The Effect of Tidal Flow Restoration on Suspended Sediments at Dingley Island

(Bowdoin College students)

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ABSTRACT

The New Meadows River Watershed Project recently sponsored an investigation of the effects of tidal flow restoration on suspended sediments in the estuarine area at Dingley Island. Data on suspended sediments were collected in May 2003, before the construction of the new causeway, which opened up water flow between the north and south sides of the bridge. To investigate any changes that occurred, we collected and analyzed similar measurements in October 2003 after the construction. The variables that we measured included total suspended solids (TSS), total particle concentration, particle size concentration, and attenuation. The results and comparisons showed that the construction of the causeway led to an increased clarity in the bottom waters and increased particle concentration in the surface. Because causeway construction was only completed in July 2003, the estuary may still be in a transitional state, subsequent data measurements may be needed in order to determine the final impact of the construction.

INTRODUCTION

Humans have long attempted to exercise our dominance over nature by altering the paths of various waterways. This is often done with little attention paid to the repercussions on the surrounding ecosystems; these actions have immense, often adverse, effects that need to be taken into consideration and are must cease to be ignored. Dams, causeways, and other forms of flow alteration have the potential to affect particle concentration, and in fragile estuarine environment this creates the potential for a major upset of the ecosystem.

Estuarine ecosystems form the transition from land to sea and fresh water to salt water. Often times these areas, weakened by the rising and ebbing tides, are protected by reefs, barrier islands, headlands, and deltas, creating a calmer environment where many animals and plants find refuge from the higher energy of the sea. Further, the estuaries' productivity makes them invaluable; they are "four times more productive in plant matter than a rye grass pasture and twenty times more productive than the open sea. [They are] extremely rich in organic matter and nutrients" (Potter, 2001). They also serve as a filtration system with microbes in estuaries breaking down organic matter and their abundant sediments binding to pollutants filtering them out of the water (Potter, 2001). Thus it is obvious that estuaries are valuable, and our effects upon them worthy of investigation.

One major aspect of human interaction with estuarine ecosystems involves the introduction of increased levels of total suspended sediments (TSS). Encompassing a wide range of solids from silt to decaying plant and animal matter, high concentrations of TSS can be extremely detrimental to health of estuaries (Murphy, 2002). Deciphering between lithogenic and organic solids will allow for an understanding of the percentage of volatile solids within the estuary, and the effect it may have on TSS. The size distribution of the particles in conjunction with the source of these particles will also be vital in understanding the manner in which sediments suspended within the water column have altered since the construction of the bridge. In studying the TSS, one can begin to create a picture of overall estuarine health; this information, in conjunction with previously documented studies and studies of surrounding areas, can be utilized to deduce just how much of an affect human-made water retention structures have on water quality and TSS.

Dingley Island is located in the New Meadows River estuary in Casco Bay near Harpswell, ME. Since at least the 1800's the estuary along Dingley Island has been harvested for soft-shelled clams, a business currently bringing in about $225,000 annually (Heining 2003).

In the 1890's, an open bridge connecting Dingley Island to the mainland was constructed which allowed tidal currents and suspended sediments to pass through. In the 1950's, the bridge was replaced by a raised causeway creating a solid barrier between the two landmasses (Figure 1), and preventing water and suspended sediments from passing through from north to south or south to north. This resulted in the deposition of sediments near and around the bridge that made conditions less favorable for clam growth and reproduction on the 45-acre flats. On May 20, 2003, a construction project was begun in an effort to restore tidal flow between the north and south sides of the causeway. The causeway remained at the same level, but a part of it was removed and replaced with a bridge (Figure 2). Construction was finished on July 31, 2003, and the hope is it that the area has been shifting towards the pre-1950's construction equilibrium.

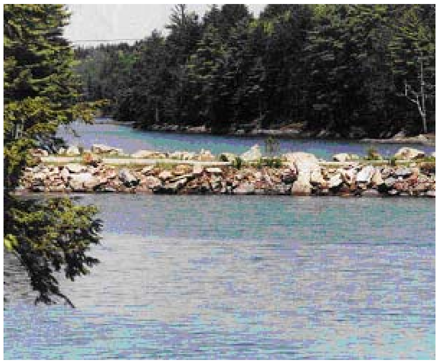

Figure 1: Dingley Island Causeway Constructed in the 1950's

Figure 2: New Dingley Island Bridge After July 2003 Construction

The main organization responsible for the state of the New Meadows estuary is the New Meadows River Watershed Project (NMRWP); a group of citizens, institutions, and federal agencies with the goal of protecting and improving the health of the New Meadows River. According to a recent survey, the New Meadows River was one of ten sites in Casco Bay that fell below the recommended state standard for dissolved oxygen because of the limited tidal flow caused by a causeway (State of the Bay Report). The Dingley Island Tidal Flow Restoration Project, supported by the NMRWP, was organized as a local citizen initiative to push for the construction of a new bridge. In this study we investigated how the sediment load has changed since the introduction of the bridge using techniques for measuring light transmission, particle size distribution, total suspended sediments and organic carbon content. This information will benefit our community partners, allowing a comparison of pre and post-construction data.

Multiple organizations conducted studies in the Dingley Island estuarine area prior to the construction of the new causeway (Heining 2003). In 2001, Duke Engineering and Services conducted two studies: "Dingley Island Sediment Assessment" and "Dingley Island Shellfish Study". In that same year, Bowdoin College students conducted two other studies: "Assessing the Oxidative State of Mudflats Prior to Causeway Restoration at Dingley Island" and "The Effect of Tidal Restrictions on Sediment Deposition at Dingley Island". In spring 2003, Bowdoin College conducted one last pre-construction study: "Effect of the Dingley Island Causeway on Mudflat Communities". In addition, in May 2003 data that was collected on the profiles of temperature, salinity, fluorescence, and light transmission, and chlorophyll *a* concentration, total suspended solids, and volatile solids. Here we compared the post-construction data that we collected to the previous studies in order to determine the effect, whether positive or negative, that the construction had on the water column habitat.

This project will hopefully provide a useful answer to the question posed by the community partners; how has the introduction of a bridge changed the sediment load of the water flowing through the Dingley Island estuary? In determining the alteration in TSS we hope to be able to interpret any changes in the overall quality of suspended sediments and their distribution. This will allow for a comparison with the previous studies performed on the area, not only allowing us to consider the change which has occurred since the introduction of the bridge, but most importantly to understand the implications of introducing a structure which alters the natural course of the water flow.

MATERIALS AND METHODS

Water Sampling

In the New Meadows River, a small estuarine area between the mainland Harpswell and Dingley Island, two samples were taken at ten total sites, five on each side of the bridge and at varying distances from it (see attached map- page 23). One sample was taken at the surface, simply by filling a one-liter water bottle by hand. A second sample was collected with a water trap one meter above the bottom, using a hand-held depth finder in order to avoid hitting the bottom and stirring up excess sediments (Figure 3). Both samples were then put in a cooler, on ice, to be taken back to the lab (Figure 4).

