4 Ln(chl *a*), TSI(SD)= 60.0-30.0 Ln(SD), TSI(TP) = 23.6 Ln(TP)-23.8

- Nitrogen-Limited (mass TN/TP<10): TSI= 1/3 [TSI(chl*a*)+TSI(SD)+TSI(TN)]

where TSI(chl*a*)= 16.8+14.4 Ln(chl*a*), TSI(SD)= 60.0-30.0 Ln(SD), TSI(TN)= 59.6+21.5 Ln(TN)

- Nutrient-balanced (10 <mass TN/TP <30): TSI = 1/3 [TSI(chl*a*)+TSI(SD)+0.5 (TSI (TP) + TSI (TN))] where TSI(chl*a*) = 16.8+14.4 Ln(chl*a*), TSI(TN) = 56+19.8 Ln(TN), TSI(TP) = 18.6 Ln(TP)-18.4 and TSI (SD) = 60.0-30.0 Ln(SD)

Statistics - T tests and regressions were computed with SPSS 20 after the data was checked for normality and homoscedasticity. All graphs presented in this report were constructed with MS Excel. All averages are expressed along with their standard deviation (±S.D.).

Sediment characteristics Interpolations – Interpolations were conducted with Surfer 8 (www.goldensoftware.com) using the inverse distance to power method. Interpolations outside the data were limited by the use of a "fault" file which avoid making assumptions outsides the grid.

Google Earth core ID file creation – Instead of adding all the pictures of the cores and their characteristics to this report's annex, pictures were compiled in a kml file which opens in Google Earth and which, upon clicking on each core location, pops up a window depicting the picture(s) of the core along with its characteristics.

Results

Bathymetry -The bathymetry is presented in Fig. 5. At the moment of the investigation the water level was flowing through the culvert into East Lake. The water surface was then 0.35m (1.15') below the top of the concrete culvert structure with a NGVD elevation of 4.23'. Thus, water level at the time of the bathymetry was 3.08' and is hypothesized to be the level when the pond is "full". When full, Spring Lake holds 25,342m^3 (6,694,599 US gallons; Figs. 6, 7, 8) of water for a pond planar surface area of 19,952m^2 (214768 ft^2, 4.9 acres; Figs. 9, 10, 11) and for roughly about the same pond bed area (Figs. 12, 13, 14). The mean depth was then 1.27m (4.17ft, Figs. 15, 16). The bathymetry depicts the pond with a quite extended shelf in its half north end and a very narrow shelf in the second half of the pond with a significant drop in depth beyond it. The northern part of the pond is shallower than the rest of the pond. The narrow umbilical channel leading to the culvert and East Lake is shallow. Additionally, the slightly north center part of the pond has a shallow submerged flat about 3 feet below the surface. Not shown on the map are the lawns abutting the pond which are very steep on the entire west shoreline and not steep on the east side of the pond.

The pond volume as a function of NGVD elevation could be determined using a simple 2nd order polynomial function (Figs. 6, 7, 8):

Volume (m^3)= 415.04 x [NGVD elevation]^2 + 4466.9 x [NGVD elevation] + 8159.4, with the NGVD elevation expressed in feet.

The pond surface area (and the lake bed area, Figs. 12, 13, 14) could be determined using a 3rd power polynomial function (Figs. 9, 10, 11) which depicts minimal surface area changes as pond level decreases and a faster constant change in surface area when the pond level is lower than 0' NGVD.

Surface (m^2)= 199.8 x [NGVD elevation]^3 – 948.84 x [NGVD elevation]^2 + 2226.4 x [NGVD elevation] + 16368, with the NGVD elevation expressed in feet.

The pond mean depth decreases linearly with water level and can be modeled as:
Mean depth (m)= 0.2276 x [NGVD elevation] +0.5419, with the NGVD elevation expressed in feet.

Water column characteristics – The water column was very well mixed with very minor changes with depth in DO (6.59±S.D.0.19 mg/L), temperature (24.6±S.D.0.0 ºC), conductivity (608 µS/cm), pH (7.8±S.D. 0.0) and ORP (219±S.D.6 mV; Fig.17).

Because of high water mixing and of the very minor differences between the nutrient levels in subsurface and above the pond's bed, water nutrients were averaged. TON 0.47±S.D.0.04mg/L largely dominated the TN pool (0.57±S.D.0.04 mg/L) since TIN accounted only for 0.12±S.D.0.01 mg/L which could be broken down into NO_2^- (0.01±S.D.0.00 mg/L) and NO_3^- (0.03±S.D.0.0 mg/L) and 0.08±S.D.0.01 mg/L for NH_4^+. Phosphorus was mostly particulate with TP averaging 141±S.D.5 µg/L and SRP was 80±S.D.2 µg/L. The TN/TP ratio was 4.0±S.D.0.2 thus resulting in a strongly nitrogen limited pond but with high concentrations of nutrients. The resulting TSI(N) was thus 47.4 (high mesotrophic).

Irradiance (PAR light) decreased exponentially with depth with a light extinction coefficient of 0.418/m thus resulting in a euphotic zone where photosynthesis can happen of 11m (36'; Fig. 17). Water clarity as assessed with the Secchi disk was 1.13m. The calculated TSI(SD) using the Secchi disk depth was thus 56.3 (low eutrophic).

Small amounts of solely green algae were found in the water samples and their total chlorophyll concentrations were not significantly different in subsurface and above the lake bed (31.3±S.D.3.3 µg totChl/L). These green algae had good photosynthetic capabilities with an average photosynthetic yield of 55±S.D.1% and they were adapted to a fairly high light regime (I_K of 663 and 343 µmol.photons.$m^2.s^{-1}$ in surface and above the lake bed, Fig. 18). By using total chlorophyll as a substitute to chlorophyll *a* concentrations, the calculated TSI(Chl tot) was thus 66.4 (high eutrophic).

Based on the water characteristics, the average aforementioned TSIs were thus 56.8 and are typical of a medium eutrophic pond.

Sediment thickness –By interpolating the sediment+floc thicknesses, it was found that their combined total volume over the pond bed was 4,087m^3 (144,331 ft^3) for an average of 20.5cm of sediment + floc (Fig. 19). When all the sediment+floc data were averaged, the average thickness was 26.7±S.D.18.4 cm for a corresponding volume of sediment over the lake bed of 5,327 m^3 (188,133 ft^3).

Using the same two computational methods, it was found that the interpolated sediment volume was 2,659 m^3 (93,901 ft^3) for an average thickness over the lake bed of 13.3 cm vs. 16.9±S.D.13.5 cm in average for a volume of sediment of 3,372 m^3 (119,081 ft^3, Fig. 20).

The interpolated floc volume was 1,427m3 (50,394 ft3) for a sediment thickness of 7.2 cm vs. 9.8±S.D.7.7cm for a total volume of 1,955 m^3 (69,053 ft^3, Fig. 21).

Sediment+floc ($r2=0.17$, $p<0.05$; fig. 22) and sediment thicknesses ($r2=0.21$, $p<0.05$; fig. 23) were poorly positively correlated with depth but floc and the total core length did not show any (Figs. 24, 25).

Sediment organic content – The combined sediment+floc organic content was 32.8±S.D.11.2% (Fig. 26) with a more organic floc fraction (40.6±S.D.9.4%, Fig. 27) and a less organic sediment fraction (29.0±S.D.10.7%, Fig. 28 p=0.004). No correlations could be found between the organic content and water depth, core thickness, sediment or floc thicknesses. The sediment organic content was higher in the south end of the pond and while the floc had higher organic content at the vicinity of the shoreline. The sediment+floc organic content logically reflected the patterns described above for the floc and sediment.

Sediment nutrient content – Sediment carbon, nitrogen and phosphorus contents were 17.6±S.D.7.5% (Fig. 29), 0.97±S.D.0.48% (Fig. 30) and 0.15±S.D.0.10% (Fig. 31) respectively. For the 5 floc samples which were analyzed for nutrients, TC, TN and TP accounted for 23.5±S.D.1.9%, 1.11±S.D.0.67% and 0.20±S.D.0.04% respectively. The sediment TC/TN ratio were constant across the sediment samples ($p<<0.05$; Fig. 32). However, the TC/TP and TN/TP were not constant because of two outliers for phosphorus from stations 22 and 23 (Figs. 4, 31). These two stations exhibit high phosphorus content with 34 and 37% for stations 22 and 23 respectively and resulted in TC/TP and TN/TP of 72-70 and 3-3 (cf. asterisks in Fig. 32). When removed, TC/TP and TN/TP were reasonably constant with 133.3 and 7.3. These ratios assert nitrogen limitation at the sediment level (Fig. 32). The carbon and nitrogen contents had similar spatial patterns with higher contents in the 1/3 north and 1/3 south portions of the pond. The umbilical channel had very low C, N and P contents.

Sediment metal contents – Ag concentration in the sediment was low at 0.45±S.D.0.73 mg/kg and was higher at station 1 in the uttermost north end of the pond (Fig. 33). Al was below residential SCTLs with 23538±S.D.22502 mg/kg with the exception of one sample located at station 22 in the south central portion of the pond (Fig. 34, Table 2). Arsenic was high to extremely high in all sediment samples (18.1±S.D.14.1 mg/kg) and, in average, 8.5 times higher than SCTLs (Fig. 35, Table 2). As was particularly high in the north and south ends of the pond. Ba was low with 14.1±S.D.9.9 mg/kg and seems higher in the south central end of the pond (Fig. 36). Cd was very low with 0.95±S.D.0.78 mg/kg and was higher in the north and south ends of the pond (Fig. 37). Cr was also low with 40.0±S.D.25.6 mg/kg with the same distribution pattern as Cd (Fig. 38). Cu was mostly higher (362±S.D.250 mg/kg) than the SCTLs with the exception of 2 samples (Station 10 and 21, Table 2). Cu was especially high in the north end of the pond (Fig. 39). Hg (Fig. 40) and Ni (Fig. 41) were low with respectively 0.32±S.D.0.21 mg/kg and 6.7±S.D.3.9 mg/kg and with higher concentrations in the north and south ends of the pond. Pb was higher than SCTLs at stations 1 and 22 (Fig. 42, Table 2) and in average 197±S.D.150 mg/kg. Se was low 0.67±S.D.0.37 mg/kg and in higher concentration in the south central portion of the pond (Fig. 43). Zn was very low (185±S.D.190) and under the SCTLs but a much higher Zn concentration was found in the uttermost north end of the pond (station 1, Fig. 44).

Discussion

Bathymetry – Spring Lake is a shallow pond with a low shoreline development index which makes it less susceptible to runoff pollutions since its relative perimeter to surface area is small. However, the nearly entire west and north shoreline is very steep and thus is prone to bank erosion and nutrients runoff from the lush lawns and surrounding urban development.

Although the original CAD file depicting the excavation at inception of Spring Lake is not available to our group at this time, it is reasonably hypothesized that the pond at inception had a narrow shelf and that depth was dropping abruptly beyond the shelf to the “bowl” of the pond’s bed which was of same elevation. The current bathymetry presented in this report drastically differs from this pattern with the exception of the east shoreline (and the low south part of the pond) not bordered by steep banks and characterized by a narrow shelf with a steep slope to the pond’s bed.

The bathymetric map clearly reveals a more extended shelf contiguous to the northwestern and northern shoreline which likely is the result of bank erosion. This erosion is especially important i) in the mid-west portion of the pond since a shallow flat is observed in the middle of the pond and ii) in the north portion of the pond which is very shallow.

This material laying on this mid-western flat is especially characterized by low nutrient and moderately low organic content, thus reinforcing the bank erosion hypothesis.

The north shelf is however very different since it is covered by materials of high organic and nutrient contents thus reflecting organic inputs such as leaf litter and/or algae. This area is bordered by trees, thus bark and leaf litter is common locally and is added on to the bank erosion. This region is also a “hot spot” with heavy metals accumulation which seems to tie partially to urban (as opposed to lawn and bank) runoffs (cf. the discussion about metals below).

Spring Lake is equipped with a fountain and two aerators, which at the time of our visit were not functioning optimally. Aerators prevent hypoxia or anoxia in the sediment by aerating the hypolimnion and as such help decrease the amount of organic in the sediment through oxidation (bacterial respiration mainly). Aerators also mix vertically and, to some extent horizontally by the formation of water convection cells in the water column which preclude i) algae to grow and ii) thermal stratification from happening. This creates conditions less prone to algal development, not only because of the cooler temperature especially during the summer, but also because algae cycle quickly through the water column which alters their light regime. However, with the current sampling design, it is not possible to assert that the two aerators are doing what they are intended to do. A different sampling design with several coring samples radiating around each aerator should have been implemented to study the aerators effects on muck reduction.

The bathymetry of Spring Lake and the resulting volume to elevation and surface area to elevation models shall prove useful to dose adequately the amount of chemicals used to treat this pond

Water quality – Based on our findings, Spring Lake is a fresh, eutrophic, and nitrogen-limited pond. However, it is important to assert that, founded on visible clues such as the tremendous growth of green filamentous algae and the characteristics of the sediment (cf. section below), this pond is more eutrophied than it actually reflects using water as proxy to gauge nutrient loading. Further, TSIs are developed to characterize natural lakes, reservoirs and ponds and they have to be used with caution in wet detention ponds since these ponds can be maintained artificially in a clear water condition by the use of algaecides or dyes. These controlled conditions can skew the TSI using the chlorophyll *a* concentration or the Secchi disk depth as proxies. It is also important to mention that fewer algae in the water would equate to fewer suspended total solids which highly contribute to the determination of TP or TN used also as proxies to calculate a TSI.

As such, TSI values are customary given in this report since it still is the standard to assess the trophic state of a water body. TSI values must however be interpreted with great care. Our group is currently developing a TSI based on the sediment characteristics which should better reflect the trophic status of a wet detention pond since the sediment is less affected by pond management implementations than the water column.

Finally, when investigated, the pond was normally at its lowest possible trophic status because it had recently underwent and was still undergoing through its annual nutrient- flushing and diluting at the end of the rainy season. The end of the rainy season indeed brings much rain which runs off on already "flushed" streets from the precipitations that occurred earlier in the season (e.g. Thomas et al. 2000).

At the time of our water column investigation, Spring Lake water column was very well mixed because of strong north sustained winds from Hurricane Sandy. Sediment resuspension was however not noted because the wind seemed to blow only over the deepest portion of the pond. DO was always above the 5mg/L threshold to sustain a healthy fish population and the pH was slightly over neutral. Equally important was the oxidation reduction potential (ORP) which was positive at all times including at the vicinity of the pond's bed.

Water clarity was very good for a eutrophic pond and allows the entire pond to be potentially colonized by algae and to some great extent submerged aquatic vegetation. A healthy phytoplankton community dominated by green algae with a quite high IK corroborates the good aforementioned water clarity.

Green algae normally do not thrive in nitrogen limited environments since they cannot acquire their nitrogen from the air (nitrogen fixation) like some blue green algae do. However, it should be emphasized that even though the N:P ratio suggests N limitation, N still is found in good concentration. Often, when N and P are high enough, the ratio of N:P does not really matter as all the nutrients are already in excess (Dr. Roger Bachman, pers. Com.).

Thus, the water quality is paradoxically good for a pond which exhibits quite advanced stages of eutrophication. Because of the wind blowing the day of the investigation and also because of the season at which the pond was visited, it likely that the trophic status calculated does not reflect the true status of the pond. Late dry season conditions likely would exhibit a much higher trophic status. It is therefore better to rely on the sediment characteristics to reflect the trophic status of the Spring Lake.

Sediment thickness and organic content – In comparison to other eutrophic and hypereutrophic ponds in Florida, it was found that Spring Lake sediment had organic contents slightly lower than the highly eutrophic Lake Jesup in Central Florida (21.7%, Anderson et al. 2011) and much lower organic content than the extremely hypereutrophic Lake Apopka (62%, Thomas, 2009). The floc had higher organic content than the sediment since it had yet to undergo through the dewatering and oxidation processes. Spring Lake floc organic content was typically in the high range when compared to the floc of Lake Jesup (33.3%) but much lower than for Lake Apopka (67%).

Spring Lake TN in the sediment and in the floc was slightly lower or equivalent to the ones found in Lake Jesup with 0.9% and 1.8% for TN in the floc and the sediment respectively. TN was however 3 times less than Lake Apopka with 3.2% TN. Sediment and floc TP were ~ ½ lower than in Lake Jesup (0.13% and 0.07% for floc and sediment TP respectively). Sediment TP was the same as for Lake Apopka (0.15%).

Subsequent to the above comparisons, it strongly appears that Spring Lake exhibits most hypereutrophic signs even though the water, at the time of sampling, suggests a eutrophic pond. This is especially true for sediment TP. Further, the TN:TP ratio pointed out nitrogen limitation and thus corroborates with the water nitrogen limitation.

Because of the high sediment thickness to mean water depth ratio of 0.16 m/m when the pond is full (this number is much less most of the year as water recedes during the dry season), it is asserted that the sediment oxygen demand, which has not been measured but which is assumed to be high because of the high organic and nutrient contents, can severely reduce DO in the entire water column. Such low DO in the water column was not found because of the thorough water column mixing which occurred during our investigation.

Spatially, larger amount of sediment accumulated in the deepest portions of the pond. However, this assertion was surprisingly not true for the floc material which is actually more fluid material and which should have accumulated in pond depressions. The high organic and nutrient contents in the sediment collected were higher at the vicinity of leaf litter producing trees. Such a litter was found in the sediment collected (cf. the Google Earth kml file to assess the pictures and close-ups photographs of the cores).

Metal contents in the sediment –When compared to the Soil Cleanup Target Levels for residential published by the Department State of Florida in 2005, two metals posed a major problem and two others were occasionally higher. As was found to be very high in all our sediment samples and it is expected that these numbers were high also in the floc.

Cu was also by several orders of magnitude higher than the SCTLs and is obviously linked to the spraying of copper sulfate or chelated copper sulfate used principally as an algaecide. Copper accumulates in the sediment and is found high near the locations where it is applied as an algal spot treatment which seems to occur mostly in the north end of the pond and to some extent in the south of the pond- both locations which have easy pedestrian accesses.

Pb was only a higher than SCTLs at the north and southeast portions of the pond. Pb is a good tracer of streets runoffs which surely reach the pond in the north end of the pond but not really at station 23 in the southeast end. This station is actually very peculiar scoring high for most of all the sediment characteristics and in particular Se, Ni, Hg, Cr and TP, all of which can be found in cement materials. It is possible that this hot spot is linked to the activities led at the nearby construction site.

