Suspended Sediments in the Channel of the Lower New Meadows Lake

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ABSTRACT

Suspended sediments can influence water quality in many ways. They can decrease the amount of light available in the water column, lead to a die-off of plant life, reduce dissolved oxygen levels, and allow pollutants to enter the body of water. This study examines the suspended sediments in the channel of the Lower New Meadows Lake, located between Bath and Brunswick, Maine, U.S.A. This lake contains a region known as the "deep hole" which has experienced problems with anoxia in the past. Water profiles were taken on two dates in fall of 2003. Continuous profiles obtained data for attenuation and fluorescence, while discrete samples were analyzed for particle size distribution, total suspended solids, percent volatile solids, and chlorophyll and phaeophytin concentrations. Our results showed that there were primarily small-sized sediments in the water column, and a high percentage of volatile solids. Total suspended solids remained relatively constant throughout the water column, while chlorophyll concentrations were greatest at the bottom depth of approximately 5 meters. The high percentage of small, organic solids is conducive to anoxic conditions because they are quickly decomposed by oxygen-consuming bacteria. Furthermore, the increase in chlorophyll concentration at the bottom of the water column suggests that there is an accumulation of dead organic matter at these depths, which will further reduce dissolved oxygen levels through decomposition. However, this increase is not as drastic as that of the deep hole, suggesting that the anoxic water is generally confined to the deeper area.

INTRODUCTION

The New Meadows River

The New Meadows River is located along the coast of Maine in the southern part of the state. (See Figure 17a in the appendix.) The lower part of the estuary is bordered by the towns of Phippsburg to the east and Harpswell to the west. The upper part of the estuary is bordered by the town of West Bath to the east and the city of Brunswick to the west. The river forms part of the boundary between Sagadahoc and Cumberland counties, which are located to the east and west of the river respectively. (See Figure 17b in the appendix.)

Between Brunswick and West Bath, two roads and one railroad cross the New Meadows River. The principle highway spanning the river is U.S. Route 1, which crosses from Brunswick into West Bath on a causeway. The portion of the river located north of Route 1 is known as the Upper New Meadows Lake. The part of the river known as the Lower New Meadows Lake, where we are conducting our study, begins south of Route 1. To the south, a railroad bridge crosses the Lower Lake. Further downstream, the Bath Road crossing marks the lower boundary of the Lower New Meadows Lake. A marina is located at this point in the river and is visible from our sampling site. (See Figure 17c in the appendix.)

The construction of these roadways has significantly altered the dynamics of the New Meadows River. Although the railroad rests on three relatively narrow supports and does not impede the river flow, the Bath Road crosses on a causeway that separates the river from the two lakes. The causeway only provides a narrow, shallow opening for the water to flow through. Heinig (2002) writes that "while the tidal range on the south side of the causeway is around nine feet, the tidal amplitude of the Lakes is measured in inches." At the same time, the land around the New Meadows River has been increasingly developed. Based on calculations from census data included in Heinig (2002), the population of the four towns bordering the New Meadows River has tripled, increasing from 10,101 in 1900 to 30,315 in 2000.

The Lower New Meadows Lake section of the river varies in depth. In our study, we have collected data in the main channel of the river. We measured the depth in the channel and found it to be 5.4 meters deep upstream from the railroad bridge. The second important site in this section of the river, found to the north of the channel, is known as the "deep hole," which we found to be approximately 8.4 meters deep. Although this site will not be our primary area of study, we have assisted other researchers in gathering data from this location and will incorporate any relevant information from their work into our report.

The New Meadows Lakes have been studied in the past by several researchers. Schaeffer (2003) collected monthly data from April 2002 to April 2003 on temperature, salinity, and dissolved oxygen throughout the deep hole. Additionally, she obtained chlorophyll *a* data and continuous measurements of temperature from August 2002 to September 2003. In the *State of the New Meadows River Report* (Heinig, 2002), the information available includes dissolved oxygen data from 1998 to 2000 in the deep hole and a profile of the river completed by Bowdoin College giving temperature, salinity, and dissolved oxygen data. However, there is a lack of information of the amount, size, and composition of sediments and a lack of information about the channel site in particular. Since we are primarily studying sediments in the river channel, the majority of our conclusions will come from our original data.

Suspended Sediments

Suspended sediments can affect water quality in many ways. First, a high concentration of sediments reduces the amount of light penetrating the water column. This will lead to decreased rates of photosynthesis, and a subsequent reduction in the number of organisms at higher trophic levels due to decreased primary production. Furthermore, the decreased rate of photosynthesis means that there would be less oxygen produced at the surface, and less organic material for bacteria to decompose at thereby consuming less oxygen in the bottom waters as well. Because the suspended particles absorb sunlight, high concentrations cause an increase in water temperature, which further reduces dissolved oxygen levels (Murphy, 2002). High levels of sediment can also affect fish and other aquatic life. For example, the sediments can clog fish's gills, inhibit their ability to see and catch prey, slow growth rates, and lead to an increase in disease (Murphy, 2002). Sediments that settle can smother fish eggs and insect larvae, and fill in spaces between rocks that provide a habitat for many organisms. As a result, changes in biodiversity will occur, as more sediment-tolerant species move in (Bartenhagen et al., 1995). Furthermore, sediments can provide a medium to which chemicals, pesticides, and heavy metals can attach, and transport these pollutants into the water. Organic sediments may also contain harmful bacteria or pathogens. In addition, dissolved organic matter can attach to inorganic particles, and lead to an increase in oxygen-consuming bacteria that feeds on such material (Lind and Davalos-Lind, 1991), which can also contribute to hypoxic or anoxic conditions. For these reasons, high sediment concentrations have a large impact on the health of the estuary.

There are many factors which influence the amount of sediment found in a body of water. Sediment, which includes both lithogenic and organic material, and can enter the water through erosion or runoff from land, inputs from tides, or as a result of re-suspension of bottom particles. Erosion can result from the weathering of bedrock from wind and water, from forest fires, and from anthropogenic factors such as road building, logging, or mining (Murphy, 2002). Runoff increases with rainfall, as well with the amount of impervious surfaces within a watershed, which cause the flow to directly enter bodies of water without first seeping through the soil. Howarth et al. (1991) have determined that urban areas contribute the greatest amount of sediments compared to other types of land cover.

Tides and other water dynamics can also have a great impact on the amount and size of particles present. Because faster currents can carry larger particles, suspended sediment concentration and size increases with flow velocities (Bartenhagen et al., 1995). Within the main channel of estuaries, currents are strongest at mid-tide (Bell et al., 2000), and there are also changes in sediment concentration with respect to neap and spring tide cycles as well (Abril et al., 1999). Within estuaries, sedimentation is greatest upstream as sediments sink to the denser salt water at the bottom of the water column, which carries them landward (Bell et al., 2000). Waves from storms can stir up estuarine sediments as well (Bell et al., 2000). Ports, marinas, and causeways can alter water currents and trap sediments (Bell et al., 2000), and dams and other obstacles reduce the amount of sediment present downstream (Willis and Griggs, 2003).

Lastly, increased sedimentation can occur from the re-suspension of bottom particles. This can result from disturbance caused by bottom-feeding fish (Murphy, 2002), as well as from wind and weather conditions. Waves created by wind have a greater capacity to re-suspend particles than currents (Luettich, et. al., 1990) and can also cause the re-suspension of bottom-dwelling phytoplankton (Carrick, et. al., 1993).

Anoxia

Anoxia occurs when the level of oxygen in the water drops to an almost non-existent level and can have a huge negative impact on the surrounding ecosystem. Oysters, clams and many other crustaceans are killed when the water where they live becomes anoxic (Officer, 1984). Many fish such as striped bass and white perch are also affected by anoxia. Fish sense the anoxic water and shy away from it, confining themselves to smaller areas with less food. In some places a lack of oxygen also prevents them from heading up the estuaries to breed (Officer, 1984). Anoxia might also affect the kind of planktonic organisms that are suspended in the estuary. In the Chesapeake Bay, where anoxic areas occur, research found that "dinoflagellates are mobile; when they encounter the anoxic water mass during their spring transport, they avoid it and continue moving up estuary along the surface of the anoxic waters near the halocline. Diatoms, on the other hand, are not mobile; when they encounter the anoxic waters in a corresponding early spring transport, they sink to the bottom and are prevented from passing into the upper and middle bay" (Officer, 1984). The severity of anoxia can depend on the season. When the water is more stratified during the spring and summer months, the anoxia is at its worst. When the winter storms come in, the estuary can become better mixed, checking the anoxia (Officer, 1984).

