ABSTRACT

THE EFFECTS OF CHROMATED COPPER-ARSENATE (CCA) PRESSURE-TREATED WOOD ON LOCAL SEDIMENTS AND BENTHOS IN A FRESHWATER LAKE

by
William A. Romeo

This study looked at the sediment and benthic organism effects of exposure to a Chromated Copper-Arsenate (CCA) treated wood bulkhead in a lake environment with respect to 1) the leaching and accumulation of chromium, copper and arsenic in the nearby sediments, 2) accumulation of these metals in local benthic organisms and 3) the effects of these metals on the local benthic community structure. Sediment samples, taken at regular distances away from a CCA bulkhead and three reference areas in a freshwater lake in Wayne, NJ, were sieved to remove the fine particle fraction (<70μm) which was then analyzed for the metals of concern. Benthic organisms were sampled at the same locations, enumerated, identified, dried and also analyzed for the metals in question. Analysis of sediment metal concentrations revealed high levels of copper at all sampling locations. This was attributed to the annual addition and accumulation of $CuSO_4$ added to the lake. There was no significant increase in chromium or arsenic concentration adjacent to the bulkheads. Although not significant, the sediment did exhibit a higher arsenic concentration adjacent to the CCA bulkhead than at the reference areas. Benthic organism metal analysis showed a trend towards increased tissue levels for the three metals in organisms collected adjacent to the wood bulkhead. This suggested that bioaccumulation of these metals was greatest at this location where leaching of these

metals could have occurred. Unfortunately this could not be statistically demonstrated due to the small sample size obtained (n = 1). Although not statistically significant, analysis of benthic organism community structure revealed that total biomass and Shannon-Wiener diversity index were lowest adjacent to the CCA bulkhead compared to the reference sampling locations. The results suggest that the leachate of CCA-treated wood may increase metal concentrations in the local sediments and benthic organisms and therefore may have potential deleterious effects upon the local benthic community. Further studies will need to be performed to prove statistically whether there is a need for concern over the addition of CCA-treated wood bulkheads in freshwater.

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This thesis is dedicated to my fiancée, Maria, for being so patient.

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CHAPTER 1

INTRODUCTION

Using wood as a building material has long been in practice ever since man has realized the beauty and efficiency of this renewable resource. However, wood tends to decay over time and then needs to be repaired and/or replaced. This is accelerated in aquatic environments as is especially seen on wooden bulkheads and dock pilings where wave action, sand, microorganisms and boring fauna slowly destroy the wood and eventually warrants its replacement. The severity of damage can be quite expensive and likewise not aesthetically pleasing. In the early part of the century a need arose to develop a form of "preservative" that could be added to the wood to extend its useful life. As a result, Creosote, Pentachlorophenol in oil (penta) and Chromated Copper-Arsenate (CCA) methods for preservation were developed. If applied, such wood treatments could extend the physical service life of the product by 20 to 50 years (Cooper, 1993). This can certainly have an economical advantage over untreated wood applications. However, we must ask ourselves if the addition of these chemicals to wood; especially chromium, copper, and arsenic (CCA) which have been heralded as being "leach resistant", will have an impact on the surrounding sediments and benthic community after application.

1.1 Creosote and Pentachlorophenol Treated Wood

Creosote and penta were developed sometime between the late 1800's and early 1900's to protect wooden bulkheads and dock pilings from attack by fungi and marine boring insects. Creosote is a complex mixture of organic molecules which is derived from coal tar produced by the carbonization of coal , while penta is a manufactured highly toxic insecticidal solvent gaining notoriety for its use in treating electrical utility poles (Brooks 1993; CDC 1990; Goodrich-Mahoney et al. 1993). Both creosote and penta are applied to lumber by allowing the wood to soak in large vats of the respective chemical which is drawn into its fibers through its cellulose structure.

There recently has been increasing concern over the use of creosote and penta treated lumber in aquatic environments. Creosote and penta contain many poly-cyclic aromatic hydrocarbons (PAHs) and solvents known to be acutely and chronically toxic to marine organisms. Creosote-treated lumber manufactured for aquatic applications is composed of approximately 50 to 65% PAHs (Ingram et al. 1982). The most notable by-product of these processes is benzo[*a*]pyrene. When ingested and metabolized this chemical can degrade to carcinogenic, teratogenic and mutagenic intermediates.

The ultimate fate of PAHs is to degrade from their substrate and break down into heavy and light fractions. The light PAHs (lPAH) are suspended in the water column and mostly taken up by fish and other macrofauna and filtered out of the water by mollusks. The heavier PAHs (hPAH) eventually end up in the sediments where they are consumed by the local benthic organism community (Brooks 1993). Eisler (1987) noted that the lPAH compounds, containing 2 or 3 rings, such as naphthalene, fluorine, phenanthrene and anthracene have significant acute toxicity to some organisms, while the higher molecular weight compounds, 4 to 7 rings, do not. Brooks (1993) stated that persistent contaminants may move up the food chain bioaccumulating to higher levels in each trophic level until, eventually, contaminants found at non-toxic levels in the ambient environment reach concentrations where they do cause stress and disease.

The toxicity of PAH's leaching from creosote applications have been well documented in the literature. Neff (1979) noted that a 300 parts per billion (ppb) addition of anthracene and 2-methylanthracene in seawater caused declines of 20% in the red alga, *Antithamnion plumula,* and at 1,000 ppb algal growth was inhibited. Moore et al. (1989) cited that long term exposure to diesel, which contains the same PAH's as those found on creosote treated wood, at 30 to 130 parts per million (ppm) caused a decrease in the mass of gametes produced by the bivalves *Mytilus edulis* and *Macoma balthica.* PAH's have also been recorded to have a direct effect on cilia, muscles and/or nervous system of mollusks. Reduced feeding in mollusks was observed at PAH levels as low as 30 to 40 ppb in seawater (Widdows, et al. 1982).

As a result of increased environmental awareness and concern for the aquatic environment, CCA treated timber, known as "green wood" not only for its color but also for its environmental implications, began to gain wider acceptance as a more "environment friendly" wood of choice in the construction of marine bulkheads while creosote and penta operations were being scaled down. This is primarily due to it being more aesthetically pleasing than creosote treated wood. Creosote treated wood can have "globs" of exposed coal tar residues on its outside which leaves an "oil sheen" on the water surface around pilings as well as making it difficult to handle and producing a definite petroleum odor. Past handling practices of creosote and penta treated wood have resulted in extensive contamination of soils and groundwater on or around these treatment facilities. Currently there are 55 creosote and penta wood treatment plants on the U. S. EPA "Superfund" National Priority List (Davis, et al. 1992)

1.2 Chromated Copper-Arsenate (CCA) Treated Wood

Since creosote and penta applications have been found to be deleterious to the environment it is understandable that we scrutinize the potential environmental implications of CCA treated wood. CCA treated wood has long been described as being clean, odorless and highly leach resistant. Literature from manufactures of CCA treated wood and from the American Wood Preservers Association (AWPA) states that tests show that "there has been no loss of treatment chemicals (after 30 years) and we estimate the life of properly treated wood will exceed 100 years...and will outlast the usefulness of the structure" (Koenigshof 1973). The literature also states that animal studies concluded that no arsenical induced cancers were acquired as a result of exposure or ingestion of CCA treated wood. It has also been noted that in 1985 the EPA concluded an eight year study concerning the potential registration of CCA preservatives and concluded that the benefits of treated wood and the preservatives used in the pressure-treating process outweighed any potential risks (Osmose 1990). CCA treated lumber has since replaced creosote and pentachlorophenol as the wood preservative of choice for aquatic uses because of concerns over human and aquatic toxicological health effects of the other two chemicals. In the 1980's CCA treated timber began to gain wider acceptance in the outdoor construction business and around 1987 CCA formulations accounted for over 90% of the market for pressure treated wood which has been estimated at over 6.5 billion board feet (Weis and Weis 1993).

The history of CCA treated wood begins with its first patent in India in 1933; that CCA formulation consisted of 5 parts potassium dichromate, 3 parts copper sulfate and 1 part arsenic pentoxide (Wallace 1968). The first known United States patent of CCA was formulated in 1938 by (a gentleman known as) Kamesam (Baldwin 1985). In 1950, a formulation called "Greensalt", very similar to that developed in India, was used by the Bell Telephone Company and approved by the American Wood Preservers Association (AWPA) to treat utility poles. During this time Boliden Mining Company in Sweden developed an unsuccessful formulation called Boliden K33 which contained a decreased chromium content while the United Kingdom began making CCA formulations known as Celcure A and Tanalith C (Wallace 1968). Waterborne arsenical wood preservatives have evolved from the known biocidal activity of various metallic salts, the oldest of which is Fluor Chrome Arsenic Phenol (FCAP) which was used in the United States in as early as 1918. This method has been phased out and replaced with more leach resistant arsenicals (Baldwin 1985).

Chromium, copper, and arsenic each aid in the preservation of wood in their own way. Chromium acts as a corrosion inhibitor, aids in the fixation of the preservative to the wood and to some degree acts as a fungitoxic constituent. In CCA fixation, chromium is part of a complex series of reactions that reduces chromium from the hexavalent to trivalent state. The resulting consequence of fixation is the eventual insolubilization of CCA components in the wood so that they *resist* leaching and provide long service even when placed in contact with the ground. In CCA formulations chromium plays more a role in the fixation of the preservative to the wood than for its fungitoxic abilities

(Hartford 1986; Wallace 1968). Copper and arsenic are used in the fixation process for their known toxicity to fungi and insects. Arsenic is very effective against insects while copper is an excellent fungicide. Arsenic will also aid in the destruction of copper tolerant fungi. Both metals interfere with the oxidative phosphorylation process in organisms and disrupting the cycles that convert nutrients into energy (Lebow 1993).

The process that incorporates these metals into the wood to obtain its longevity is know as "Wolmanizing." The process begins by loading untreated wood into a treating cylinder using locomotives, forklifts, etc. The cylinder's pressure-tight door is closed and a vacuum is applied to remove air from the cylinder and the wood cells. The treating solution, consisting of a slurry of metal oxides (CrO_3, CuO, As_2O_5), at varying percentages depending on the type of treatment to be performed (See Table 1), is pumped into the cylinder which is then pressurized to approximately 150 pounds per square inch (psi). The total treating time is dependent on the species of wood used and the desired chemical retention to be achieved. The applications high temperature and pressure reached during this process forces the slurry of chemicals into the wood where it reacts with the woods sugars to form insoluble arsenate precipitates. This reaction is termed "fixation" because the preservative compounds are supposed to be "permanently fixed" to the treated wood in a highly insoluble state. This in turn accounts for the manufactures claim that this treated material is of high "leach resistance and durability." However, the definition of "fixation" must be investigated because even fully fixed CCA will leach to some degree depending on the exposure conditions (Ruddick 1990). Fixation then should be defined as the process that *minimizes* the leaching of CCA components. Cooper et al.

(1990) stated that the definition for fixation should be defined as "the state of the chemical components of the preservative and wood or other substrate when all chemical reactions are complete." Fixation is considered to be complete when there is no sign of hexavalent chromium detected in the leachate or expressate of the treated wood. Cooper and Ung (1992) state that this is actually a fairly conservative measure when compared to levels of copper, arsenic and chromium actually leached from CCA treated wood.

The interactions of CCA preservatives with wood during and after the treating process are very complex and poorly understood. The aspects of these reactions have been studied by many researchers and interest in CCA effectiveness and permanence has led to research in this area (Cooper 1993, Dahlgren and Harford 1972; Dahlgren 1974, 1975; Fahlstrom et al. 1967; Hagar 1969; Henshaw 1979; Pizzi 1983; Warner and Solomon 1990; Weis et al. 1992; Weis et al. 1993; Weis and Weis 1994). There are many variables within the CCA process which limit the efficiency of the fixation process from the treated wood. Some known variables are: the wood itself due to difference between wood species, other factors such as extractive content, presence of heart or sapwood and the proportion or type of lignin present, the temperature during and after treatment, CCA formulation, concentration and pH (Coggins and Hiscock 1979; Cooper and Ung 1989; Dahlgren 1975; McNamara 1989; Ostmeyer et al. 1988; Pizzi 1983; Pizzi et al. 1984; Wilson 1971).

Today CCA exists as three separate formulations generated by the American Wood Preservers Institute (AWPI) and are designated as types A, B, and C. Type C has gained greater acceptance since its introduction in 1968 and today is the dominant formulation due to its optimum cost and minimum leachability. These formulations are based on AWPA standards and the preservatives are made up of water soluble compounds of 95% purity on an anhydrous basis (Baldwin 1985). See Table 1 for CCA formulation concentrations.

TABLE 1 Formulation Concentration of CCA Preservatives

Chemical	Type A	Type B	Type C
$Cr(VI)O_3$	65.5%	35.3%	47.5%
$Cu(II)O$	18.1%	19.6%	18.5%
$As(V)_2O_3$	16.4%	45.1%	34.0%

Source: Baldwin, William J. 1985. "CCA Marine Piling, A Review of its Safe Use."

The AWPA regulates seven concentrations for application of CCA Type C preservative for various uses; 0.25 pounds of Type C slurry per cubic foot (pcf) of lumber for above ground exposures, 0.4 pcf for ground contact exposures, 0.6 pcf for poles and foundations, 0.8 and 1.0 pcf for land and fresh water. Wood intended for marine use receives 1.5 lbs/ft^3 (24 kg/m^3) of this metal oxide slurry and in some areas, including Florida, 2.5 lbs/ft^3 (40 kg/m^3) (AWPA 1992; Weis and Weis 1994).

