

**MINUTES OF A SPECIAL MEETING WORKSHOP OF  
BIG BEAR MUNICIPAL WATER DISTRICT  
HELD ON WEDNESDAY, JUNE 18, 2014**

The Open Session workshop began at 1:00 PM. Those in attendance included President Murphy, Director Lewis, Director Eminger, Director Smith, General Manager Scott Heule, Lake Manager Mike Stephenson, and Board Secretary Vicki Sheppard.

**STATEWIDE MERCURY TMDL**

Mr. Heule made a PowerPoint presentation (copy attached) regarding mercury levels in Big Bear Lake. He reported on how mercury has affected the lake's bass population. He explained the 10 year goal of measurably reducing fish methyl-HG explaining that a baseline must be developed studying multiple species, a large sample size, and multiple years. He reported that the only choice the District seems to have at this time is to try and figure what baseline levels are in all species and how to monitor it through the years.

Mr. Stephenson reported on the alum treatment project passing out an interim report from Michael Anderson, University of Riverside (copy attached). The timeline for permits and RFP's in order to meet the timeline was discussed. The option of completing the project this year or waiting until next year (2015) was also discussed. Mr. Stephenson explained that Michael Anderson feels it would be better to shoot for next year. It was the consensus that it seems better to wait until next year.

**ADJOURNMENT**

There being no further business, the workshop was adjourned at 1:54PM.



Vicki Sheppard  
Secretary to the Board  
Big Bear Municipal Water District

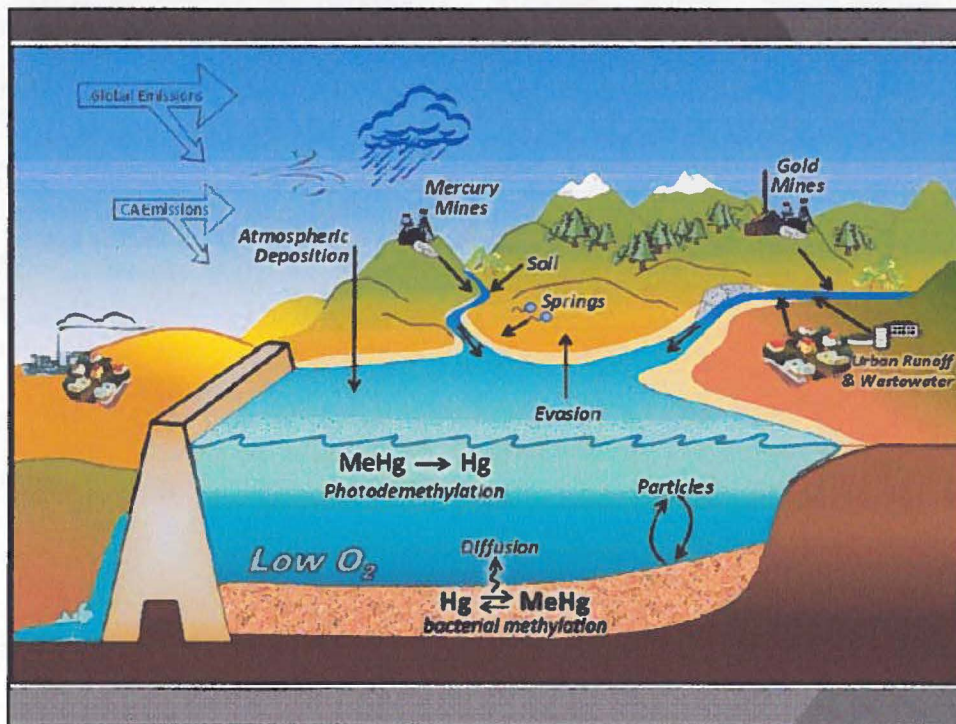
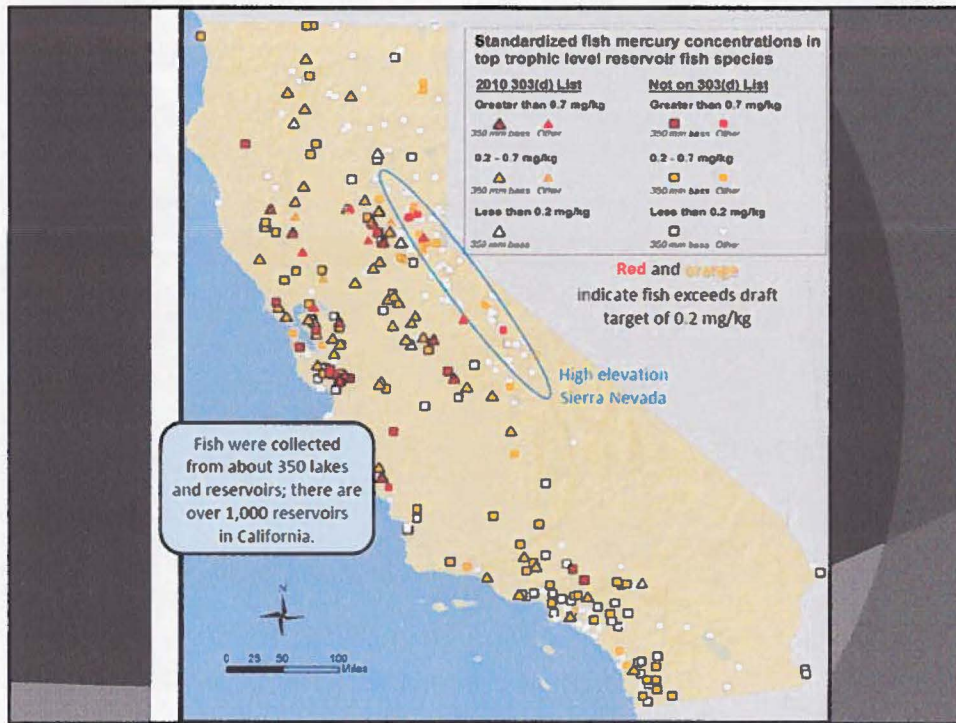
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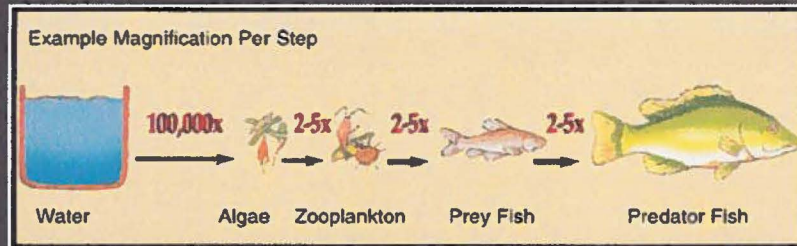
June 18, 2014