Figure 3: Water Trap

Figure 4: Water Samples

Total Suspended Solids (TSS)

Filters for quantifying TSS were prepared by muffling at 450 degrees Celsius for one hour to remove any organic materials that could contaminate sample measurements. All filters were weighed and recorded in milligrams. A known volume of sample water was vacuum pumped through the filters. The filters were then dried in a drying oven at 100 degrees Celsius for one hour and reweighed. TSS was computed from the difference between the final weight and the weight of the filter. The filter was then muffled again, and then weighed. This weight plus that of the filter, subtracted from the TSS, was used in an equation to quantify the total volatile solids, an indicator of organic carbon. For more specific methods, please refer to the EPA procedure.[1]

Attenuation

Continuous profiles of attenuation were collected at each station using a YSI profiler. Measurements were binned at half-meter resolution (Figure 5). The instrument internally recorded the data for each site, which was then transferred to the lab computers, and evaluated the data.

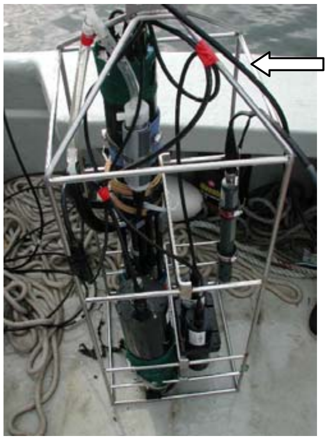

Figure 5: Profiling Instrument

Particle Size Distribution

The Sequoia LISST-100 (laser in-situ scattering and transmissometer) measured particle size distribution of the water samples (Figure 6). One hundred mL of water was poured into a beaker, and using a syringe, the sample well was filled until the sensor was submerged. Particle size distributions (in microns) were measured at one-second intervals. Triplicate measurements were run on each sample from each site.

Figure 6: LISST-100 Instrument

http://oceanography.tamu.edu/~pdgroup/photo.htm

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[1] U.S. Environmental Protection Agency, 1979. Methods for Chemical Analysis of Water and Wastes. Publ. 600/4-79-020, rev. March 1983. Environmental Monitoring and Support Lab., U.S. Environmental Protection Agency, Cincinnati, Ohio.

RESULTS

Total Suspended Sediments Measurements

Figure 7 displays TSS measurements for both May and October. In October total suspended sediment levels decrease nearest the bridge (stations N5 and S5) as compared to stations furthest from the bridge (S1 and N1). There is a similar relationship between suspended sediments in surface and deep waters. In general, the TSS levels in October of the surface water were higher than those of the deep water, except for at stations S1 and S2, where levels of suspended sediment in the deep sample were higher than the total suspended sediments at the surface. The range of data was, for bottom measurements, five to forty-five mg/L, and for surface, fifteen to thirty mg/L. At S3, however, surface and deep measurements showed TSS levels to be almost exactly equal. At the stations moving further from the causeway on the southern side, however, the pattern reversed, and TSS levels in deep water declined pronouncedly as levels in surface water experienced a strong increase. The overall pattern evident in relation to distance from the causeway shows a decrease in suspended sediment levels at the stations closest to the causeway in the surface waters, while variable data in bottom waters shows that bottom waters had somewhat less suspended sediments as well.

The May data observations prior to construction (Figure 7) are distinctly different from those in October 2003. The May data show little change in suspended sediment on either side of the causeway (note: there is no bottom data for station N5 deep), indicative of well-mixed suspended sediments throughout the estuary. Bottom water values are generally higher than those of the surface; except for at station N4, and most likely N5 can be extrapolated to be lower as well.

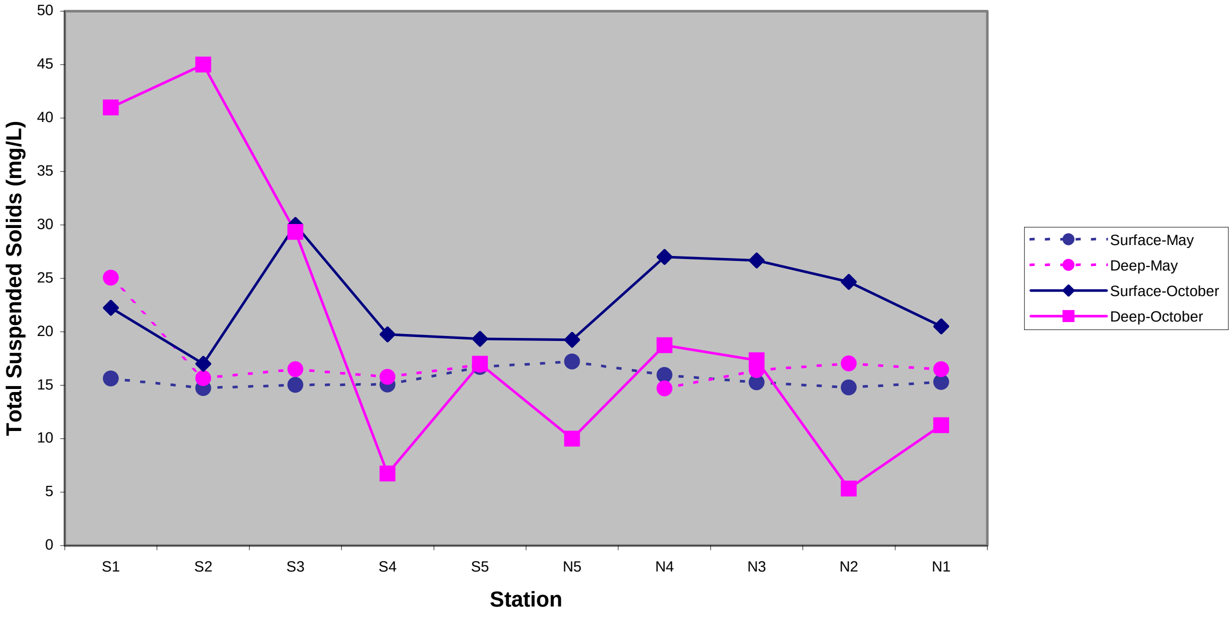

Figure 7. Measurement of total suspended sediments (mg/L) at surface and bottom depths before (May) and after (October) bridge construction. Dingley Island. 2003.

Total Particle Concentration (# of particles/mL)

Figure 8 displays data for total particle concentration for both May and October 2003. Overall, the concentration of suspended particulate matter in October 2003 remained relatively constant among all stations. There were exceptions at the deepwater sections S1 and N1, where average concentration increased relative to other stations, whose concentration ranges from 30mg/L to 5mg/L. Between stations S3 and N4, the sediment concentration in surface and deep water are similar, with surface and bottom sediment concentrations at S3 and S5 being almost exactly the same. The highest number of particles/mL was found at S1 with 98,473 particles/mL in the deep sample, and the lowest was found at N2 with 1,730 particles/mL in the surface sample.