Closing thoughts

Spring Lake has an adequate shape to limit pollutant entry into the pond. However, this is negated by the fact that this pond is i) bordered by very steep banks on its north and west sides, ii) that the shelves were originally narrow and did not allow much room for riparian rooted plants to establish, iii) that most riparian plants are leaf litter producing trees and iv) that it is heavily surrounded by impervious surfaces and residential houses with lush lawns. All of the aforementioned likely pushed the pond to reach its current state: a low-end hypereutrophic pond with some obvious sediment filling of bank erosion origin and organic/nutrient rich sediment which accumulated in the pond's deepest depressions.

Algal developments are a natural consequence of the process of eutrophication and their development actually helped reduce the nutrient export during the annual pond's flushing effect. Unfortunately, for obvious and understandable reasons, algae were controlled with algaecides and these treatments exacerbated the lake's health condition by pushing it even further and faster through its process of eutrophication.

Last resort and costly solutions involving aerators and floating islands were implemented but the pond still is full of organic/nutrient rich sediment. The process of eutrophication, especially when pushed to the extreme, is difficult to reverse because physical and ecological mechanisms maintain it in its current state (e.g. Scheffer, 2001). Generally, the amount of efforts to restore the pond to an acceptable state is more costly energetically (and this equates also to money) compared to the energy (in terms of nutrients and algaecides) used to "eutrophy" it (Hysteresis, Scheffer 2001).

Dredging the pond would be one of the most drastic, yet efficient, solution to remove the floc and the organic sediment. However, dredging is a costly process which, will have to be done from a barge because of the shape of the pond, the steepness of the banks and the residential houses surrounding it. An additional consideration is that the sediment does not meet the SCTLs for at least two major metals and this will figure in the cost of dredging since disposing off the material will be difficult. An alternative to hauling off the sediment from the site would be to use geotubes left in place around the pond and on top of the pond on which plants could be planted. However, such practices sometimes raise problems since plants may not establish on these tubes (Ernesto Lasso de la Vega, Pers. Com.). Further some tubes can burst during their filling or after they are left onsite.

Due to the complexities of dredging, other remediation techniques should be considered. More aerators should be placed in the deepest locations of the pond (the available bathymetry should help in that process). These aerators should be frequently maintained and selected for their ability to create nanosize bubbles which should rise slowly in the water column and have a high surface to volume ratio for a better oxygen exchange rate with the pond water. Aerators should not be needed in the shallow pond locations since the water is shallow enough and clear enough to mix naturally.

Other techniques complementary to the above involve the use of bacteria to digest the organic portion of the sediment and floc which are available commercially. Our group recognizes that there is still a need for more research done on this particular topic as bacteria require the right micro environmental condition to thrive and not be consumed rapidly by protozoa. Our group believes that promoting the right conditions to foster the growth of beneficial bacteria through the use of the aforementioned aerators is essential.

Finally, “shock treatments” like the ones utilized in wastewater treatment plants could be used. Devices that put the sediment and muck in suspension with some aeration should digest the organic matter efficiently. Such a technique may be implemented in the near future by our group in conjunction with FDEP.

In conjunction with some of the above measures, steps to control the runoff and leaf litter accumulation in the pond should be undertaken. During our investigation, garbage bins were washed at the wooden deck located north of the pond and drained into it. Such a practice should be prevented. Rain gardens should be planted to pre-treat the water runoff before it enters the pond and riparian should be densely established on the shelf wherever possible.

Finally, the use of algaecides and other pesticides should be applied parsimoniously and eventually eliminated from the arsenal to control algae. Raking filamentous is actually a good way to remove nutrients from a pond although, admittedly, this can be a time consuming task to complete.

Lastly, our group would like to emphasize that breaking down organic matter releases nutrients and most of these nutrients (unless they are harvested with algae or plants or vent in the atmosphere subsequent to denitrification) will be back in the water column. If timed right, these nutrients will be flushed down the system during the rainy season; yet, obviously the flushing of the pond will not lead to a positive outcome for the downstream natural hydrosystems, in particular the bay. Our group believes that this dilemma might be acceptable in the event that ponds are managed in a sustainable way in the future.

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Figures

Fig. 1. Aerial photograph depicting Spring Lake (courtesy of Google Earth)

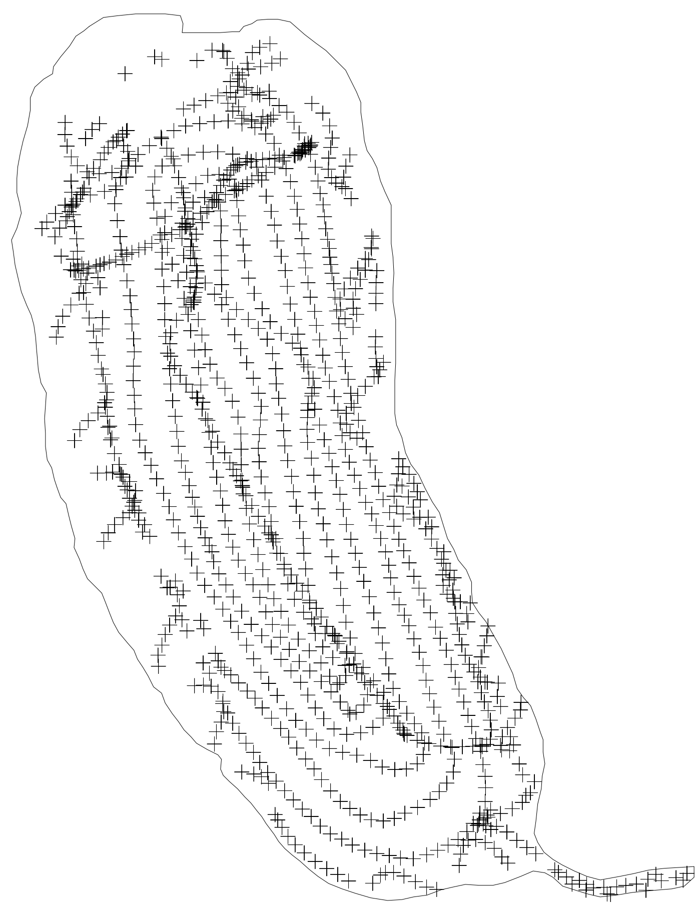

Fig.2. Sonar depth soundings (cross symbols) within the perimeter determined by walking the shoreline with a Garmin Etrex GPS.

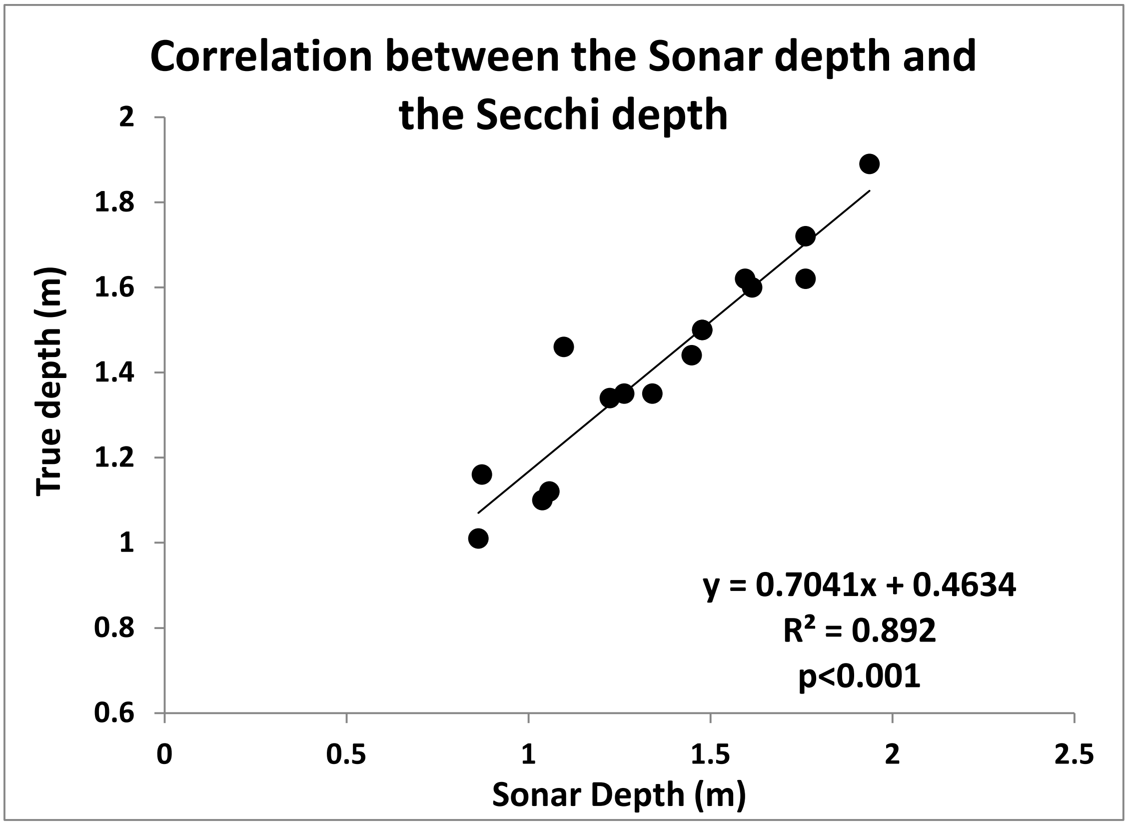

Fig.3. Determination of the correction factor to correct the true depth estimated by the SONAR.

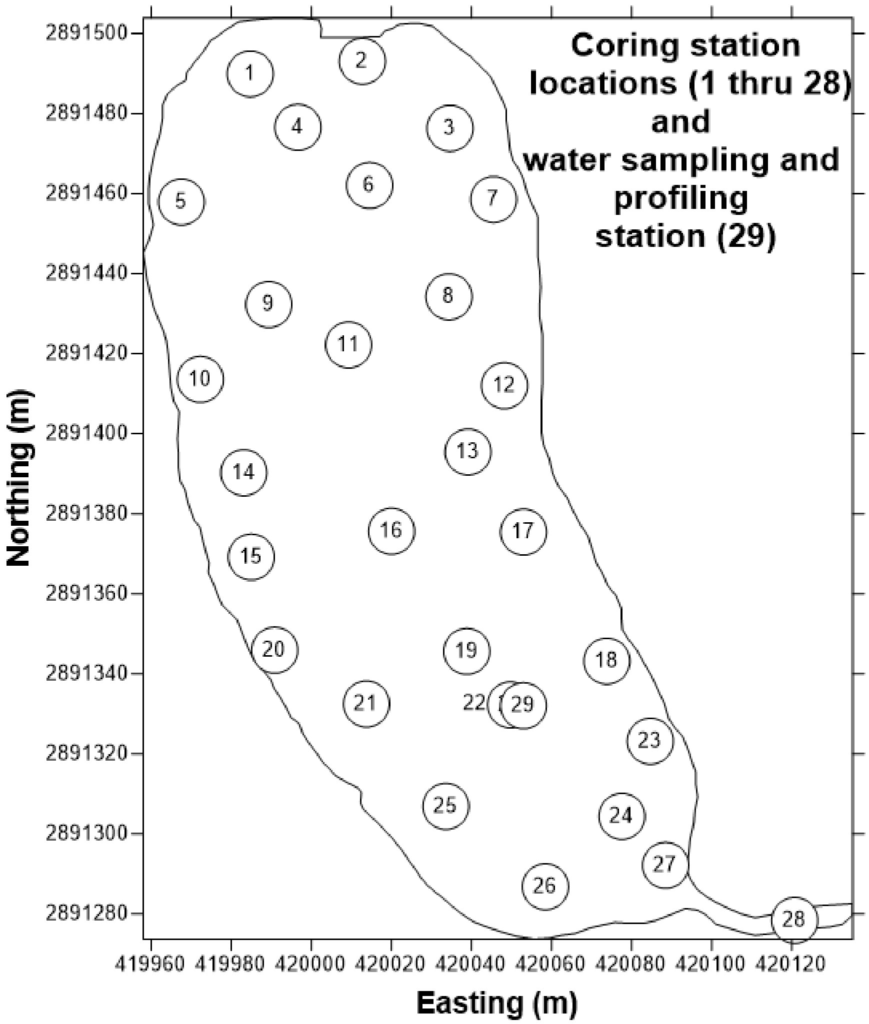

Fig.4. Sampling locations

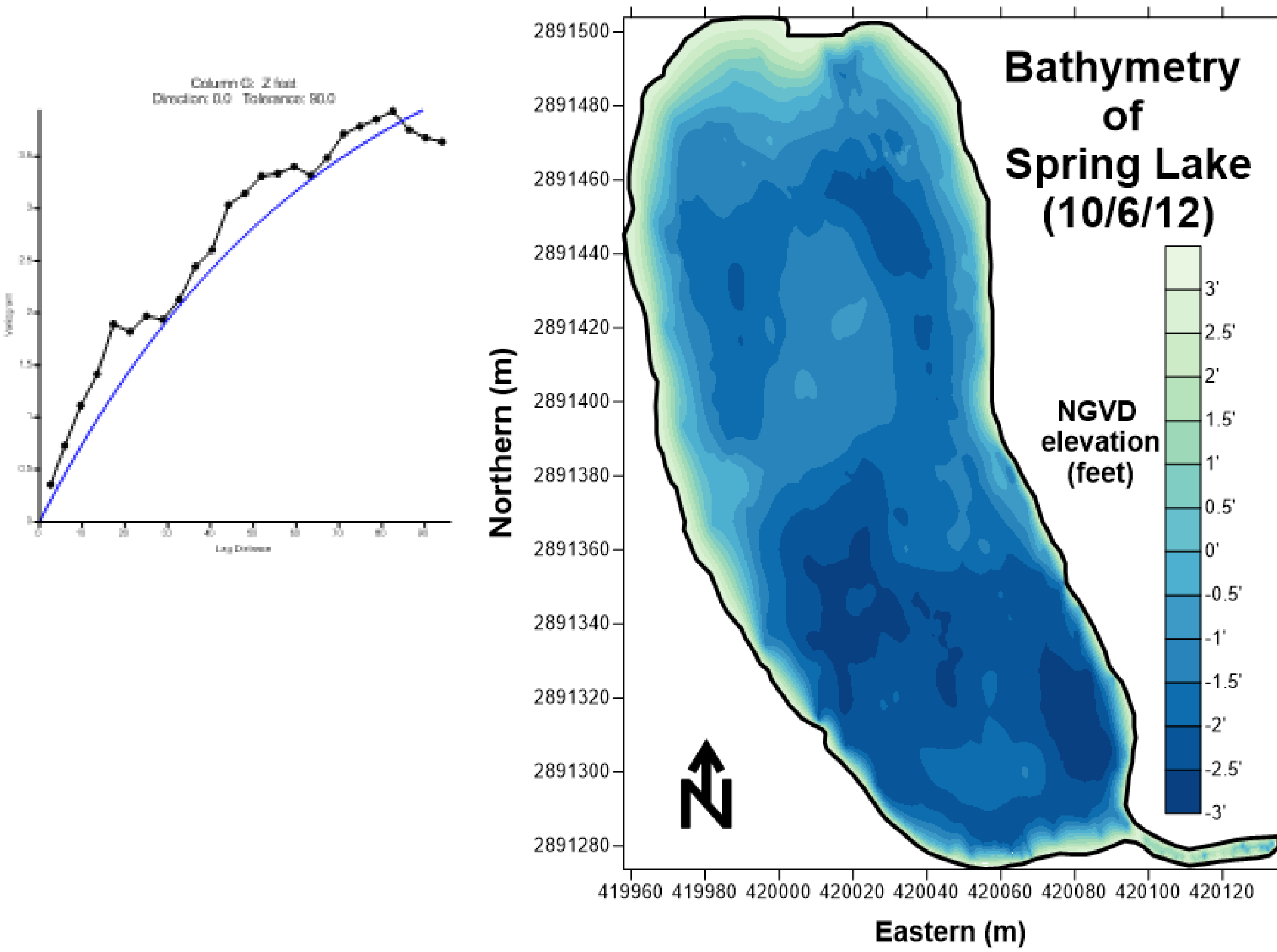

Fig.5. Bathymetry of Spring Lake (right) and of the variogram used to interpolate the data (exponential model without any nugget effect).