## WATERSHED WORKSHOP

- Mercury (Hg) in any form is toxic
- Hg + sulfate reducing bacteria + anoxic = Methylmercury
- Methylmercury most bio available form of Hg
- Bass in BBL exceed health standard of 0.2mg/kg
- BBL one of 74 reservoirs on Clean Water Act 303(d) listed as impaired for Hg







- Not looking at methods that impact water flows
- 10 year Goal = measurably reduce fish methyl-Hg
- Must develop a baseline
  - Multiple species
  - Large sample size
  - Multiple years
- Identify a sentinel species
  - Analyze yearly to measure progress
- Get fish survey reports from Calif. F&W



- Studies in BBL by District and Regional Board
  - Fish tissue
  - Water column
- Reduce Methylmercury in fish
  - Decrease bio-available Hg in reservoir
    - HOS – additional aeration
  - Manipulate food web = increase growth rate
    - Intensive fishing – cull large bass
    - Increase numbers of prey fish

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**ALUM TREATMENT IN BIG BEAR LAKE:**  
**JAR TEST RESULTS, MOBILE-P MEASUREMENTS AND APPLICATION STRATEGY**

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*Department of Environmental Sciences*  
*University of California - Riverside*

## **Introduction**

Alum applications to lakes have been shown to effectively reduce internal loading of phosphorus (P), reduce algal levels and increase water clarity. Previous studies have found that Big Bear Lake is generally P-limited, with a substantial portion of P available in the water column for phytoplankton production derived from recycling from sediments (Anderson and Dyal, 2003). An alum treatment in 2004 reduced phytoplankton concentrations and increased transparency (Berkowitz and Anderson, 2005), and successfully reduced internal P loading rates by up to 90% following treatment, with successful suppression of internal loading for several years thereafter (Anderson and Paez, 2007). These reductions were achieved despite the near-record precipitation and runoff in early 2005 that greatly increased external nutrient loading, lake volume and surface area and depth. Alum treatments have a finite capacity and lifespan however; for example, internal P recycling rates increased each year following treatment (Anderson and Paez, 2007). Based upon measured increases from 2004 to 2006, internal nutrient recycling rates are projected to have returned to baseline levels, and are thus a significant factor contributing to algal growth and water quality in the lake. Only a fraction of the total P in sediments is available for release, however, with internal P recycling strongly correlated with a mobile fraction (mobile-P) that includes soluble/exchangeable and reductant-soluble forms (Reitzel et al., 2005; Pilgrim et al. 2007).

The objective of this study was to assess pH-alkalinity response to added Al, quantify mobile-P contents in the sediments and their distribution within the lake, and develop an alum application strategy.

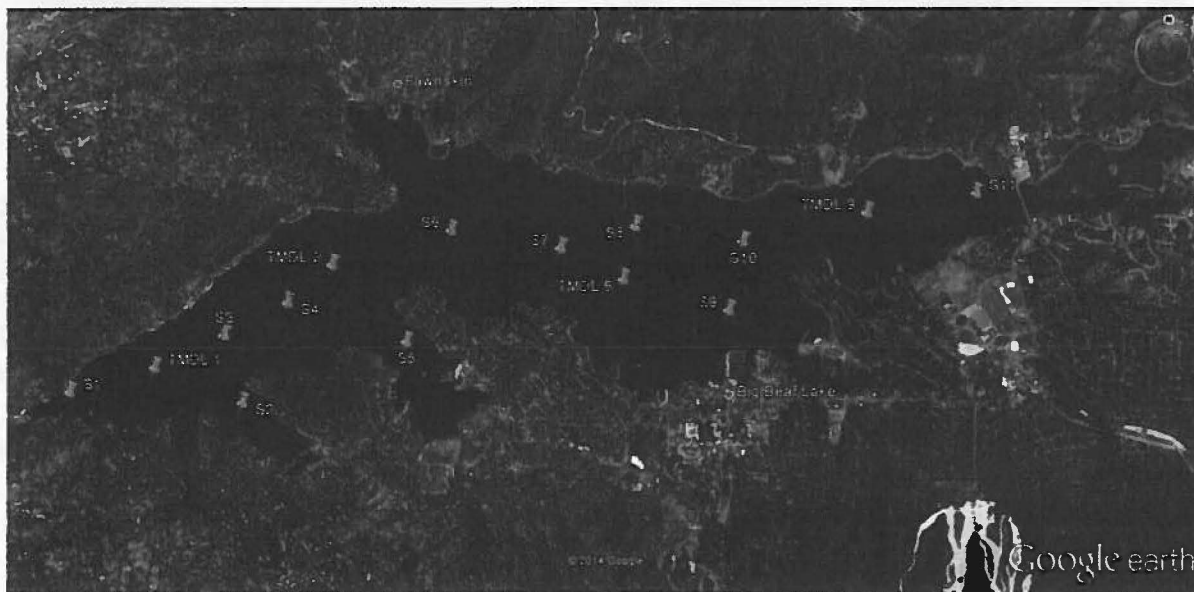
## **Methods**

### **i. Sediment sampling and locations**

Intact sediment cores and sediment grab samples were collected at TMDL stations 1, 2, 6 and 9 on March 26, 2014. Samples were collected with an Ekman dredge, homogenized and



subsampled into 500 mL wide-mouth jars with Teflon lined screw top lids. A second sediment sampling campaign was conducted on April 7, 2014 that collected grab samples and short intact cores from 11 additional sites across the lake (Fig. 1). Short (10 cm) intact cores were obtained by inserting 10 cm x 6.35 cm diameter clear polycarbonate tubes into sediment within the dredge and sealed with plastic end caps. All samples were stored in a cooler and returned to the lab for analyses.