In May 2003 (Figure 8) the concentration of suspended particles remained somewhat constant throughout the sample sites, with a significant increase in bottom sediments and surface sediments at S1. The lack of surface data at N5 must again be noted. The overall surface suspended sediments have increased from May to October 2003. There is also more difference in total suspended solids between the stations in October than there was in May. In general, there was a higher concentration of particulate matter in the bottom sample, increasing dramatically at the stations N and S5 closest to the causeway. Other than this spike, though, concentrations generally decreased from the furthest points (S and N1) as the samples moved towards the causeway. The deep samples display this trend most obviously. In analyzing the numerical concentrations, samples taken before the construction of the bridge had relatively high overall concentrations, with the lowest number of particles per mL reading 104,382 particles/mL and the highest at 191,475 particles/mL, both in surface samples.

In a comparison of the two data sets, it is most important to note the considerably lower concentrations of suspended sediment in the October samples. Whereas the lowest concentration in May was 104,382 particles/mL, the lowest concentration in October was 1,730 particles/mL. A change is also noticeable in the difference between surface and deep concentrations. In October, concentrations in both samples remained very similar, at S3 and S5 almost identical, while in May the surface samples generally had higher concentrations of particulate matter than deep samples. Deep samples did increase at the furthest points (S1 and N1) in both sets of data, however, with the deep sample in October rising nearly to 100,000 particles/mL. Although surface and deep samples showed nearly the same levels, deep samples contained slightly lower concentrations of particular matter in October 2003, while n May deep samples contained consistently higher concentrations than surface samples.

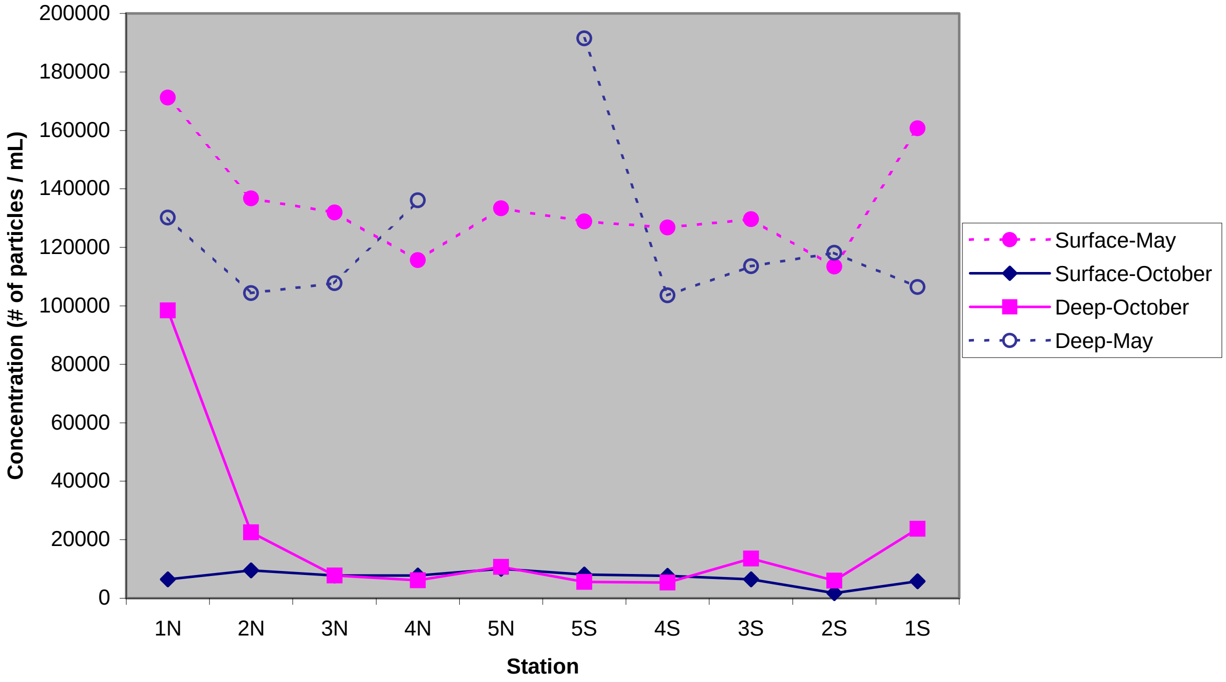

Figure 8. Total Concentration of suspended sediments before (May) and after (October) bridge construction. Dingley Island. 2003.

Attenuation

Closest to the bridge, attenuation measurements show distinct features of suspended sediment presence, that contrast sharply with nearly constant profiles taken further away from the bridge, showing that attenuation is relatively constant at all depths. This means that near the bridge there is a presence of suspended sediment present throughout the water column. There is a wide range in attenuation values (2.113 to 6.293 m^-1). Stations N5 and S5, closest to the bridge, do not follow the more linear pattern of constant attenuation found at the other stations except for the pattern of increasing towards the surface which occurs at N5 as well. Attenuation changes greatly as depth increases, with no apparent pattern except an overall increase in attenuation with depth at S5 and a decrease in attenuation with depth at N5 (Figure 9).

May 2003 data shows generally linear patterns of attenuation throughout the water column at all stations. There was a relatively small range of attenuation values (1.150 to 1.99 m^-1). In comparing data from May and October there appears to be a great change in attenuation ranges especially in those stations nearest the bridge. The stations closest to the bridge, S4 through N4, show minor changes in attenuation as depth increases, but still maintain an overall linear pattern (Figure 10).

A comparison of the two data sets shows a drastic change in attenuation pattern from October to May. Whereas May's data shows linear patterns at all stations, attenuation displayed vertical features closest to the bridge in October, indicative of much higher amounts of suspended sediment present in the water column, especially at N5 and S5.