We have read in the literature that CCA wood is "highly leach resistant," safe to the environment and safe to work with when handled using "common sense" precautions and hygiene (Baldwin 1993). Unfortunately, few studies have been performed to assess the potential toxic and/or bioaccumulative effects due to the leaching of these metals from CCA-treated wood bulkheads into the surrounding sediments and its effect on the benthic community living near these bulkheads in marine environments. It is known that chromium leached from CCA bulkheads exists in the aquatic environment as chromate

Cr(VI) which is known to be carcinogenic and mutagenic. It is analogous to sulfate which could then be taken up by phytoplankton causing deleterious effects and a potential for bioaccumulation. However, under oxidizing conditions Cr(VI) may be reduced to Cr(III) which is less toxic (Sanders and Riedel 1987). The effects of copper are widely known and it is currently used as an algicide and molluscicide. Most copper in the aquatic environment is bound to organic matter which is less toxic than its free ion form (Newell and Sanders 1986). Arsenic is carcinogenic, mutagenic and teratogenic. Because of its chemical similarity to phosphate it is readily taken up by phytoplankton which then makes it accessible to the food web. It can exist in four oxidation states with As(III) and As(V) being the most abundant. Fortunately, for aquatic organisms, As(V) is less toxic and more prevalent in the environment.

Recent studies show (Weis and Weis 1993, 1994, 1995; Weis et al. 1991, 1993) that all three chemicals do leach out of CCA wood when exposed to sea water, have the potential to accumulate in the nearby sediments and possibly cause adverse effects on the local benthic community. Fine-grained sediments (silts and clays) absorb contaminants much more readily than sand and provide the most important sink and source for metals (Luoma and Davis 1993). Weis et al. (1993) have noticed that in marine environments, specifically in poorly flushed canals, sediments immediately adjacent to CCA wood bulkheads had very low percentages of the fine-grained particles ($<70\mu m$) but very high concentrations of chromium, copper and arsenic. Sediments away from the bulkheads (up to 10m) were in deeper water and had a higher percentage of silts and clays but with lower concentrations of the three metals in this fraction ($<70\mu m$). Benthic organisms living near these structures also had elevated concentrations of the metals presumably obtained from the sediments (Weis and Weis 1995). The polychaete worm, *Neanthes succinea,* was collected from sediments adjacent to a CCA bulkhead in open water. It was noted that these worms had higher levels of copper and arsenic compared to those worms collected at a reference location.

Studies by Weis et al. (1992) have shown that in confined laboratory aquaria CCA leachates were toxic to a variety of esturine biota including algae, snails, crabs, sea urchins and fish embryos and that the rate of leaching decreases over time. However, toxic effects resulting from laboratory exposure to the initial leaching of these metals were noticed. Weis and Weis (1992) and Weis et al. (1991, 1992) observed mortality and retardation of limb regeneration in fiddler crabs (*Uca pugilator*), loss of chlorophyll (bleaching) in green algae (*Ulva lactuca*), mortality in fish embryos *(Fundulus heteroclitus)*, reduction of egg fertilization and development of sea urchins *(Arbacia punctulata)*, and mortality in the mud snail *(Nassarius obsoletus)* due to direct and indirect exposure to CCA treated lumber. Predators that feed on "fouling" organisms, organisms that live directly on the wood, can conceivably accumulate these metals through the food chain. It has been recorded that oysters *(Crassostrea virginicus),* living inside a residential canal lined with CCA bulkheads, contained elevated levels of metals, most notably copper, were green in color and reflected exposure to toxic agents compared to oysters from a reference location (Weis, Weis and Couch 1993). When the oysters were provided as food for the carnivorous snail *(Thais haemastoma)* it was noted that the snails also increased their body burden for copper four-fold over an eight-week period (Weis and Weis 1993). A similar study collected algae (*Ulva and Enteromorpha)* from a CCA treated wood bulkhead and fed them to snails (*Nassarius obsoletus).* It was observed that snails which were fed the algae from the CCA wood retracted into their shell and lay motionless on the bottom of their containers, and eventually died. Weis and Weis (1992) and Weis et al. (1993) also showed that chromium, copper and arsenic leached from the wood bulkheads, accumulated in the nearby sediments and became bioavailable.

Tests to compare species diversity of the "fouling community" on CCA treated wood to other substrates were also performed. Using recycled plastic "lumber" placed in an estuary along with CCA boards, Weis and Weis (1992) found lower species richness, diversity and biomass on the CCA-treated boards compared to those on the plastic or untreated wood. They also found that organisms settling on the CCA boards had elevated levels of chromium, copper and arsenic. They found the greatest difference between both communities on treated and untreated wood during the first month when the leaching of metals from the treated wood was at its greatest.

Due to documented studies showing the hazards of CCA leaching in marine environments, a need arose to pursue this type of study in a fresh water environment to see if similar effects, or any at all, are found in the surrounding sediments and benthic community. It has been demonstrated that the leaching of metals from CCA-treated wood in fresh water is greatest at low pH's therefore indicating that areas subject to more acidic conditions may be more at risk (Warner and Solomon 1990). This study was designed to look at the potential leaching of a CCA-treated wood bulkhead in a freshwater lake in Wayne, New Jersey (See Appendix A, Figures 1a & b). It is similar to some of the marine studies performed by Weis and Weis. A CCA bulkhead was identified along with three reference bulkheads at the same lake. As in the other published studies, sediment samples were taken at varying distances away from each bulkhead and analyzed and compared for chromium, copper, arsenic, percent fine fraction and percent total carbon. All locations were re-sampled for benthic organisms which were analyzed for the metals in question as well as community characteristics such as the total number of taxa per location, total number of individuals per location, total biomass per location and their overall diversity.

Growing environmental awareness has placed emphasis on understanding the fate of "leach-resistant arsenicals" used to pressure-treat wood for the construction of freshwater bulkheads. This thesis attempts to ascertain if there is significant concern of metals leaching from CCA-treated lumber in a fresh water environment, if there is accumulation in surrounding sediments and accumulation and/or effects in the benthic community compared to adjacent reference areas.

CHAPTER 2

SITE BACKGROUND

2.1 Lake History

Pines Lake began as a small meandering brook that cut through undeveloped farmland in the early 1900's. As more people began to inhabit this area, land on the south end of the lake was sold and developed. Around 1929 the brook was dammed to form Pines Lake as we know it today. Eventually homes were erected all around the shore of the lake. These homes began as summer cottages and now have turned into full time residences. Since its beginning in 1929 this community and its outlying areas have seen tremendous growth which, unfortunately, has been reflected on the lake. The increase in development and use of fertilizers for lawn maintenance around the area has caused the lake to stratify sharply in the summer and therefore become eutrophic. As a result, herbicides and algicides must be added to the lake on a continual basis to keep it from reaching eutrophication as well as to maintain its aesthetics.

The lake is governed and managed by an organization known as the Pines Lake Association. This groups oversees the maintenance and use of the lake and has ownership of the lake bottom and approximately 10 feet of shoreline around the entire lake. Their primary function is to oversee the yearly water quality testing required by the New Jersey Department of Environmental Protection for use as a recreational lake. This is a year round recreational lake sponsoring activities such as swimming, sailing, fishing and ice skating. To the best of my knowledge the only parameter the lake has tested for is Total Coliform Count. The lake also has an extensive large-mouth bass and sunfish community and therefore many more benthic organisms to support this population (Westman 1973).

The Pines Lake community has also built beaches, public and private, on its shores. The shoreline has been altered greatly over the years due to the encroachment of homes and subsequent weathering and as a result many bulkheads and retaining walls have been built. A CCA bulkhead was installed approximately two years ago on the east side of the lake as a retaining wall to hold sand for a private beach.

The addition of this CCA bulkhead created an opportunity to perform this study and see if the addition of this bulkhead is having any effects due to the potential leaching of chromium, copper and arsenic from the treated wood to the nearby sediments and local benthic community.

2.2 Bulkhead Locations

The CCA bulkhead, known as the "Wood Bulkhead" in this study (See Appendix B, Figure 2c) was approximately 13.2m x 1.0m. The Wood bulkhead was approximately 2-3 years old and was constructed of 1.5 lbs/ft^3 of CCA Type C treated lumber (railroad-ties). During installation some of the existing sediment was removed in order to lay the first railroad-tie flush with the ground. Only one tie is located in the sediment with the rest making up the remainder of the bulkhead. Water stains on the face of the bulkhead show that at certain times of the year, one third to one half of the bulkhead can be submerged under water.

Two control sites were located to the south and one to the north of the CCA treated wood bulkhead (See Appendix A, Figure 1b and Appendix B, Figures 2a, b & d). The one farthest to the south of the CCA bulkhead was 55.4m away and labeled "Dirt" reference area. This was an undeveloped lot with a dirt embankment leading to the water. The next control site, approximately 7.6m to the south of our study site, was labeled as "Rock" reference bulkhead. The owner of this lakefront property had placed soccerball sized rocks at the foot of the lawn before it reached the water. The northern side of the Rock bulkhead was located adjacent to an embankment that jutted out into the water approximately 10 feet separating itself from the CCA-treated wood bulkhead. The third control was a bulkhead located approximately 3.0m to the north of the study location and was labeled "Concrete" reference bulkhead. This bulkhead was separated from the study site by a concrete dock that extended into the water for approximately 10 feet.

CHAPTER 3

MATERIALS AND METHODS

3.1 Sediment Analysis

3.1.1 Sediment Sampling

Sediment samples were collected using a stainless steel Ekman grab sampler. Each bulkhead was divided into thirds. Two replicate sampling locations were formed from this division and were labeled A and B respectively. Locations were measured away from the bulkhead at 0, 1, 3, and 10 meters away. Four grabs were made at each sampling location. One Ekman grab samples an area of 15cm x 15cm therefore each sample covered an area of approximately 225cm^2.

The Ekman was lowered into the water over the sampling location engaged and ready to take the sample. Once the Ekman hit the lake bottom and was allowed to settle a "messenger weight" was sent down the rope to hit a trigger which closed the sampler. The Ekman, now containing the sediment sample, was then raised to the surface. All samples were placed into plastic 250ml jars and refrigerated.

3.1.2 Sediment Sieving

Our sediment samples were sieved so that we could obtain the fine fraction of sediments (silts and clays <70μm). It is in this fine fraction that we expect to see a greater accumulation of the metals of concern for our study (Luoma and Davis 1993; Weis et al. 1993). To accomplish this a sieving protocol was necessary to remove the fine fraction (<70μm) from the rest of the sediment sample. During this process the sand -

(70µm-160µm and 160µm-1.18mm) and gravel (>1.18mm) content were also recorded. The total weight of all four fractions were expressed as percent (%) of the total sample.

The sample was first homogenized with an acid-washed glass stirring rod. All utensils that came in contact with the sample were acid-washed in baths containing 10% HCl and glass distilled-deionized water (GD-DI) so as to avoid cross-contamination. A 250ml plastic jar was then placed on a scale and a tare weight was taken. An aliquot of homogenized sample was then taken with plastic spoon, placed into the plastic jar and the aliquot weight recorded. Approximately 3-5ml of GD-DI was added to the aliquot which was then shaken for approximately 1 to 2 minutes to free up the fine particles that may be clumped together and allow for a more thorough homogenization.

The homogenized aliquot was then rinsed out of the 250 ml plastic jar onto a pre-wetted 1.18mm mesh nylon screen lying over a plastic collection bucket. The sample was then rinsed thoroughly with GD-DI water to wash all particles less than 1.18mm into the collection bucket. The particles retained by the screen (>1.18mm) were placed into a petri dish. This dish was then placed into a Scientific Products (S/P) drying oven overnight and its weight recorded the next day using a Fisher Scientific Model 2000 scale. The particles that passed through the 1.18mm screen and into the collection bucket were then rinsed onto a 160µm nylon mesh screen with a second collection bucket underneath. The rinsing process was repeated and those particles that were retained by the 160µm nylon mesh screen were rinsed into a pre-weighed petri dish, placed into a drying oven overnight and its weight recorded the next day. The particles that passed through the 160µm nylon mesh screen were rinsed out of the second plastic collection bucket and onto a 70µm nylon mesh screen with a third plastic collection bucket underneath. Again the sample was rinsed with GD-DI water and all particles that were not able to be rinsed through the 70μm nylon mesh screen were rinsed into a pre-weighed petri dish, placed into a drying oven overnight and its weight recorded the next day.

The particles that passed through the 70μm nylon mesh screen were considered the "fine fraction". This fraction was then rinsed into 50ml centrifuge tubes and centrifuged for approximately 11-15 minutes in an International Clinical Centrifuge. This compacted the fines making them easier to collect without having a significant amount adhere to the sides of the plastic container. Once centrifuged, the fine fraction was placed into a 50ml pre-weighed glass beaker, placed in a drying oven overnight and its weight recorded the next day.

3.1.3 Total Carbon Analysis

When the dry weights for all fractions of a particular sample were obtained, the petri dishes and the 50ml beaker were placed into a Thermolyne Model F-A 1630 muffle furnace with a Temcometer Input Controller Model CP-A 510T, ranging from 0-1250°C (0-2500°F), at 150°C overnight. They were then cooled and a second dry weight was obtained. This difference in weight from the original dry weight was known as the "muffle weight" and informed us of how much organic carbon was contained in the fractions. Lastly the petri dishes and beaker were placed into the muffle furnace overnight which would reach a maximum temperature of 450°C. The sample was allowed to cool to room temperature at which time a third dry weight would be recorded. The difference between this weight and the second muffle weight informed us of how much inorganic carbon was contained in our sample. Exposing our fine fraction to this drying regimen helped to remove all potential carbon interference from our samples prior to being digested and analyzed for the metals in question.

A small portion of our fine fraction (<70μm) was sent out for total carbon analysis for quantification of percent total carbon contained in our samples. Total Carbon analysis was performed on a Carlo Erba NA 1500 Series L N_2/C/S Analyzer with Acetanilide (C=71.09%) as the standard reference material. All samples were weighed out on a Sartorius Micro XM 1000P balance to the nearest 0.001 mg prior to analysis.

3.1.4 Sediment Digestion

Prior to analyzing the fine fraction (<70μm) of the sediment sample for Cr, Cu, and As, it first had to be digested in acid. Ten milliliters of Fisher Trace Metal Grade Perchloric acid ($HClO_4$)/Nitric acid (HNO_3) at a ratio of 3:1 was added to the fine fraction of the sediment sample. The sample was then covered with a watch glass and simmered on a hot plate for approximately three hours until almost dry. The sample was allowed to cool and then placed into a funnel lined with Fisher Brand Q8 filter paper (coarse porosity, fast flow rate) with a diameter of 9 cm. Fisher Trace Metal Grade 1% Nitric Acid was rinsed over the sample and the extract was collected by a labeled volumetric flask with stopper. The extract was then poured into a plastic 10ml vial to be used during analysis with the rest remaining as a backup supply. Three replicates of N.I.S.T. Standard Reference Material 1645 (River Sediment) and one reagent blank were run along with each “batch” to ensure quality of the extraction process.