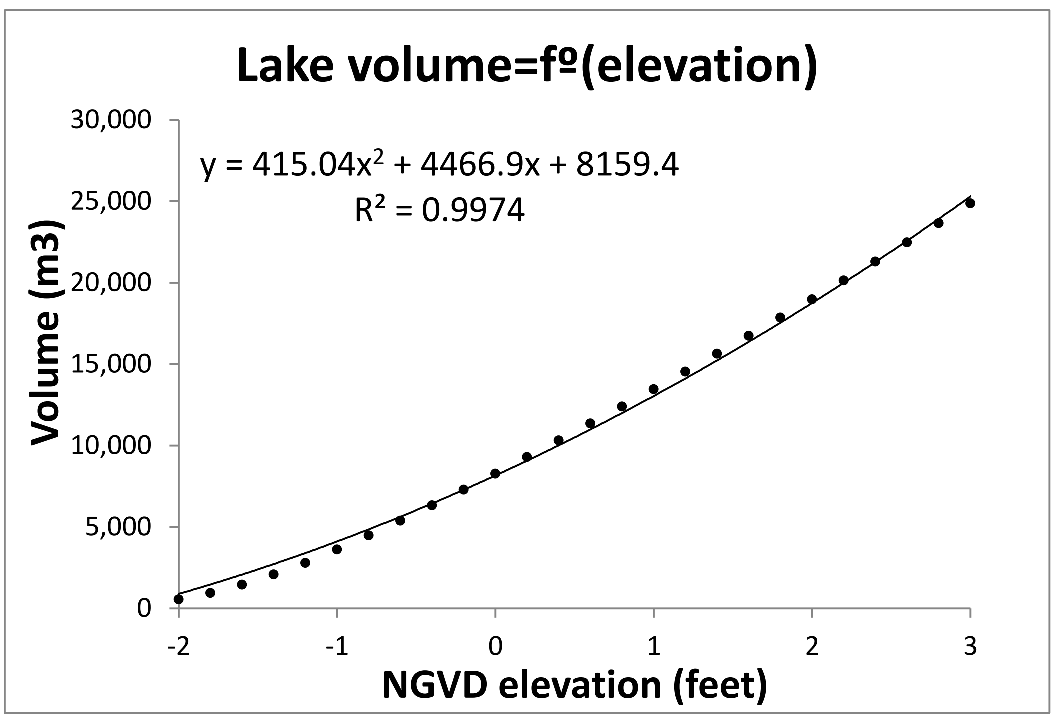

Fig.6. Volume=fº(elevation)

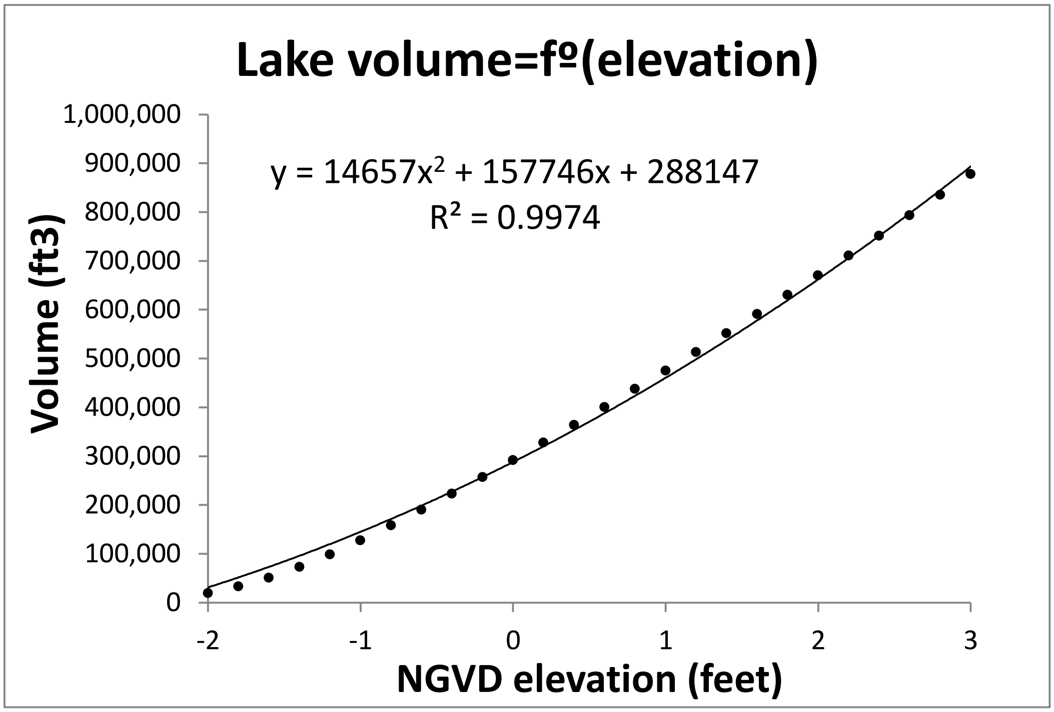

Fig.7. Volume=fº(elevation)

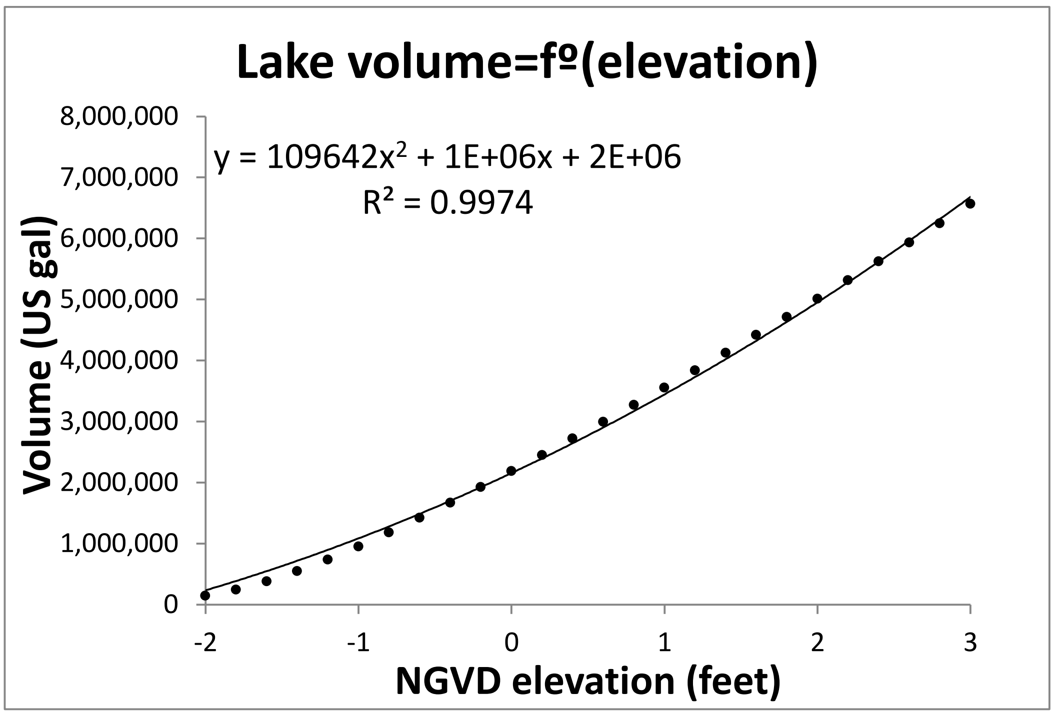

Fig.8. Volume=fº(elevation)

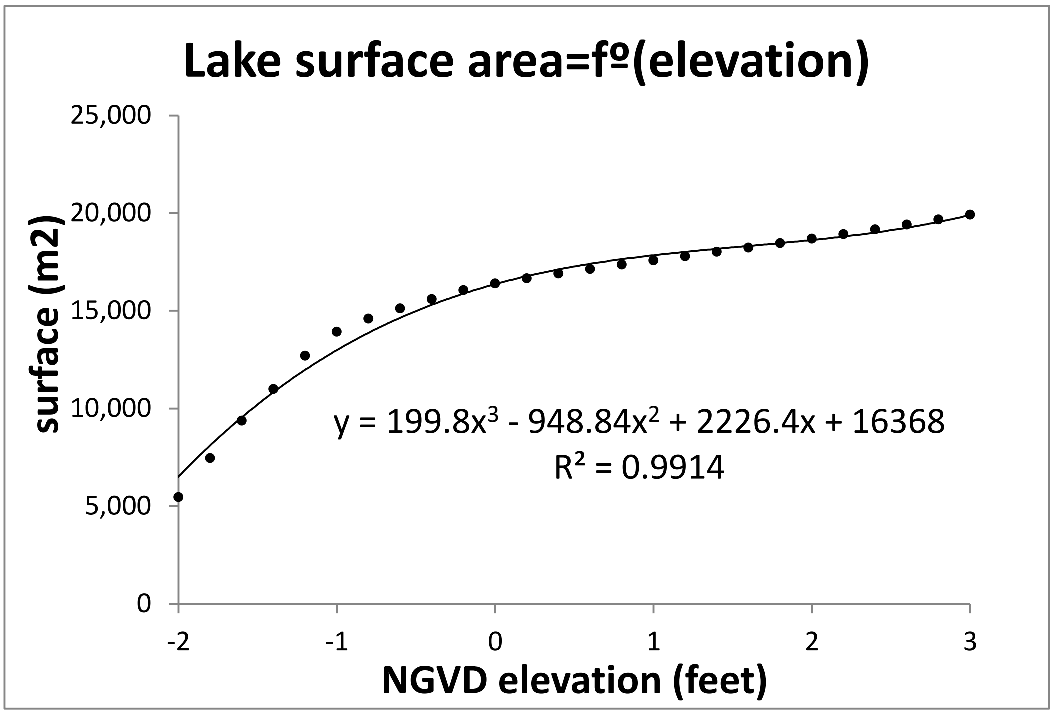

Fig.9. Lake surface=fº(elevation)

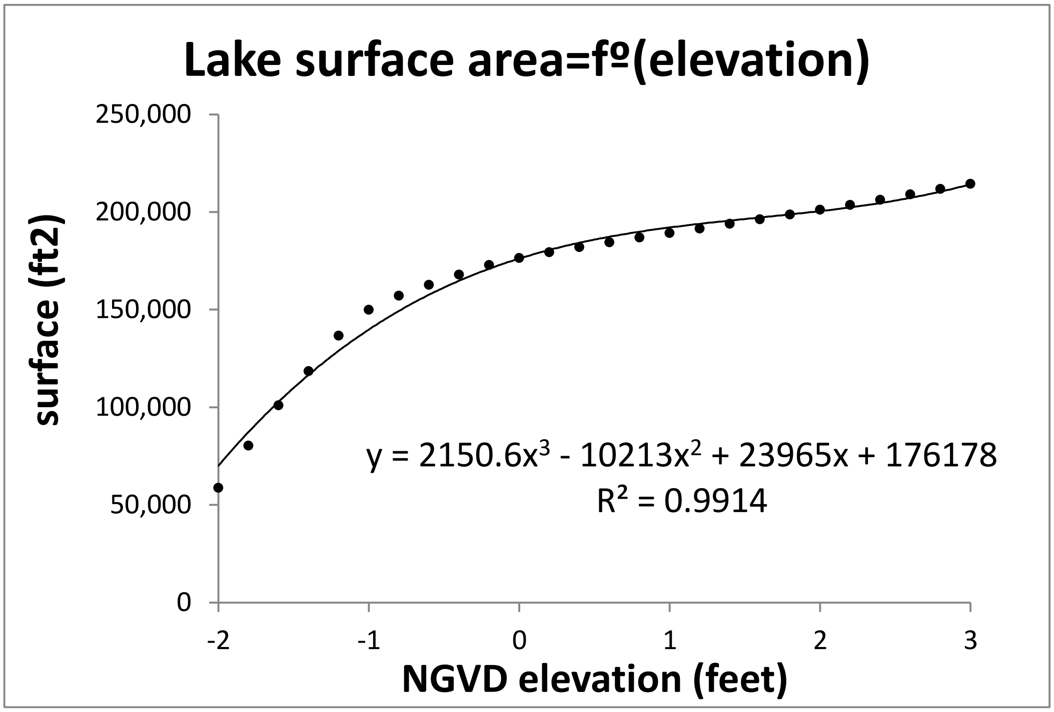

Fig.10. Lake surface=fº(elevation)

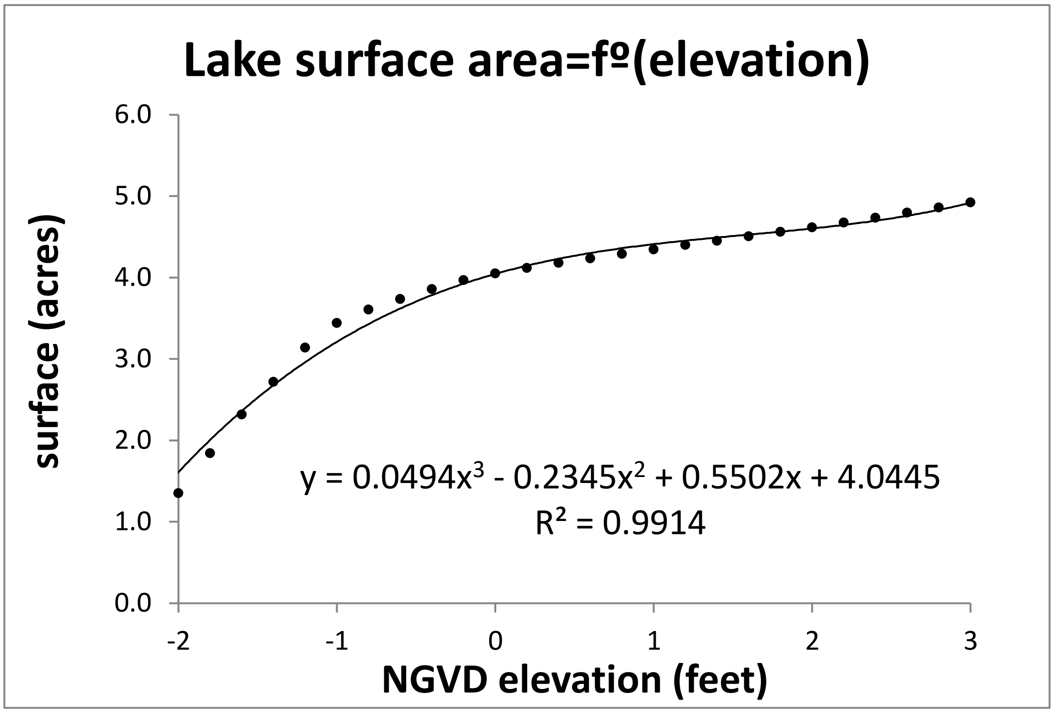

Fig.11. Lake surface=fº(elevation)

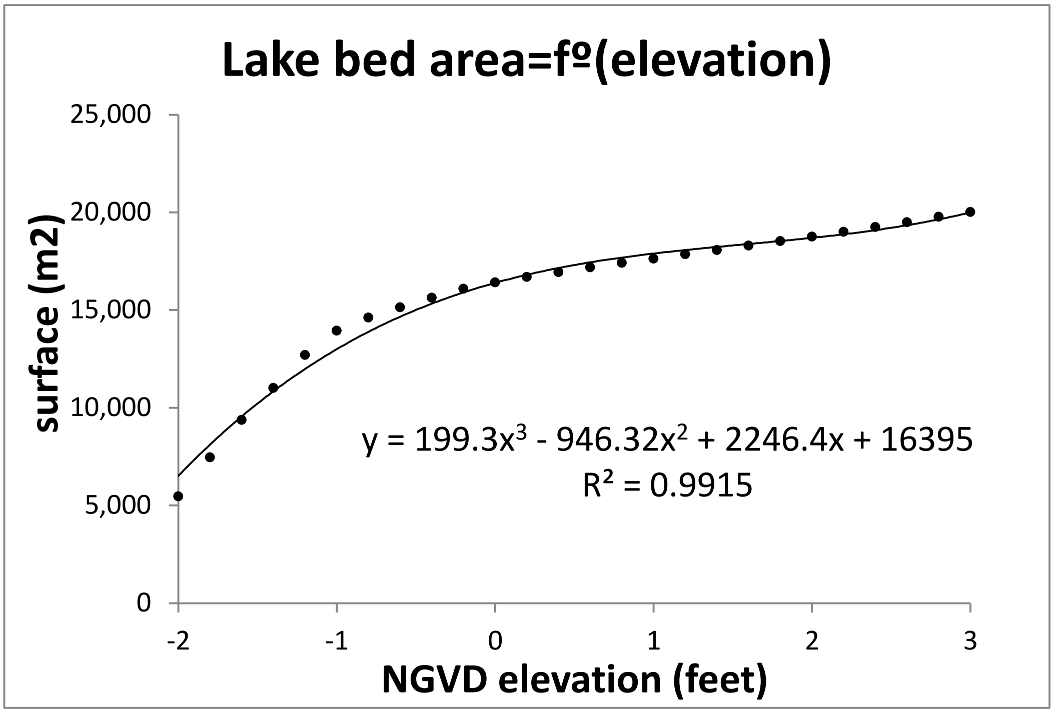

Fig.12. Lake bed=fº(elevation)

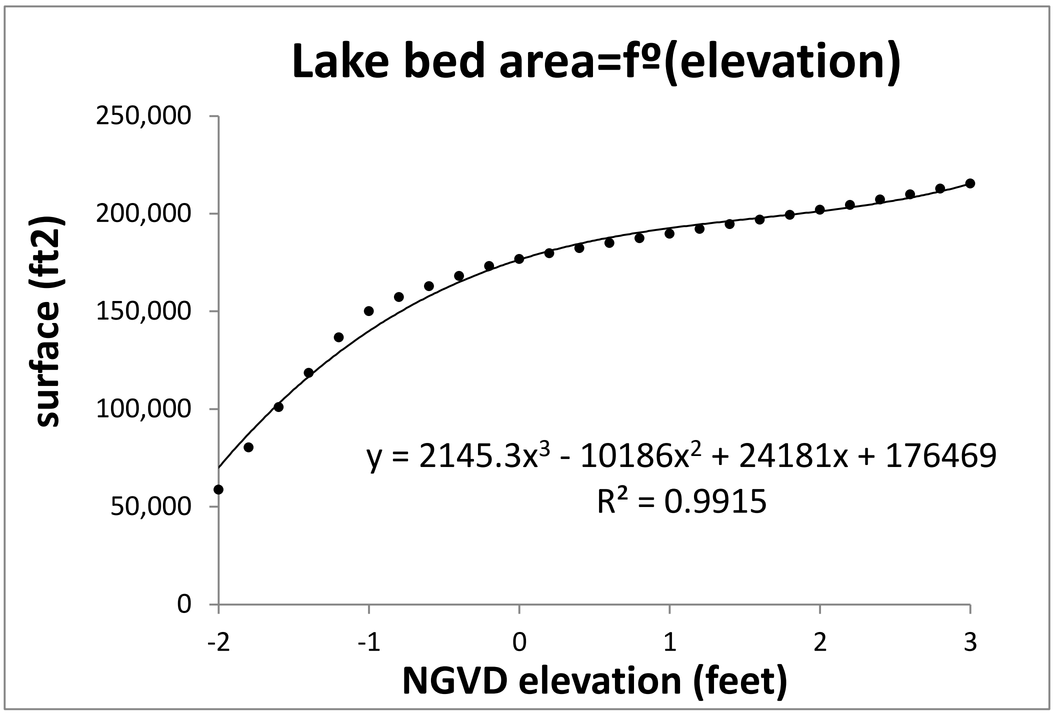

Fig.13. Lake bed=fº(elevation)