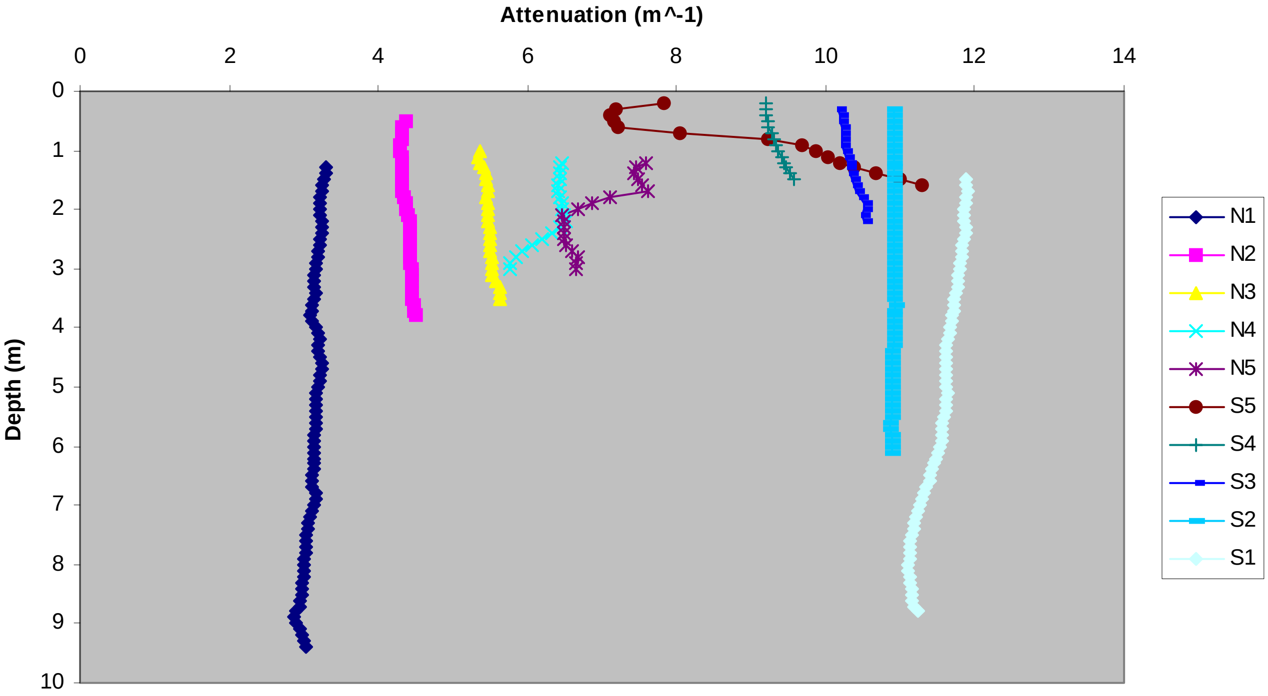

Figure 9: Attenuation (m^-1) measured as a function of depth (m) after bridge construction. Dingley Island. October 2003. Offset by a factor of 1.

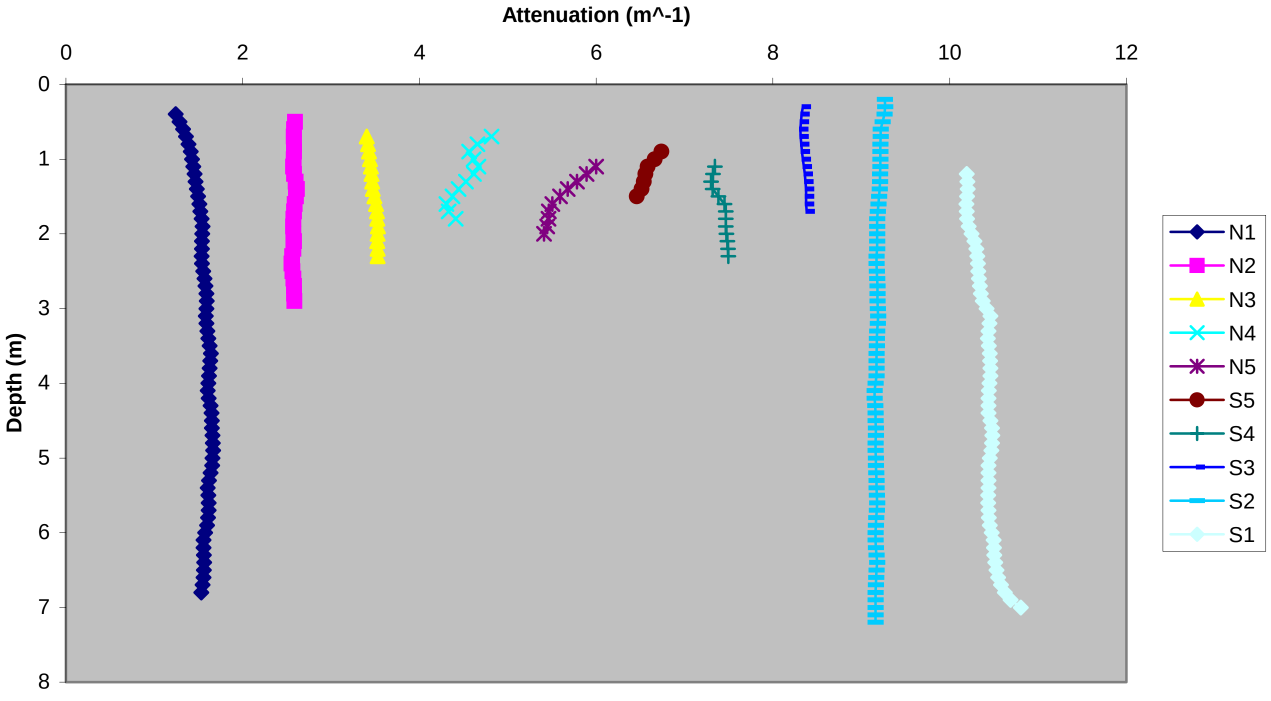

Figure 10: Attenuation (m^-1) measured as a function of depth (m) before bridge construction. Dingley Island. May 2003. Offset by a factor of 1

TSS vs. Attenuation

It is evident in that there is no correlation between total suspended sediments and attenuation in the October 2003 data. As total suspended sediment increases, attenuation remains fairly constant between three and four m^-1. The highest attenuation level was 5.98 m^-1 with TSS at 17 mg/L, and the lowest was an attenuation of 2.14 m^-1 with TSS at 41 mg/L (Figure 11).

The May 2003 data shows a weak correlation, as is apparent by the trend line between total suspended sediment and attenuation. (Figure 12) TSS levels are clustered at 15 mg/L, and attenuation remains constant between one and two m^-1 (Figure 12).

The only comparison to be made between the two sets of data is the numerical increase in both attenuation and TSS levels in October and the large amount of scattering present. This data covers a much wider range, with the highest attenuation level at 5.98 m^-1, while in May the highest attenuation level was nearly 2 m^-1.