3.1.5 Sediment Metal Analysis

A Perkin Elmer Model 603 Atomic Absorption Spectrophotometer with the appropriate hollow cathode lamp for each element was used to analyze the sediment (and benthic organism) samples for chromium, copper and arsenic concentrations. Appendix C, Table 9 contains the Atomic Absorption settings used for each lamp prior to analysis. Copper and chromium analysis were performed by Flame Atomic Absorption. There were no modifications made to the instrument besides using the hollow cathode lamp specific for copper and chromium and the settings listed in Appendix C, Table 9. Figure 3a in Appendix C shows the Atomic Absorption Spectrophotometer used during this study. Arsenic concentrations were determined by using Atomic Absorption via hydride generation which required a specific setup procedure.

Arsenic determination via hydride generation included the use of a Perkin Elmer Deuterium Arc Power Supply (DAPS), an EDL Power Supply (used as background correction for the DAPS) and a Buck Scientific Cold Vapor Generator (See Appendix C, Figure 3b). This method consisted of adding 50ml of a 5% HCl/GD-DI water solution containing a known volume of our sample to the cold vapor generator. Argon gas was then allowed to "bubble" through the sample. After approximately 30 seconds, 5ml of a Potassium Hydroxide (KOH)/Sodium Borohydride ($NaBH_4$) solution was added to the generator at a steady rate. This resulted in the liberation of highly reactive Hydrogen ions (H^+). These ions would then bind with any arsenic in our sample to form Arsine gas (AsH_3). This gas was then carried by the Argon gas into a heated quartz tube where the Arsenic was broken down to its elemental form and quantitatively measured by atomic absorption in a Perkin-Elmer Model 603 Atomic Absorption Spectrophotometer. The equations are as follows:

1. $$\mathbf{KOH + NaBH_4 + HCl + Sample \longrightarrow H^+ \text{ (Highly Reactive)} + As^{-3}} \tag{3.1}$$

2. $$\mathbf{As^{-3} + H^+ \longrightarrow AsH_3} \tag{3.2}$$

3. $$\mathbf{AsH_3 \xrightarrow[\Delta]{} As + 3H^+} \tag{3.3}$$

Standards were prepared from Fisher Brand Cr, Cu and As standards of 1000ppm and diluted to desired concentrations.

3.2 Benthic Organism Analysis

3.2.1 Benthic Organism Sampling

Macroinvertebrates began to hatch in the spring but were not harvested until the end of May through the end of July using a modification of the sediment sampling procedure. We waited until this time period for collection so as to obtain some bioaccumulation of metals from their foraging in the sediments. Once a location was sampled with the Ekman (four grabs per location) and brought to the surface, the contents were placed into an 12 inch diameter, 1 mm plastic mesh sieve. The 1mm mesh sieve was chosen in the attempt to obtain only those macroinvertebrates large enough to acquire enough mass to perform elemental analysis. The contents were then rinsed with lake water to remove any of the smaller particle fraction. The remaining larger particle fraction (>1mm), detritus and organisms, were placed into a tupperware tray where all of the benthic organisms were sorted, removed with forceps, placed into a 250ml plastic sample jar containing some lake

3.2.2 Benthic Organism Digestion

The digestion procedure is dependent on sample weight to determine the amount of other chemicals to be added in the process (See Table 2).

TABLE 2 Amount of Acid, Magnesium Nitrate and Antifoam B versus Tissue Weights

Sample Weight (g)	Step 4 Acid Added (ml)	Step 5 $Mg(NO_3)_2$ added (ml)	Step 5 Antifoam B (ml)
0.0-0.29	2.0-3.0	5.0	0.5
0.3-0.59	4.0-5.0	10.0	1.0
0.6-0.99	6.0-7.0	15.0	1.5
1.0-1.5	6.0-7.0	20.0	2.0

Source: Sanders, J. Academy of Natural Sciences, Philadelphia.

Ideally we wanted to digest "similar" organisms to obtain a concentration of contaminants for a particular genus or species. However, this was not feasible in this study. The organisms encountered were small and few; therefore they had to be composited to obtain a minimum desirable weight for analysis which was approximately 100mg. The dried organisms for each sample location (excluding the occasional snail and clam since they occurred infrequently and would throw off the results and statistical analysis) were composited to make one benthic organism sample for each sampling location. The sample weight for all locations ranged from 0.017g to 0.265g. Two reagent blanks and three replicates of N.I.S.T. Standard Reference Material 1566A (Oyster Powder) were run along with the rest of the specimens to ensure quality of the extraction process.

Digestion of the samples began with the addition of 3ml Aqua Regia (25% conc. HCl/75% conc. HNO_3) which were then heated on a hot-plate until almost dry. Extra care was taken to not let the sample dry or burn. Then, 5ml of 40% $Mg(NO_3)_2$ and 0.5ml

Antifoam B was added to the sample, swirled thoroughly and heated until very dry (looked like white ash/bone) on the hot plate. The sample was then covered with aluminum foil and placed into the muffle furnace (same as described in Section 3.1.3) which was heated to 100°C for 1 hour, ramped to 350°C for 1 hour and finally to 450°C overnight. The next morning the samples were removed from the furnace, cooled, and the foil was removed. Ten milliliters of 4M HCl, a few Teflon boiling stones, and a watch glass were added to each sample. They were each boiled for approximately 30 min. until everything in the beaker was dissolved. Once the sample was dissolved and cooled it was decanted into a labeled plastic vial and made up to 10ml with 1% HNO_3. The samples were now ready for analysis.

3.2.3 Benthic Organism Metal Analysis

The materials and methods used for the determination of chromium, copper and arsenic in our benthic organism samples can be found in Section 3.1.5 - Sediment Metal Analysis.

3.3 Benthic Organism Community Structure

3.3.1 Total Number of Taxa, Individuals and Total Biomass

After the organisms were allowed to "purge" they were recorded by counting (to obtain the total number of individuals) and identified to the lowest applicable taxa with the aid of a Bausch and Lomb stereo microscope and a variety of identification keys and books (Ferraro and Cole 1995; Merritt and Cummins 1984; Pennak 1978; Peckarsky et al. 1990; Thorp and Covich 1991). Total biomass was obtained following benthic organism identification. Organisms of the same taxa were placed into a pre-weighed 20 ml glass vial and dried overnight at 95^{0}C in a Precision Scientific (P/S) drying oven. A final dry weight for the sample was recorded. The samples were then held at room temperature until needed for digestion.

3.3.2 Species Diversity (H′)

The Shannon-Wiener diversity indices (H′) were calculated for all sampling locations at each bulkhead. The equation used to calculate the indices is as follows:

$$\mathbf{H'} = 3.3219 \times \log N - \frac{1}{N} \; (n_1 \times \log n_1 + n_2 \times \log n_2 + \ldots\ n_n \times \log n_n) \qquad \mathbf{(3.4)}$$

Where N equals the total number of individuals for *all* taxa at a sampling location and n equals the total number of individuals *per* taxa at each sampling location.

3.4 Lake Parameters

The water quality parameters taken at each bulkhead consisted of temperature, dissolved oxygen, pH, and conductivity. Three different types of instruments were used for obtaining these readings. Temperature (°C) and dissolved oxygen (mg/L) were determined using a YSI Model 51B Oxygen meter with a YSI 5739 Probe. Calibrations were done in “air.” Conductivity (µmohs/cm) was measured with a YSI Model 33 S-C-T Meter with a Model 3300 Probe. This unit was calibrated using a known concentration of a KCl solution. Water pH was determined using a Corning pH 106 Meter that was calibrated with a 7.03 pH buffer solution. All instruments were calibrated prior to use and adjusted if necessary.

3.5 Statistical Analysis

Sediment results, benthic organism community structure and lake parameters were statistically analyzed using ANOVA and Bonferroni's test of the means. The analytical software used was Statistix® Version 4.1. The term (SD) refers to the Standard Deviation of a particular value.

CHAPTER 4

RESULTS

4.1 Sediment Metal Concentrations

All sediment metal concentrations were obtained by analyzing the fine fraction (<70μm) of our sediment samples. It is in this fraction which we expect to see the greatest concentration of metals (Weis et al. 1993). A summary of all metal concentrations and percent fine fraction for each sample can be seen in Tables 3 and 4.

4.1.1 Chromium Concentrations

Sediment chromium concentrations among all sampling areas (0-10m) were not statistically different from one other (P>0.05). When each sampling location (i.e.: 0-meters, 1-meter, etc.) was compared to all the other sampling areas for that same location, it was noticed that the Dirt reference 0-meter location had the highest chromium concentration of 57.20μg/g +/- 20.27(SD) which was significantly different from that of the Wood bulkhead, 29.99μg/g +/- 5.70(SD) at the same location (F=133.06, P=0.0002). See Table 3, Figure 4. The Wood bulkhead 0-meter chromium concentration was consistent with those from the Rock and Concrete reference bulkheads. We must look into the possibility of external contamination at the Dirt 0-meter reference location since it does not exist in other areas.

Table 3 Summary of Sediment Metal Concentrations in the Fine Fraction, Percent Fines and Percent Total Carbon for all Sampling Locations[1]

DIRT

Distance (M)eters	Chromium (ug/g)	Copper (ug/g)	Arsenic (ug/g)	Percent Fines (%)	Total Carbon (%)
0	***57.20*** +/-20.27	***195.44*** +/-108.02	***30.79*** +/-0.11	***0.10*** +/-0.004	***1.76*** +/-1.33
1	***34.5*** +/-1.202	***133.21*** +/-35.41	***7.18*** +/-0.39	***0.63*** +/-0.06	***3.43*** +/-0.077
3	***23.65*** +/-0.042	***93.25*** +/-4.83	***6.37*** +/-1.47	***2.90*** +/-0.58	***0.12*** +/-0.09
10	***19.56*** +/-3.25	***155.91*** +/-39.05	***9.92*** +/-1.34	***5.72*** +/-3.47	***0.22*** +/-0.00

ROCK

Distance (M)eters	Chromium (ug/g)	Copper (ug/g)	Arsenic (ug/g)	Percent Fines (%)	Total Carbon (%)
0	***31.78*** +/-15.23	***112.29*** +/-51.84	***4.63*** +/-1.96	***0.46*** +/-0.14	***2.62*** +/-2.67
1	***29.83*** +/-0.29	***144.22*** +/-39.75	***10.04*** +/-2.97	***1.93*** +/-0.19	***0.20*** +/-0.11
3	***23.22*** +/-1.14	***178.22*** +/-26.95	***10.86*** +/-3.53	***4.47*** +/-1.04	***0.52*** +/-0.16
10	***22.62*** +/-0.11	***185.06*** +/-7.19	***15.20*** +/-5.13	***3.06*** +/-0.32	***0.64*** +/-0.01

WOOD

Distance (M)eters	Chromium (ug/g)	Copper (ug/g)	Arsenic (ug/g)	Percent Fines (%)	Total Carbon (%)
0	***29.99*** +/-5.70	***28.99*** +/-6.22	***24.07*** +/-25.84	***3.23*** +/-0.38	***1.46*** +/-0.29
1	***20.21*** +/-0.72	***24.19*** +/-0.77	***3.26*** +/-1.39	***5.81*** +/-3.14	***0.87*** +/-0.72
3	***24.18*** +/-1.28	***78.57*** +/-34.28	***5.63*** +/-1.96	***3.18*** +/-0.77	***0.31*** +/-0.04
10	***24.16*** +/-4.89	***116.15*** +/-61.35	***7.80*** +/-3.22	***8.42*** +/-8.02	***0.19*** +/-0.09

CONCRETE

Distance (M)eters	Chromium (ug/g)	Copper (ug/g)	Arsenic (ug/g)	Percent Fines (%)	Total Carbon (%)
0	***31.07*** +/-4.65	***204.91*** +/-33.40	***11.12*** +/-2.91	***1.40*** +/-0.05	***2.21*** +/-2.52
1	***27.22*** +/-0.30	***213.98*** +/-5.50	***9.04*** +/-3.48	***2.03*** +/-0.49	***0.41*** +/-0.03
3	***30.22*** +/-9.09	***165.47*** +/-89.07	***9.64*** +/-6.25	***2.87*** +/-3.40	***0.36*** +/-0.16
10	***24.98*** +/-4.00	***216.60*** +/-66.90	***6.92*** +/-1.22	***3.05*** +/-1.43	***0.63*** +/-0.90

1 = All values are the mean of that particular sampling location (n=2)