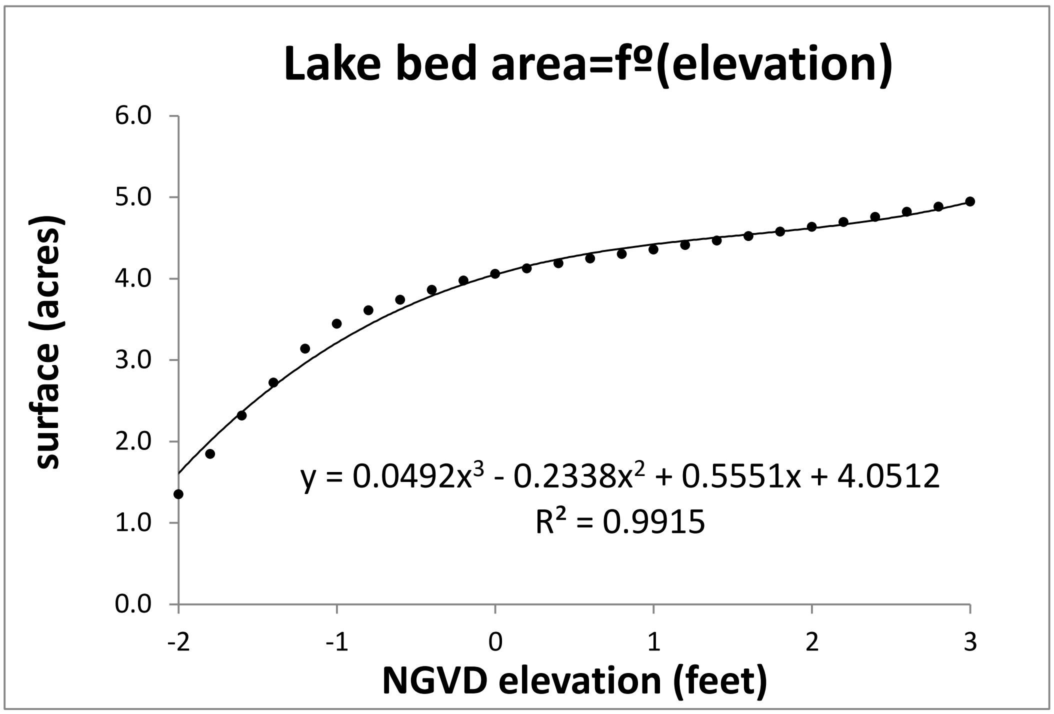

Fig.14. Lake bed=fº(elevation)

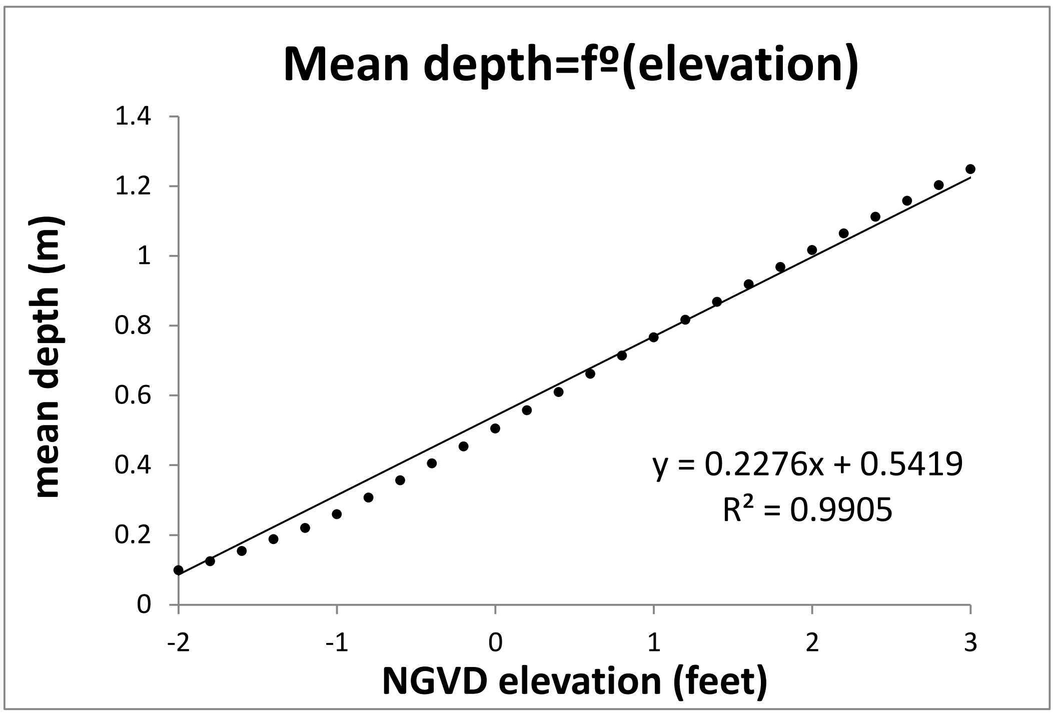

Fig.15. Mean depth=fº(elevation)

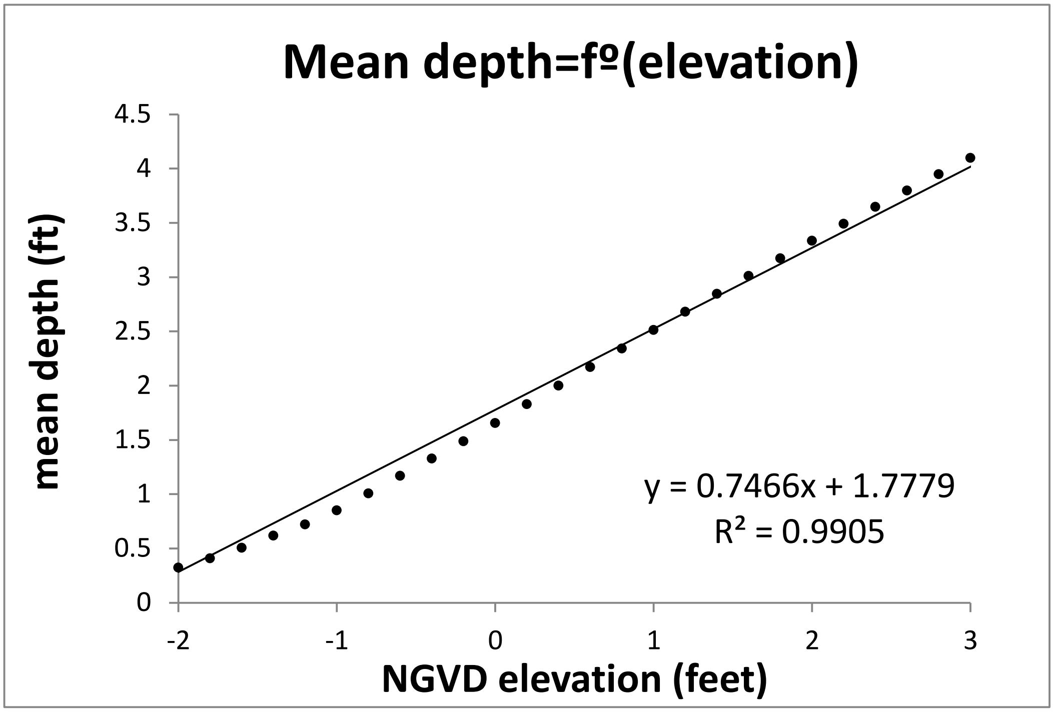

Fig.16. Mean depth=fº(elevation)

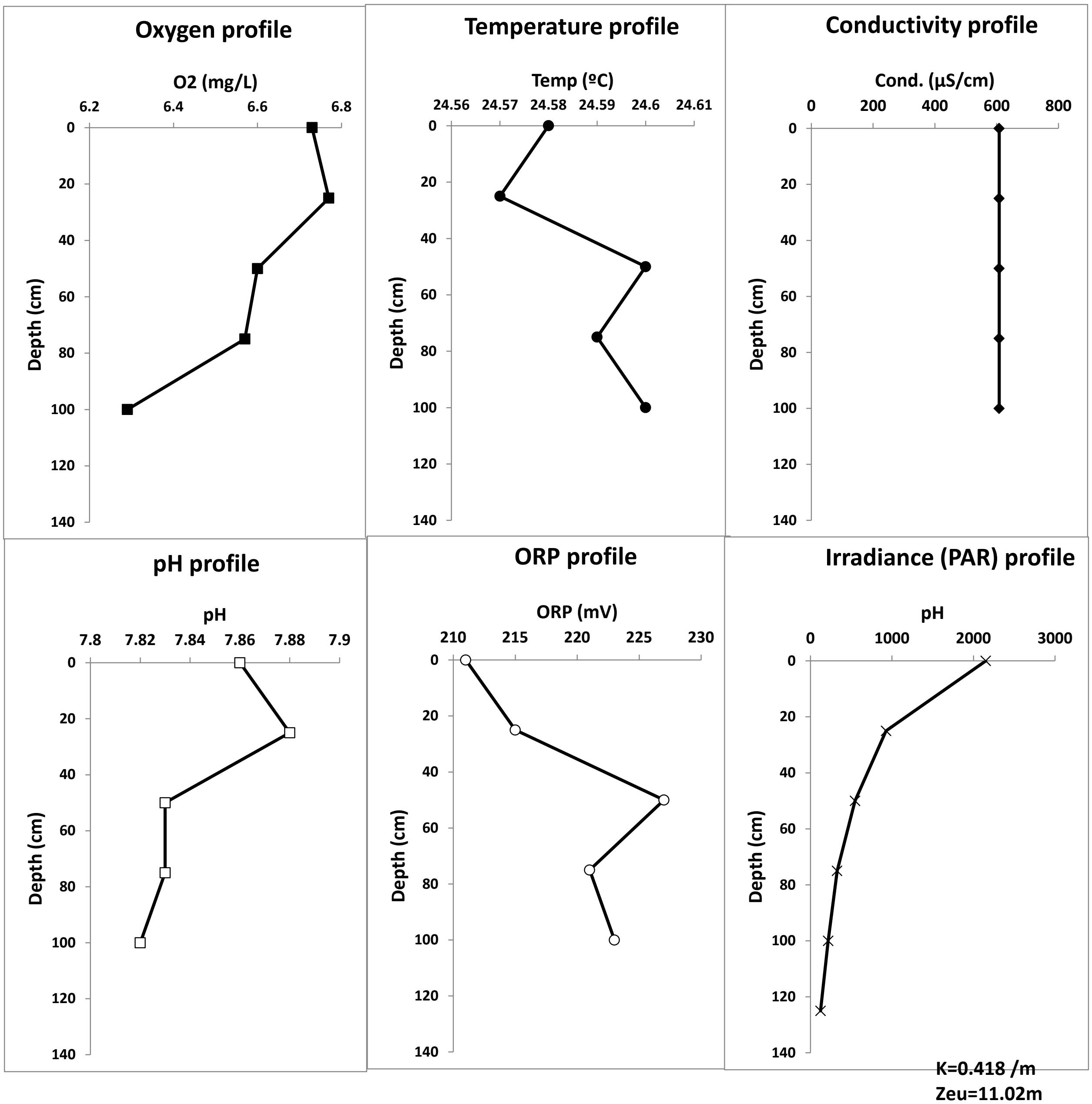

Fig.17 Profiles of dissolved oxygen, temperature, conductivity, pH, ORP and irradiance (light)

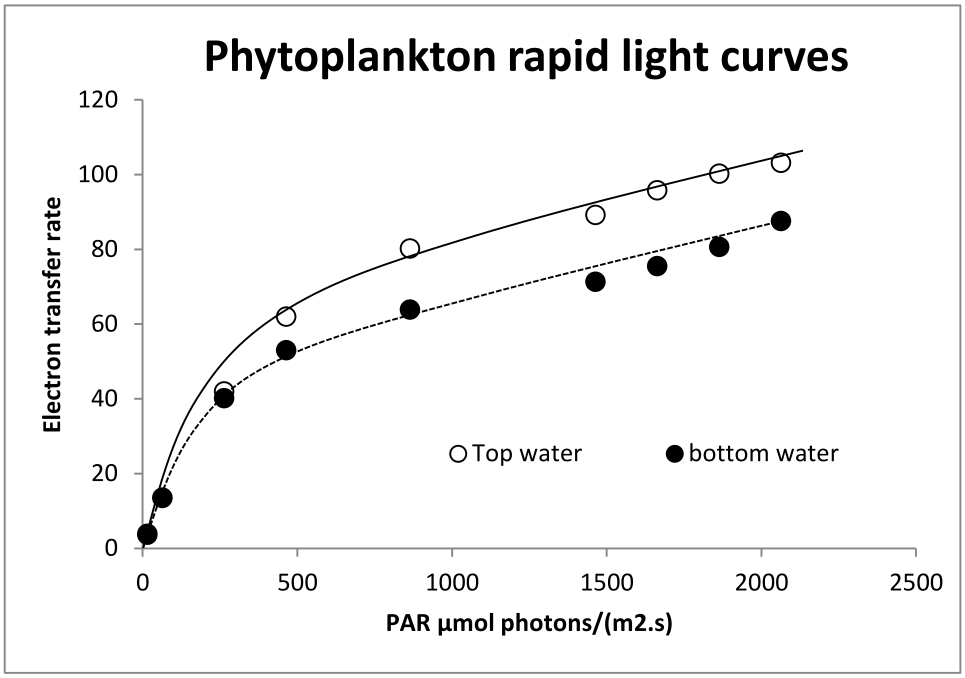

Fig.18. Phytoplankton rapid light curves.