Sediments in anoxic areas are characterized by being black and foul smelling (Officer, 1984). Usually anoxia is confined to relatively deep channels or holes in estuaries where it is hard for the water to be well mixed. Last summer in the Lower New Meadows Lake, anoxia was detected in both the eight-meter hole and the channel but the channel has not been well studied and there is concern that the anoxia might spread even further downstream, into the healthy water of the Upper New Meadows River

We are working with the Friends of Casco Bay in order "to gain a better understanding of the processes driving the observed high nutrient-low oxygen cycle by doing a more detailed analysis of the particulate matter, including both living and non-living material, in the water column". (Friends of Casco Bay, 2003) The Friends of Casco Bay believe that studying several sites in the lake will allow people in the community to gain a better understanding about what affects the water quality in their area and will also help planners to prevent future problems such as hypoxia, shellfish closures and fishkills. This study of the main channel in the Lower New Meadows Lake examines the amount, size distribution and composition of suspended sediments. It includes a chlorophyll analysis and quantifies volatile solids.

METHODS

Background

For this project, we studied the channel of the Lower New Meadows Lake, sampling just north of the railway bridge. Water samples and/or profile data were collected on two dates in fall of 2003: September 25th and October 9th. On both days, the weather was sunny and in the low 70°'s; however, on the first day, there was a strong wind present. We located the deep channel leading out of the lake with a depth sensor, which showed a bottom depth of 5.4 meters at its deepest point. On the first sampling date, we took one-liter water samples every meter from the surface to a depth of five meters using a water bottle sampler. We stored these samples in lightproof bottles and packed them in ice to prevent further growth or degradation of organic material. These samples were later analyzed in the lab for chlorophyll and phaeophytin, total suspended solids, volatile solids, and particle size distribution. On both sampling dates, we also obtained continuous data *in situ* for fluorescence and attenuation using an optical profiler.

Fluorescence and Attenuation

Fluorescence and attenuation were measured using a WETlabs ac9 optical profiler with a depth sensor and digital chlorophyll fluorometer. The profiler was deployed over the side of the boat and lowered to the bottom of the lake, and then retrieved. Two profiles were taken at the site on each date. The data from these two profiles were then averaged and graphed using Excel, plotting points for every tenth of a meter throughout the water column.

Chlorophyll Analysis

In order to determine the amount of chlorophyll in our samples, we filtered 50mL triplicates from samples taken every meter from zero through five meters, giving us eighteen filtered samples. We placed each filter in a labeled centrifuge tube with ten milliliters of 90% acetone solution. vortexed them, and immediately placed the samples in the freezer to ensure that they were preserved without too much change. We returned a week later to finish processing the samples. The Turner Fluorometer was calibrated with a blank tube with 90% acetone solution at each scale. We then processed our samples in groups of six, shaking, vortexing, and centrifuging each one for five minutes. For each sample, we filled a glass fluorometer vial from the centrifuge tube and placed it into the fluorometer, changing the scale so that the sensitivity would read between two and eight. We recorded the reading and the scale for each sample. Three drops of HCL acid were added to each sample. Once we had a reading on each of the six samples we used the same process to obtain readings on the now acidified samples. We then converted our results into mg/m^3, the units for chlorophyll and pheophytin concentration.

Total Suspended Solids and Volatile Solids

In the Bowdoin College geology laboratory, we filtered 500 ml of each water sample through a glass fiber filter to trap all the suspended solids in the water. These filters had been combusted in a muffle furnace to remove any preexisting matter that could contaminate our samples. We pre-weighed each individual filter after combusting them because variations in manufacturing cause slight differences in weight. After filtering, we then dried our filters in a drying oven for one hour at 100º C to remove moisture and weighed them again. The difference between the original filter weights and the new weight allowed us to determine the *total amount of suspended solids* (TSS) by weight in the volume of water filtered. We then calculated the TSS concentration in milligrams per liter (mg/L).

Once we obtained the TSS per unit of water, we differentiated between organic and inorganic solids. The organic, or volatile, solids burn off under substantial heat while the inorganic solids are resistant to heat. We placed our filters in a 450º C muffle furnace for five hours and compared the new weights of the filters with the previous weights to find the *percentage of volatile solids* (% VS).

Particle Size Distribution

Attenuation is the scattering of light by particles. Particles of greater size tend to scatter the light in forward angles. Therefore, we can determine the quantity of particles per milliliter and their size distribution by measuring the amount of light reflected at any given angle. We used an instrument called a LISST (Laser In Situ Scattering Transmissometer, Sequoia Inc.) to measure the size distribution of the samples collected on September 25. The instrument projects light through a container filled with the sample water and measures the amount of light scattered into various rings representing scattering angles. Although the instrument is capable of taking measurements at the actual site, we found it more convenient to bring samples into the lab. The actual test consists of filling the container and running a computer program which operates the LISST and records data. We repeated each test three times to ensure accuracy.

Data Analysis

We graphed all the discrete raw data we obtained for chlorophyll and phaeophytin concentration, total suspended solids, total volatile solids, and percent volatile solids using Microsoft Excel. These graphs showed us the changes in concentrations of the various parameters with respect to depth from the surface to five meters deep. In addition, we graphed the total number of particles and the particle size distribution, which we obtained from the LISST, for every meter in depth.

We also graphed the raw continuous data for attenuation and fluorescence. However, because these parameters are indirect indicators of the amount of suspended solids and chlorophyll present in the water, rather than the actual values, we needed to convert these results to units of TSS and chlorophyll, calibrating the in situ observations based upon discrete sample analysis. We did this by plotting the values obtained for TSS at each meter vs. the values of attenuation at the same depth on one chart, and the values of fluorescence vs. the values of chlorophyll concentration on another. For each chart, we calculated a linear regression line and used the equation of the line to convert the attenuation to TSS and fluorescence to chlorophyll concentration. We then created graphs showing the new, continuous profiles for total suspended solids and chlorophyll concentration.

RESULTS

Suspended Sediments

The data in Figure 1 were obtained by using a LISST. The figure represents the number of particles in the water sample. The concentration of particles was greatest at the surface. It then decreased between the surface and the 1-meter depth, stayed constant until the depth of 3 meters, increased slightly at approximately 4 meters, and decreased by the same amount at 5 meters.

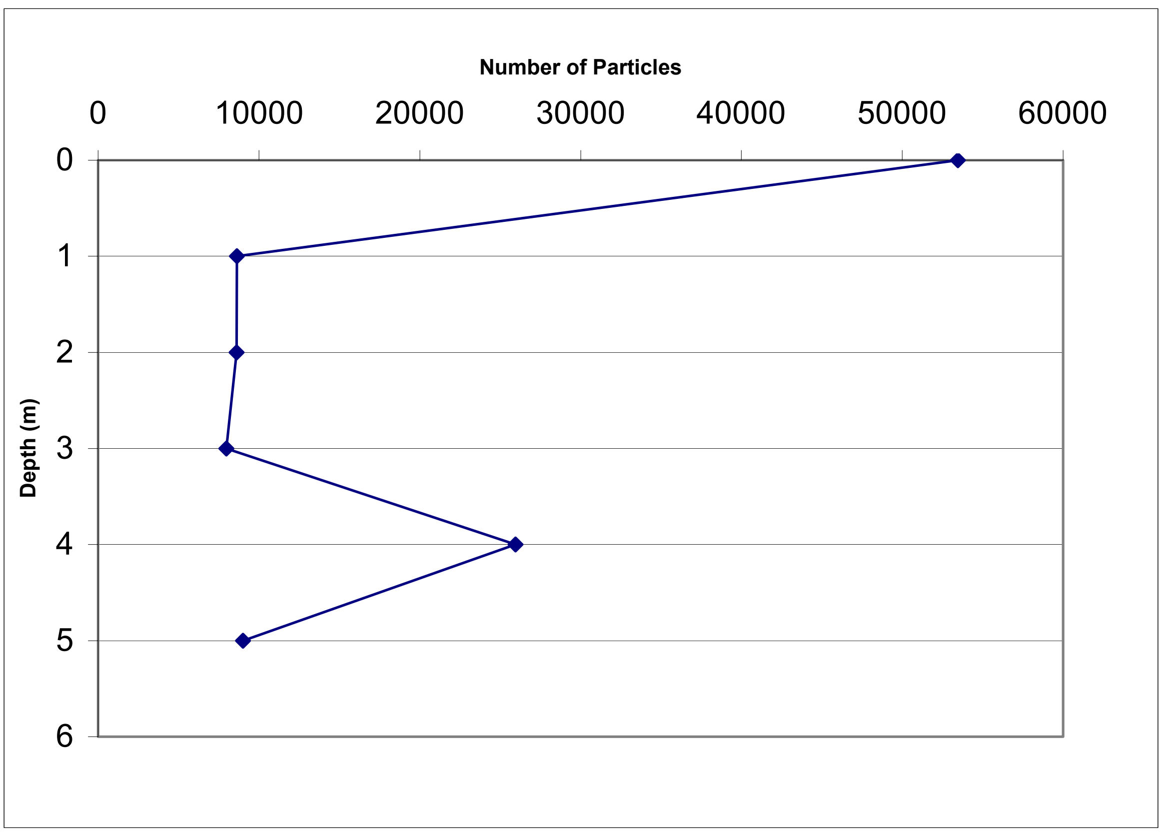

Figure 1. Concentration of particles in the water column using LISST. Channel observation site, Lower New Meadows Lake, September 25, 2003.