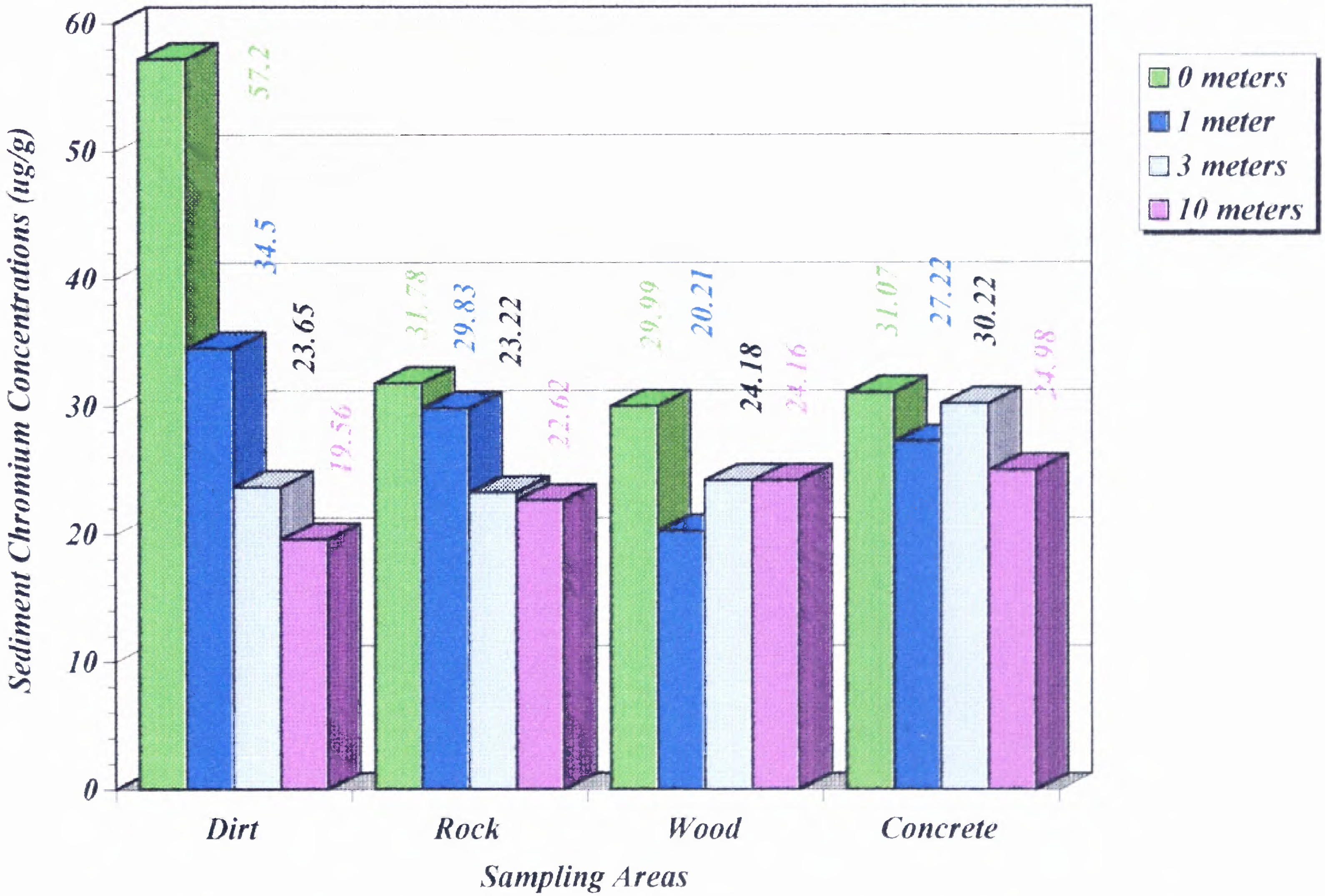

Figure 4 Sediment mean chromium concentrations expressed in micrograms/gram for all sampling locations.

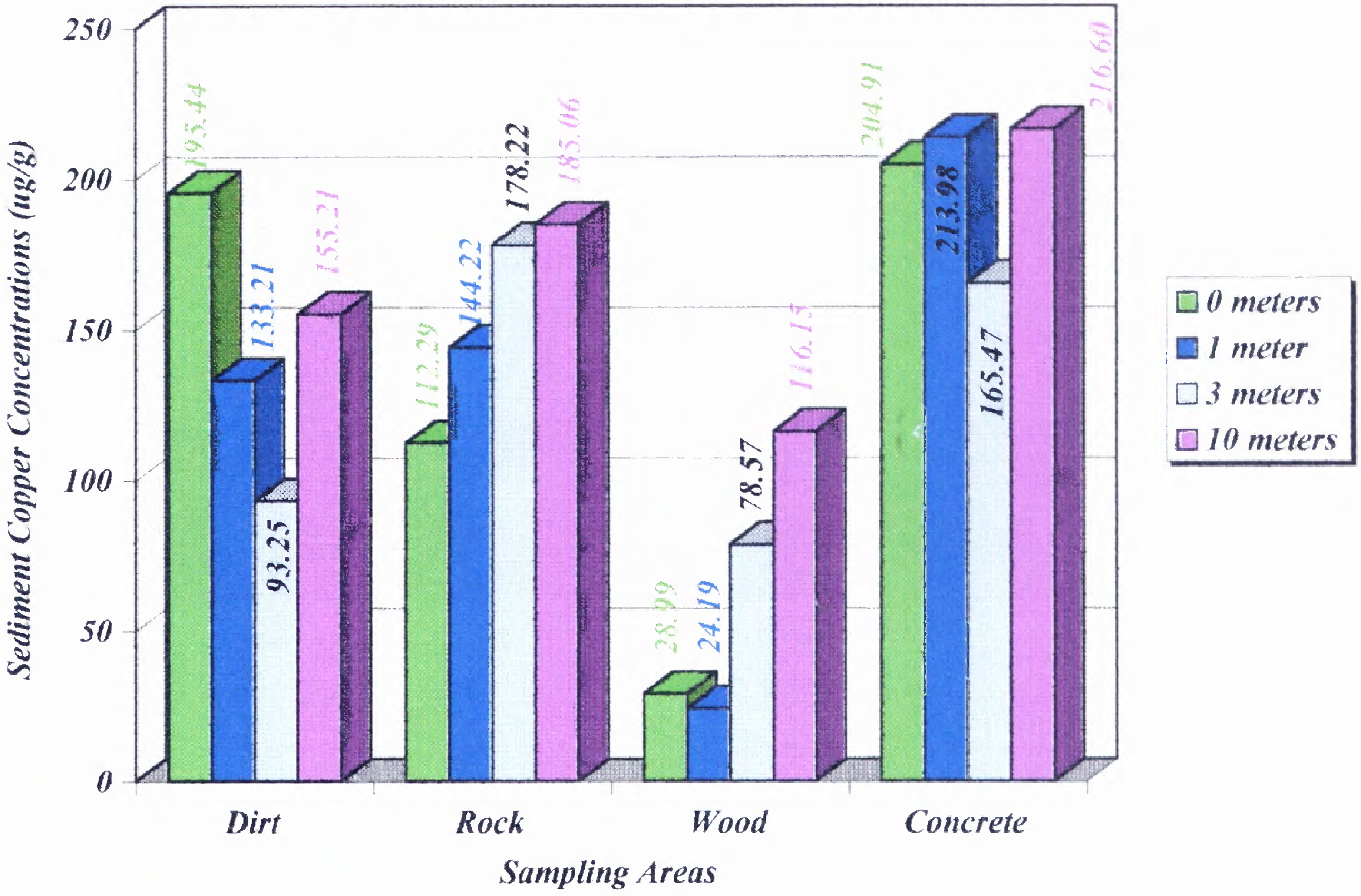

Figure 5 Sediment mean copper concentrations expressed in micrograms/gram for all sampling locations.

4.1.2 Copper Concentrations

Copper concentrations at the reference areas (Dirt, Rock, and Concrete) for each sampling location were higher than the Wood bulkhead. Copper concentration comparisons between similar sampling location show that there is a significant difference between the concentration by the Wood bulkhead at 0-meters, 28.99μg/g +/- 6.22(SD), and that of the Concrete bulkhead at the same location, 204.91μg/g +/- 33.40(SD) (F=17.18, P=0.0095). Concentrations of copper for each bulkhead at all sampling locations (0-10m) were not significantly different. See Figure 5 and Table 3.

4.1.3 Arsenic Concentrations

Sediment arsenic analysis shows statistical significance among all Dirt reference sampling locations (F=261.01, P=0.000) with the highest concentration, 30.79μg/g +/- 0.11(SD), located at 0-meters and the lowest, 6.37μg/g +/- 1.47(SD), at 3-meters. See Table 3 and Figure 6. There was no significance among or between the other reference areas. It can be seen from Figure 6 that there is an increase in arsenic concentration at the 0-meter location for the dirt reference area (30.79μg/g +/- 0.11(SD)) and at the Wood bulkhead (24.07μg/g +/- 25.84 (SD)) compared to the same locations at the Rock and Concrete reference bulkheads. This raises the question as to why there are increased arsenic levels at only these two locations. If it were only seen at the Wood bulkhead, we could possibly attribute this to the leaching of arsenic from the treated wood; however, we also see a similar increase at the Dirt reference area, located approximately 40 meters away to the south, which may have been caused by some form of external contamination.

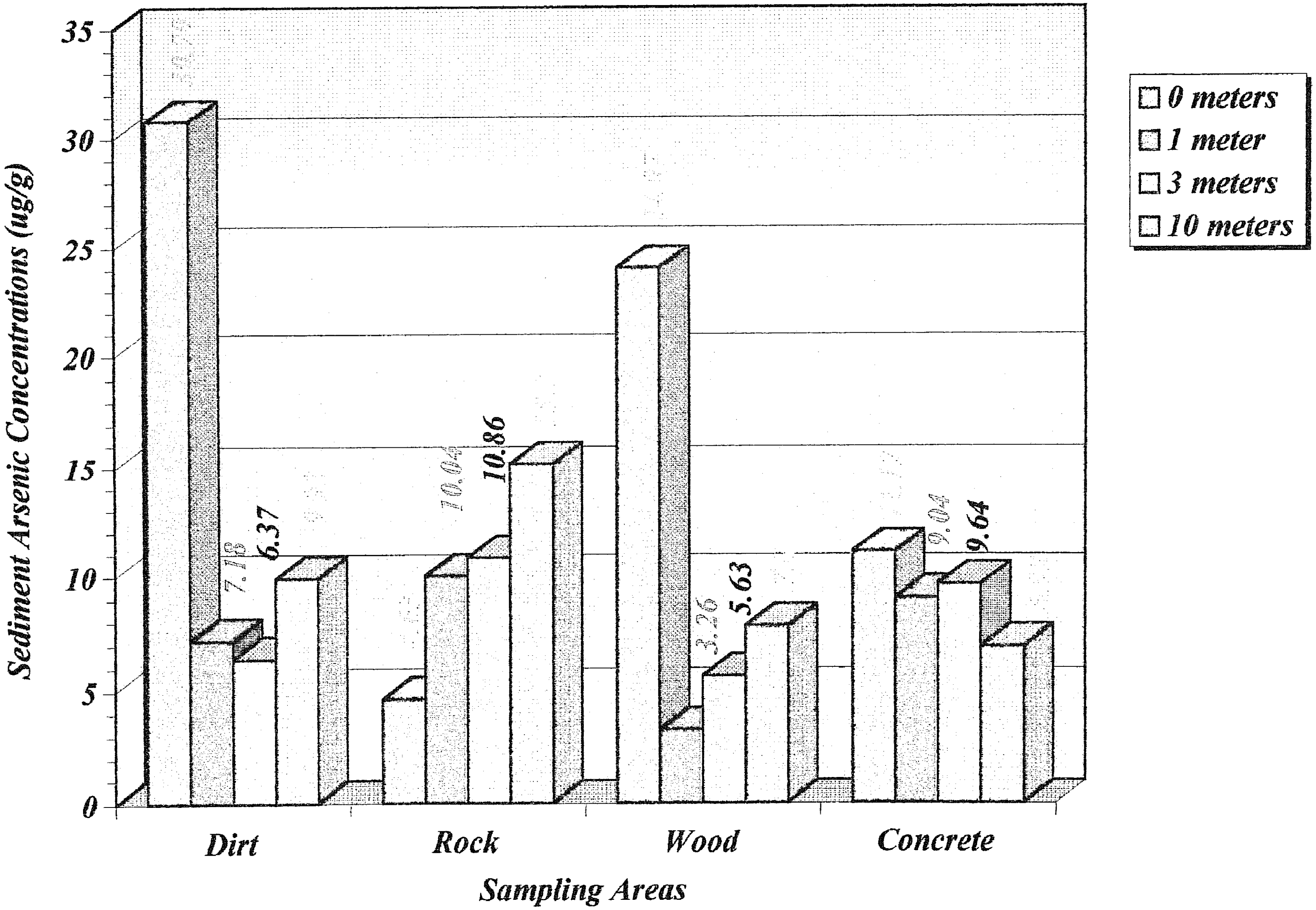

Figure 6 Sediment mean arsenic concentrations expressed in micrograms/gram for all sampling locations.

Table 4 Summary of Particle Fraction Anaylsis for all Sampling Locations[1]

DIRT

Distance (M)eters	Total wt. (g)rams	1.18mm (%)	160um (%)	70um (%)	Percent Fines (%)
0	***85.27*** +/-20.42	***2.44*** +/-3.02	***72.01*** +/-0.92	***4.18*** +/-3.06	***0.10*** +/-0.004
1	***40.55*** +/-13.90	***28.96*** +/-29.91	***46.17*** +/-25.41	***5.22*** +/-0.05	***0.63*** +/-0.06
3	***45.83*** +/-6.51	***12.71*** +/-4.38	***51.01*** +/-5.52	***10.39*** +/-2.09	***2.90*** +/-.58
10	***23.28*** +/-2.55	***12.75*** +/-6.29	***33.73*** +/-8.09	***12.60*** +/-4.92	***5.72*** +/-3.47

ROCK

Distance (M)eters	Total wt. (g)rams	1.18mm (%)	160um (%)	70um (%)	Percent Fines (%)
0	***23.40*** +/-3.20	***9.28*** +/-0.93	***64.65*** +/-2.74	***5.71*** +/-0.68	***0.46*** +/-0.14
1	***20.88*** +/-0.63	***14.02*** +/-0.99	***50.35*** +/-0.67	***8.54*** +/-1.36	***1.93*** +/-0.19
3	***25.34*** +/-0.36	***11.00*** +/-9.90	***36.80*** +/-2.71	***14.57*** +/-6.56	***4.47*** +/-1.04
10	***23.05*** +/-0.69	***7.36*** +/-2.28	***56.03*** +/-1.65	***6.45*** +/-0.34	***3.06*** +/-0.32

WOOD

Distance (M)eters	Total wt. (g)rams	1.18mm (%)	160um (%)	70um (%)	Percent Fines (%)
0	***23.63*** +/-3.82	***17.86*** +/-4.45	***57.98*** +/-4.16	***5.59*** +/-0.73	***3.23*** +/-0.38
1	***20.70*** +/-0.21	***20.85*** +/-6.19	***52.65*** +/-3.08	***7.08*** +/-0.72	***5.81*** +/-3.14
3	***35.25*** +/-0.17	***18.46*** +/-4.70	***50.91*** +/-4.20	***7.49*** +/-0.38	***3.18*** +/-0.77
10	***25.36*** +/-0.49	***16.95*** +/-18.34	***31.17*** +/-7.03	***13.39*** +/-10.21	***8.42*** +/-8.02

CONCRETE

Distance (M)eters	Total wt. (g)rams	1.18mm (%)	160um (%)	70um (%)	Percent Fines (%)
0	***22.66*** +/-3.39	***15.80*** +/-8.50	***53.24*** +/-5.03	***6.06*** +/-1.44	***1.40*** +/-0.05
1	26.07 *+/-1.08*	***22.81*** +/-4.25	***44.42*** +/-2.24	***6.89*** +/-1.37	***2.03*** +/-0.49
3	***38.02*** +/-17.11	***42.87*** +/-15.98	***41.69*** +/-18.20	***6.76*** +/-7.45	***2.87*** +/-3.40
10	***33.35*** +/-10.19	***8.22*** +/-5.35	***52.78*** +/-10.25	***3.98*** +/-1.03	***3.05*** +/-1.43

1 = All values are the mean of that particular sampling location (n=2)

4.1.4 Percent Fines

The percent fine fraction (<70µm) for all sampling areas at each location can be seen in Figure 7 and Table 4 along with the breakdown of all other particle fractions obtained. All sampling areas show that percent fines increase with increasing distance away from the 0-meter location. Comparing all locations for each sampling area showed no significant difference for the Wood bulkhead, Concrete reference bulkhead and the Dirt reference area in the amount of percent fines found from 0 to 10 meters. The Rock reference bulkhead did show significance at its 3-meter location, which contained its highest percentage of 4.47% +/- 1.04(SD) compared to that of its 0-meter location, 0.46% +/- 0.14(SD) (F=18.66, p=0.0082).