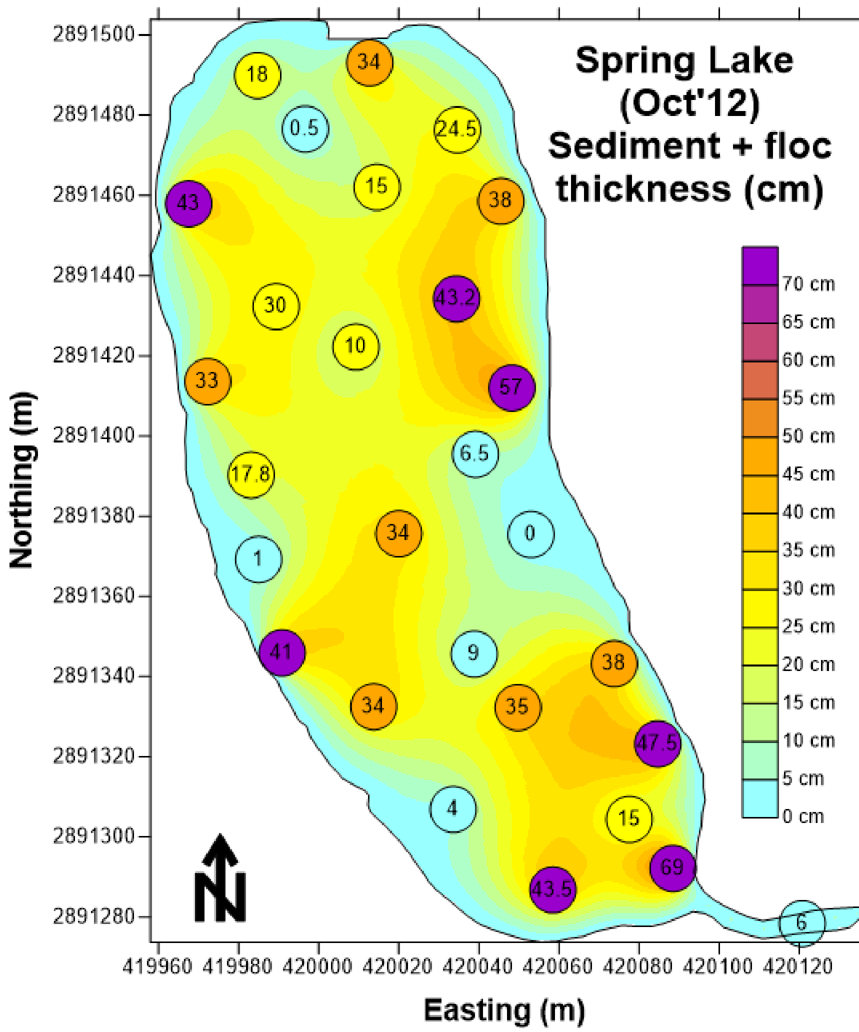

Fig.19. Spatial distribution of sediment + floc thickness

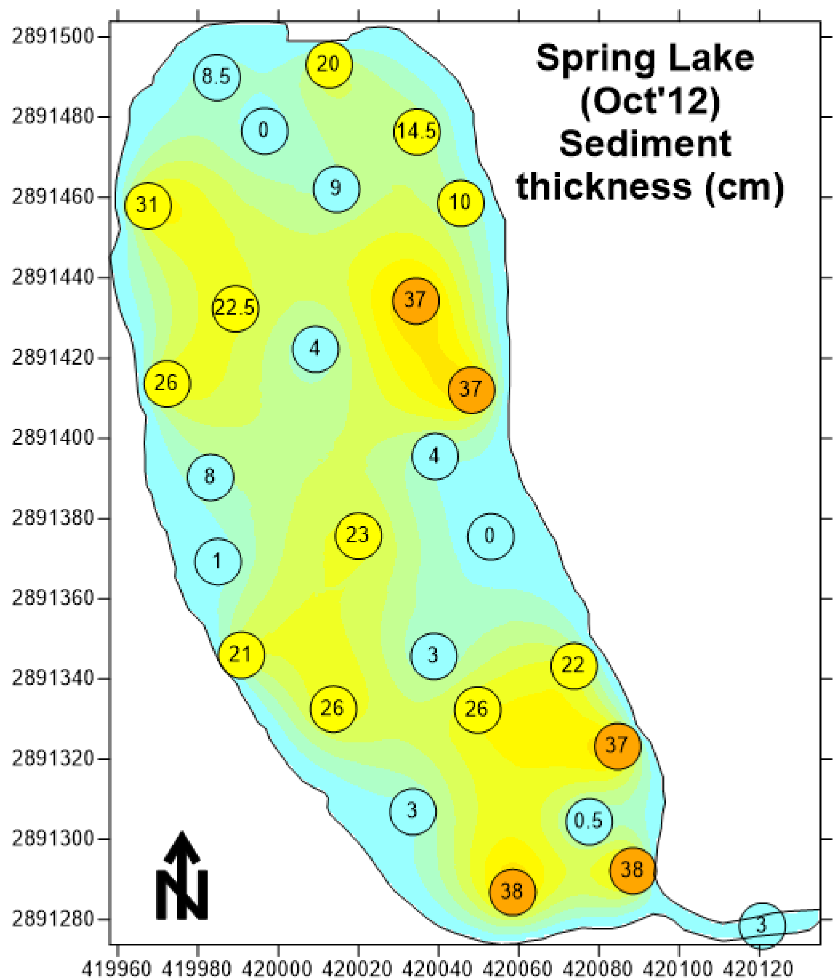

Fig.20. Spatial distribution of sediment thickness

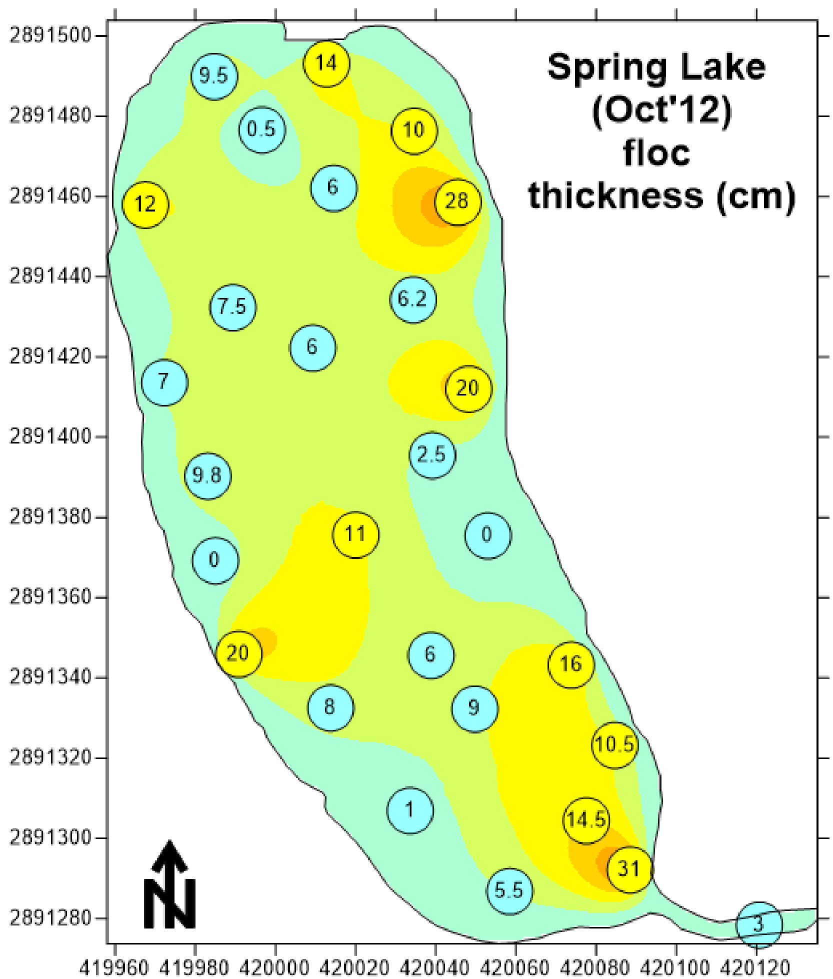

Fig.21. Spatial distribution of floc thickness

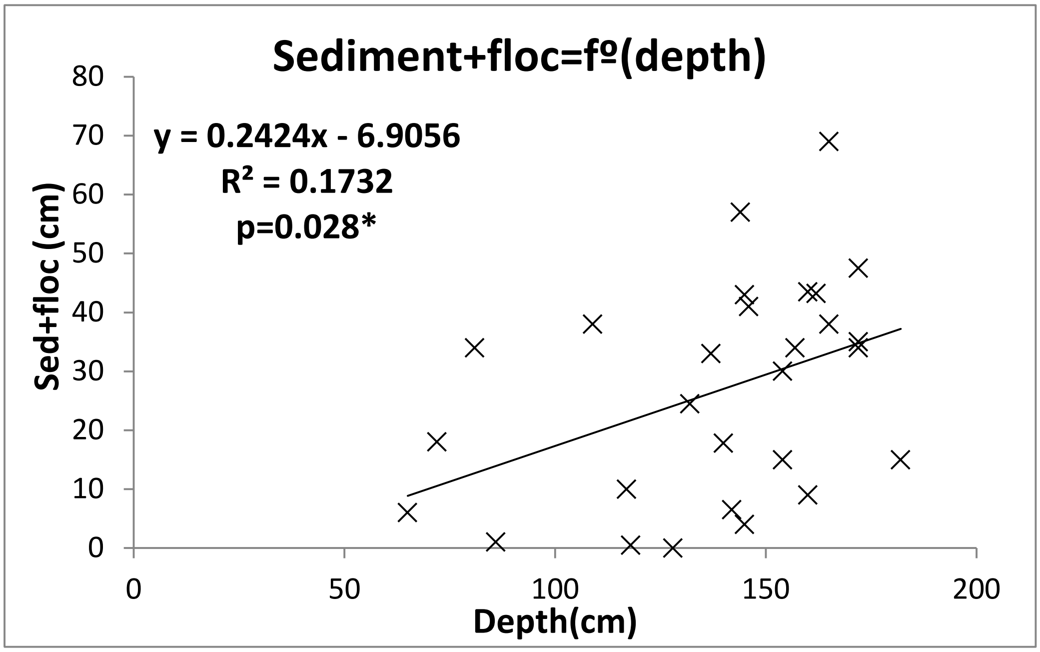

Fig.22. Linear regression between the sediment+floc thickness and the depth

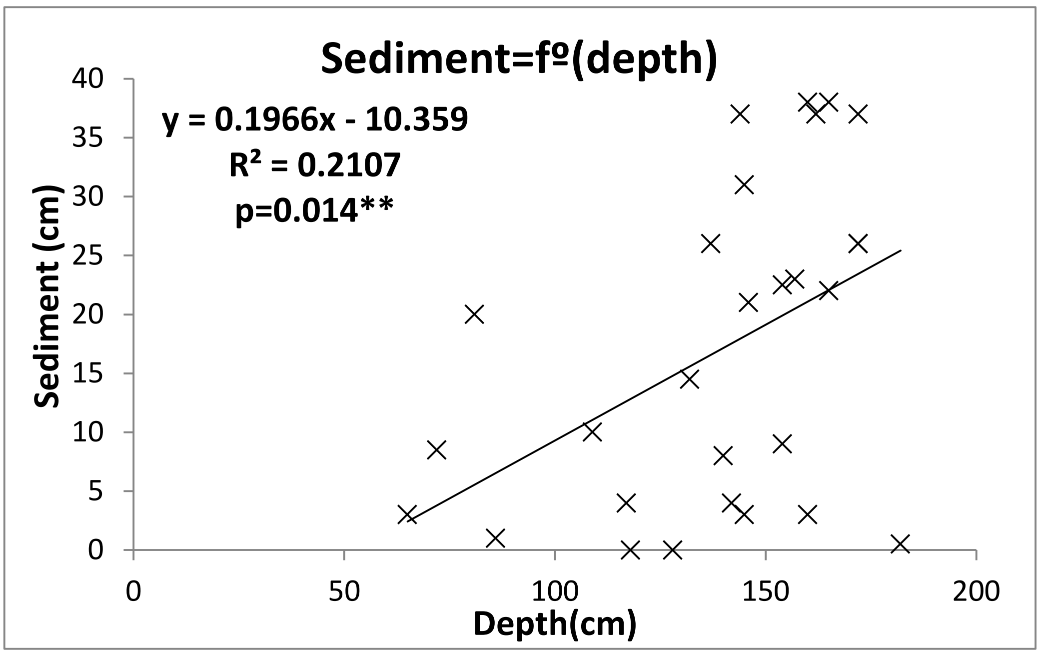

Fig.23. Linear regression between the sediment thickness and the depth

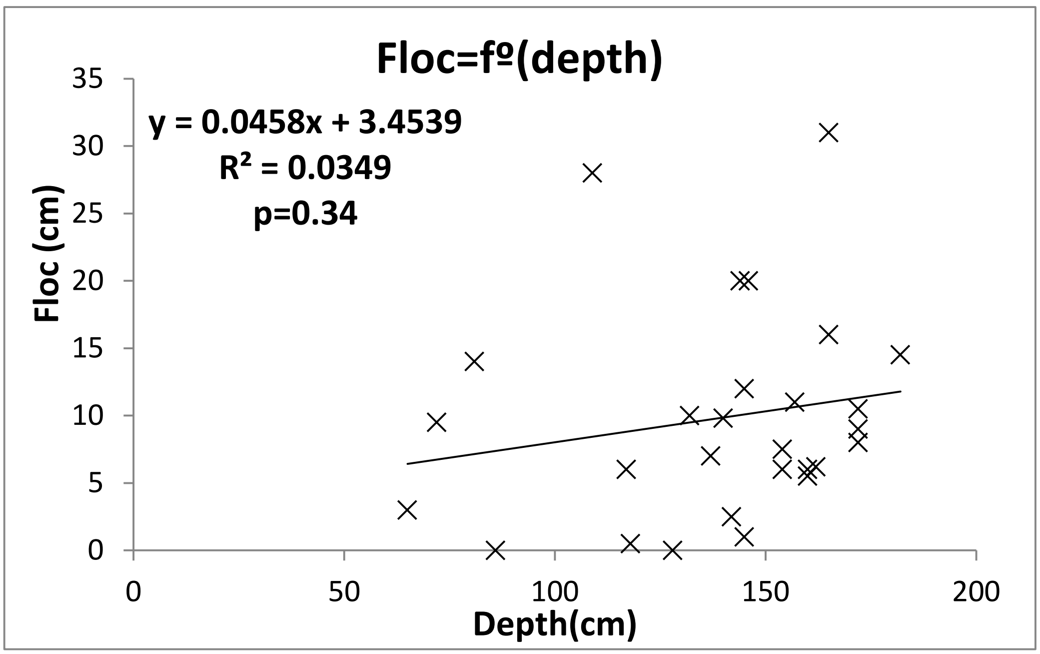

Fig.24. Linear regression between the floc thickness and the depth

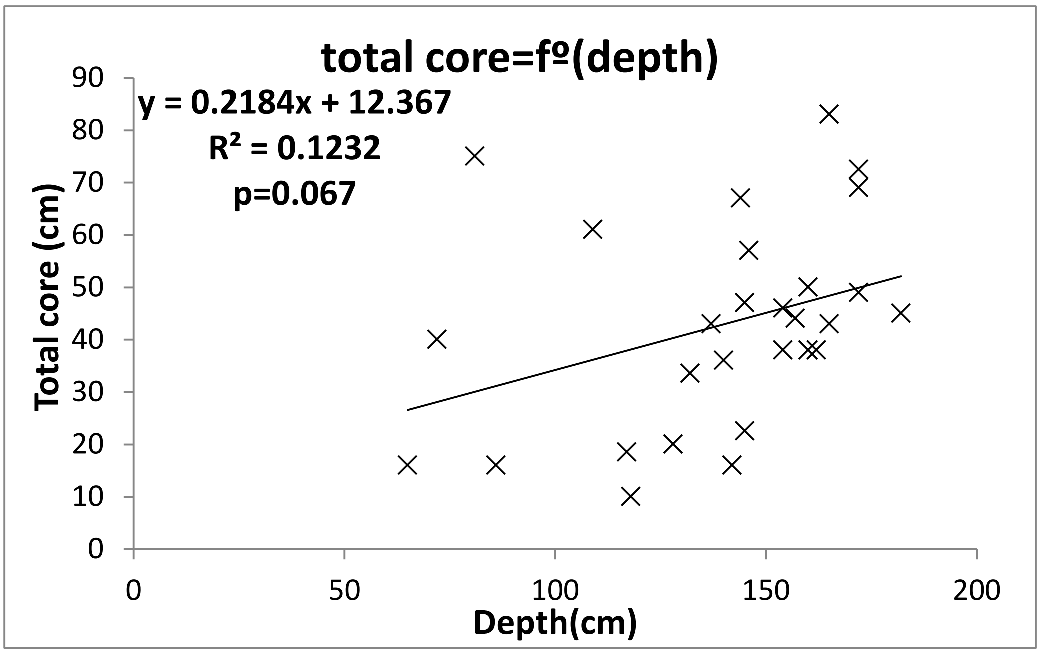

Fig.25. Linear regression between the total core length and the depth