Figures 2 displays the number of particles of different diameters found at each measured depth. There were large quantities of small particles between 1 and 12 um at the surface and at a depth of four meters. At other depths, large quantities of these particles between 3 and 12 um were seen. The greatest concentration of all particle sizes was at the surface and at 4 meters. The largest particles were only found at the surface.

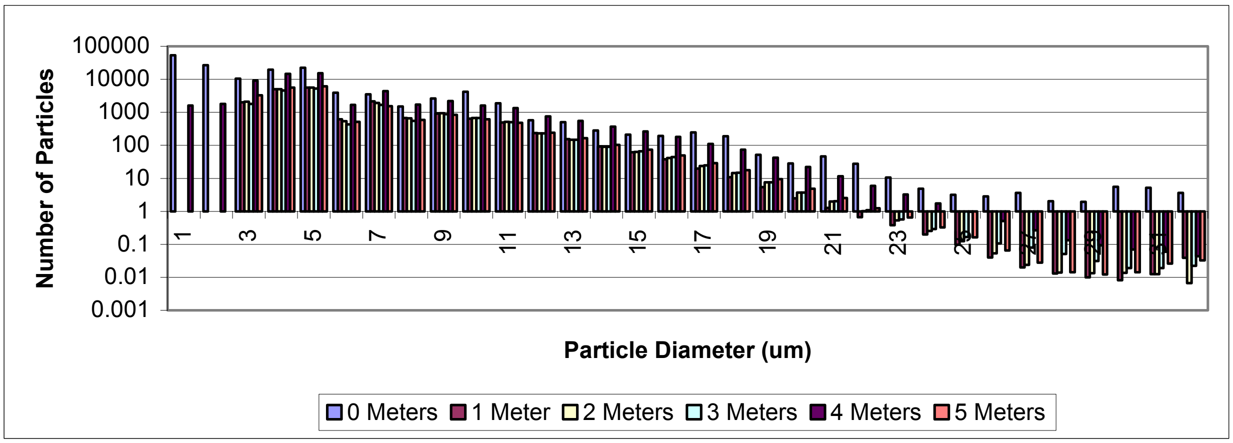

Figure 2. Quantity of particles of different sizes throughout the water column. Obtained using LISST, September 25, 2003.

Figure 3 shows the relationship between attenuation and depth. Attenuation was greatest between 1.5 meters and 3 meters. Attenuation then decreased at a constant rate and reached its lowest levels at the bottom of the profile. The profiles were very similar on both days.

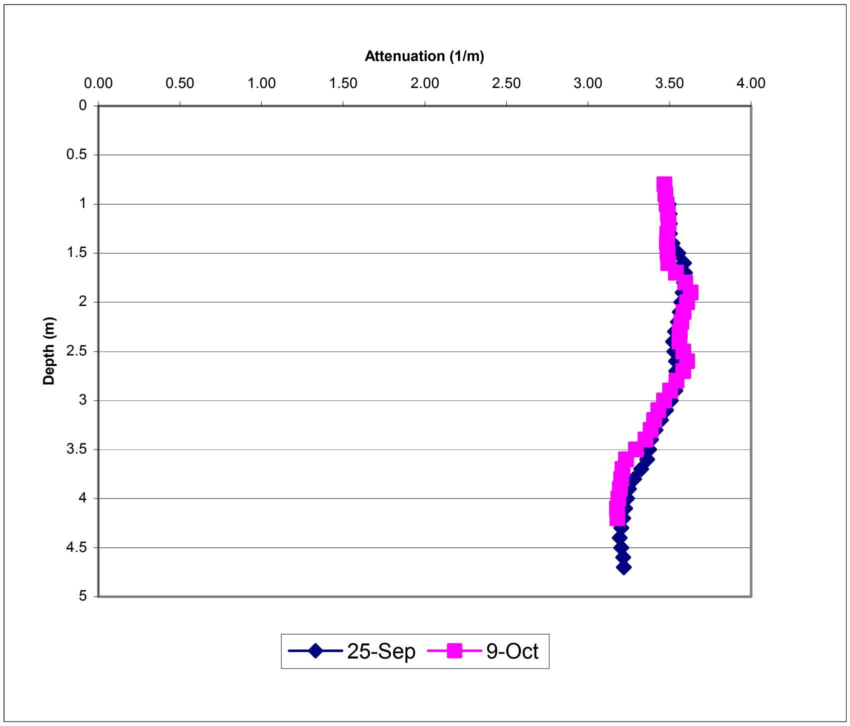

Figure 3. Continuous profiles of attenuation using AC9 Optical Profiler. Channel observation site, Lower New Meadows Lake. Fall 2003.

Figure 4 shows the amount of total suspended solids (TSS) throughout the water column. TSS was steady between the surface and three meters. It increased from three meters to its highest point at four meters before it decreased at the bottom of the water column.

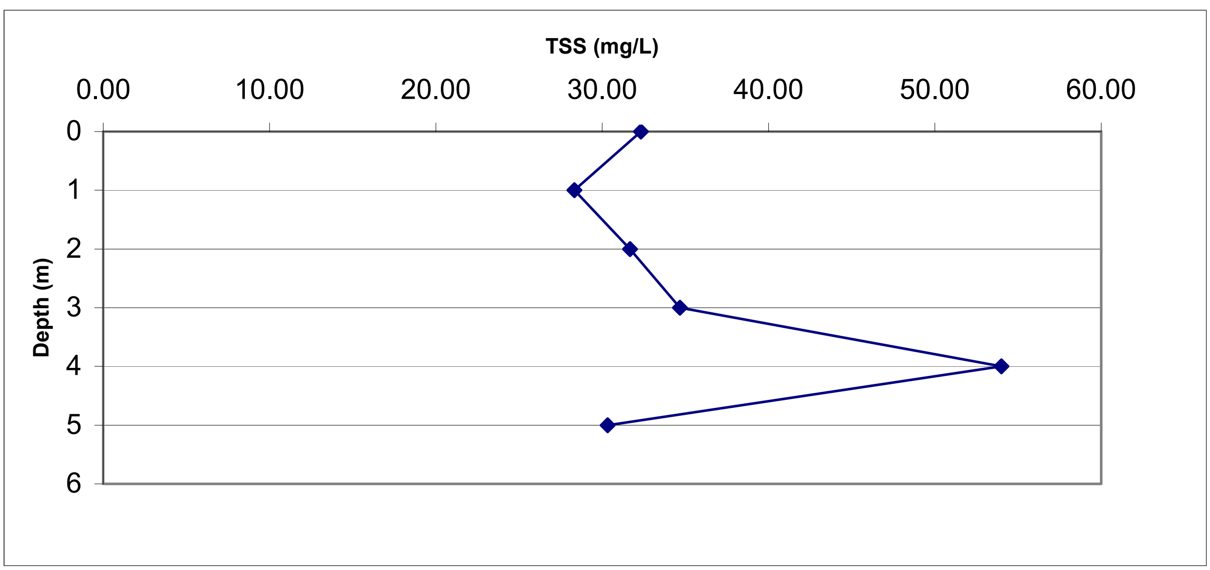

Figure 4. Discrete measurements of total suspended solids (mg/L). Channel observation Site, Lower New Meadows Lake. September 25, 2003.

Figure 5 shows the linear relationship between attenuation and total suspended solids. Attenuation is significant because it is an indicator of total suspended solids. We plotted the two parameters against each other and found a linear regression line showing the relationship of attenuation to total suspended solids. These data points are taken from observations made at the deep-hole sampling site by Perry and Voinot-Baron (2003).

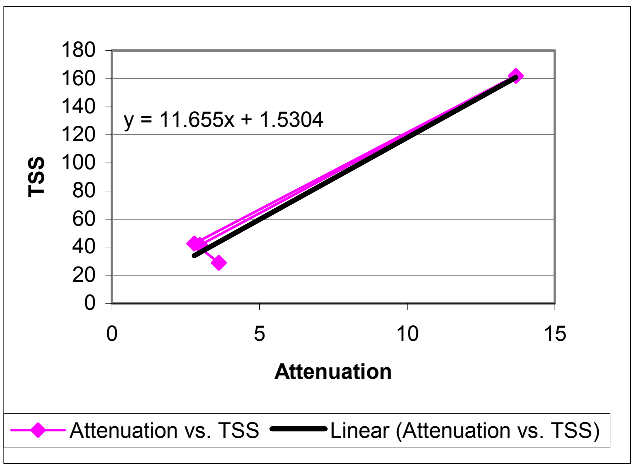

Figure 5. Comparison of attenuation versus total suspended solids, with regression line.

Using the relationship found in Figure 5, we converted our measurements of attenuation into concentrations of total suspended solids throughout the water column. Figure 6 is a continuous plot of total suspended solids throughout the water column. The values remain relatively constant throughout, with a slight peak between 2 and 3 meters.