It was noticed that the Wood bulkhead did contain the greatest amount of fines at its 0-meter location (3.23% +/- 0.38(SD)) when compared to the other reference areas at that same location. This was found to be significant when compared to the 0-meter location at the Dirt reference area which contained the least amount of fines (0.10% +/- 0.004(SD), F=93.46, p=0.0004). Figure 7 does show that the sampling locations at the Wood bulkhead contain a greater amount of fines than at the other reference locations (excluding the amount of percent fines found at the 3-meter location which was surpassed by the Rock reference bulkhead). It was also noticed during sampling, and eventually sieving, that the sediment samples from the Wood bulkhead contained some clay that was not found at the other reference areas. This could account for the high percentage of fines found at this bulkhead.

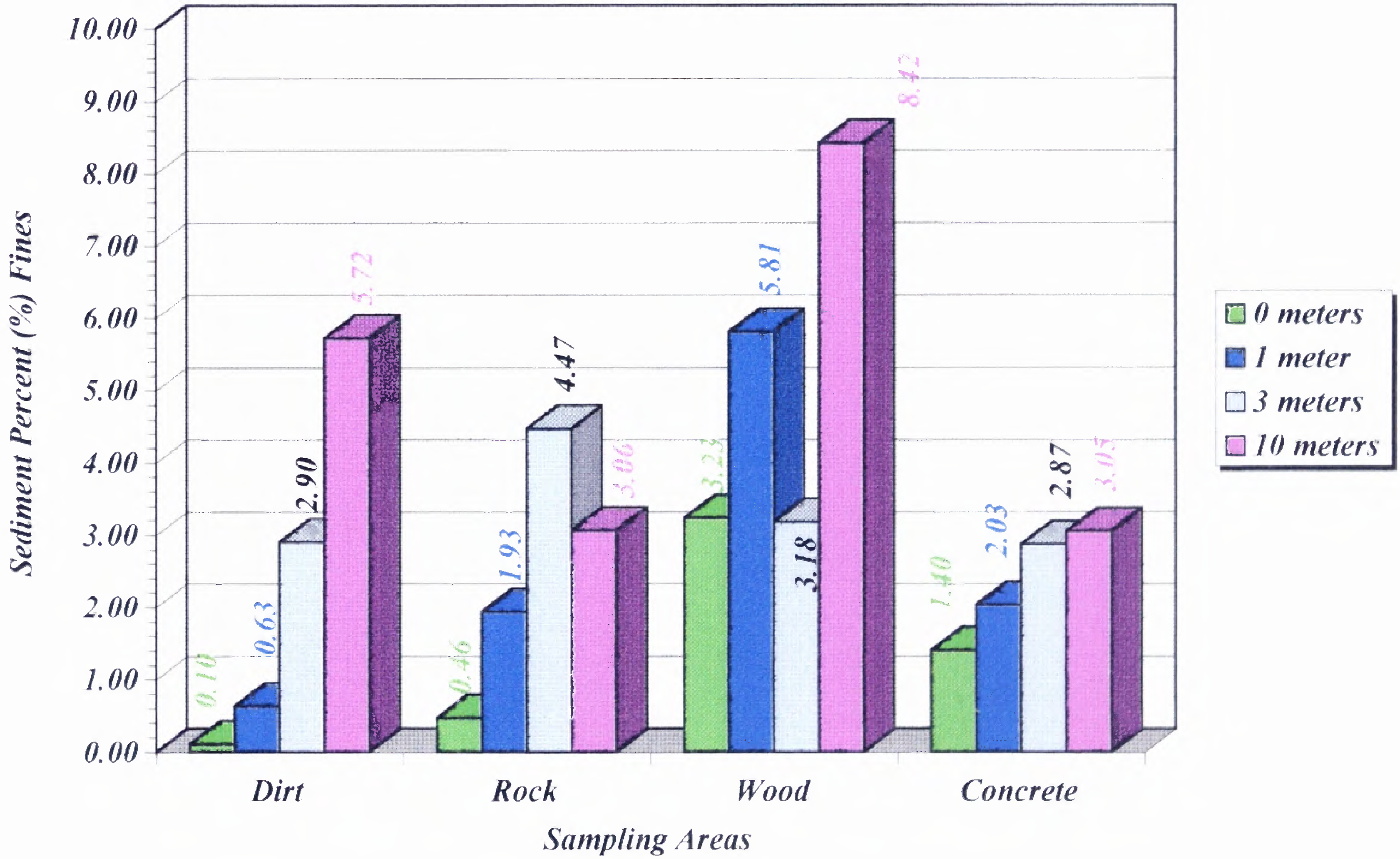

Figure 7 Sediment mean percent fines for all sampling locations.

It was noticed that the percent fines for each location at all sampling areas was inversely proportional to the concentration of metals found at the same location. Percent fines were lower at the 0-meter locations and conversely increased with increasing distance away. See Figures 8, 9, 10 and 11. It was noticed at the Rock reference bulkhead that the percent fines decreased slightly after the 3-meter location (See Figure 9). The Wood bulkhead also saw a decline in percent fine fraction after the 1 meter location but sharply increased to the 10 meter location (See Figure 10). All percentages of fines at the 10-meter locations were greater than those observed at the 0-meter locations.

Copper concentrations for all sampling areas were high and a decreasing gradient away from each 0-meter location was not seen. At times it appeared that copper concentrations increased with an increase in percent fines at the 3 and 10-meter locations. Chromium and arsenic concentrations at the Dirt and Concrete reference areas decreased with increased distance away (See Figures 8 and 11). The Rock reference bulkhead showed a decreasing gradient of chromium but conversely showed an increase in arsenic from 0 to 10-meters (See Figure 9). The Wood bulkhead also displayed a slight increase in arsenic concentration at 10-meters, see Figure 10, while also showing a leveling of chromium at the 3 and 10-meter locations.

4.1.5 Percent Total Carbon

The percent total carbon for all sampling locations can be seen in Figure 12 and Table 3. Comparison of all individual sampling areas in percent total carbon from 0 to 10-meters did not show significance. The highest percentage of total carbon for all sampling locations, although not statistically significant, was found at the Dirt reference area 1-

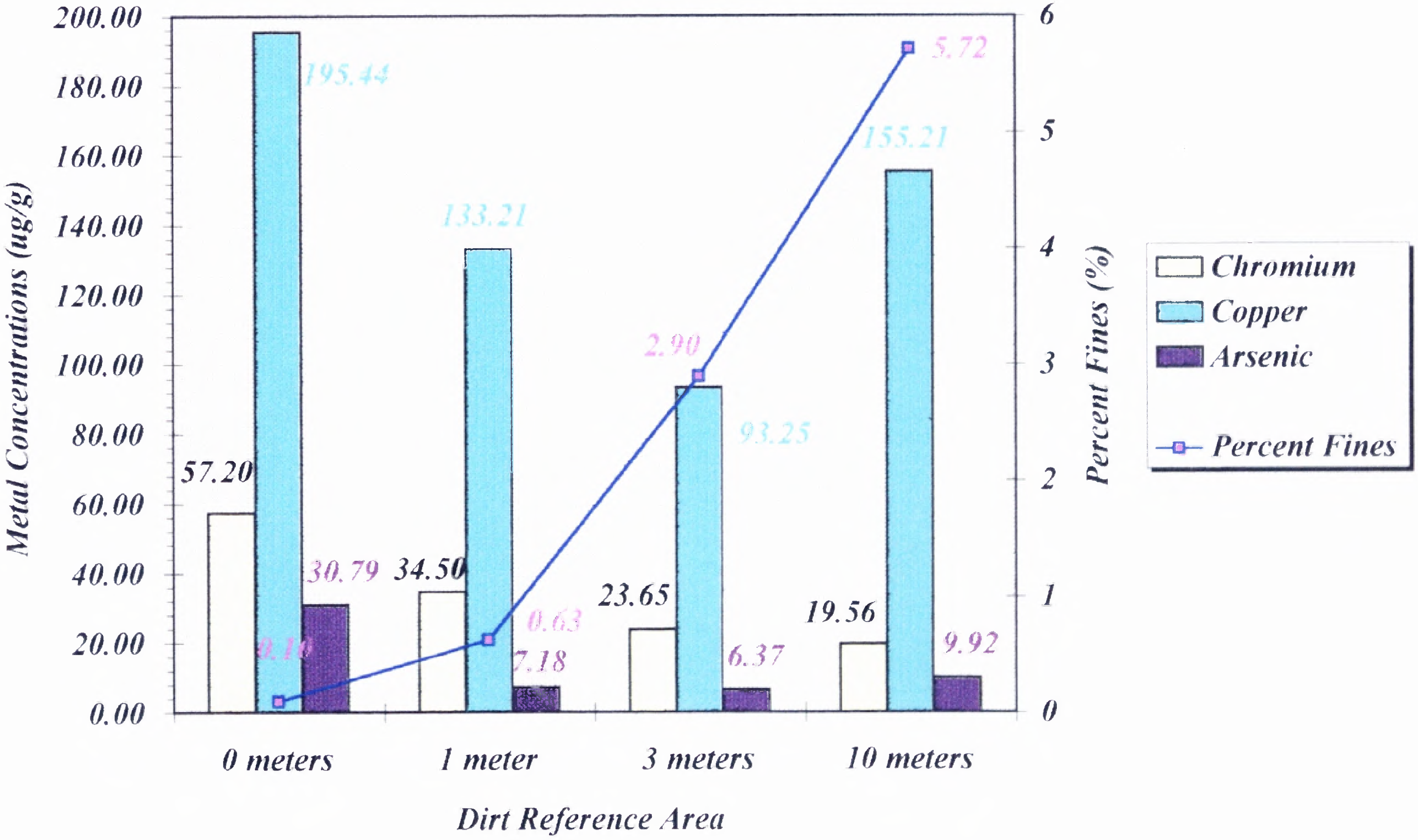

Figure 8 Dirt reference area - mean chromium, copper and arsenic metal concentrations vs. percent fines.

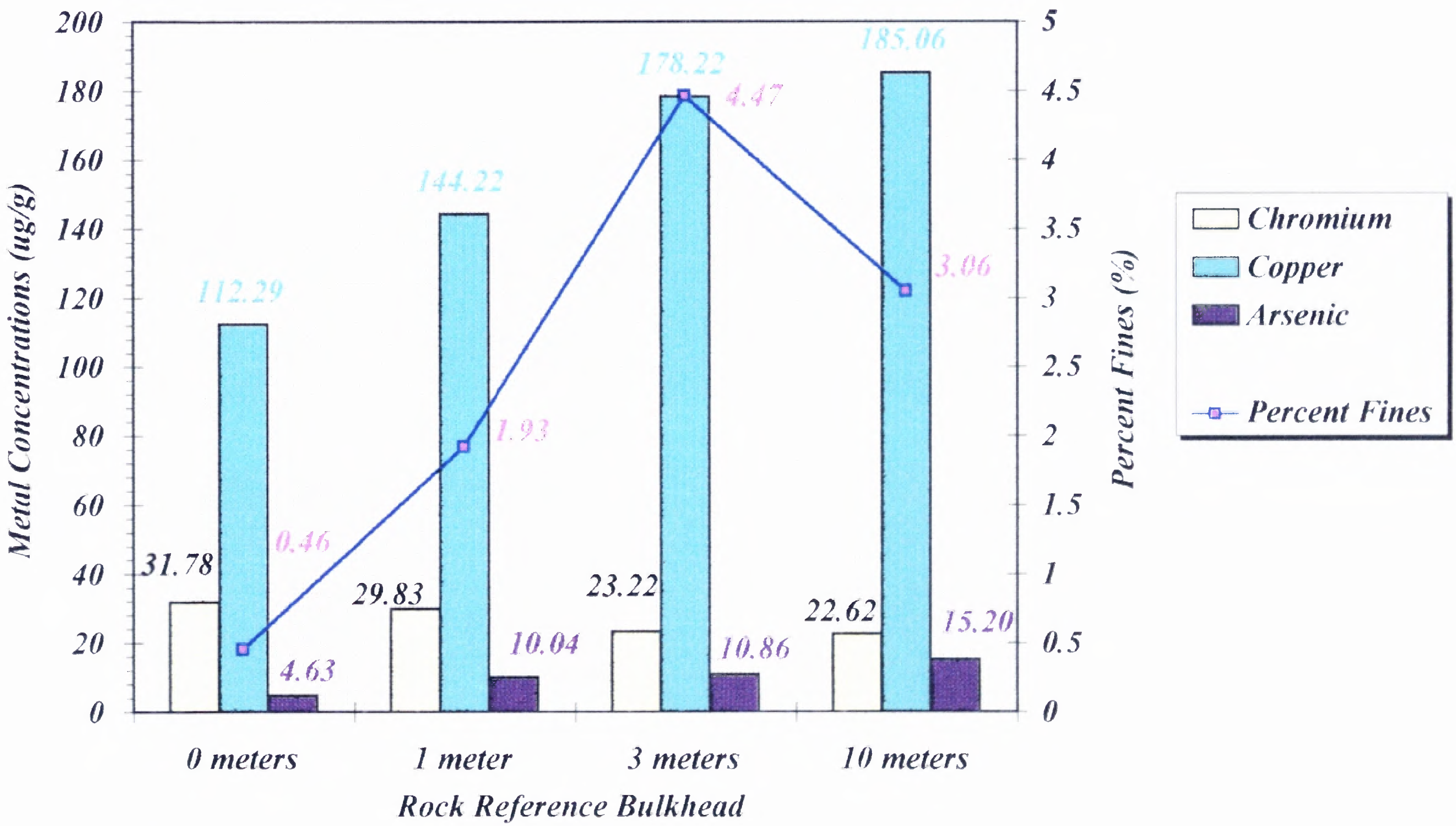

Figure 9 Rock reference bulkhead - mean chromium, copper, arsenic metal concentrations vs. percent fines.