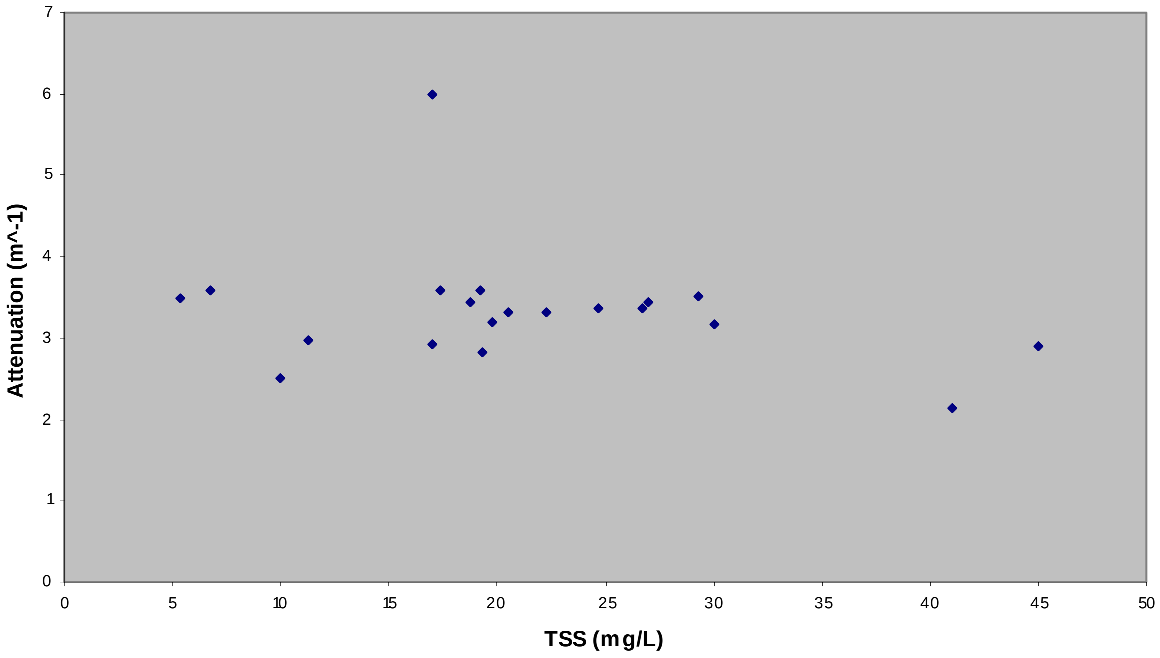

Figure 11: Attenuation (m^-1) vs. TSS (mg/L) after bridge construction. Dingley Island. October 2003.

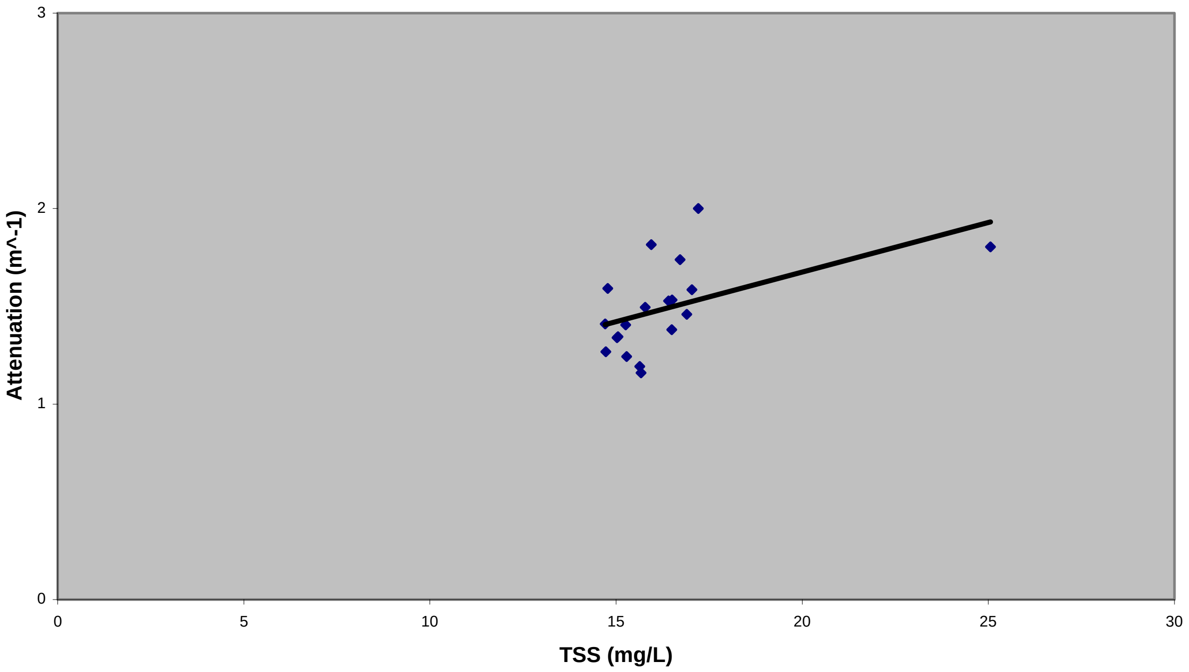

Figure 12: Attenuation (m^-1) vs. TSS (mg/L) before bridge construction. Dingley Island. May 2003.

TSS vs. Particle Concentration

Figures 13 and 14 show that there is no correlation between TSS and particle concentration in either October or May. Surface levels of TSS and concentrations do appear somewhat clumped in both months, but deep measurements in October are scattered in no particular pattern.

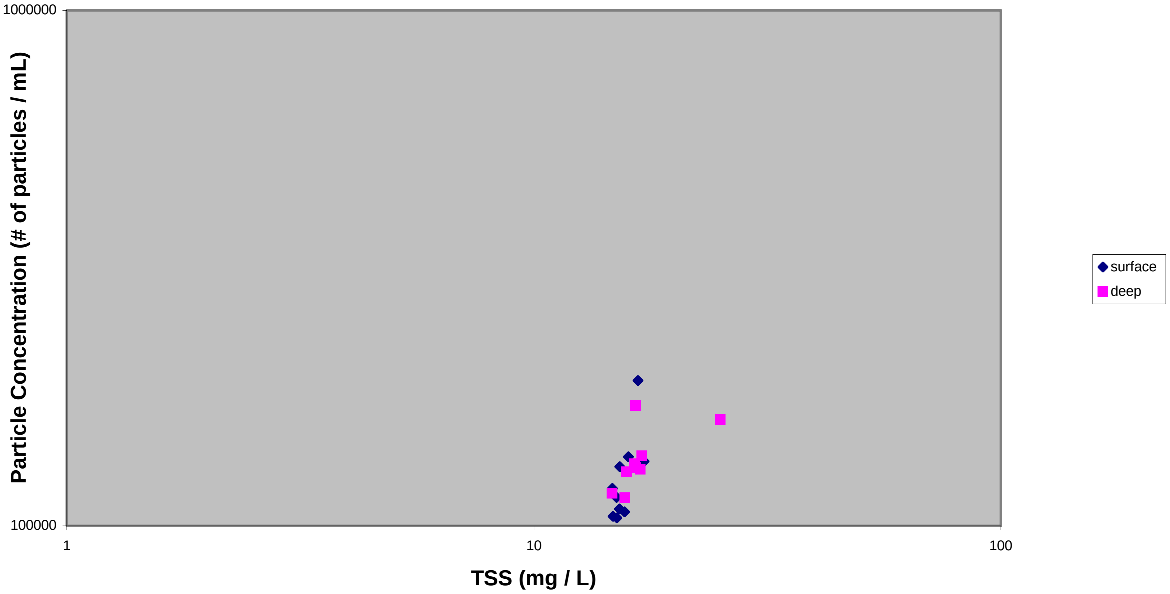

Figure 13: TSS (mg/L) as a function of particle concentration (# of particles/mL) after bridge construction. Dingley Island. October 2003.