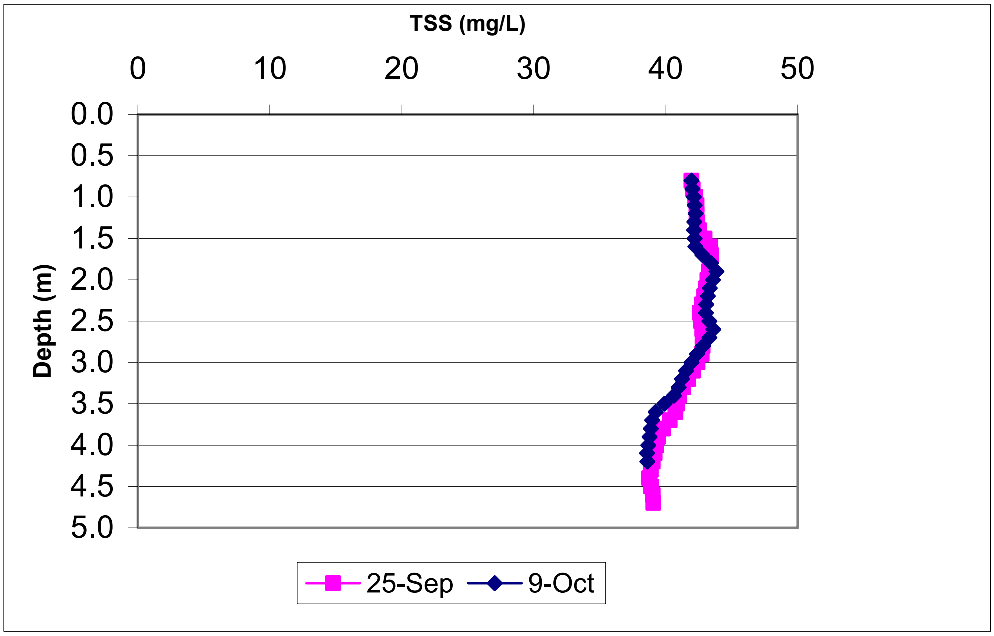

Figure 6. Profiles of total suspended solids (TSS in mg/L) based on attenuation. Channel observation site, Lower New Meadows Lake. Fall 2003.

Figure 7 shows the percentage of the total solids that were comprised of volatile material. Throughout the entire water column, a large percentage (between 70% and 80%) of the solids were volatile. Most of the suspended matter that we see is organic material.

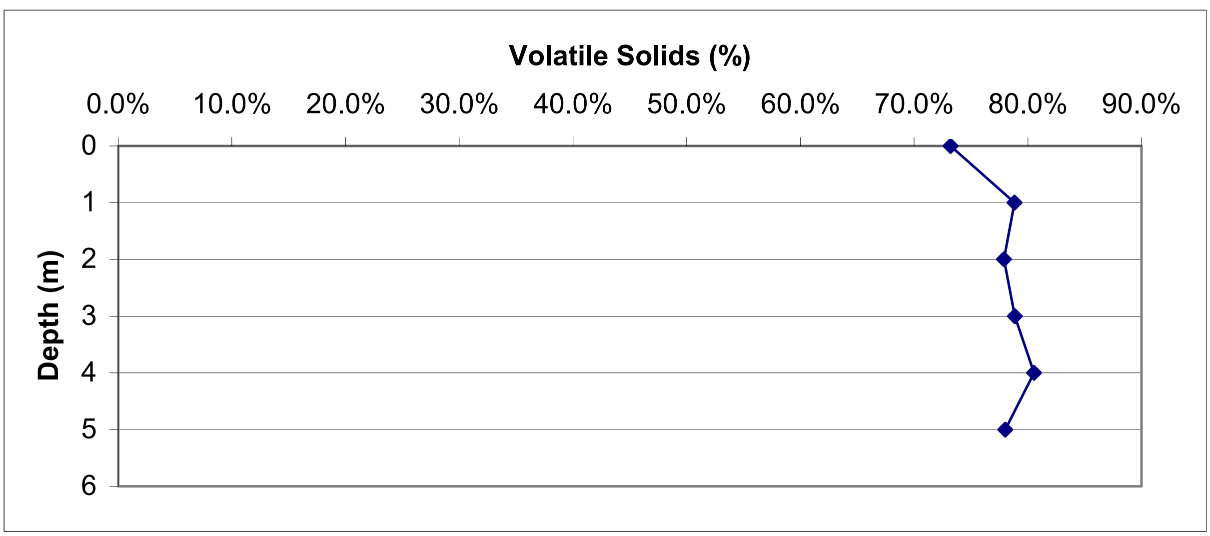

Figure 7. Percentage of total suspended solids comprised of volatile material. Channel observation site, Lower New Meadows Lake, September 25, 2003.

Chlorophyll and Phaeophytin

Figure 8 shows our discrete measurements of chlorophyll. We observed negative values at depths of 2, 3, and 5 meters and positive values at 0, 1, and 4 meters.

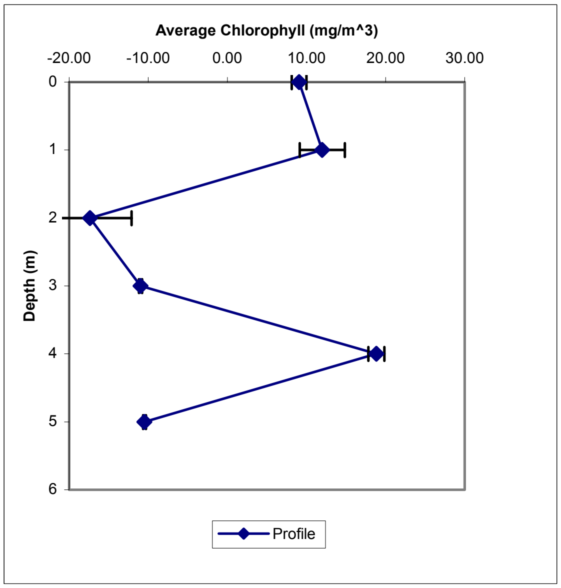

Figure 8. Discrete observations of chlorophyll *a*. Channel observation site, Lower New Meadows Lake. September 25, 2003.

Figure 9 shows how fluorescence counts vary with depth throughout the water column. The fluorescence counts increase to a depth of about 2.5 meters and then decrease slightly until increasing again at depths of between 4 and 4.5 meters to a peak at the bottom of the profile.

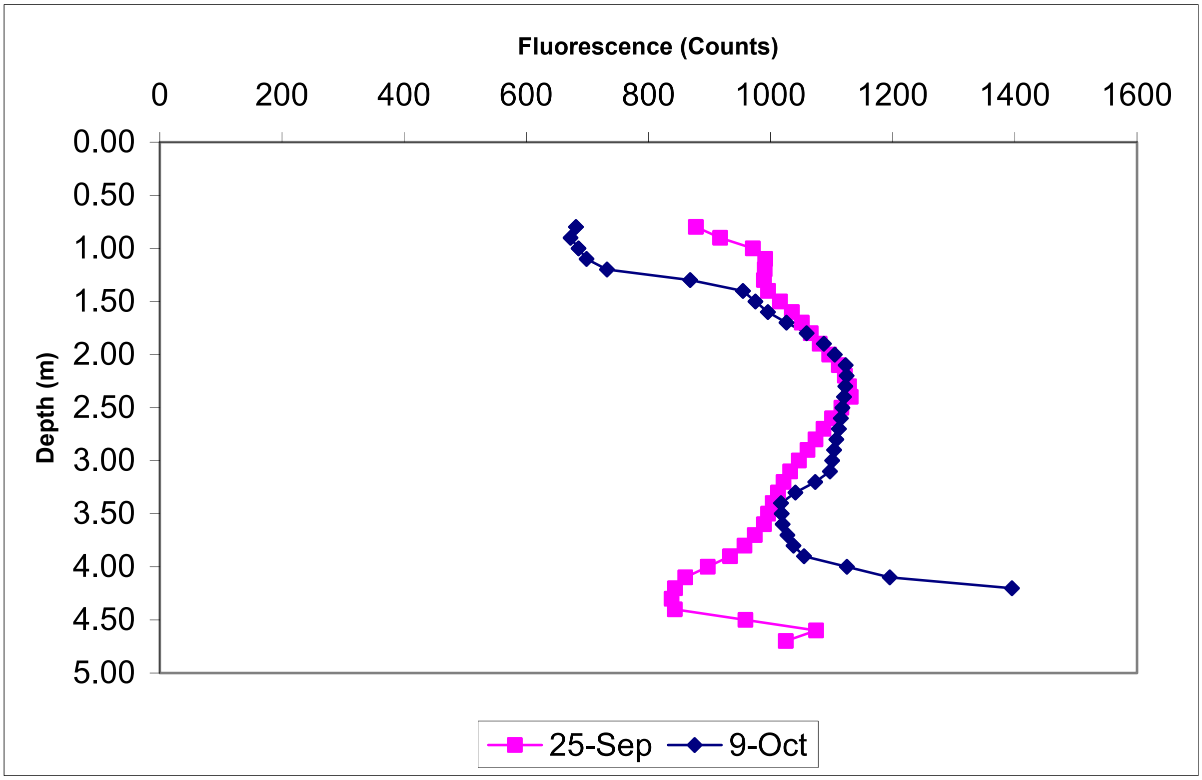

Figure 9. Fluorescence counts throughout the water column. Channel observation site, Upper New Meadows Lake. Profile 1 recorded on September 25, 2003. Profile 2 recorded on October 9, 2003.