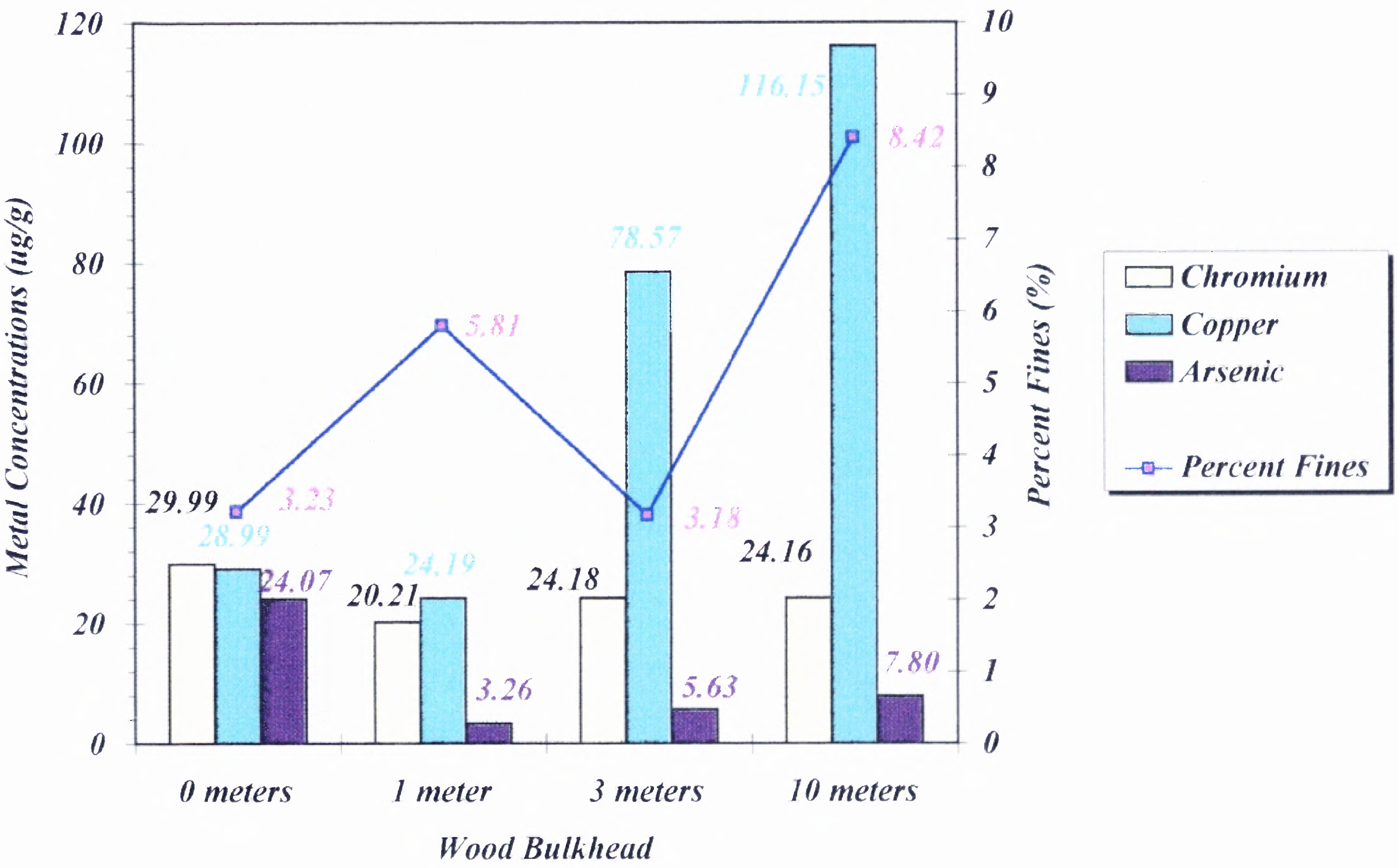

Figure 10 Wood bulkhead - mean chromium, copper, arsenic metal concentrations vs. percent fines.

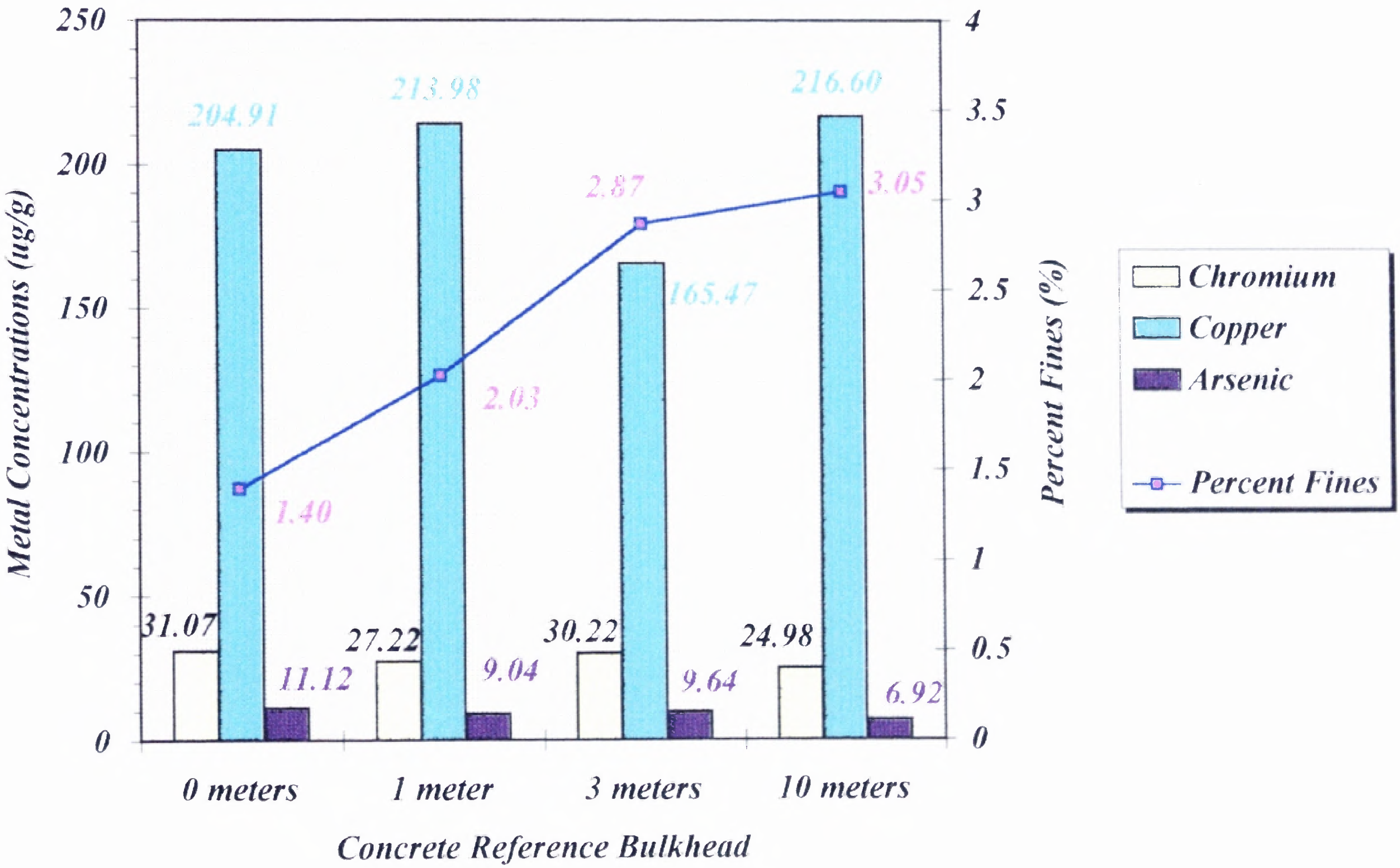

Figure 11 Concrete reference bulkhead - mean chromium, copper, arsenic metal concentrations vs. percent fines.

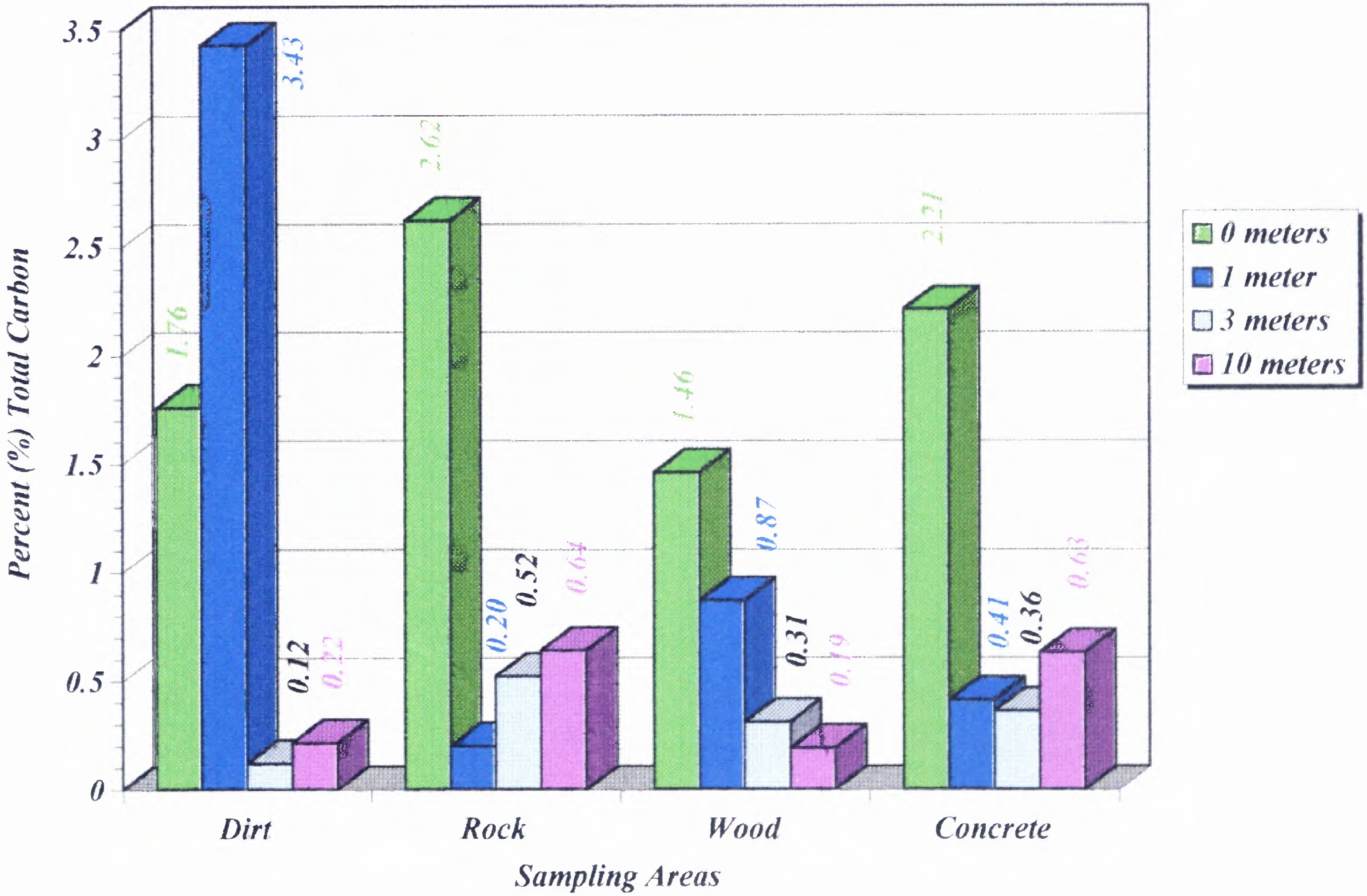

Figure 12 Sediment mean percent total carbon for all sampling locations.

Table 5 Summary of Benthic Organism Sample Weight and Metal Concentrations for all Sampling Locations

Dirt

Distance (M)eters	Sample Wt.* (g)	Chromium (ug/g)	Copper (ug/g)	Arsenic (ug/g)
0	0.121	24.0	52.9	7.29
1	0.123	40.7	34.2	4.20
3	0.085	58.8	50.6	4.85
10	0.083	21.7	73.5	6.26

Rock

Distance (M)eters	Sample Wt.* (g)	Chromium (ug/g)	Copper (ug/g)	Arsenic (ug/g)
0	0.021	1285	110	6.39
1	0.063	318	73.0	5.15
3	0.141	81.6	90.0	4.50
10	0.046	370	41.3	2.96

Wood

Distance (M)eters	Sample Wt.* (g)	Chromium (ug/g)	Copper (ug/g)	Arsenic (ug/g)
0	0.017	371	118	9.90
1	0.076	42.1	46.1	3.18
3	0.090	73.3	50.0	2.98
10	0.170	135	48.8	4.01

Concrete

Distance (M)eters	Sample Wt.* (g)	Chromium (ug/g)	Copper (ug/g)	Arsenic (ug/g)
0	0.236	84.7	49.6	2.59
1	0.087	50.6	71.3	3.92
3	0.265	128	51.7	3.84
10	0.059	356	102	7.39

* Sample weight reflects the composite of both replicate samples

meter location (3.43% +/- 0.077(SD)) while the lowest percentage was found at the 3-meter location within the same area (0.12% +/- 0.09(SD)). Comparing similar locations to all sampling areas revealed significance at the Dirt reference area 1-meter location compared to all other sampling areas at that same location (F=15.76, p=0.0111). The Rock reference area also showed significance at 10-meters (0.64% +/- 0.01(SD)) compared to the same location at the other sampling areas. Percent total carbon values for all locations at the Wood bulkhead and Concrete reference bulkhead were not significantly different from one another.