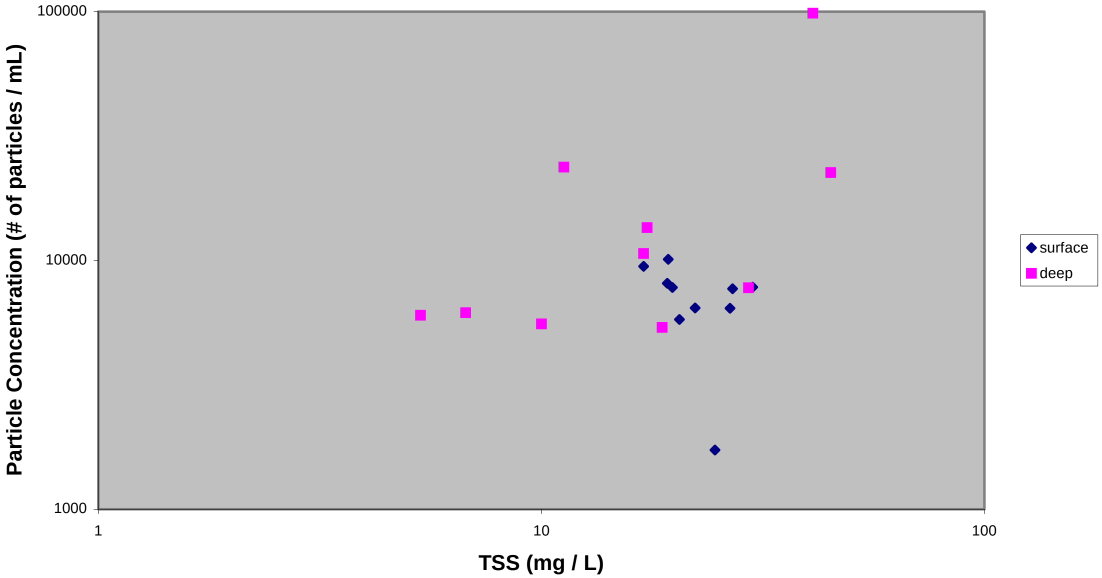

Figure 14: TSS (mg/L) as a function of particle concentration (# of particles/mL) after bridge construction. Dingley Island. May 2003.

Particle Size Distribution

The October 2003 data shows a distinct prevalence of particles with a diameter of 1.25-6.54 um, the smallest particle size, throughout the water column but with higher levels in the deep waters at points furthest from the bridge and in surface waters at the points on either side of the bridge. This trend continues in the other size categories- higher levels of each particular size in deep waters at points furthest from the bridge and reversal at the bridge with slightly higher levels in surface waters. There is a substantial difference in concentration between the two highest size brackets, with concentrations of particles in the 47.68-211.47 um category reaching 42 particles/mL at most, found at S1. Overall, particle size concentration does not differ drastically within each size bracket, but does change enough to be of interest (Figure 15).

The May 2003 data shows relatively constant levels of concentration within each size category at each of the sampling sites. A slight trend is found as the samples near the bridge, where concentrations in surface samples become higher than those in deep samples. Around stations N3 and S5, this relationship is reversed and concentrations in surface waters are higher than those in deep waters in each size category. Station N5 once again does not have surface data (Figure 16).

The May 2003 data shows much higher concentrations of each size category overall than October 2003. May 2003's smallest size category consistently had concentrations above 100,000 particles/mL, while in October this size category exceeded the 100,000-particles/mL mark only once. Similarly, the concentrations of the largest category consistently exceed 10 particles/mL in May 2003, while in October levels exceed this mark only three times and, for the most part, remain significantly lower. Both data sets share the same trend of surface/deep concentration reversals nearest the bridge, near S5 and N3 for particles 250 um.

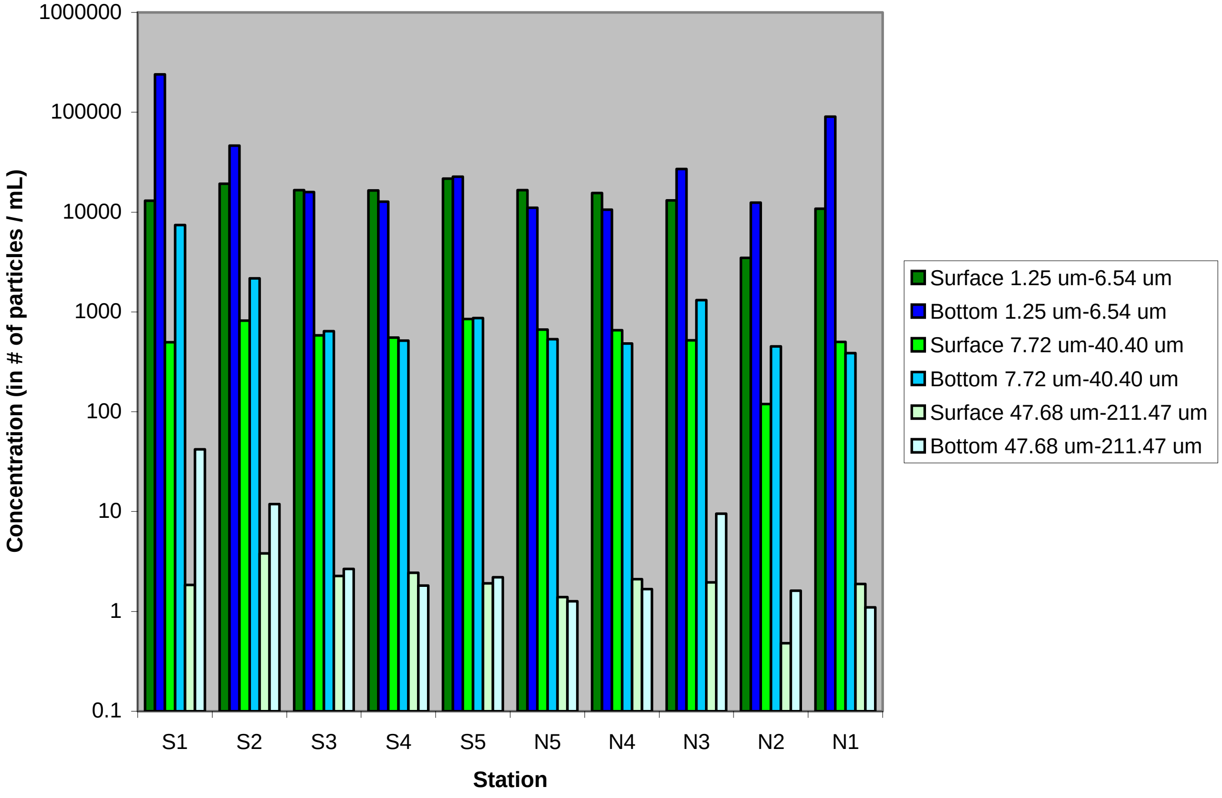

Figure 15: Particle size concentration (#of particles/mL) after bridge construction. Dingley Island. October 2003**.**