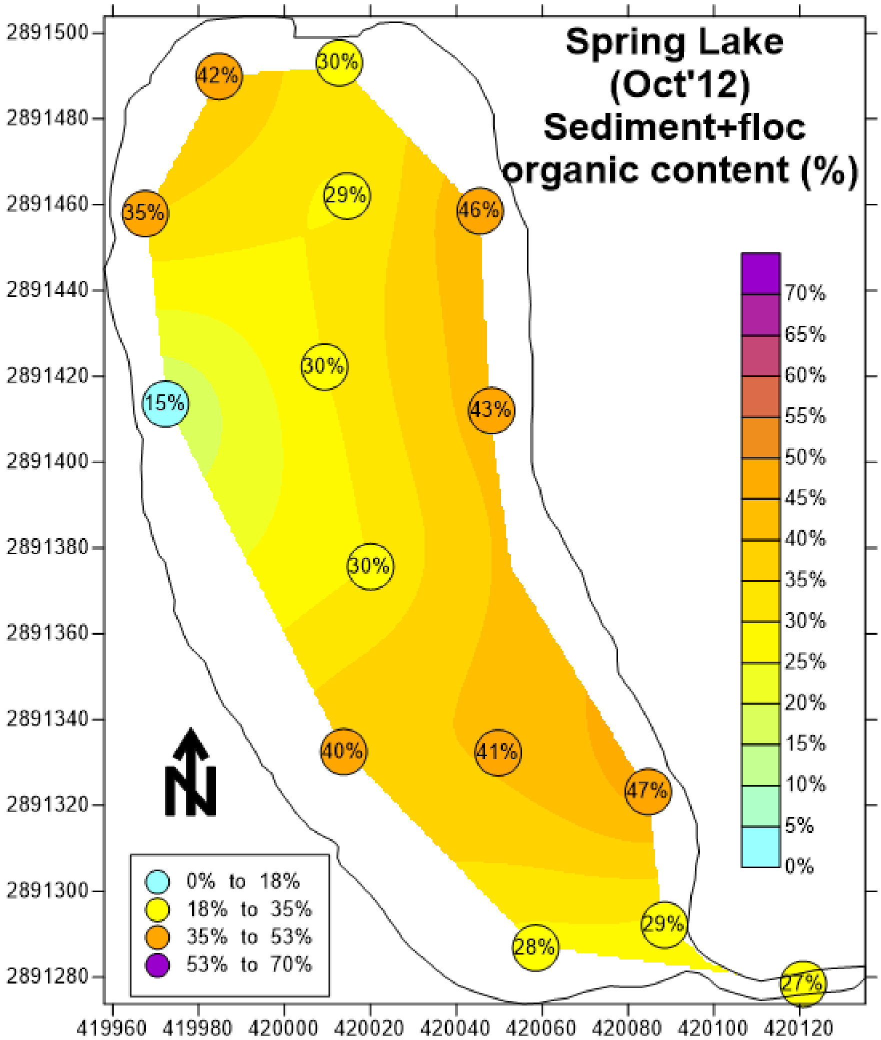

Fig.26. Spatial distribution of sediment + floc organic content

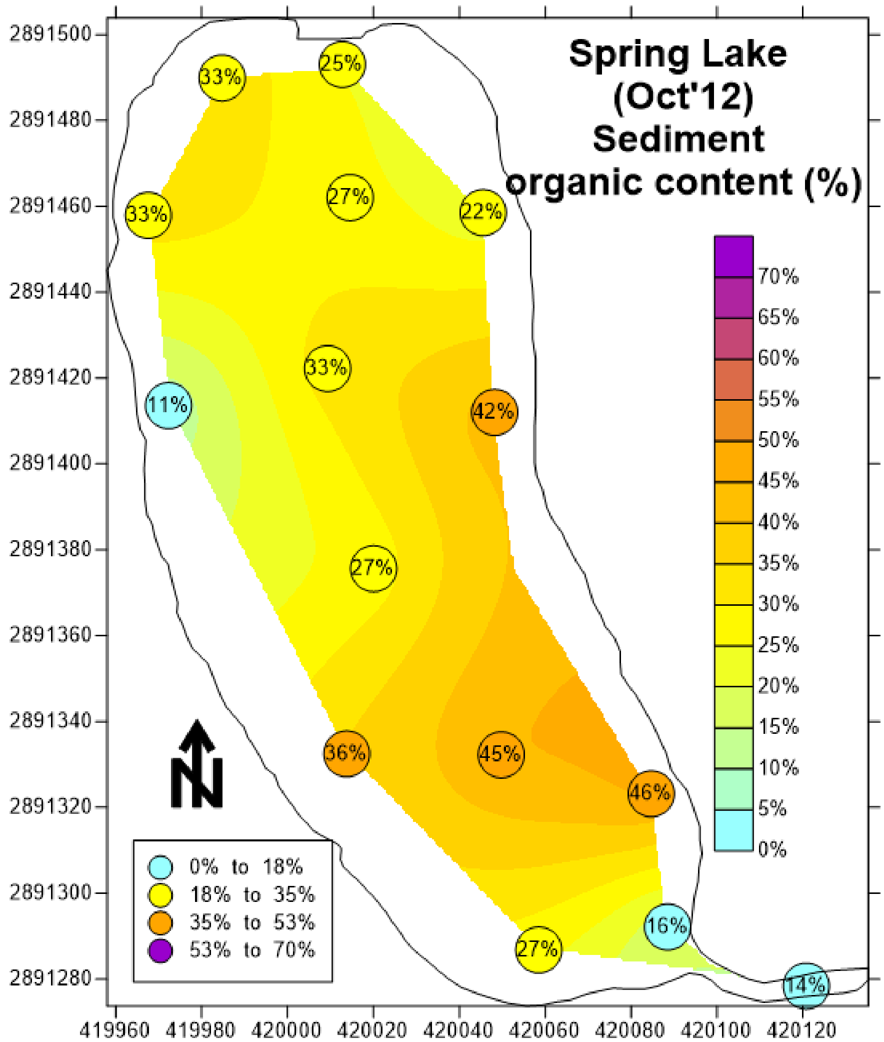

Fig.27. Spatial distribution of sediment organic content

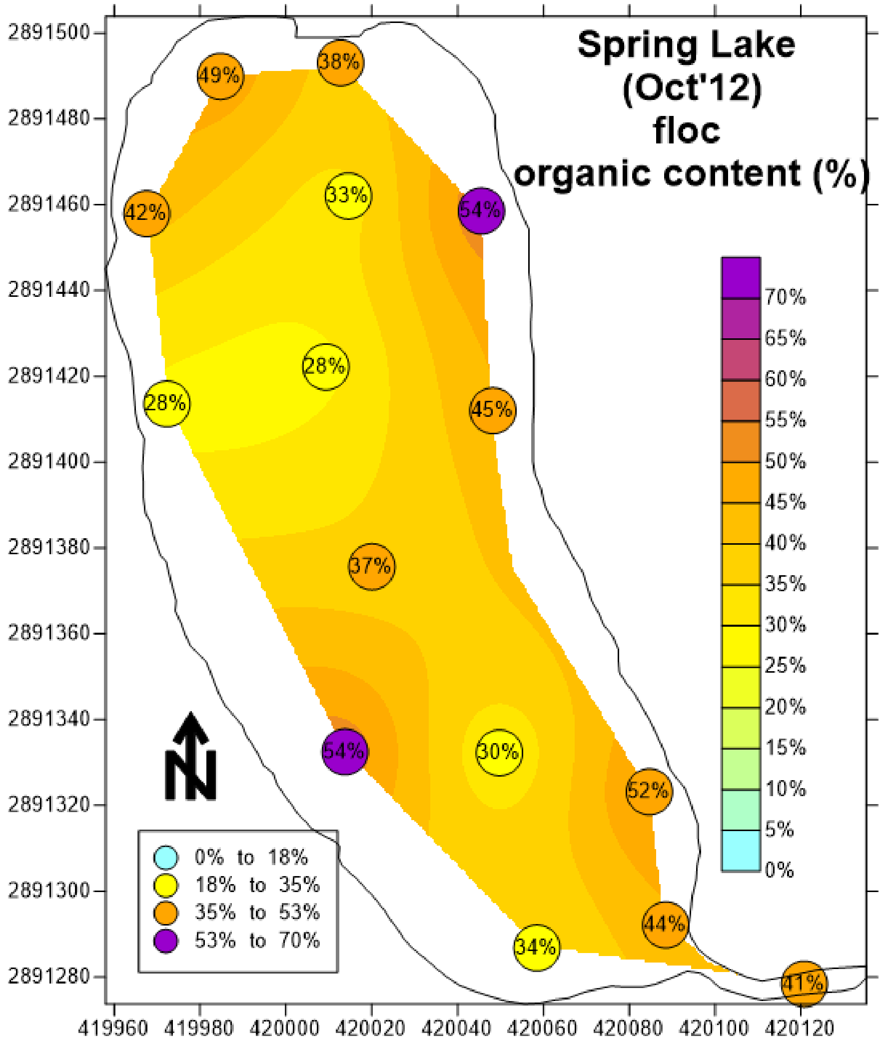

Fig.28. Spatial distribution of floc organic content

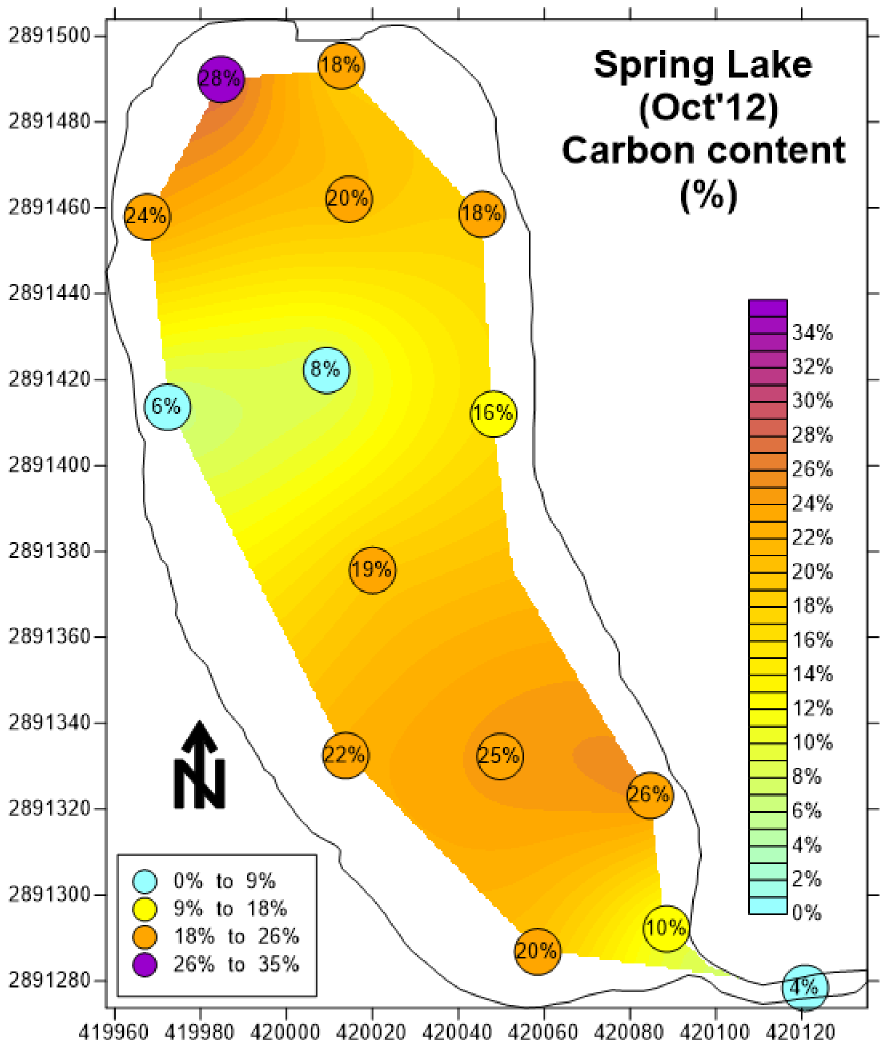

Fig.29. Spatial distribution of carbon content

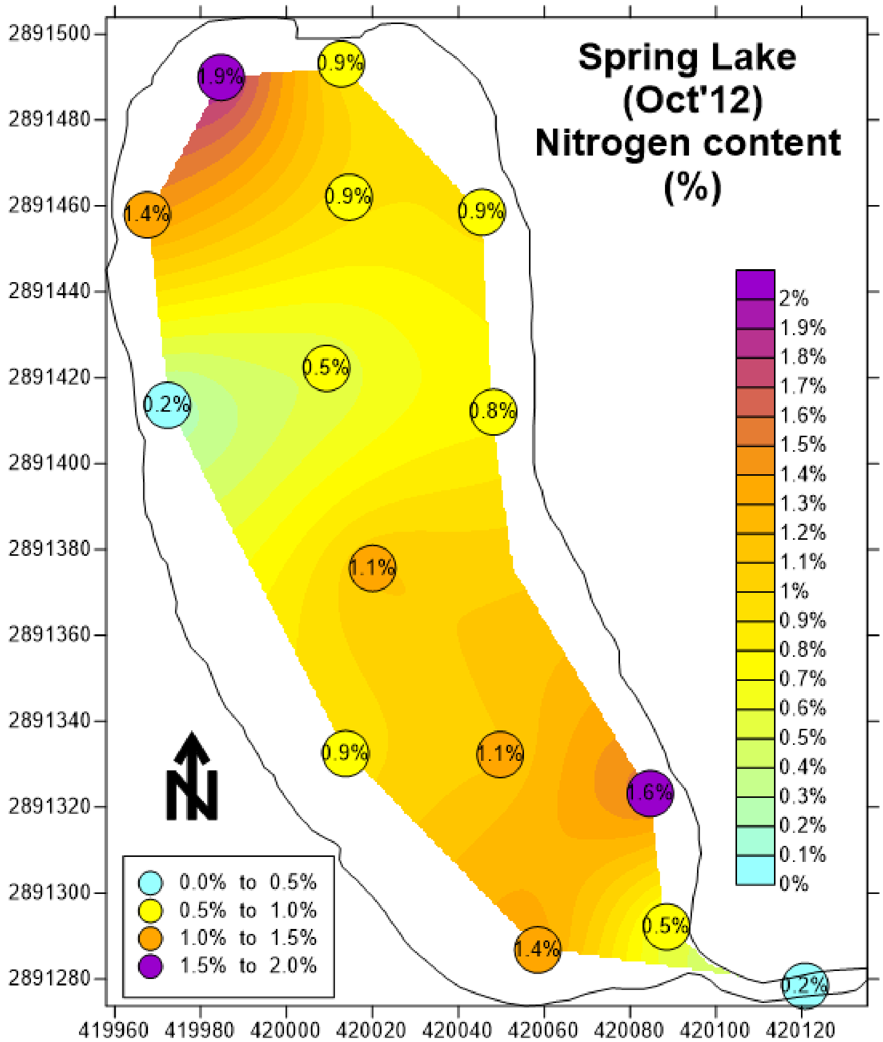

Fig.30. Spatial distribution of nitrogen content

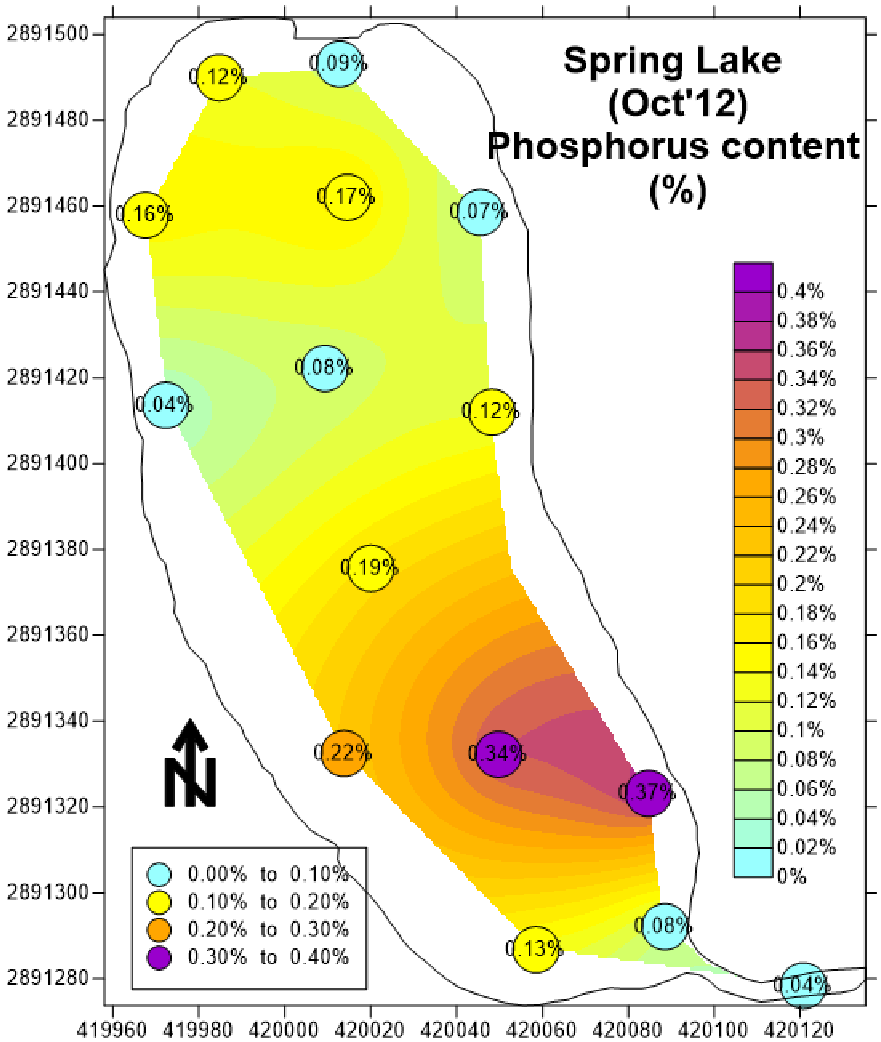

Fig.31. Spatial distribution of phosphorus content

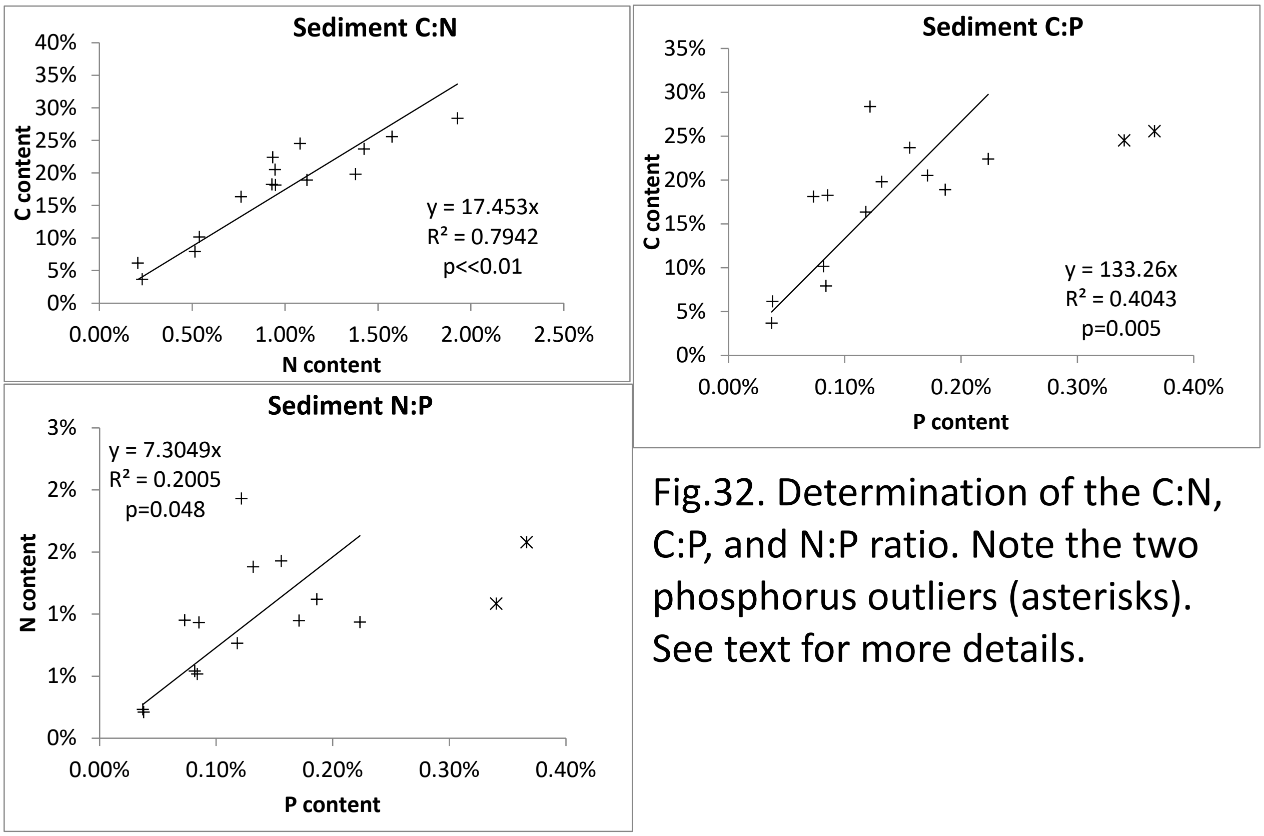

Fig.32. Determination of the C:N, C:P, and N:P ratio. Note the two phosphorus outliers (asterisks). See text for more details.