Using the relationship between chlorophyll and fluorescence found by Perry and Voinot-Baron (2003), we calculated chlorophyll levels throughout the water column based on our fluorescence data, as shown in Figure 10 using the equation *Chlorophyll = (Fluorescence – 285.95) / 42.508*. Chlorophyll values were lowest at the surface. A local maximum was found around 2.5 meters and an absolute maximum chlorophyll concentration was recorded near the bottom of the profile.

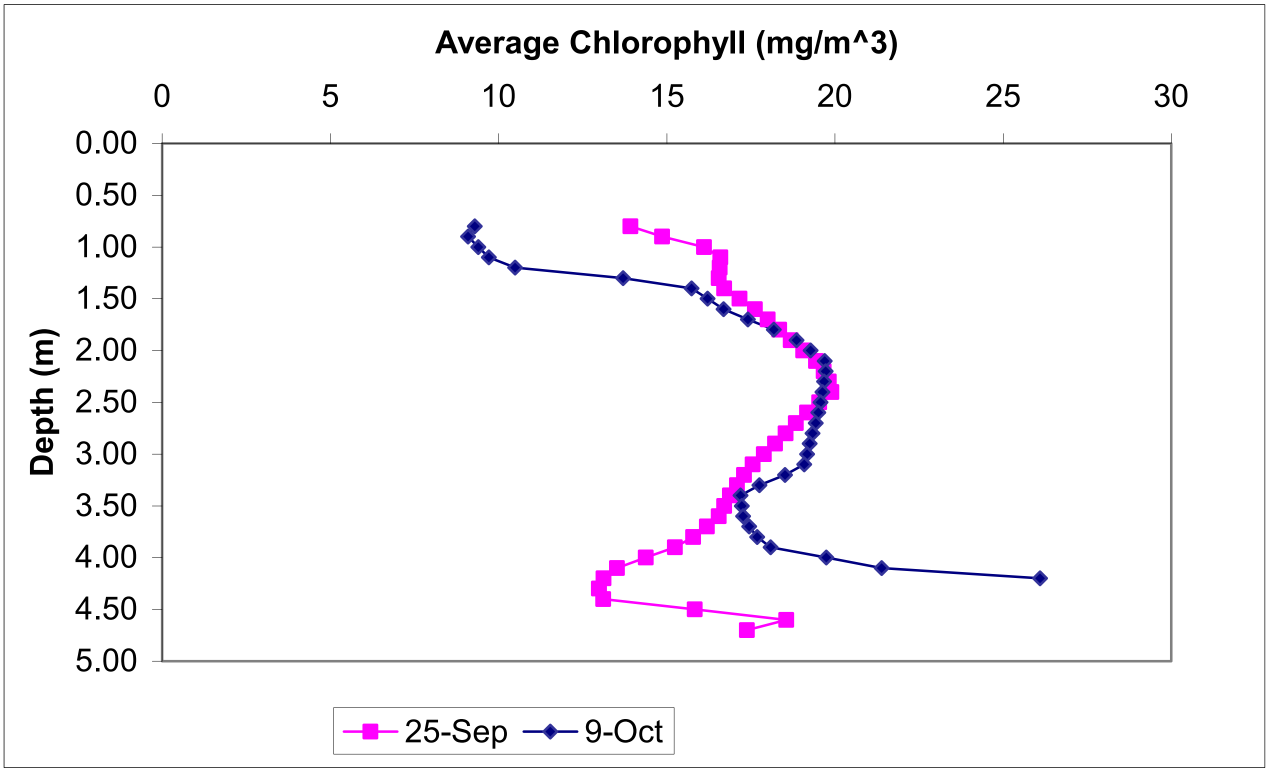

Figure 10. Chlorophyll throughout the water column as calculated from levels of fluorescence. Channel observation site, Lower New Meadows Lake. Fall 2003.

Figure 11 displays the average amount of phaeophytin throughout the water column. Very little phaeophytin was present at the surface, but the quantity rapidly increased to a maximum at 2 meters. The quantity decreased at 4 meters but rose considerably at the bottom of the water column.

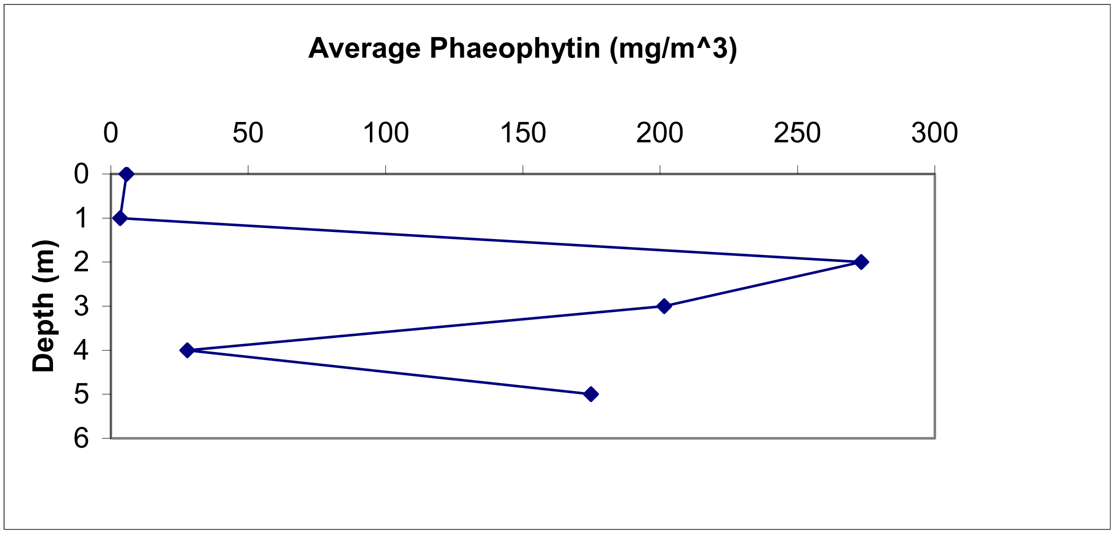

Figure 11. Average amount of phaeophytin present throughout the water column. Channel observation site, Lower New Meadows Lake, September 25, 2003.

DISCUSSION

Total Suspended Solids

The results of our study have numerous implications for the water quality of the Lower New Meadows Lake. First of all, we found a relatively high concentration of total suspended sediments--between approximately 35 and 45 mg/L, which was consistent throughout the water column. This is likely to contribute to hypoxic or anoxic conditions because the high turbidity would prevent sunlight from reaching the lower depths of the lake, leading to a die-off of plants and phytoplankton. This would cause a decrease in the amount of oxygen produced through photosynthesis, as well as an increase in the oxygen-consuming bacteria that decompose dead organic matter (Murphy, 2002). Furthermore, the sediments would absorb sunlight, leading to an increase in water temperature, and a further reduction of dissolved oxygen levels (Murphy, 2002). The sediments would also provide a means for pollutants such as chemicals, heavy metals, pesticides or pathogens to enter the lake (Bartenhagen et al., 1995).

In addition, we found that an extremely high percentage of the suspended sediments consisted of organic material--between 70 and 80 percent. This pattern is characteristic of eutrophic conditions, in which high nutrient levels lead to a bloom in algae or other plant matter, as well as the oxygen-consuming bacteria that decompose them, reducing dissolved oxygen levels. These findings verify the cause of the anoxic conditions that were detected in the deep hole and channel of the lake this past summer. Such conditions are likely to adversely affect shellfish, fish and other life forms in the lake (Officer, 1984).

When we compare the distribution of total suspended sediments and volatile solids throughout the water column, we can see that there are more inorganic solids at the top of the water column. This suggests that the inorganic sediments we saw were from erosion and runoff rather than stirred up sediments from the bottom. The lack of inorganic solids at the bottom of the water column tells us that there was little current movement there, both to move the sediments and to move the water. Therefore we do not expect to see much movement of water from the deep hole out into the channel.

Particle Size Distribution

The particle size throughout the water column gives us information about the amount of decomposition in the water. Smaller particles decay faster than larger particles and faster decay uses more oxygen (Roesler, 2003). In the water column at the channel, we saw mostly very small particles through the whole water column, contributing to low levels of oxygen in the water.