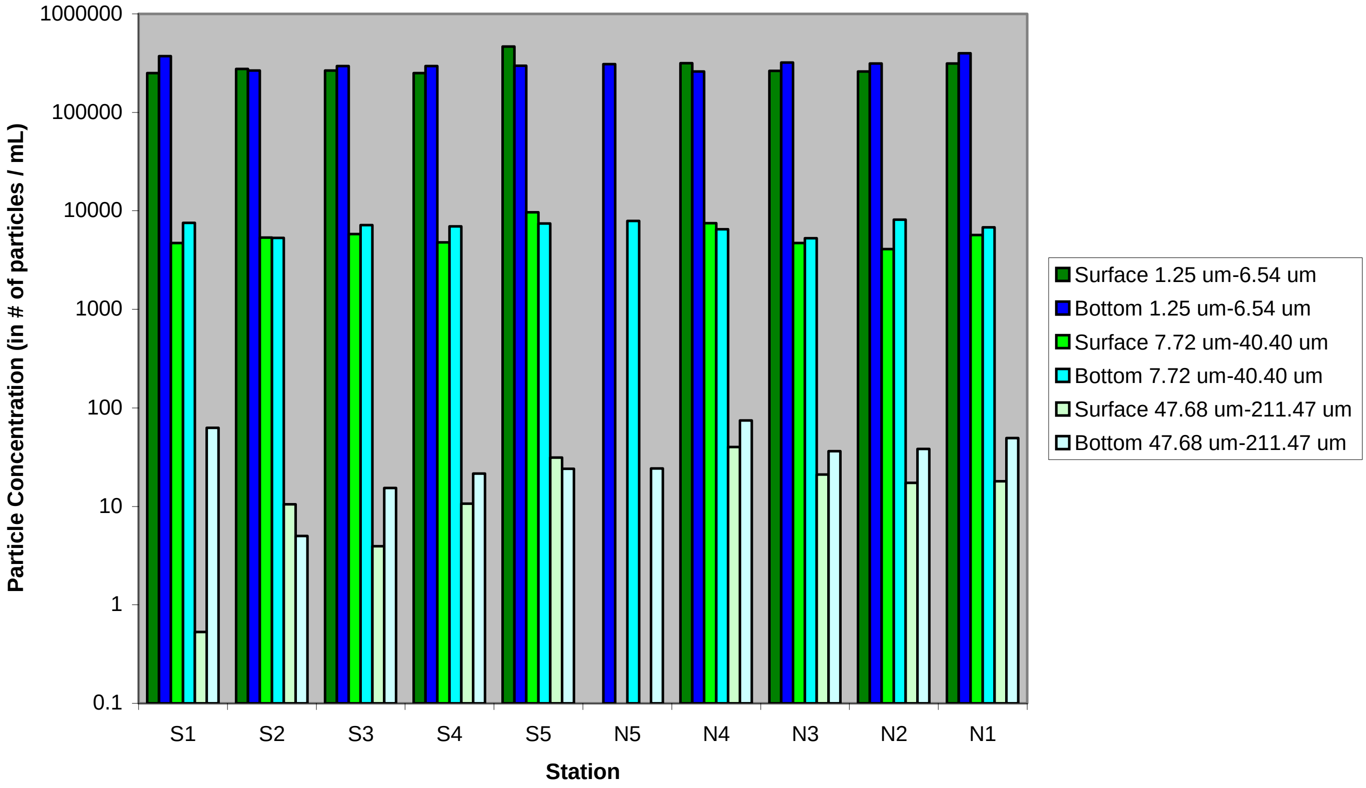

Figure 16: Particle size concentration (# of particles/mL) before bridge construction. Dingley Island. May 2003.

Total Organic Suspended Solids

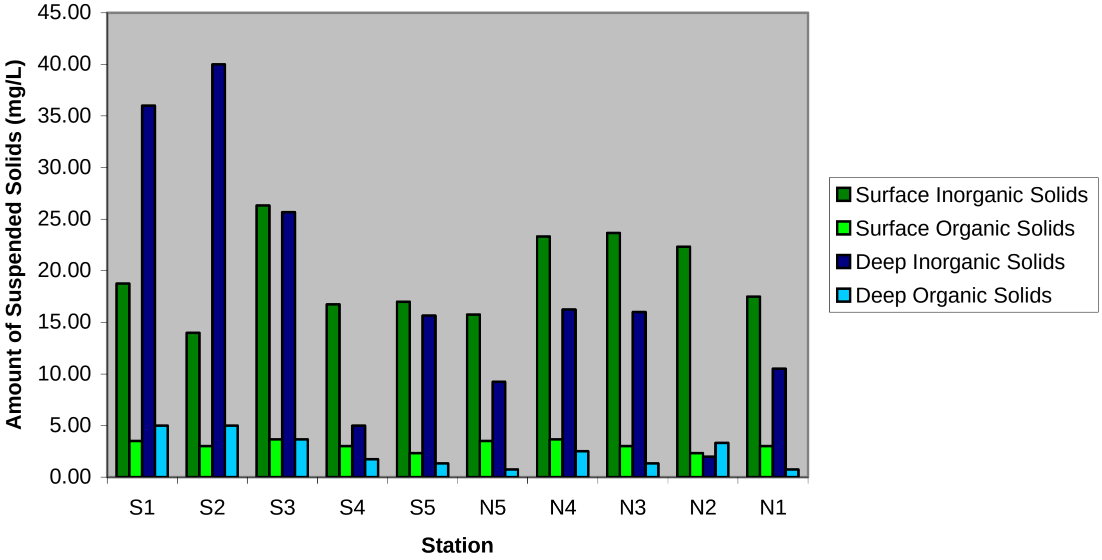

Figure 17. Breakdown of Total Suspended Solids measurements by Organic content at both the Surface and Depth sampling sites. October 2003.

In general organic content was significantly lower compared to the inorganic solid measurements. Stations N1 through S3 had a higher mass of inorganic solids at the surface level (ranging from 5.00 to 26.33 mg/L). Stations S1 and S2 had higher inorganic solids at the deep levels (36 and 40 mg/L respectively). Organic content, particularly in the deep levels, was lowest near the bridge (ranging from 0.75 to 1.75 mg/L). There is no data from May 2003 to allow for comparison between pre and post construction organic and inorganic content in the water column.