*Fig. 1. Sediment sampling sites: Big Bear Lake.*

#### ii. Jar Test: pH-Alkalinity Assessment

Jar tests were conducted to quantify the effect of different doses of Al (added as alum) on equilibrium pH and alkalinity levels. pH is a critical variable in alum applications, regulating solubility and speciation of Al (Berkowitz et al., 2005). Approximately 20-L of water was collected from Big Bear Lake on March 26, 2014 and returned to the lab for analysis. One-L samples of Big Bear Lake water were then dosed with 0, 5, 10, 15, 20, 25, 30, 35 and 40 mg L<sup>-1</sup> Al<sup>3+</sup> as alum (Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>•18H<sub>2</sub>O) and subsampled after 24 hours. The pH was measured using an AccuMet pH meter with Fisherbrand pH electrode calibrated with Fisher pH 4 and 7 buffers. Alkalinity was determined on subsamples with potentiometric titration with standardized acid to a pH endpoint of 4.5 following method 2320 B (APHA, 1998). Measurements were also taken 72 hours later after equilibrium was reached.

### iii. Sediment Analyses

Phosphorus in bottom sediments of lakes exists in numerous forms, including a mobile form (mobile-P) that includes soluble/exchangeable forms as well as that associated with iron (Fe)(III) phases that can be released upon reduction of Fe(III) under low dissolved oxygen (DO) conditions (Reitzel et al., 2005; Pilgrim et al., 2007). Mobile-P in surficial sediments has been shown to be strongly correlated with internal recycling rates (Pilgrim et al., 2007), with the mobile-P pool reduced by amounts consistent with that released to the water column (Reitzel et al., 2005).

Sediment grab samples were subsampled for dry-weight determination and extracted for mobile-P following Pilgrim et al. (2007). Water content was determined on subsamples that were heated overnight at 105 °C. Total C and N were measured by dry-combustion methods using a Thermo Flash EA NC soil analyzer (Nelson and Sommers, 1982). Inorganic C and CaCO<sub>3</sub> were determined manometrically following Loeppert and Suarez (1996), with organic C taken as the difference between total C and inorganic C. Duplicate analyses were conducted at a rate of at least one every 10 samples within an analytical batch.

### iv. Hydroacoustic Survey

The acoustic signature of bottom sediments is increasingly used to classify sediment hardness and roughness (Sternlicht and de Moustier, 2003), thickness (Odhiambo and Boss, 2004), and has also been found to correlate with organic C and total nutrient contents as well as rates of nutrient release and sediment oxygen demand (Anderson and Pacheco, 2011). A multi-frequency hydroacoustic survey was conducted on March 28, 2014 to map out acoustical properties of sediments, sediment mobile-P distribution, and alum dose across the lake. Measurements were made using a BioSonics DTX echosounder multiplexed to a 201-kHz split-beam transducer and 430-kHz and 38-kHz single beam transducers with integrated pitch-roll sensors (Table 1) and JRC Model 202W real-time differential GPS. Data were collected on a Dell ATG laptop running BioSonics Visual Acquisition 6 software. The ping rate was set to 5 pings per second for each channel, with 0.4 ms pulse durations. Transducers were calibrated at BioSonics (Seattle, WA) in February 2014. Attributes of the bottom echo included the maximum sediment volumetric backscatter strength ( $Sv_{max}$ ) that was extracted directly from echogram .dt4 binary files, while fractal (box) dimension (FD), first part of the first bottom echo (E1'), and second part of first bottom echo (E1) were calculated using BioSonics VBT software. Values were calculated using a 20-ping averaging window.



| Property                                      | DTX-38 | DTX-200 | DTX-420 |
|---|--------|---------|---------|
| Frequency (kHz)                               | 38     | 201     | 430     |
| Beam angle (°)                                | 10.0   | 6.6     | 7.0     |
| Source level (dB $\mu\text{Pa}^{-1}$ )        | 217.0  | 221.3   | 220.0   |
| Receive sensitivity (dB $\mu\text{Pa}^{-1}$ ) | -41.1  | -57.6   | -62.9   |
| Pulse length (ms)                             | 0.4    | 0.4     | 0.4     |
| Pings per second (pps)                        | 5      | 5       | 5       |

## Results

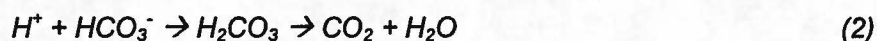
### i. Jar Test Results: pH-Alkalinity Response

The native pH of the water collected from Big Bear Lake was 8.2, similar to other values measured at the lake (e.g., Berkowitz and Anderson, 2004; Anderson and Paez, 2006) and consistent with surface water in a calcareous watershed in equilibrium with atmospheric  $\text{CO}_2$ . Alkalinity was 3.6 meq/L, representing good acid-neutralizing capacity, although the value was somewhat lower than the value of 4.0 meq/L found in 2004 (Berkowitz and Anderson, 2004).

Addition of alum resulted in an approximately linear decrease in both post-treatment pH and alkalinity (Fig. 2). Alum readily dissociates to  $\text{Al}^{3+}$  that then undergoes a hydrolysis reaction at circumneutral pH to produce 3 mols  $\text{H}^+$  per mol  $\text{Al}^{3+}$ :



Alum treatments thus generate a significant amount of acidity that can be neutralized by bicarbonate ( $\text{HCO}_3^-$ ) and other sources of alkalinity in the water via the reaction:



The reaction of  $\text{HCO}_3^-$  with  $\text{H}^+$  produces  $\text{CO}_2$  that can then be lost to the atmosphere, although the volatilization reaction occurs more slowly than the chemical reaction. It is for this reason that the approximate equilibrium pH (after 72 h) was consistently higher than after 24 h (except at the highest Al dose, when all alkalinity was consumed) (Fig.2). Alkalinity was unchanged over time however. Moderate doses of alum ( $\leq 20$  mg/L) maintained  $\text{pH} > 7$  (slightly basic conditions) near equilibrium, while higher doses yielded weakly acidic conditions; at high doses of alum, acid production exceeded the alkalinity of the water and resulted in strongly acidic conditions that would be unfavorable for trout and numerous other aquatic species (Fig. 2).