4.2 Benthic Organism Metal Concentrations

Organisms were sieved from sediments and only those greater than 1 mm were kept for analysis. All organisms were identified using various identification keys, digested and analyzed by Atomic Absorption Spectrophotometry for chromium, copper and arsenic. The total weight obtained for all organisms at each location was less than desired for analysis. As a result, samples at replicate locations (A & B) had to be composited so as to increase the total sample weight. Therefore, statistical analysis of the benthic organism metal concentrations could not be performed due to the small sample size (n = 1) and inferences pertaining to the potential contaminant source for metal bioaccumulation in benthic organisms cannot be made.

4.2.1 Chromium Concentrations

Organism analysis revealed elevated chromium concentrations adjacent to the Rock and Wood bulkheads at the 0-meter location (1290 µg/g and 371 µg/g respectively). See Table 5 and Figure 13. These concentrations were much higher than those for the

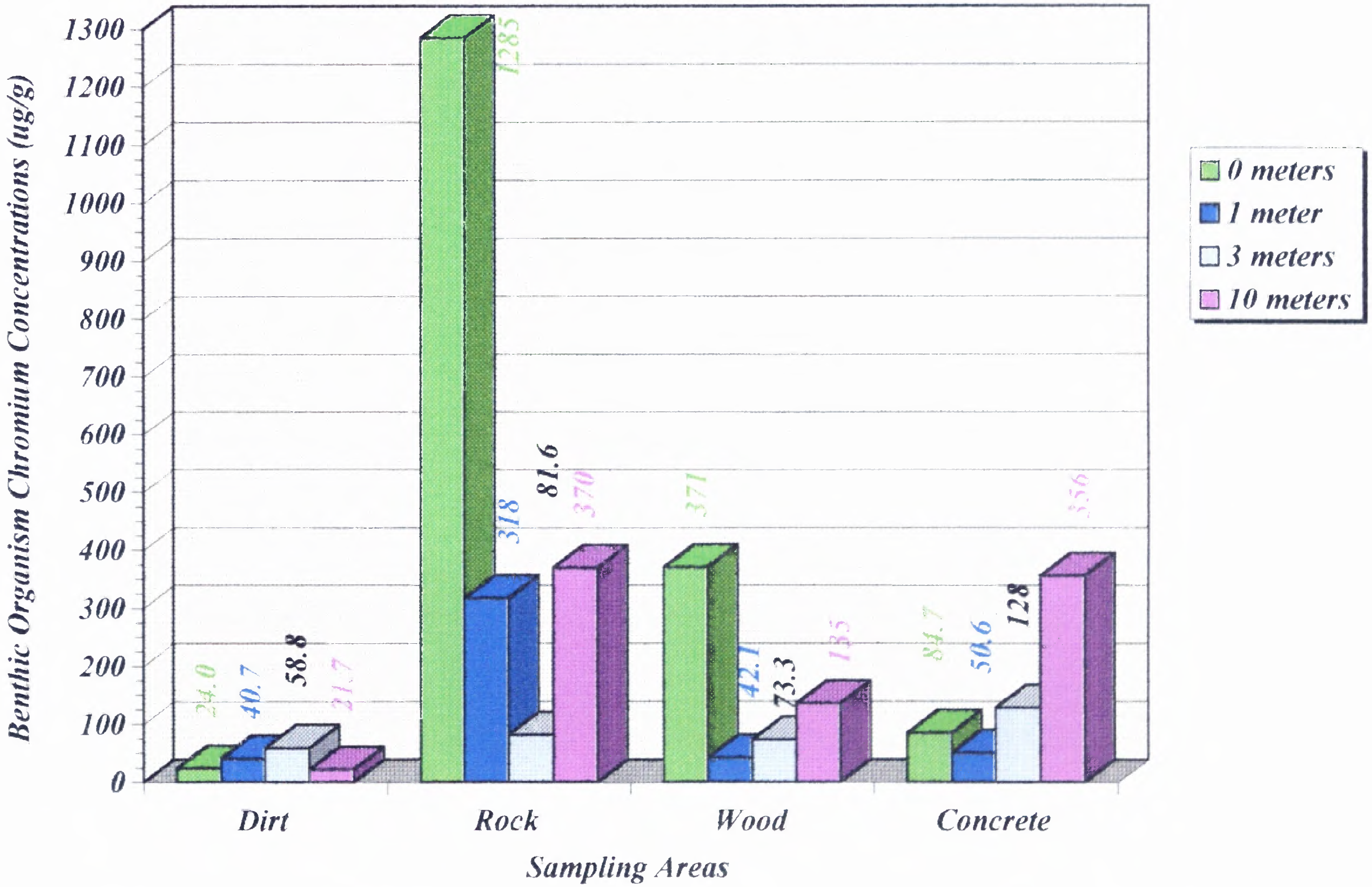

Figure 13 Benthic organism chromium concentrations expressed in micrograms/gram for all sampling locations.

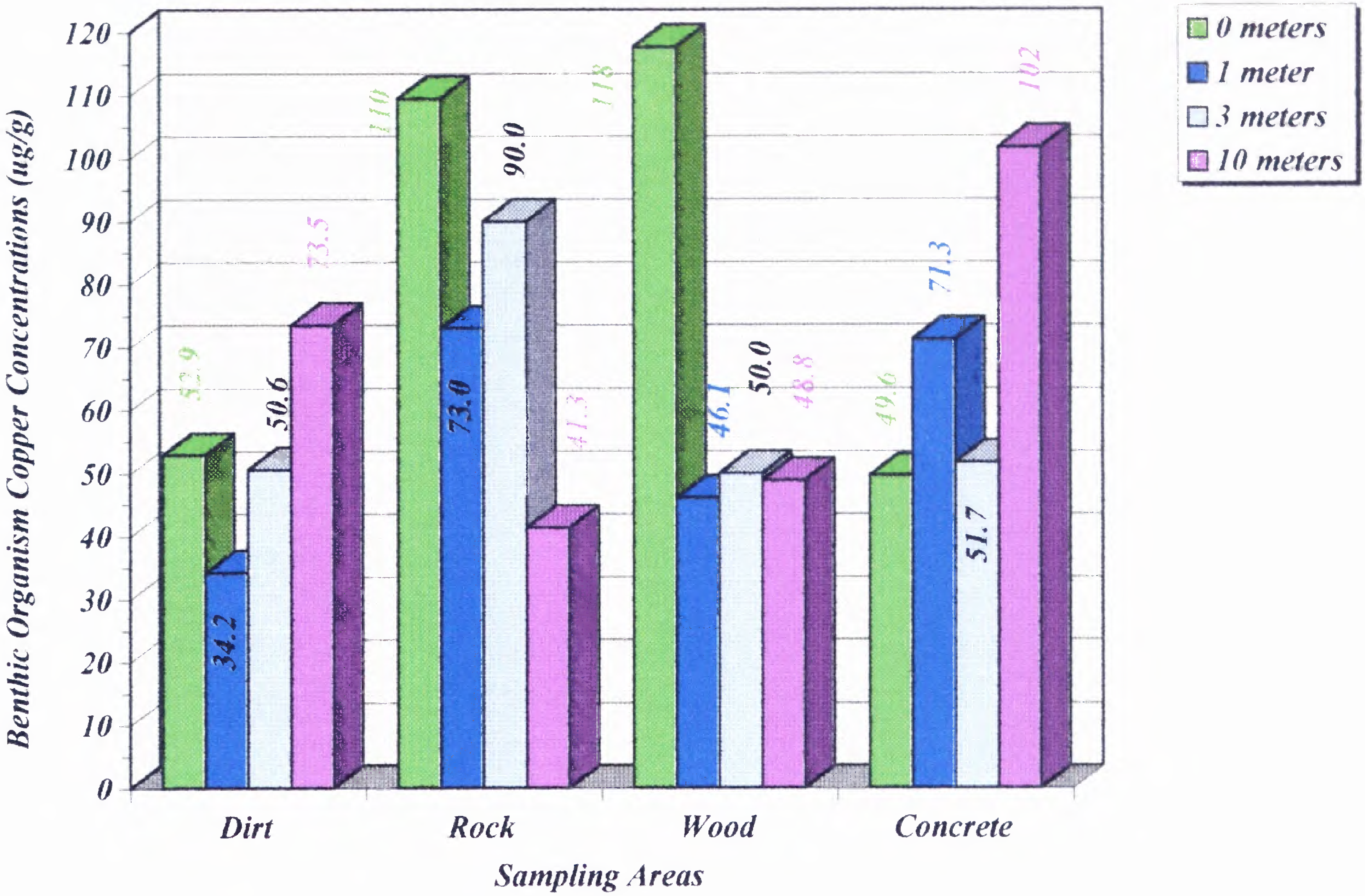

Figure 14 Benthic organism copper concentrations expressed in micrograms/gram for all sampling locations.

Concrete and Dirt reference areas at the same location but could not be proven to be significant. The lowest benthic organism chromium concentration was recorded at the Dirt reference area 10-meter location with 21.7 µg/g. Concentration gradients for all sampling locations appeared to increase, to some extent, away from the 0-meter location.

4.2.2 Copper Concentrations

There were three sampling locations that contained benthic organism copper concentrations greater than 100 µg/g. Figure 14 and Table 5 show these to be at the 0-meter location by the Wood bulkhead and Rock reference bulkhead, and also by the Concrete reference bulkhead 10-meter location with 118 µg/g, 110 µg/g and 102 µg/g respectively. The lowest benthic organism copper concentration was observed at the Dirt reference area 1-meter location with 34.2 µg/g. The Rock reference bulkhead and Wood bulkhead appeared to have decreasing concentration gradients away from their 0-meter location while the gradients for the Dirt and Concrete reference areas showed an increase.

4.2.3 Arsenic Concentrations

Benthic organism analysis showed, although could not be statistically proven, that those organisms living adjacent to the Wood Bulkhead had the highest concentration of arsenic with 9.90 µg/g. See Figure 15 and Table 5. The lowest arsenic concentration was recorded at the 0-meter location by the Concrete reference bulkhead with 2.59 µg/g. The Dirt and Concrete reference areas had increasing concentration gradients of arsenic which were the opposite to the Rock and Wood bulkheads. These gradients were similar to those seen for

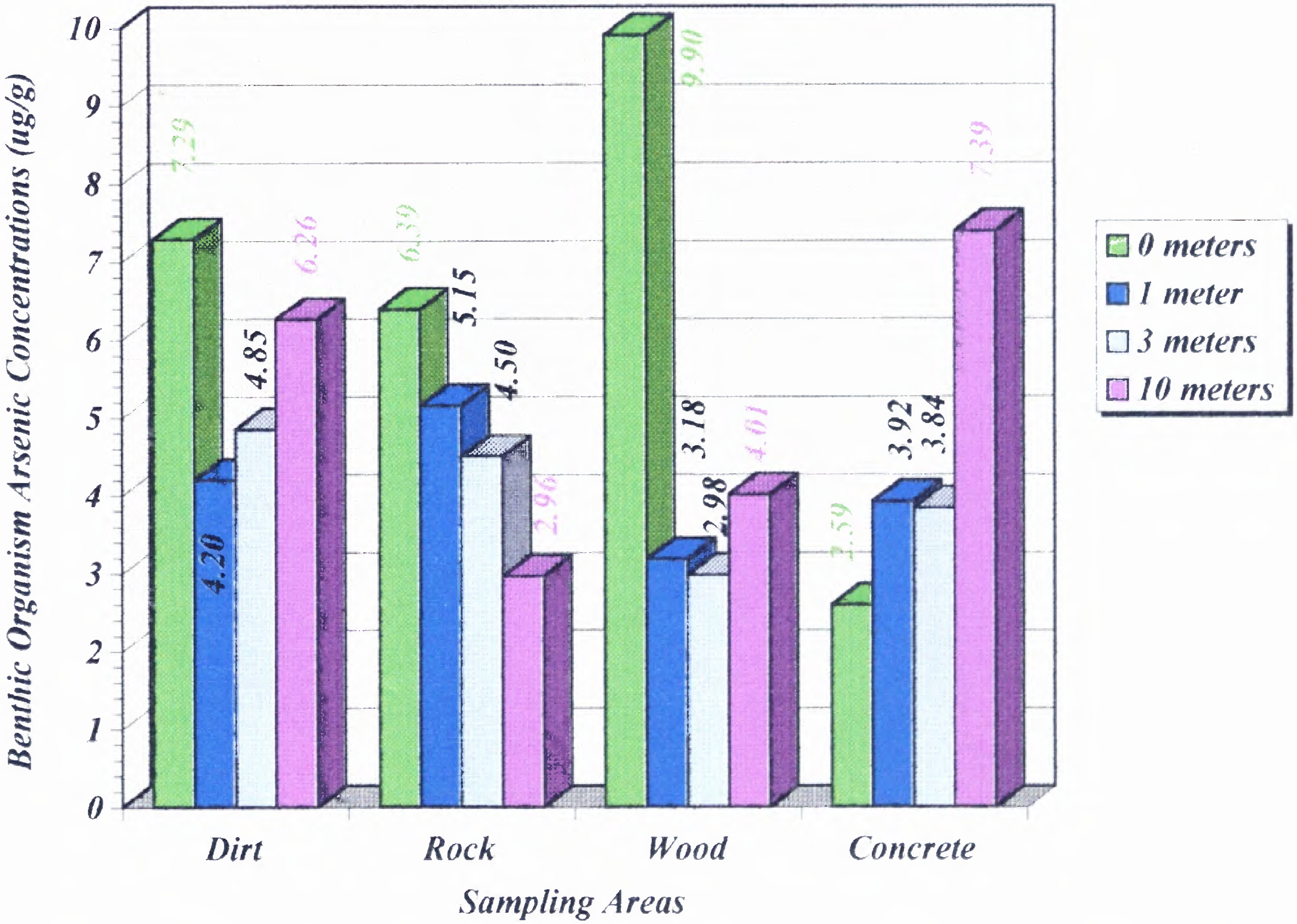

Figure 15 Benthic organism arsenic concentrations expressed in micrograms/gram for all sample locations.