Chlorophyll and Phaeophytin

The levels of chlorophyll and phaeophytin found at our site were key indicators of the causes of dissolved oxygen levels. Chlorophyll levels indicate the amount of phytoplankton throughout the water column, which produce oxygen during photosynthesis. Phytoplankton is the major source of dissolved oxygen production. Conversely, the phaeophytin levels indicate the amount of decaying plant matter, because phaeophytin is produced when chlorophyll disintegrates. As discussed in Murphy (2002), bacteria decompose this decaying plant matter and consume oxygen during this process. Because the total amount of suspended solids was overwhelmingly organic, the organic components of our analysis become very significant.

We found negative values for chlorophyll in our discrete samples at depths of 2, 3, and 5 meters. It is not scientifically possible to have negative amounts of chlorophyll. Our samples were distorted by the presence of large amounts of colored dissolved organic matter. Normally, this dissolved matter and chlorophyll fluoresce under different wavelengths of light, but the unusually large amount of dissolved matter overlapped with the chlorophyll and caused an inaccurate reading. The levels of dissolved matter were reflected in high levels of phaeophytin that we found at the same depths.

More accurate values of chlorophyll were derived from the continuous fluorescence profiles. When converted into values of chlorophyll, the trends mimicked known phytoplankton growth patterns as discussed in Garrison (2003). The values were relatively low at the surface because direct exposure to sunlight and harmful ultraviolet light can damage chlorophyll. It was sunny and very warm on October 9, which may have harmed surface growth even more and contributed to the difference in surface values between our two profile dates. The profiles converged to their local maxima at a depth of around 2.5 meters and tended to show similar values in this range. At lower depths the amount of chlorophyll decreased slightly as lower levels of light could penetrate to those depths. Throughout our water column we found evidence of ample amounts of phytoplankton to produce oxygen. The hypoxic and anoxic conditions found in this area do not appear to be related to low oxygen production at our site.

Interestingly, the profile indicates a spike in chlorophyll levels at the bottom of the profile. As chlorophyll levels declined at upper depths due to lack of light for photosynthesis, it is improbable that phytoplankton could have thrived here. This spike can probably be attributed to dead organic matter. There was an increase in phaeophytin at the lowest sample depth. The presence of bacteria decomposing this dead matter could have led to a higher demand for oxygen resulting in a decrease in dissolved oxygen quantity.

Our second profile shows the location of this spike to be about 0.5 meters higher in the water column than in the earlier profile. Theoretically, this could be explained by a change in the stage of the tidal cycle between sampling dates, but the low tidal range in this part of the estuary defies this explanation. If one sample had been taken during a spring tide and another during a neap tide, the change in water level could also explain this. However, spring tides and neap tides repeat every two weeks (Garrison, 2003) and our samples were taken two weeks apart, meaning that they would have been taken at the same tidal stage. Dead matter falling from the productive upper regions of the water column provides a logical source for the deep layer of decaying material. However, given the mobility of this layer, it is possible that it could have originated at the deep-hole sampling site or at another location.

Implications for Anoxia

Finally, one of the purposes of our study was to determine whether it was likely for the anoxic water from the deep hole to flow out of the lake through the channel, and contaminate the Upper New Meadows River downstream of the Bath Road causeway. When we compare our TSS profiles to those obtained in the deep-hole region of the lake (Perry and Voinot-Baron, 2003; see appendix), it is evident that the two sampling sites show similar concentrations of suspended solids from the surface until a depth of approximately 4.5 meters. This trend is evident with respect to chlorophyll concentrations as well. The similarity between the two sites suggests that the same water mass encompasses both the deep hole and the channel of the lake. However, our profiles were more closely related to the profiles taken from the deep hole on the first sampling date, September 25, than the ones taken on October 9. This suggests that there is at least some flow from the shallower depths of the deep hole region downstream toward the channel, although it is a very slow process that requires several weeks' time.

Although the water column in the channel showed a similar profile to that of the deep hole until a depth of 4.5 meters, it does not necessarily mean that the anoxic water from the deep hole will spread into the channel. Whereas the TSS concentrations were all below 50 mg/L between the surface and 4.5 meters for both sites, there was a sharp increase to upwards of 150 mg/L in the deep hole between 5 and 8 meters. These values were not evident in the channel site. Similarly, the chlorophyll concentrations were below 25 mg/m^3 between the surface and 4.5 meters in both sites, but increased to almost 50 mg/m^3 below 5 meters in the deep hole. Again, such high concentrations were not found in the channel. Because high TSS and chlorophyll concentrations both indicate anoxic or hypoxic conditions, it would appear that the water with the lowest dissolved oxygen levels is confined to the greater depths of the deep hole. Dissolved oxygen data from the two sites verifies this prediction (Smith et al.; Rodriguez and Dunham, 2003; see appendix). Although there is a decrease in dissolved oxygen content from between 110-140 percent saturation at the surface to about 50 percent saturation at a depth of 5 meters at both sites, only in the deep hole does the water become nearly anoxic below 5 meters in depth. Therefore, we may conclude that, at the time of the study, the anoxic water was confined to the deeper regions of the lake. However, because the water at shallower depths appears to flow from the deep hole to the channel, it is possible that, if the anoxic level were to rise above 5 meters in depth, this water could spill over the lip of the deep hole and into the channel, getting transported further downstream.

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LITERATURE CITED

Abril, G., Etchebar, H., Le Hir, P., Bassoullet, P., Boutier, B., Frankgnoulle, M. 1999. Oxic/Anoxic Ocillations and Organic Carbon Mineralization in an Estuarine Maximum Turbidity Zone (The Gironde, France). *Limnology and Oceanography*. Vol. 3, No. 5.

Bartenhagen, K.A., Turner, M.H., Osmond, D.L., 1995. "Water Shedss: Sediment." North Carolina State University. Internet. Available at http://h2osparc.wq.ncsu.edu/info/sediment.html. (Accessed October, 2003).

Bell, R., Green, M., Hume, T., and Gorman, R., 2000, "What regulates sedimentation in estuaries." National Institute of Water & Atmospheric Research. Internet. Available at http://www.niwa.cri.nz/pubs/wa/08-Dec-2000/estuaries.htm. (Accessed October, 2003).

Carrick, H.J., Aldridge, F.J., Schelske, C.L., 1993. Wind Influences Phytoplankton Biomass and Composition in a Shallow, Productive Lake. *Limnology and Oceanography*. Vol. 38, No.6.

Friends of Casco Bay, 2003. "Examining Suspended Sediments in Lower New Meadows Lake." Internet. Available at http://academic.bowdoin.edu/courses/f03/geo103/dissemination/NM_SS_descr.pdf (Accessed December, 2003).

Garrison, T., 2002. *Oceanography: An Invitation to Marine Science* (4th ed.): Pacific Grove, CA, Brooks/Cole, 554 p.

Heinig, C.S., 2002. State of the New Meadows River: A report on the current environmental and resource status of the New Meadows River and surrounding watershed: New Meadows River Watershed Project. Internet. Available at http://academic.bowdoin.edu/courses/f03/geo103/NM_SS.shtml. (Accessed October, 2003).

Howarth, R.W., Fruci, J.R., and Sherman, D., 1991. Inputs of Sediment and Carbon to an Estuarine Ecosystem: Influence of Land Use. *Ecological Applications*. Vol. 1, No. 1. p. 27-39.

Lind, O.T., Davalos-Lind, L., 1991. Association of Turbidity and Organic Carbon with Bacterial Abundance and Cell Size in a Large, Turbid, Tropical Lake. *Limnology and Oceanography*. Vol. 36, No. 6.

Luettich, Jr., R.A., Harleman, D.R.F., Somlyody, L., 1990. Dynamic Behavior of Suspended Sediment Concentrations in a Shallow Lake Perturbed by Episodic Wind Events. *Limnology and Oceanography*. Vol. 35, No. 5.

Murphy, S., 2002. "General Information on Solids." Boulder Area Sustainability Information Network. Internet. Available at http://bcn.boulder.co.us/basin/data/FECAL/info/TSS.htm/. (Accessed October, 2003).

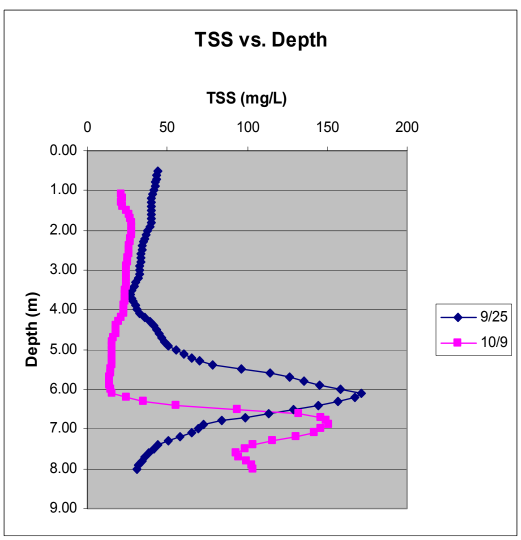
Officer, C. et al., 1984. Chesapeake Bay Anoxia: Origin, Development, and Significance. *Science*. Vol. 223, No. 4631.