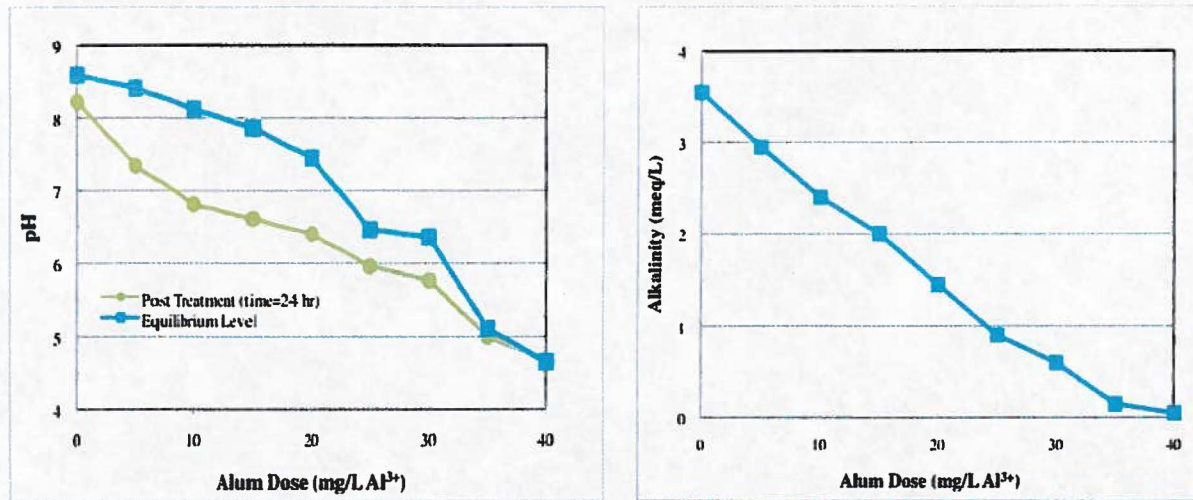


Fig. 2. Jar test results: a) pH vs alum dose (as Al), and b) alkalinity vs alum doses (as Al).

ii. Sediment Analyses

Properties of surface sediment sampled across the lake (Fig. 1) varied markedly in water content, organic C content and other properties (Table 2). Depths ranged from 14.9 m at site S1 near the buoy line at the west end of the lake to 2.4 m at S11 near the Stanfield Cutoff (Fig. 1). Sediment properties varied along this longitudinal gradient as well, with higher water contents and mobile-P concentrations generally present in the deeper waters on the western part of the lake, and much lower values on the east end (e.g., S9-11) (Table 2).

calcium

| Site   | Depth (m) | H <sub>2</sub> O Content (% ww) | Organic C (% dw) | Total N (% dw) | CaCO <sub>3</sub> (% dw) | Mobile-P (ug/g dw) |
|--------|-----------|---------------------------------|------------------|----------------|--------------------------|--------------------|
| TMDL 1 | 12.7      | 85.6                            | 6.66             | 0.84           | 7.32                     | 270                |
| TMDL 2 | 9.9       | 84.8                            | 5.99             | 0.75           | 4.68                     | 214                |
| TMDL 6 | 7.9       | 78.5                            | 12.05            | 1.26           | 3.41                     | 67                 |
| TMDL 9 | 5.1       | 64.7                            | 3.58             | 0.49           | 11.85                    | 43                 |
| S1     | 14.9      | 84.0                            | 5.53             | 0.7            | 6.28                     | 219                |
| S2     | 8.3       | 77.6                            | 5.57             | 0.65           | 3.31                     | 123                |
| S3     | 12.0      | 84.6                            | 6.13             | 0.79           | 5.86                     | 227                |
| S4     | 11.0      | 85.9                            | 6.11             | 0.83           | 7.89                     | 312                |
| S5     | 6.7       | 66.1                            | <0.1             | 0.08           | 2.58                     | 86                 |
| S6     | 6.0       | 26.9                            | <0.1             | 0.10           | 0.63                     | 25                 |
| S7     | 7.7       | 80.2                            | 13.18            | 1.32           | 3.74                     | 141                |
| S8     | 7.9       | 77.0                            | 10.79            | 1.13           | 5.67                     | 89                 |
| S9     | 5.7       | 48.0                            | 1.61             | 0.26           | 2.15                     | 41                 |
| S10    | 7.5       | 74.1                            | 4.63             | 0.63           | 12.59                    | 65                 |
| S11    | 2.4       | 57.0                            | 2.19             | 0.35           | 16.49                    | 29                 |