DISCUSSION

Our findings overall point to an increase in TSS levels nearest the causeway from May 2003 to October 2003. Although deep measurements in October show a decrease in TSS levels at stations closest to the causeway, it is important to note in comparison to May 2003's data that overall levels, especially in surface waters, have risen. "Evidence from longer-term sediment load records indicates that river sediment fluxes are sensitive to many influences, including reservoir construction, land clearance, and land use change, other forms of land disturbance, including mining activity, soil and water conservation measures, and sediment control programs, and climate change" (Walling and Fang, 2003). It is most likely that the construction of the causeway introduced a great deal of new sediments that originally comprised the causeway into the water column, especially those in the smallest size bracket, which are easily transported by any current once introduced into the water column but take the longest to settle to the estuary floor (Garrison, 2002). Data found by the east transect mudflat group supports this assertion, as their data shows an overall increase in sediment depth from May to October at most stations south of the bridge (Gates and Gott, 2003). It is important to note the scoured appearance of the estuary floor directly under the bridge; the overwhelming presence of larger grain size sediments indicates that any smaller sediments that had been introduced to the floor of the estuary by the construction of the bridge or existed there previous to construction have been swept into the water column, leaving behind only particles too large to be picked up by the current. The flushing of the restored flow is also in the process of a return to equilibrium, redistributing sediments that had built up on either side of the causeway over time.

It is also probable that the well-mixed levels of TSS in May reflect the mixing forces of the winter storms. "Seasonal variability in the supply of erodible sediment is the primary factor affecting near-bottom SSC (suspended sediment concentration)" (Schollhamer, 2002). This explains the difference in surface versus bottom waters in October; the waters were not subject to the forces of winter waves due to storm activity, and there is also a lack of seasonal stratification in the water column.

While particle size distribution in October were overall much lower than those found in May, there were not a lot of changes along the estuary within each size bracket. There is a noticeable trend in both data sets, however. At points furthest from the bridge, surface samples have a higher concentration of particles in all size categories, while points closest to the bridge (S5 through N3) show a reversal of this pattern, with particle concentrations being higher in deep waters. In comparing the October particle size distribution to the other graphs of October data, this trend is visible in total particle concentration (where surface levels are marginally higher than deep levels at the bridge), but not as much in the TSS graph (where surface levels are higher than deep levels as a general rule). This discrepancy could be due to larger sized particles that were not accounted for by the total particle concentration readings, but had a significant effect on TSS measurements. Thus the TSS graph is implicated as the more encompassing picture of the total material mass situation. This reading of the data is also supported by notes taken on the date of measurement regarding the visual quality of the surface waters. As we moved further away from the causeway, the waters began to have a milky, dirty film on the surface, indicative of high levels of suspended sediments and other particulate matter.

In conjunction with TSS measurements, it is important to consider that total concentration of particles was considerably lower in October than in May. This finding is interesting to compare to the increased TSS levels; they seem to contradict each other. We propose that this is again a result of very large particles being introduced into the water column in October that would have been accounted for in weight by TSS measurement, but would not have registered in the total particle concentration calculations because they were larger than the highest size bracket. Also note that while October's deep levels of TSS were only slightly lower than surface levels, May's surface samples had consistently lower concentrations than deep samples near the causeway; increased circulation of deep waters most likely played a large role in this change. As bottom currents increased with the restoration of tidal flow, the increased flow would most likely have begun to mix sediments up through the water column, causing the water column to become more well-mixed overall (Roesler, 10/03/03). Our sampling time, although aimed to coincide with the slack period of high time, still experienced a current under the bridge that could stir up sediments and increase levels of suspended sediments (Bell et al, 2000).

Attenuation in May describes a linear pattern at all stations except for N4-S4, showing that the sediments throughout the estuary were indeed relatively well mixed. In October however, attenuation at N5 and S5 show very stratified patterns showing decreased attenuation with depth at N5 and increased attenuation with depth at S5. It is also important to take into consideration the findings of the physical properties group, who found levels of chlorophyll in October to be higher at sampling stations furthest from the bridge. Chlorophyll levels at sampling stations nearest the bridge were similar from May to October however, which rules out increased chlorophyll or phaeophytin as the cause of the change in attenuation (Abbruzzese, Bartovics, and Hart, 2003). Our organic sediment data correlates with the chlorophyll data and we can infer that there has been little change in organic content since the introduction of the bridge, despite our lack of comparative data. Organic content, however, could have been seasonally affected as it is "…variable and depends upon the supply of organic material from the terrestrial surroundings as well as the productivity of [the body of water]." (Sanei et al, 2000) Attenuation increased overall at stations furthest from the bridge from May to October as well. This information, however, does not correlate with our readings of the TSS information. We would have assumed that variable attenuation throughout the water column at S5 would have indicated higher levels of suspended sediment in deep waters, but the TSS data instead shows that there is a trend of less suspended sediment in deep waters. At this time, we are unsure why this data is as such. We recommend that more, longer-term research should be done to assure that this trend is not due to other extenuating circumstances that have not been accounted for.

We hypothesize that the estuary will never return to its status pre-human interference, as the opening of the bridge is merely 25 feet wide in a 200-foot causeway. A healthy estuary is defined as "…free from "distress syndrome"… stable and sustainable… active and maintains its organization and autonomy over time and is resilient to stress" (Fairweather, 1999). Thus the removal of a segment of the bridge will not be drastic enough to return the estuary to its original status, but could certainly aid in the creation of a more healthy environment. "Human activities have changed this balance in estuaries in various ways- mainly by increasing erosion and by changing water-flow patterns and sediment movement...Causeways for roads can change both current patterns and the way sediment is carried in and trapped." (Bell. 2000) As Bell suggests, human activities will continue to play a large role in the continued life of the estuary.

In conclusion, despite the changes in data between May and October, we are unaware as to whether the changes are as a result to the construction of the bridge, or a mere response to a changed environment. Estuaries are known to be highly sensitive to changes in their environment. Therefore, it must be noted that the changes viewed between May and October may only be a response to seasonal change. "Some of these influences cause sediment loads to increase, whilst others, namely, soil and water conservation and sediment control programmes, and reservoir construction cause decreased sediment fluxe" (Walling and Fang. 2003) As other research indicates, the average water temperature in October was raised almost 10◦C, which may have adversely affected our results because of the effects that temperature has on phytoplankton production as well as circulation (Abbruzzese, Bartovics, and Hart, 2003). Similarly, the construction of the bridge resulted in a changed environment, something that is certain to have had an effect upon the estuary. We remain uncertain of the repercussions the introduction of the bridge will have on the local clamming industry. Further research should be done as suspended sediments within estuaries are responsible for "…transporting absorbed contaminants" (Prandle, 1997), which can be detrimental to the coastal environment especially if sediments continue to accumulate. It would, therefore, be beneficial to recommend that more data be collected as the seasons change and the estuary begins to settle into more of equilibrium, perhaps measuring again in the early fall when sediments have not been stirred up by winter storm waves. This ongoing data would be far more instrumental in determining the true effect of the causeway removal.

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