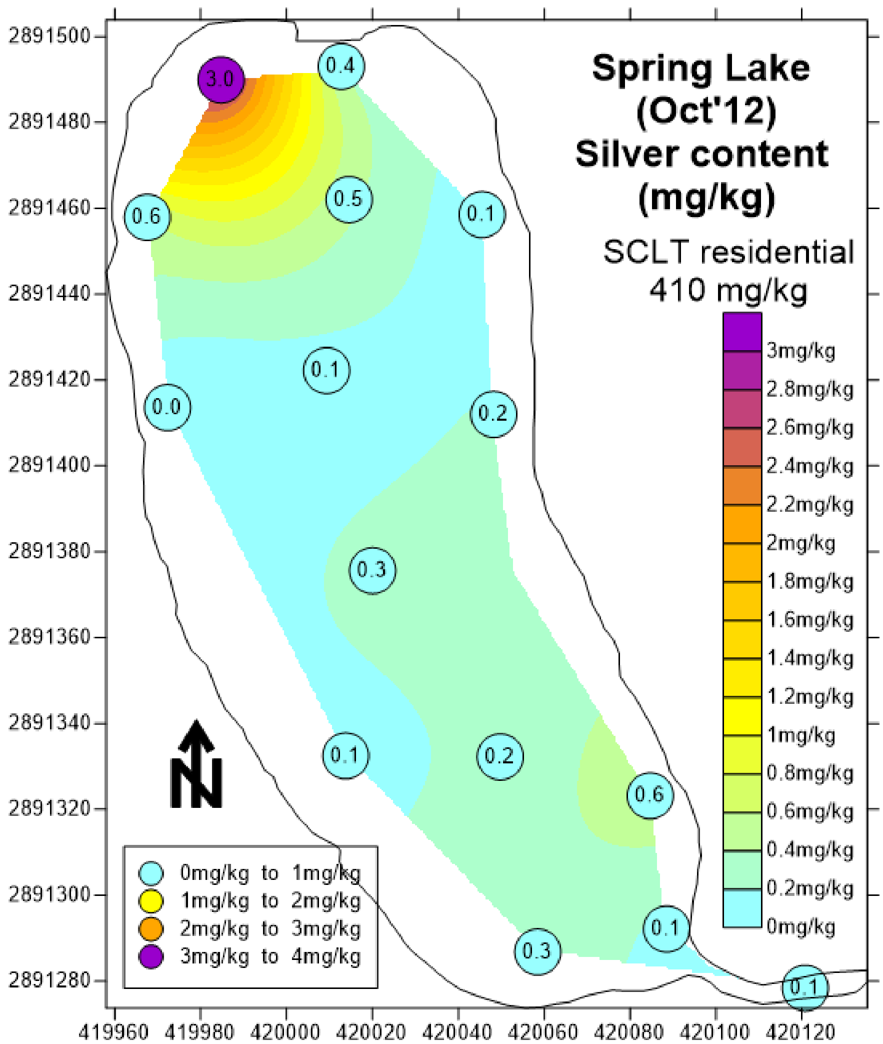

Fig.33. Spatial distribution of Silver content

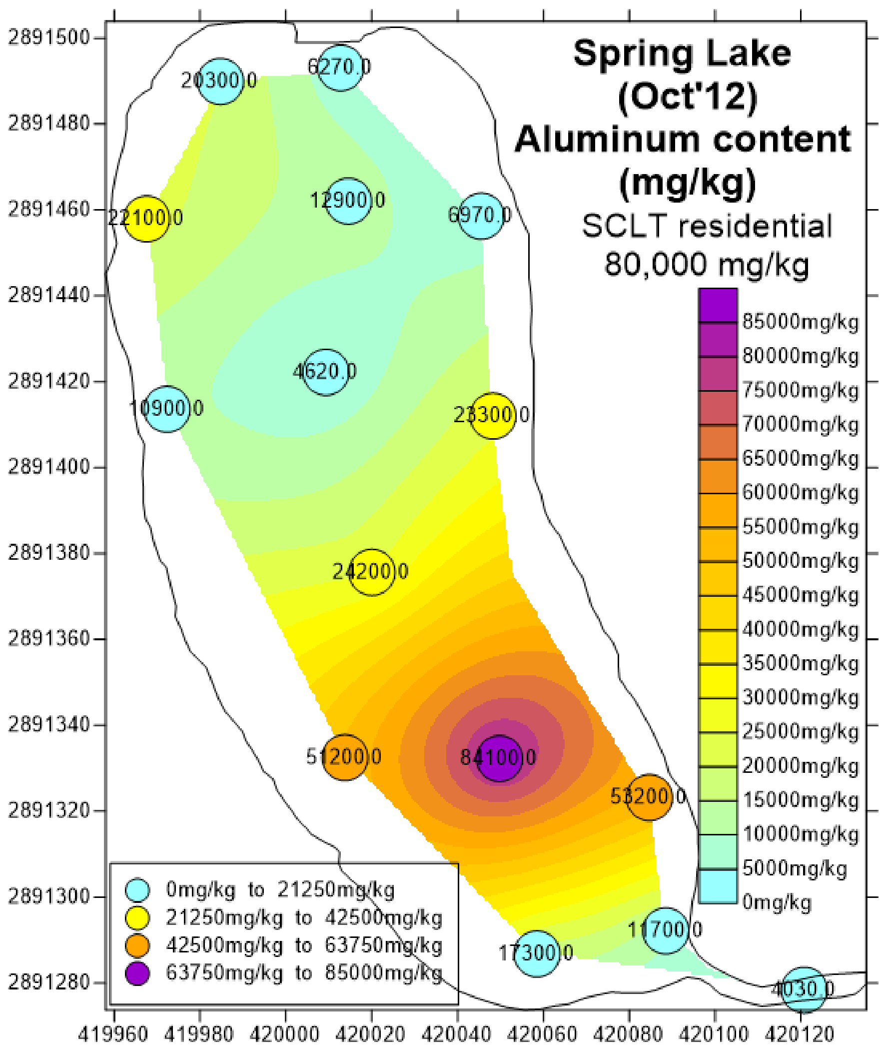

Fig.34. Spatial distribution of Aluminum content

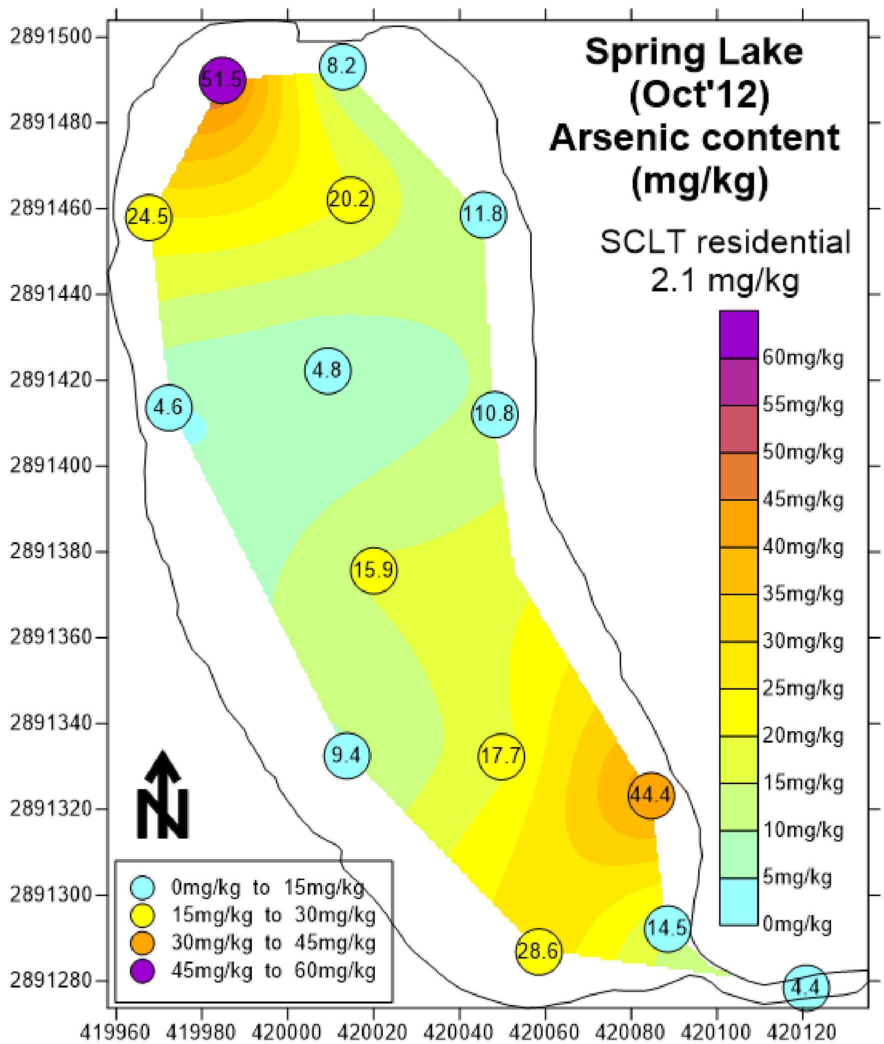

Fig.35. Spatial distribution of Arsenic content

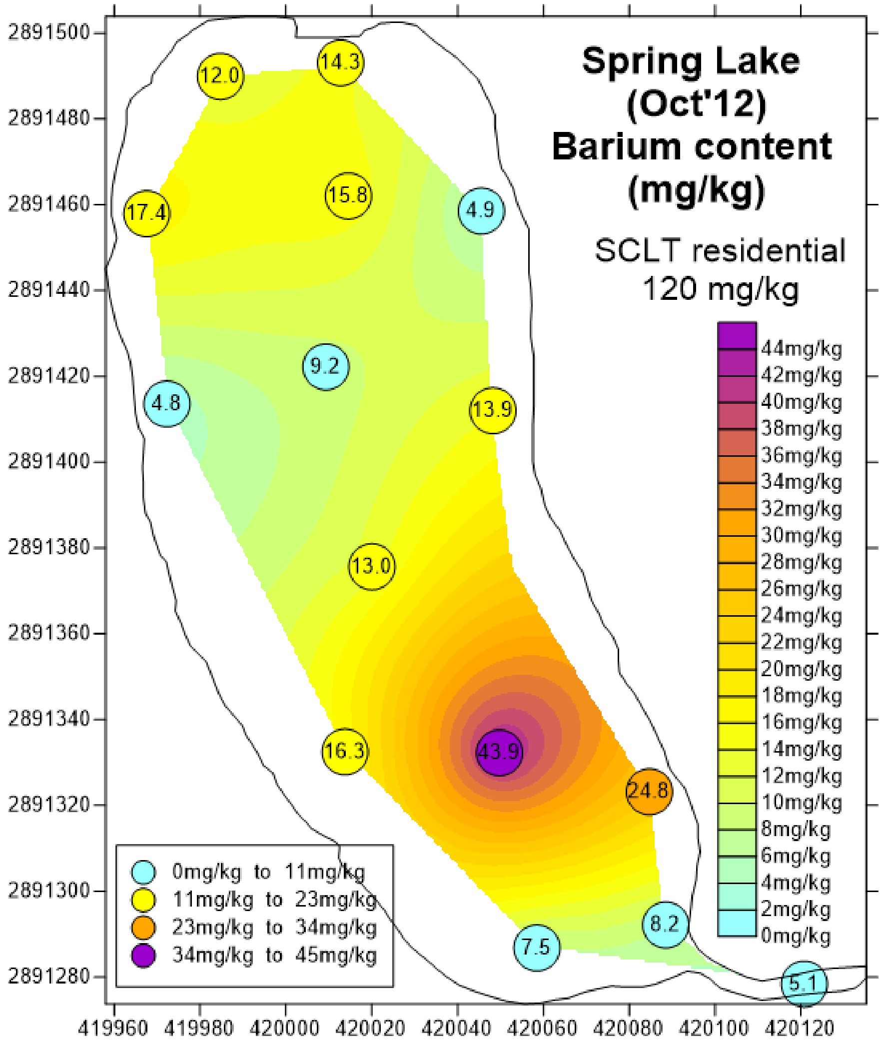

Fig.36. Spatial distribution of barium content

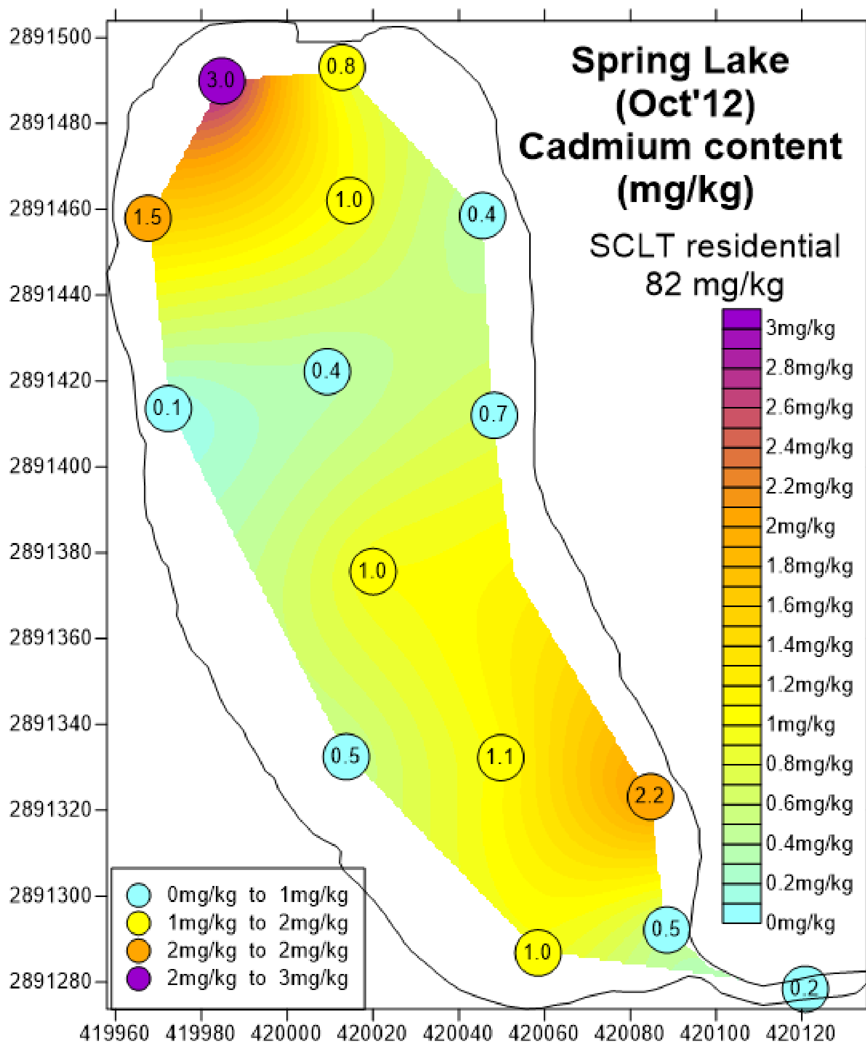

Fig.37. Spatial distribution of cadmium content

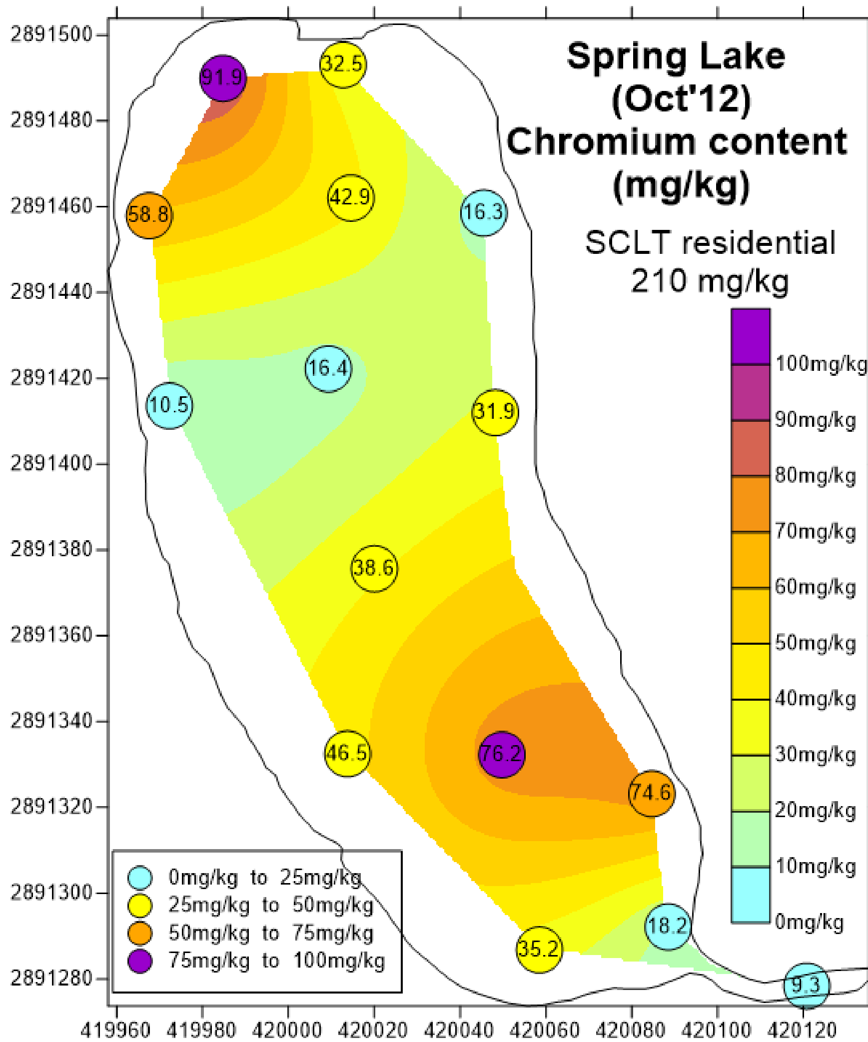

Fig.38. Spatial distribution of chromium content

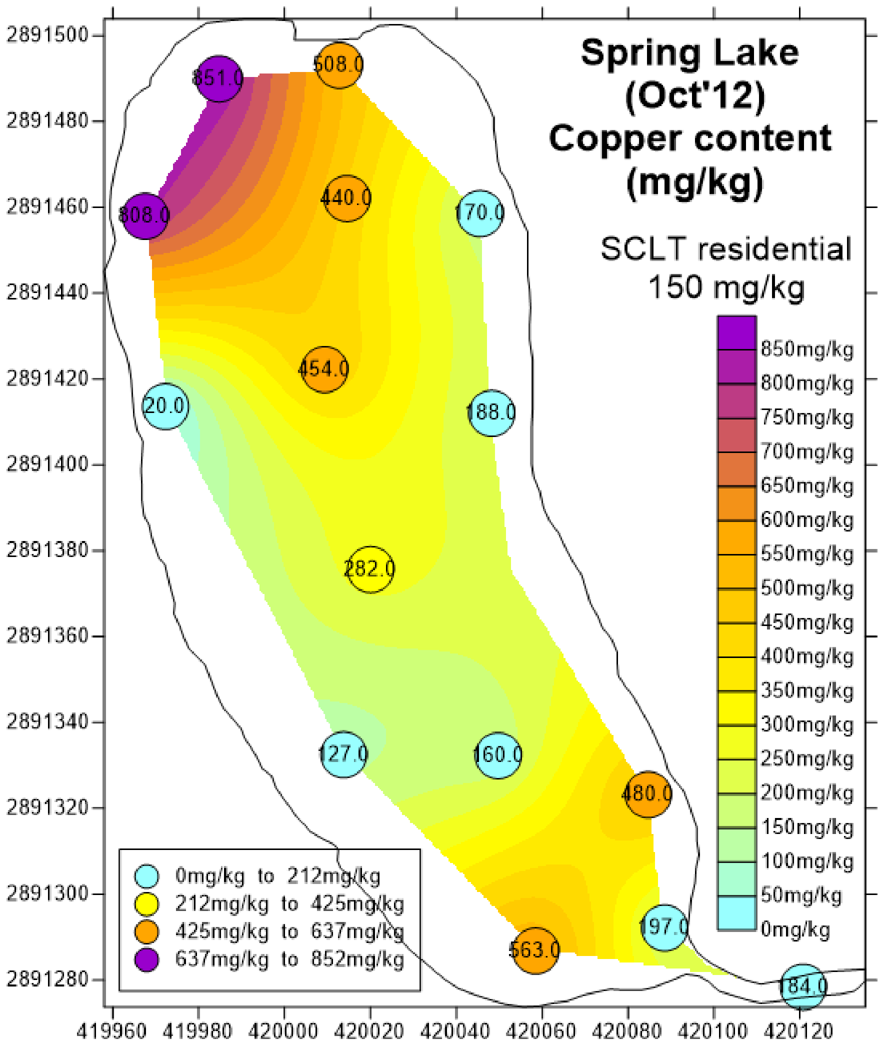

Fig.39. Spatial distribution of copper content

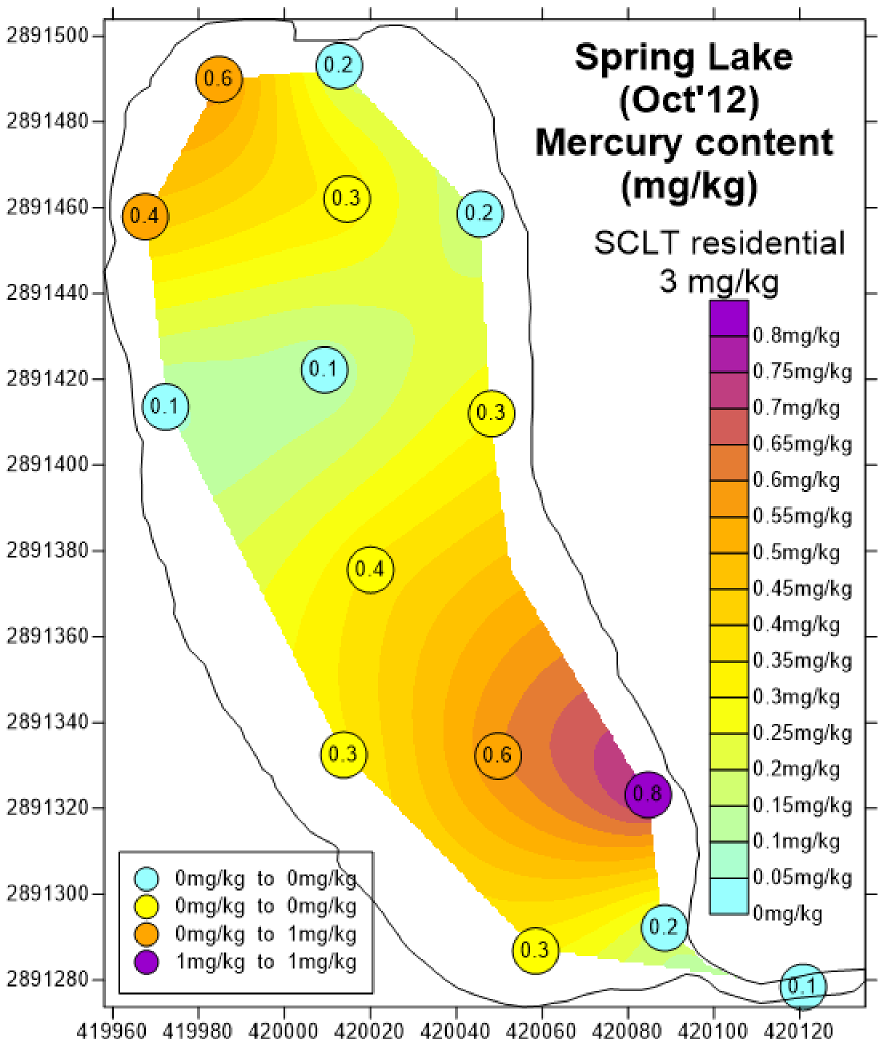

Fig.40. Spatial distribution of mercury content

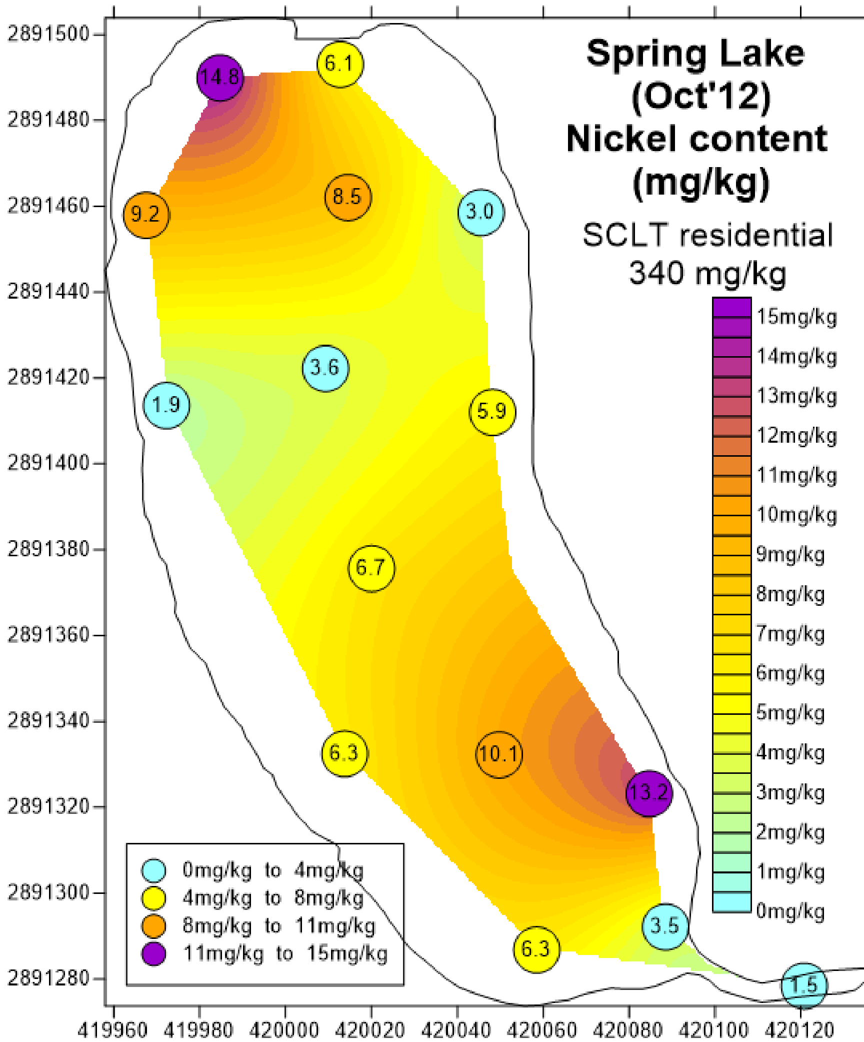

Fig.41. Spatial distribution of nickel content

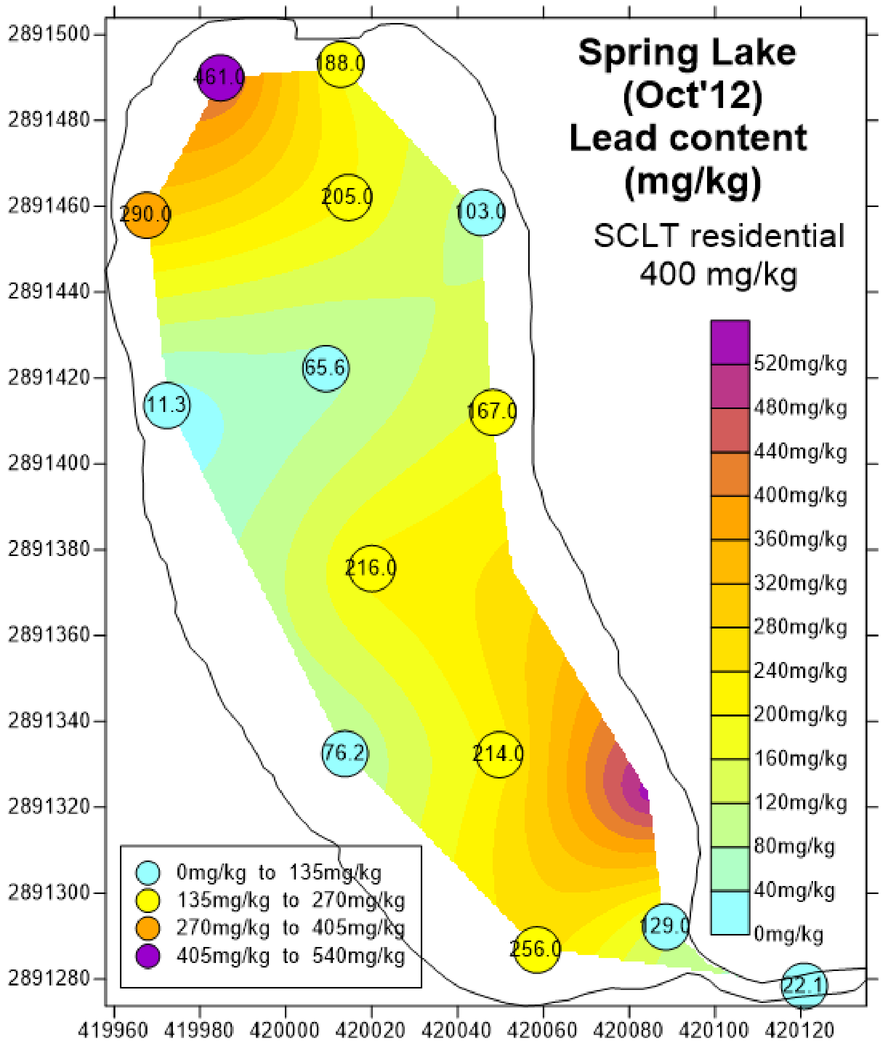

Fig.42. Spatial distribution of lead content

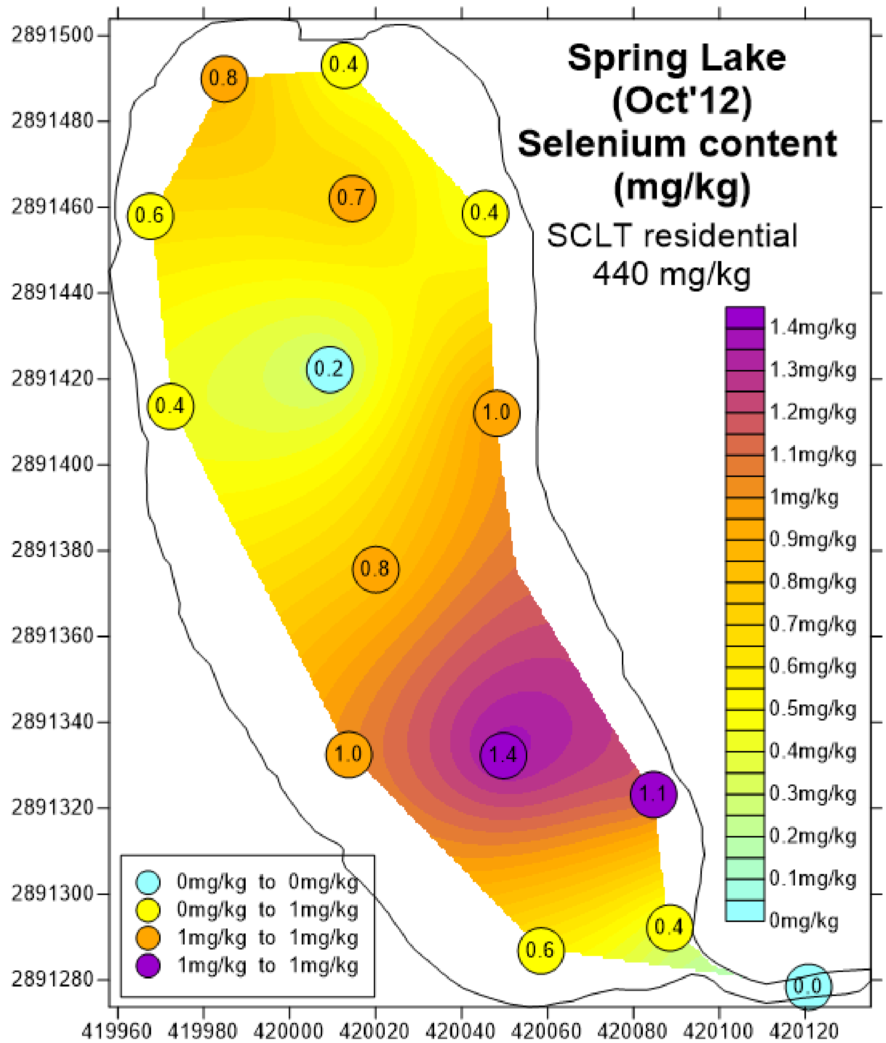

Fig.43. Spatial distribution of selenium content

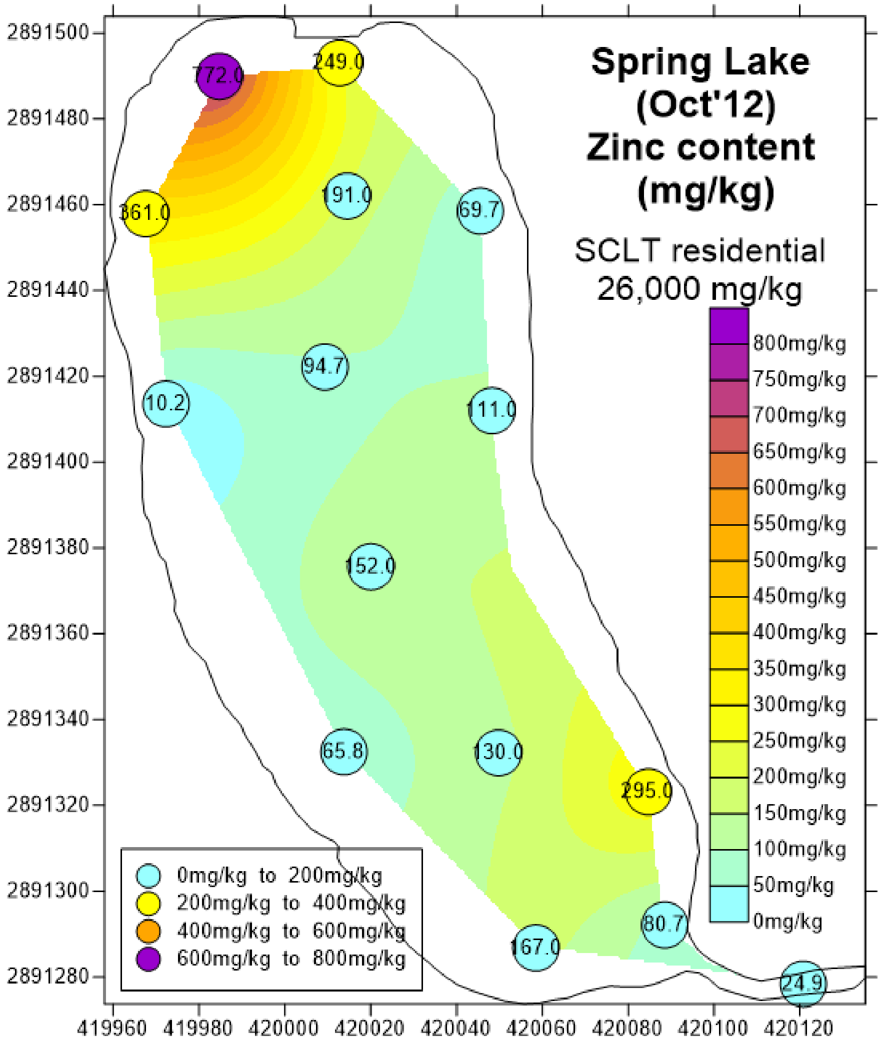

Fig.44. Spatial distribution of zinc content

Tables

		Sediment							Floc						
Variables	**Units**	Average	SD	Median	Max	Min	range	n	Average	SD	Median	Max	Min	range	n
Water depth	**cm**	138.6	31.6	145.0	182.0	65.0	117.0	28	138.6	31.6	145.0	182.0	65.0	117.0	28
tot. length		42.6	19.7	43.0	83.0	10.0	73.0	28	42.6	19.7	43.0	83.0	10.0	73.0	28
thick		16.9	13.5	17.3	38.0	0.0	38.0	28	9.8	7.7	8.5	31.0	0.0	31.0	28
bulk density	**g FW/ml**	1.06	0.10	1.04	1.37	0.94	0.43	15	0.99	0.15	0.96	1.50	0.92	0.58	14
bulk density	**g DW/ml**	0.22	0.13	0.17	0.61	0.09	0.51	15	0.05	0.02	0.05	0.09	0.01	0.08	14
inorganic content	**%**	71.0%	10.7%	73.1%	88.8%	53.9%	34.9%	15	59.4%	9.4%	60.0%	71.7%	45.6%	26.2%	14
organic content		29.0%	10.7%	26.9%	46.1%	11.2%	34.9%	15	40.6%	9.4%	40.0%	54.4%	28.3%	26.2%	14
C content		17.6%	7.5%	18.9%	28.4%	3.7%	24.7%	15	23.5%	1.9%	23.4%	26.5%	21.8%	4.7%	5
N content		0.97%	0.48%	0.95%	1.93%	0.21%	1.72%	15	1.11%	0.67%	1.52%	1.68%	0.36%	1.32%	5