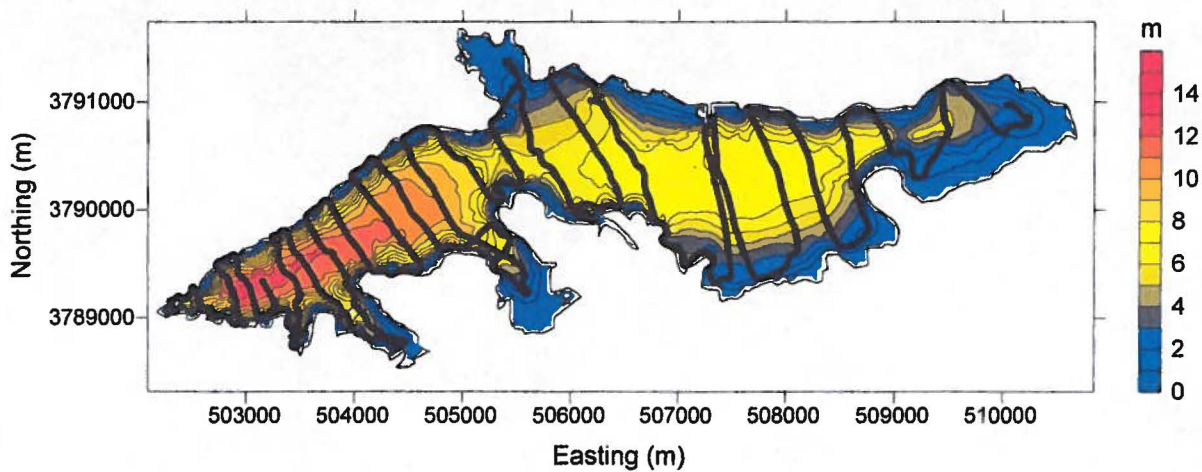


The mobile-P contents at TMDL sites were in good agreement with measurements made on samples collected on November 6, 2003, with depth-averaged concentrations of 311 (vs. 270), 67 (vs. 67) and 75 (vs. 43)  $\mu\text{g/g}$  at TMDL sites 1, 6 and 9, respectively (Aquatic Research, Inc., 2003). The longitudinal trends (Fig. 1, Table 2) are thought to result in part due to the strong winds from the west that introduce a great deal of turbulent kinetic energy, especially to the eastern end of the lake, and thus limit settling of fine organic matter and clay particles, resuspend bottom sediments, and transport/focus this material to deeper regions of the lake. Notwithstanding, there was heterogeneity that was not well-described simply by depth or longitude. For example, sediments at TMDL 6 and supplemental sites 7 and 8 had markedly higher organic C and total N contents than elsewhere in the lake, despite moderate depths and mid-longitudinal location.

While these 15 sites provide key information about sediment properties, including the amount of mobile-P available for release to the overlying water content through internal recycling, it is difficult to extrapolate to other regions on the lake. As a result, these results are used in conjunction with hydroacoustic measurements described below to develop a more complete understanding of how sediment properties vary across the lake.

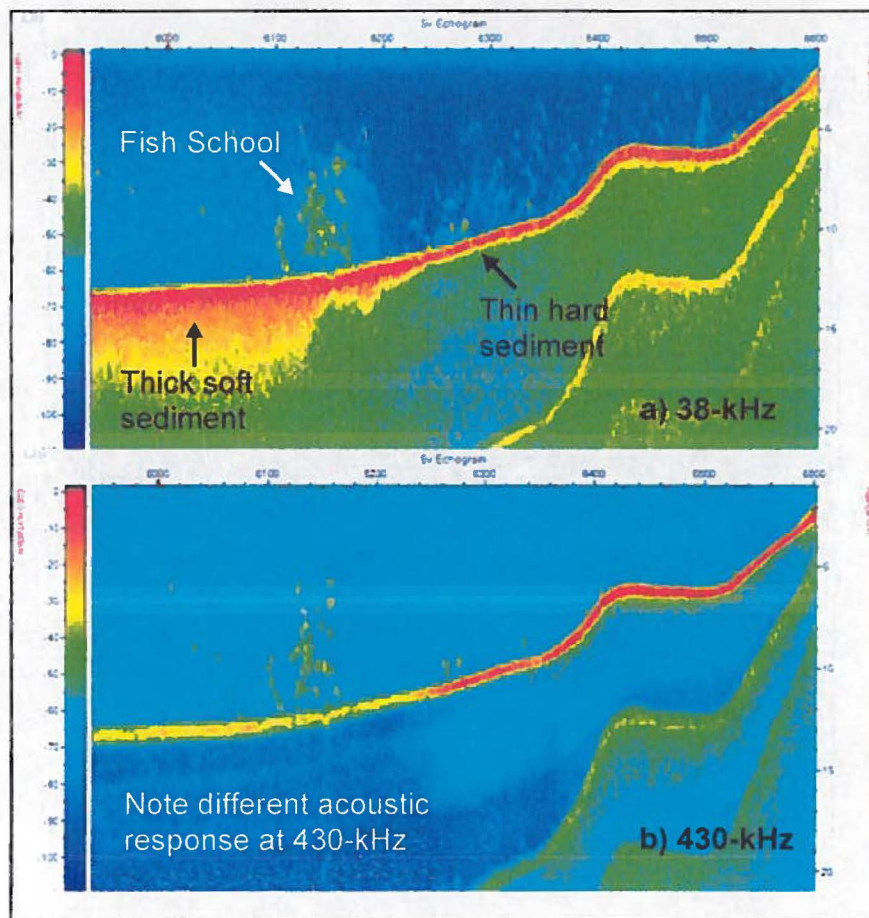
### iii. Hydroacoustic Results

Hydroacoustic measurements were made across 42 km of survey on March 28, 2014 that involved a series of transects across the lake, with somewhat greater density of measurements in the western portion of the lake (Fig. 3). The transects are overlain on a bathymetric map developed from the data. Approximately 100,000 pings were recorded, and averaged into 20-ping ensembles for  $\sim 5,000$  measurements of sediment acoustic signatures.



*Fig. 3. Hydroacoustic survey track (March 28, 2014).*

Acoustic backscatter strength as a function of depth (or range) below the transducer face, based upon the 2-way time of travel and known speed of sound in water (approximately 1500 m/s), is recorded with corresponding differentially-corrected GPS coordinates. The echo amplitude is corrected for absorption and spreading using the sonar equation and provides a measure of the bottom sediment's hardness, roughness and density contrast with water. Example echograms collected at 38-kHz and 430-kHz for a short section of the survey are shown in Fig. 4.



*Fig. 4. Example echograms: a) 38-kHz and b) 430-kHz.*

Low frequency soundwaves (e.g., 38-kHz, upper echogram) experience little absorption within water or soft cohesive sediments, and thus can penetrate significant distances into fine-textured organic sediments, as seen around ping 6000. Here strong acoustic backscatter (-10 to



-20 dB) was found extending up to about 5 m into the sediments. Fine-textured organic sediment has thus accumulated to a significant depth at this location in the lake. A short distance away (e.g., ping 6300), reverberation was limited to a very narrow region at the sediment surface, consistent with a hard dense substrate. Acoustic backscatter at 430-kHz (Fig. 4, lower echogram) revealed a very different echogram, with limited penetration of the soundwaves into soft (ping 6000) or hard (ping 6300) bottom sediment. Moreover, much weaker backscatter strength was measured from the soft thick sediments (-35 dB) when compared with the thin harder/denser sediment (-10 dB). These differences in acoustic properties for various types of sediments and different frequencies can, with adequate ground-truthing, provide a way to rapidly map the distribution of sediment type and thickness across a lake or reservoir. Hydroacoustic measurements have not heretofore been used to estimate and map mobile-P in sediments.