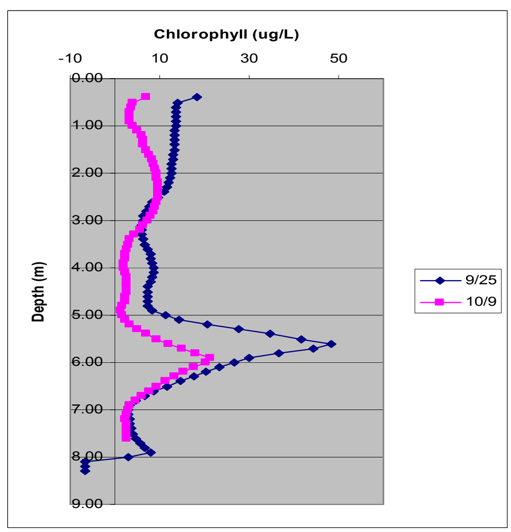
Roesler, Collin. Personal Interview. Nov. 20, 2003.

Schaeffer, D., 2003, Seasonal Trends Affecting Water Quality in the Lower Lake of the New Meadows River Estuary: Bowdoin College. Internet. Available at http://academic.bowdoin.edu/courses/f03/geo103/NM_SS.shtml. (Accessed October, 2003).

Willis, C.M., Griggs, G.B., 2003. Reductions in Fluvial Sediment Discharge by Coastal Dams in California and Implications for Beach Sustainability. *Journal of Geology*. Vol. 111, No. 2.

APPENDIX





Figures 13 and 14. Profiles of total suspended solids and chlorophyll in the deep hole observation site, Lower New Meadows Lake. Fall 2003. Courtesy of Becca Perry and Will Voinot-Baron.

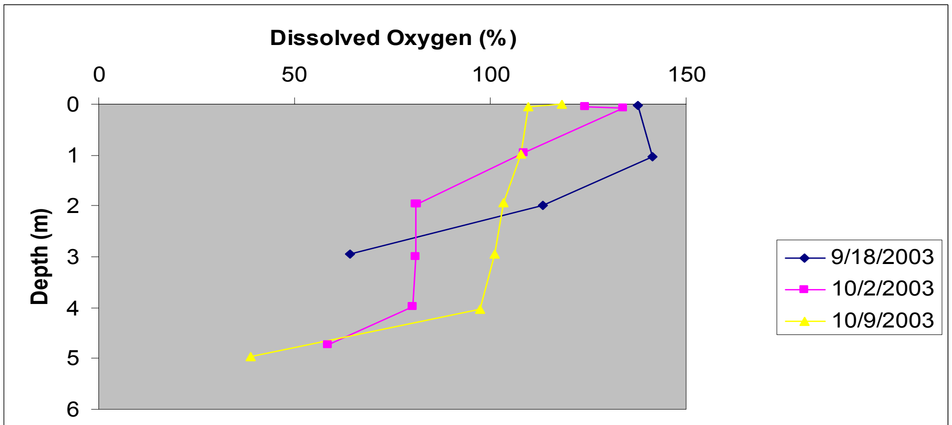


Figure 4. Dissolved Oxygen in realtion to depth at Channel sampling site.
New Meadows Lake, 2003

Figure 15. Dissolved oxygen concentration in the channel observation site, Lower New Meadows Lake. Fall 2003. Courtesy of Ben Smith, Kristen Lycett and Maya Jaafar.

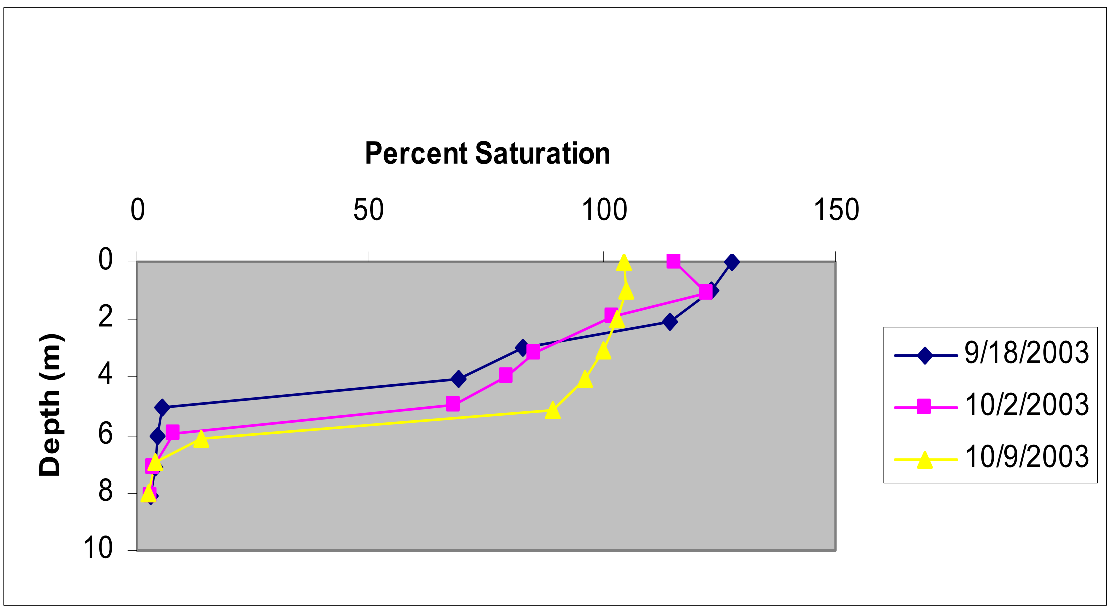


Figure 16. Dissolved oxygen concentration in the deep hole observation site, Lower New Meadows Lake. Fall, 2003. Courtesy of Astrid Rodriguez and Honora Dunham.