P content		0.15%	0.10%	0.12%	0.37%	0.04%	0.33%	15	0.20%	0.04%	0.19%	0.24%	0.16%	0.09%	5
mass C/N	-	18	15	20	15	18	-	14	21	3	15	16	61	-	5
mass C/P	-	119	75	155	77	99	-	14	116	55	121	109	139	-	5
mass N/P	-	7	5	8	5	6	-	14	5	19	8	7	2	-	5
C or N limitation	-	N	-	N	N	N	-	14	N	-	N	N	N	-	5
C or P limitation	-	P	-	P	P	P	-	14	P	-	P	P	P	-	5
N or P limitation	-	N	-	N	N	N	-	14	N	-	N	N	N	-	5
Ag content	**mg/kg**	0.45	0.73	0.24	3.03	0.03	3.00	15	-	-	-	-	-	-	-
Al content		23539	22502	17300	84100	4030	80070	15	-	-	-	-	-	-	-
As content		18.1	14.1	14.5	51.5	4.4	47.1	15	-	-	-	-	-	-	-
Ba content		14.1	9.9	13.0	43.9	4.8	39.1	15	-	-	-	-	-	-	-
Cd content		0.95	0.78	0.84	2.99	0.09	2.90	15	-	-	-	-	-	-	-
Cr content		40.0	25.6	35.2	91.9	9.3	82.6	15	-	-	-	-	-	-	-
Cu content		362	250	282	851	20	831	15	-	-	-	-	-	-	-
Hg content		0.32	0.21	0.31	0.78	0.09	0.69	15	-	-	-	-	-	-	-
Ni content		6.7	3.9	6.3	14.8	1.5	13.3	15	-	-	-	-	-	-	-
Pb content		197	150	188	544	11	533	15	-	-	-	-	-	-	-
Se content		0.67	0.37	0.64	1.39	0.00	1.39	15	-	-	-	-	-	-	-
Zn content		185	190	130	772	10	762	15	-	-	-	-	-	-	-

Table 1. Summary table of the sediment characteristics.

Station	Ag	Al	As	Ba	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
#	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
1	OK	OK	2452%	OK	OK	OK	567%	OK	OK	115%	OK	OK
2	OK	OK	392%	OK	OK	OK	339%	OK	OK	OK	OK	OK
5	OK	OK	1167%	OK	OK	OK	539%	OK	OK	OK	OK	OK
6	OK	OK	962%	OK	OK	OK	293%	OK	OK	OK	OK	OK
7	OK	OK	562%	OK	OK	OK	113%	OK	OK	OK	OK	OK
10	OK	OK	220%	OK	OK	OK	OK	OK	OK	OK	OK	OK
11	OK	OK	227%	OK	OK	OK	303%	OK	OK	OK	OK	OK
12	OK	OK	514%	OK	OK	OK	125%	OK	OK	OK	OK	OK
16	OK	OK	757%	OK	OK	OK	188%	OK	OK	OK	OK	OK
21	OK	OK	448%	OK	OK	OK	OK	OK	OK	OK	OK	OK
22	OK	105%	843%	OK	OK	OK	107%	OK	OK	OK	OK	OK
23	OK	OK	2114%	OK	OK	OK	320%	OK	OK	136%	OK	OK
26	OK	OK	1362%	OK	OK	OK	375%	OK	OK	OK	OK	OK
27	OK	OK	690%	OK	OK	OK	131%	OK	OK	OK	OK	OK
28	OK	OK	211%	OK	OK	OK	123%	OK	OK	OK	OK	OK

Table 2. Table showing when metal contents were higher than SCTLs and to which extent.