Regression analyses were used to determine which acoustic attributes were most strongly correlated with mobile-P content of the sediments. The fractal dimension (FD) of the bottom echo envelope at 430-kHz was found to be the strongest correlate, capturing 78% of the variance in measured mobile-P (Fig. 5). Multiple linear regression analyses did not improve the overall goodness of fit when compared to  $FD_{430}$  alone.

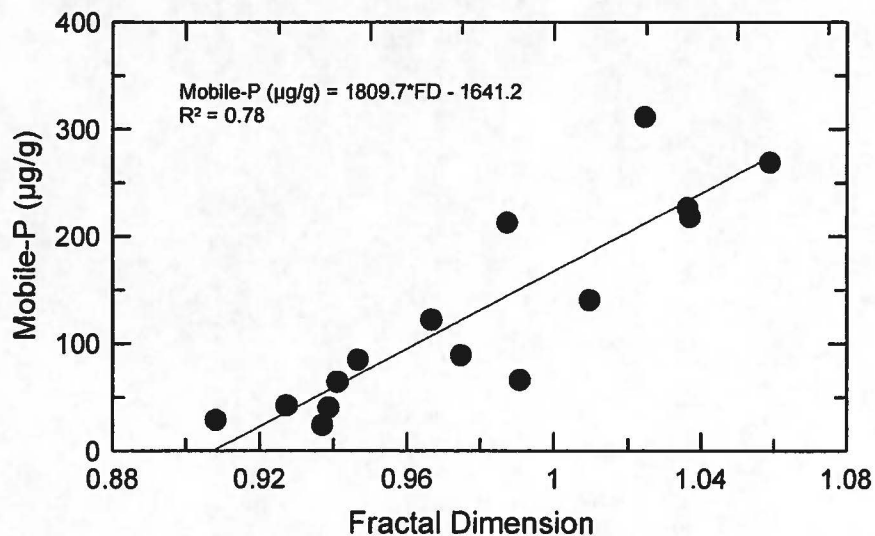


Fig. 5. Mobile-P content correlated with fractal dimension of bottom echo envelope.

The mobile-P content of the sediment, expressed on a dry-weight basis (Table 2; Fig. 5) was then converted to an areal concentration ( $\text{g mobile-P/m}^2$ ) based upon measured water



content, a particle density of  $2.65 \text{ g/cm}^3$ , and thickness of the reactive surface layer. The thickness of the reactive layer can vary, with Pilgrim et al. (2007) reporting mobile-P in the upper 4-7 cm predictive of P-release, while Reitzel et al., (2005) found mobile-P in the upper 10 cm depleted during core-flux studies and in field samples collected through the summer. Based upon previously measured vertical gradients, strong wind mixing and high rates of internal recycling, a reactive sediment thickness of 10 cm was used.

The representation of mobile-P in mass per unit area ( $\text{g/m}^2$ ) corrects for differences in water content and, combined with hydroacoustic measurements of fractal dimension (Fig. 5), allowed extrapolation of mobile-P contents beyond the original 15 sites reported in Table 2 to the entire lake basin (Fig. 6). This geospatial processing was performed using the kriging algorithm within Surfer software (Golden, CO). The highest concentrations of mobile-P were found in the western portion of the lake, while much lower concentrations were present in the eastern part of the lake, with especially low levels near the Stanfield Cutoff (Fig. 6). Very low concentrations were also present near the mouth of Grout Bay. Mobile-P concentrations in Big Bear Lake are broadly consistent with those for a number of lakes in Minnesota that ranged from about  $0.3 - 4 \text{ g mobile-P/m}^2$  assuming a 4-5 cm reactive layer (Pilgrim et al., 2007), but quite a bit lower than the value reported by Reitzel et al. (2005) of about  $9 \text{ g mobile-P/m}^2$  for a shallow hypereutrophic lake in Denmark. (Since hydroacoustic measurements were not made in very shallow water at the far ends of Grout, Boulder and Metcalf Bays (Fig. 3), the mobile-P contents there are extrapolations subject to high amounts of uncertainty.)

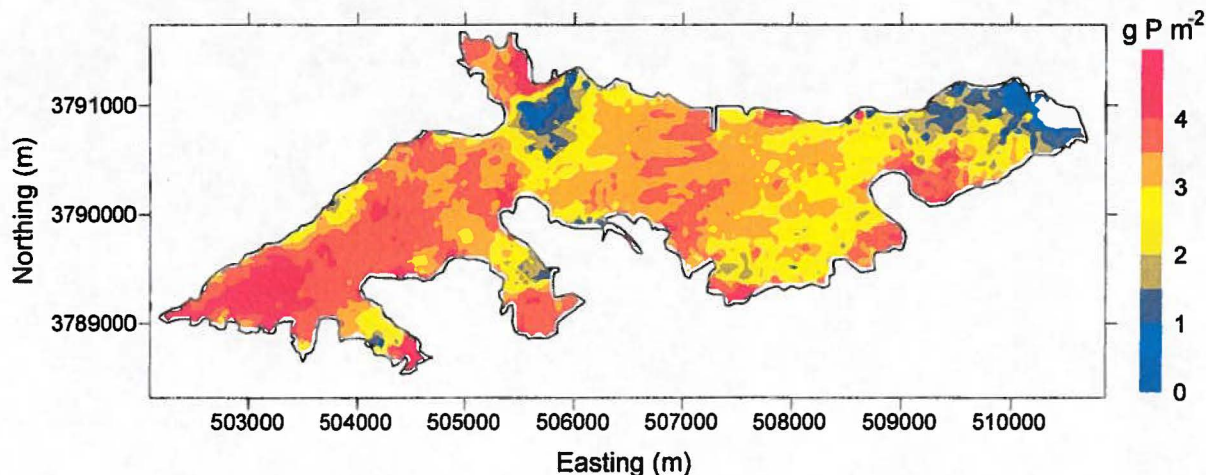


Fig. 6. Distribution of mobile-P across Big Bear Lake based upon hydroacoustic data.