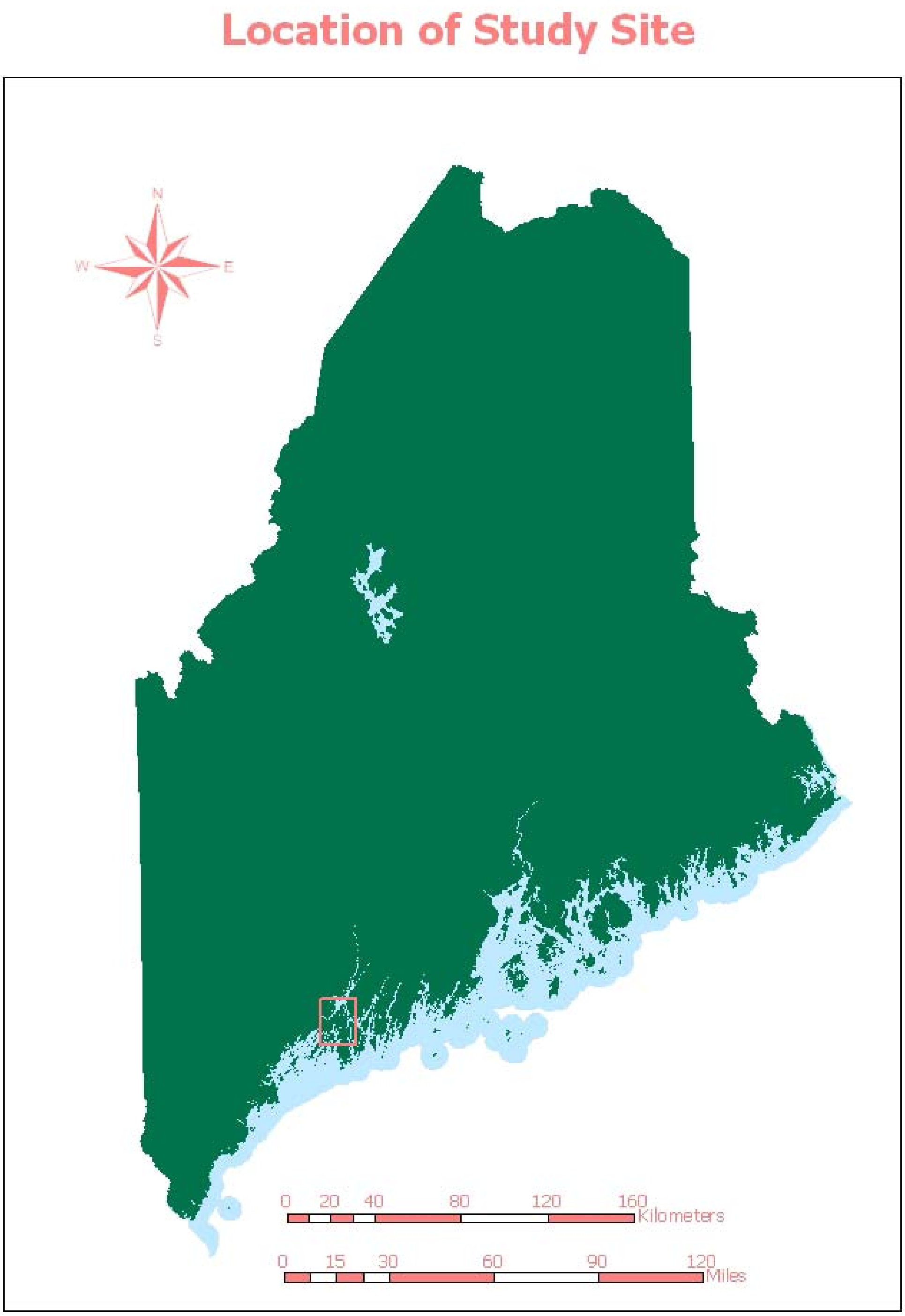


Figure 17a. Location of the New Meadows River with respect to the state of Maine

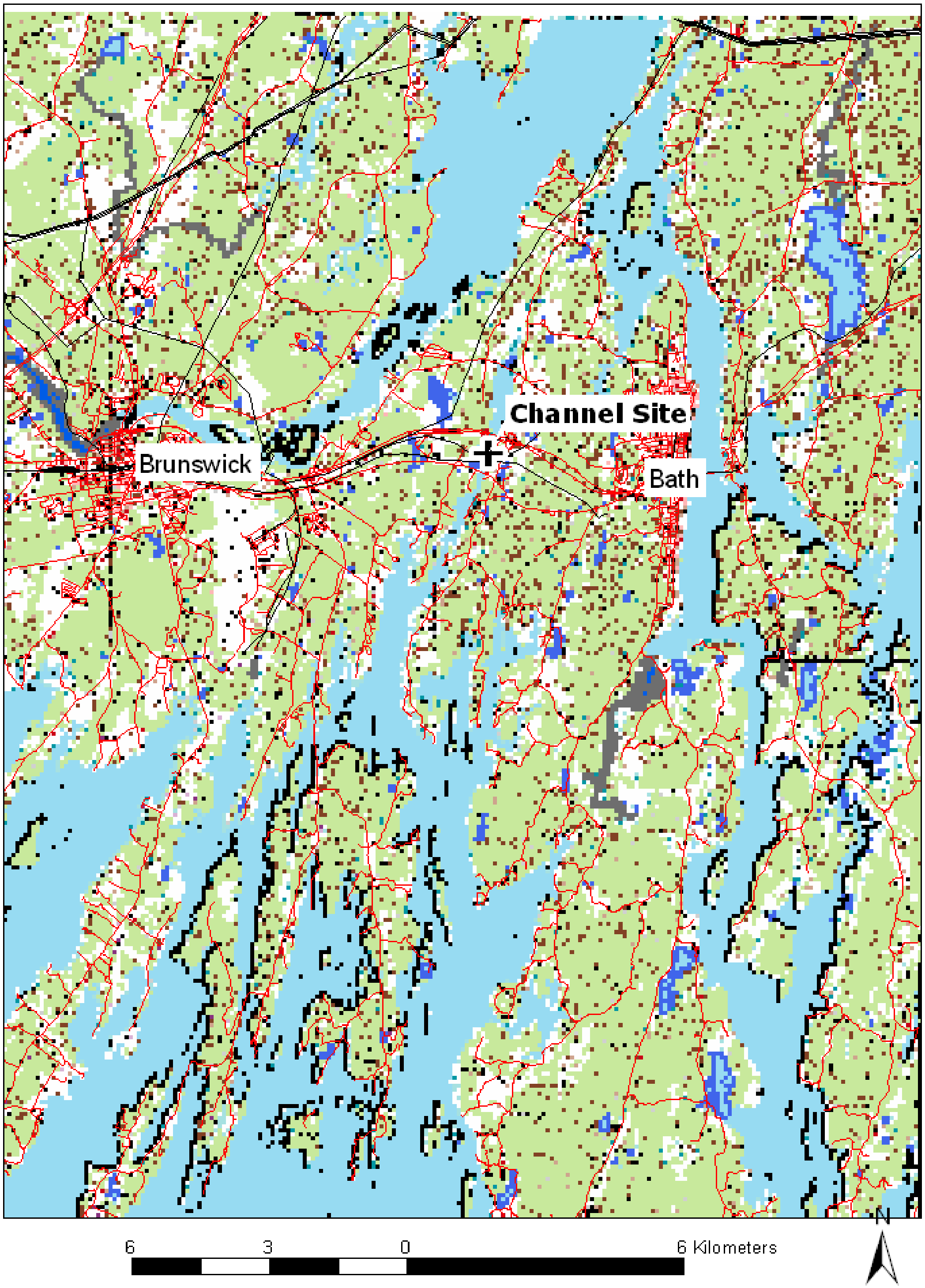


Figure 17b. Map of channel site in regards to the New Meadows River and the cities of Bath and Brunswick

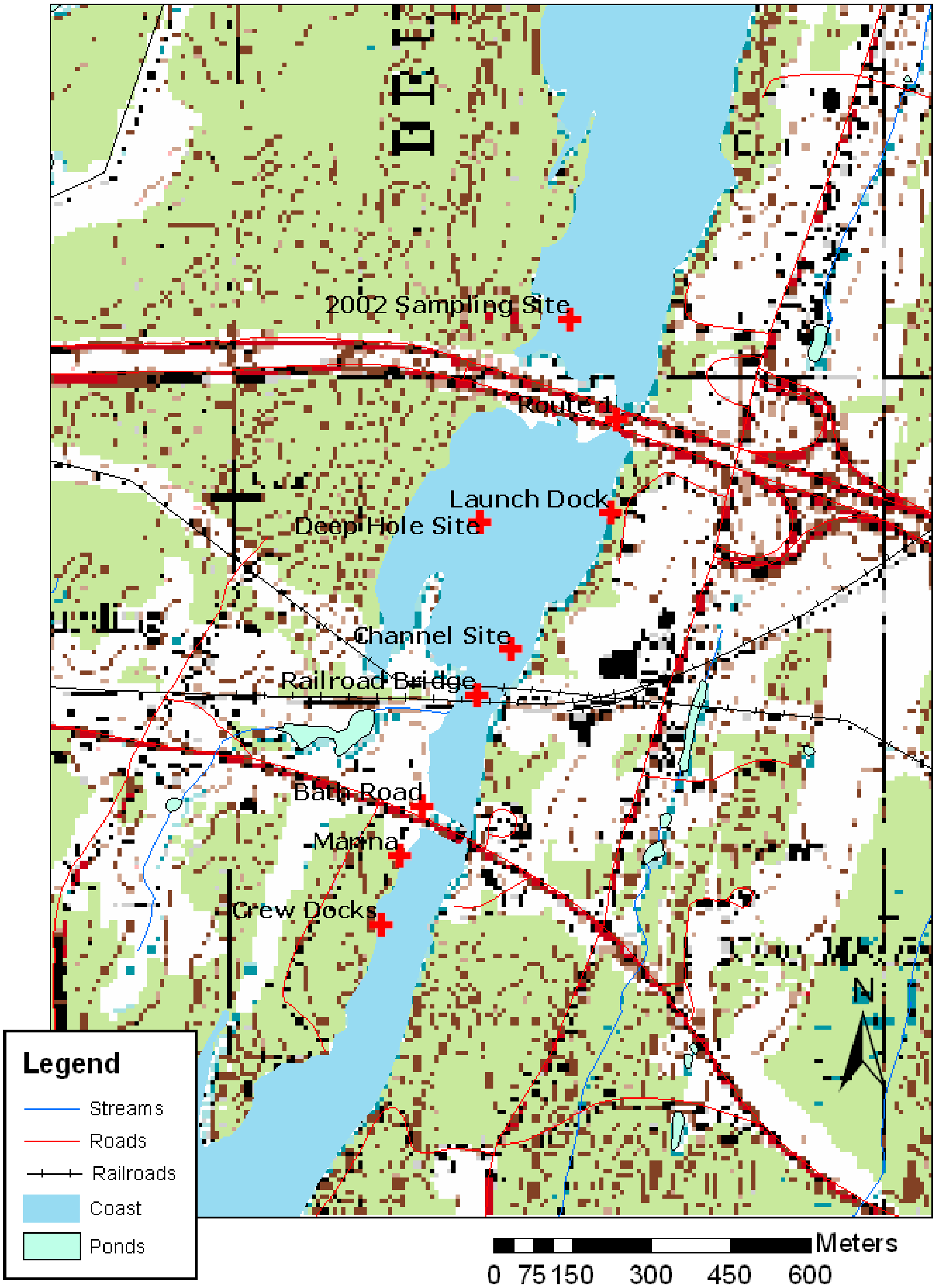


Figure 17c. Map of channel site within the Lower New Meadows Lake