#### iv. Considerations for Alum Treatment

With an understanding of the mobile-P contents across the lake (Fig. 6), and by extension internal P-loading, it is possible to design an alum application strategy that efficiently targets strongest sources areas with optimized alum dosages. Nonetheless, other factors must be considered in design of the treatment strategy. As indicated by the jar tests, there are upper limits to the amount of alum that can be applied before pH and alkalinity drop to ecologically critical values. The results shown in Fig. 2 thus provide a boundary condition for the amount of alum that can be added; setting a protective lower limit on equilibrium pH of 7.0, the concentration limit for Al is approximately 20 mg/L. Care is needed during application to avoid hotspots of locally higher concentrations.

Suitability of a region for treatment is also dependent upon water currents and bottom shear stress. Wind shear on the lake surface transfers momentum to the water, setting up surface waves, surface and bottom currents, and potential for sediment resuspension. Sediment resuspension has been reasonably predicted in a number of studies with relationships that use wind speed, wind direction, fetch and depth to sediment to infer loci and extent of resuspension (e.g., Carper & Bachmann, 1984). It has been shown that resuspension and erosion of fine-textured bottom sediment occurs when deep-water waves enter water shallower than one-half the wave length (Bloesch, 1995). The wavelength,  $L$  (m), of a deepwater wave is related to its period,  $T$  (s), by the relation:

$$L = \frac{gT^2}{2\pi} \quad (3)$$

where  $g$  is the gravitational constant (Martin & McCutcheon, 1999). A wave's period can be estimated using the empirical equation developed by the US Army Coastal Engineering Research Center (Carper & Bachmann, 1984) that states:

$$T = \frac{2.4\pi U \tanh \left[ 0.077 \left( \frac{gF}{U^2} \right)^{0.25} \right]}{g} \quad (4)$$

where  $U$  is the wind speed (m/s) and  $F$  is the fetch (m).

With typical afternoon windspeeds of 12-14 mph, orbital motion associated with surface waves would be expected to resuspend bottom sediments at depths up to about 3.5 m (Fig. 7, solid line). Ignoring the protective effect that rooted aquatic vegetation would provide, this corresponds to as much as 730 acres that would not be amenable for treatment. Periodic winds



up to about 25 mph could resuspend bottom sediments to depths >6.5 m especially at the east end of the lake (potentially up to 1300 acres) (Fig. 7, dashed line). Steep bottom slopes also inhibit sediment accumulation (Blais and Kalff, 1995). Thus, depending upon the wave-mixed depth criterion used, potentially only about 1000-1600 acres of the lake is suitable for an alum treatment based upon flocculation and resuspension considerations, *i.e.*, where a stable floc could be delivered and maintained on the sediments. Moreover, many of these same shallow regions of the lake are also subject to extensive rooted aquatic macrophyte growth which directly extract nutrients from the sediments and thus limit recycling of P to the water column.

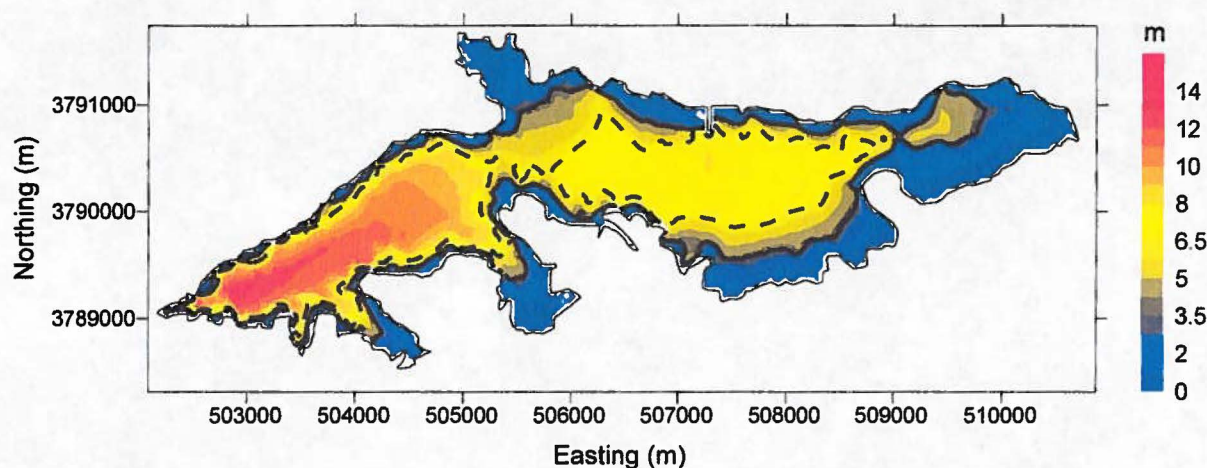


Fig. 7. Region of lake subject to wave resuspension of bottom sediments. Area outside of solid line at 3.5 m depth contour represents region potentially resuspended from typical afternoon winds of 12-14 mph; area outside dashed line at 6.5 m depth contour represents larger region potentially resuspended by periodic windspeeds of 25 mph.

With these constraints in mind, about 420 acres of sediment present in the deeper western portion of lake, with mobile-P concentrations >3.5 g/m<sup>2</sup>, are a logical target for alum treatment (Fig. 8). This region possessed an average mobile-P content of 3.84 g/m<sup>2</sup>, and was thus near 2x higher than the average content for remainder of the lake (2.07 g/m<sup>2</sup>). Treating this portion of the lake is thus expected to sequester/inactivate more than 35% of the total mobile-P and about 60% of the mobile-P in the lake basin that is amenable to treatment.

Based upon this treatment area, the final step is to establish the appropriate areal dose of Al, subject to any limitations based upon pH. The amount of mobile-P bound per mass of Al has been found to vary, from an Al:P ratio as low as 7 for a highly eutrophic lake with about 9 g/m<sup>2</sup> mobile-P (Reitzel et al., 2005), to as high as 25-100 (Pilgrim et al., 2007). A lower ratio represents more effective binding of P and lower required dose.



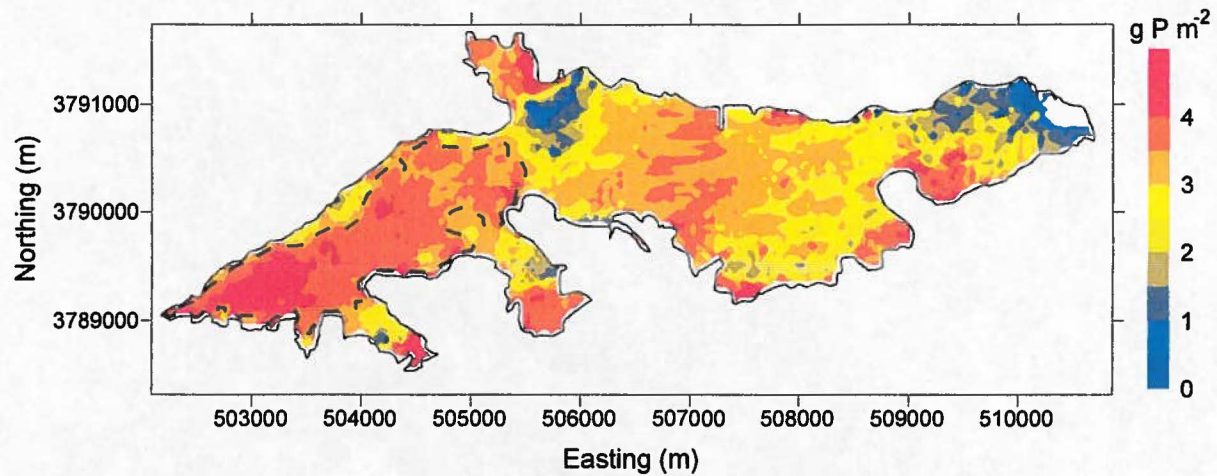


Fig.8. Spatial distribution of mobile-P in Big Bear Lake showing proposed treatment area.

Sorption experiments conducted using alum floc in Big Bear Lake water found Al:P ratios of 15-23 depending upon age of the floc (Berkowitz et al., 2006). A median Al:P ratio of 20:1 was assumed for these calculations, implicitly assuming that much of the binding of mobile-P would be accomplished within 1-2 months following application. The mobile-P values in Fig. 8 were thus simply multiplied by 20 to get the Al dose in g per m<sup>2</sup> required to sequester this labile form of P within the sediments (Fig. 9).

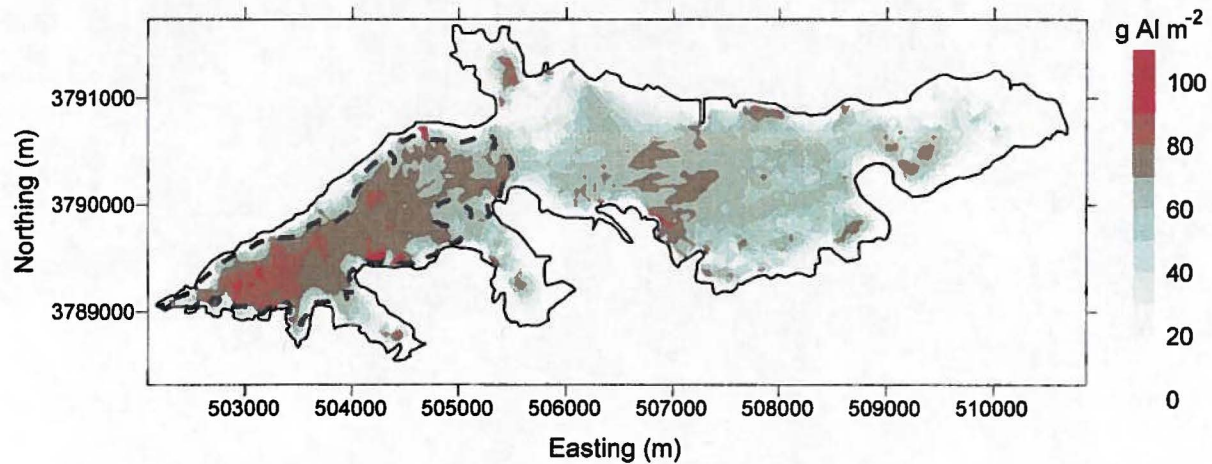


Fig.9. Spatial distribution of Al dose needed to bind mobile-P (assuming 20:1 Al:P ratio).

As one would expect, the highest Al doses would be required at the west end of the lake (Fig. 8), where the highest mobile-P concentrations were found (Fig. 9). Application rates of 70-100 g Al/m<sup>2</sup> would be needed for this region (average of 77 g Al/m<sup>2</sup>) which is located at 8-15 m

depth. Assuming the alum is applied in a single application across this region at about 8 m depth, below the thermocline, one estimates a hypolimnetic concentration of 34 mg/L, a value that will exhaust the available alkalinity of the water and drive the pH to unacceptably low levels (Fig. 2). As a result, a near-surface application will be necessary to deliver the prescribed dose of alum to this region of the lake and yield a lower Al concentration (approximately 7.5 mg/L). Based upon Fig. 2, such a dose would result in a short term reduction in pH from about 8.2 to 7, although equilibrium pH is expected to rebound to about 8. Approximately 25% or 0.9 meq/L of alkalinity would be consumed at this dose. Exact material and application costs are not known, but assuming material costs are near \$0.60/gal of liquid alum (delivered), material costs for treatment of 420 acres to an average dose of 77 g Al/m<sup>2</sup> are estimated to be approximately \$335,000.

### Conclusions

Mobile-P concentrations in the sediments of Big Bear Lake have returned to levels comparable to late 2003 and are near 300 µg/g dry-weight in the deeper, western part of the lake. Lower concentrations were found in the eastern portion of the lake that tends to be shallower and also subject to more intense wind- and wave-action. The mobile-P content of sediments was strongly correlated with the fractal dimension of the bottom echo, which allowed use of hydroacoustic measurements to map mobile-P across the lake. Based upon the distribution of mobile-P, wave-theory calculations that delineate regions of potential sediment (and floc) resuspension, and jar test results, a region of approximately 420 acres extending about 3 km out from the dam at the western edge of the lake is thought to be most suited for an alum treatment. A dose of 70-100 g Al/m<sup>2</sup> will be needed to inactivate the mobile-P in these sediments.

### References

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