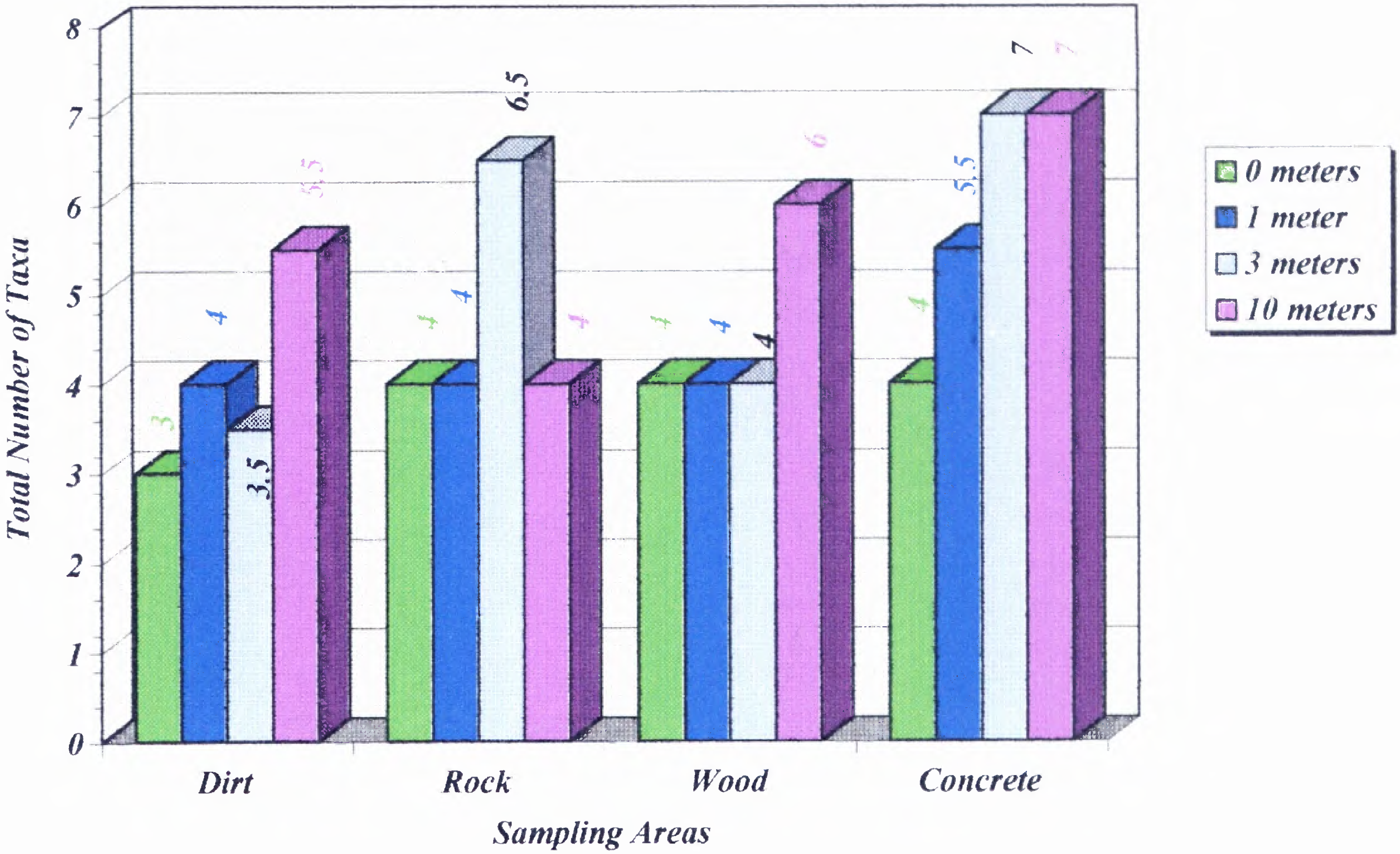

Figure 16 Total number of taxa (mean) for all sampling locations.

benthic organism copper concentrations in Figure 14. Due to a small sample size (n=1) statistical analysis could not be performed on the data.

4.3 Benthic Organism Community Structure

4.3.1 Total Number of Taxa

For the purpose of this study all organisms were identified to the lowest possible taxa (Ferraro and Cole 1995). It was found that identifying organisms past genus was very time consuming even with the use of appropriate identification keys and was not pertinent to the outcome of this study. A list of identified benthic organisms and total number of taxa collected at each sampling location can be seen in Tables 6 and 7.

The greatest number of taxa found at all 0-meter locations were noticed at the Wood, Rock and Concrete sampling areas with 4 +/- 1.41(SD), 4 +/-1.41(SD) and 4 +/- 0.00(SD) taxa respectively. The sampling locations with the greatest number of taxa collected was at the Concrete reference bulkhead 3 and 10-meter locations with a quantity of 7.0 +/- 4.24(SD) and 7.0 +/- 0.00(SD) taxa respectively (See Figure 16, Table 6 and Table 7). The smallest number of taxa was found by the Dirt reference area 0-meter location with 3.0 +/- 0.00(SD). All sampling areas showed an increase in total taxa away from their 0-meter location. Overall there were no significant differences in the number of taxa found between or among the bulkheads ($p>0.05$). It can then be postulated that there was no significant impact on the taxa due to the presence of a CCA treated wood bulkhead.

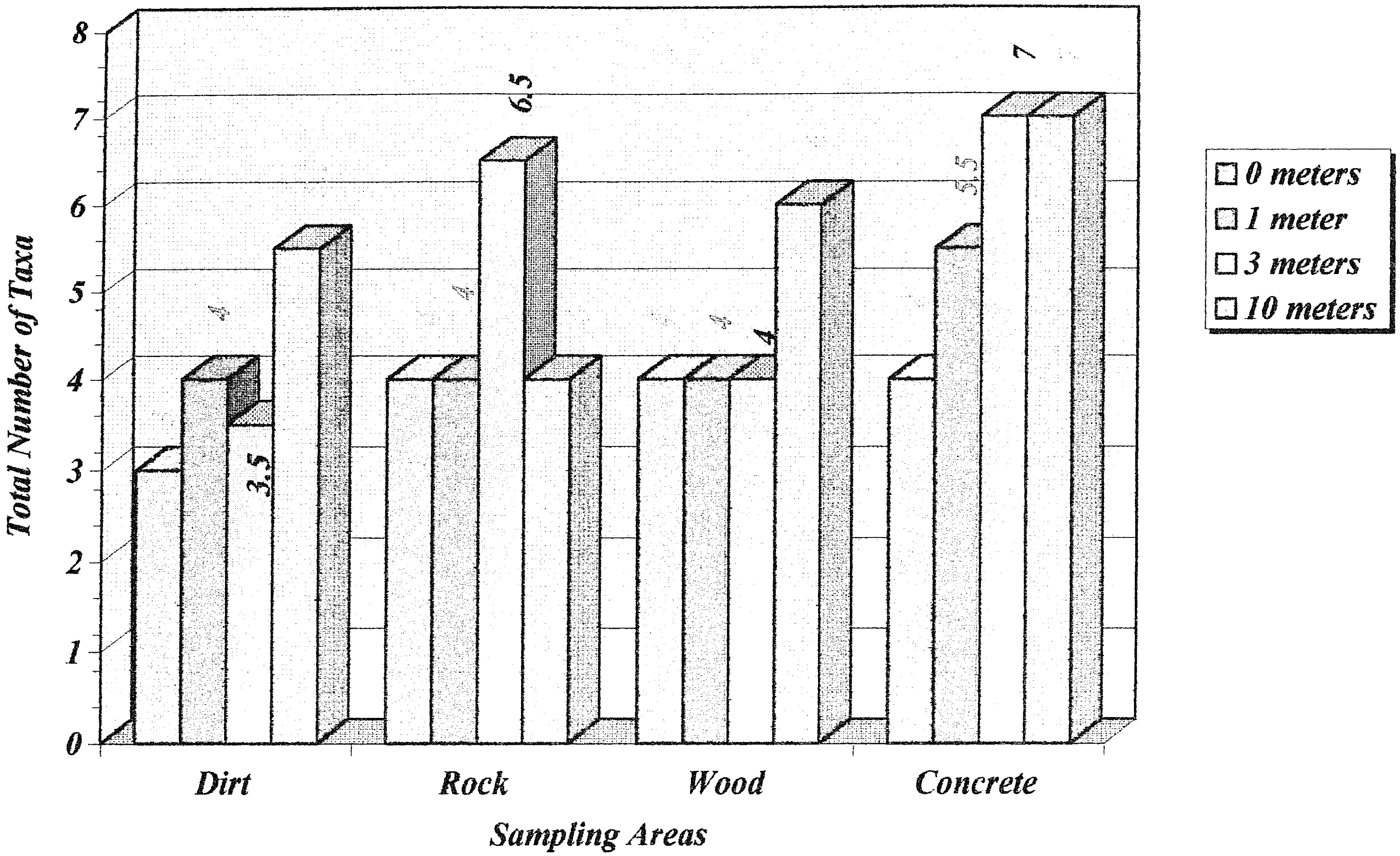

Figure 16 Total number of taxa (mean) for all sampling locations.

Table 6 Identified Benthic Organisms Collected at all Sampling Locations

						Sampling Areas			
Class	**Order**	**Family**	**Genus**	**Species**	**Common Name**	**Dirt**[2]	**Rock**	**Wood**	**Concrete**
Arachnoidea	Hydracarcina	Hydracnidae	-	-	Water Mite	0	0	0	7
Bivalvia	Pelecypoda	Unionidae	Anodonata	*cataraca*	Freshwater Mussel	1	0	1	1
Oligochaeta[1]	-	-	-	-	Worm	223	27	69	196
Crustacea	Amphipoda	Gammaridae	Gammarus	-	Freshwater Shrimp	60	303	190	512
Crustacea	Decapoda	Cambaridae	Orconectes	*virilis*	Crayfish	0	1	0	0
Gastropoda	Pulmonata	Planorbidae	Planorbula	*armigera*	Freshwater Snail	2	0	0	0
Gastropoda	Pulmonata	Planorbidae	Planorbula	*trivolvis*	Freshwater Snail	2	0	2	2
Gastropoda	Pulmonata	Planorbidae	Planorbula	*helisoma*	Freshwater Snail	0	0	1	6
Gastropoda	-	Bithyniidae	Bithynia	*tentaculata*	Freshwater Snail	0	1	1	1
Insecta	Coleoptera	Haliplidae	Haliplus	-	Aquatic Beetle	0	5	0	0
Insecta	Diptera	Ceratopogonidae	Probezzia	-	Biting Midge	0	3	8	11
Insecta	Diptera	Chironomidae	-	-	Midge	117	98	177	605
Insecta	Ephemeroptera	Ephemeridae	Hexagenia		Mayfly	2	5	5	4
Insecta	Ephemeroptera	Ephemerellidae	Euoylophella	-	Mayfly	0	0	6	0
Insecta	Ephemeroptera	Tricorythidae	Tricorythodes	-	Mayfly	0	0	0	3
Insecta	Odonata	Aeshnidae	Boyeria		Dragonfly	1	0	0	0
Insecta	Odonata	Libellulidae	Perthemis	-	Dragonfly	0	0	0	1
Insecta	Odonata	Gomphidae	Dromogomphus	-	Dragonfly	0	0	0	2
Insecta	Trichoptera	Psychomyiidae	-	-	Caddis Fly	0	10	1	2
Insecta	Trichoptera	Hydropyilidae	-	-	Caddis Fly	0	0	0	1
Insecta	Megaloptera	Sialidae	Sialis	-	Alderflies	0	12	0	0

1 = Organisms were only identified to class
2 = Number of organisms found at each sampling area
- = could not be identified

Table 7 Summary of Benthic Organism Total Taxa, Total Individuals, Total Biomass and Diversity Index for all Sampling Locations[1]

Dirt

Distance (M)eters	Total Taxa	Total Individ.[2]	Total Biomass (g)	Diversity Index (H')
0	***3.0*** +/-0.00	***17.5*** +/-9.19	***0.0605*** +/-0.058	***1.41*** +/- 0.238
1	***4.0*** +/-0.00	***39.0*** +/-4.24	***0.0615*** +/-0.011	***1.46*** +/- 0.113
3	***3.5*** +/-0.71	***74.0*** +/-21.21	***0.0425*** +/-0.015	***1.07*** +/- 0.306
10	***5.5*** +/-2.12	***88.0*** +/-9.90	***0.0415*** +/-0.016	***1.62*** +/- 0.064

Rock

Distance (M)eters	Total Taxa	Total Individ.	Total Biomass (g)	Diversity Index (H')
0	***4.0*** +/-1.41	***15.0*** +/-4.24	***0.0135*** +/-0.006	***1.41*** +/- 0.305
1	***4.0*** +/-0.00	***75.0*** +/-18.38	***0.0315*** +/-0.0191	***1.39*** +/- 0.435
3	***6.5*** +/-2.12	***117.0*** +/-83.43	***0.0705*** +/-0.046	***1.06*** +/- 0.235
10	***4.0*** +/-0.00	***25.5*** +/-3.54	***0.0235*** +/-0.004	***1.70*** +/- 0.043

Wood

Distance (M)eters	Total Taxa	Total Individ.	Total Biomass (g)	Diversity Index (H')
0	***4.0*** +/-1.41	***16.0*** +/-1.41	***0.0085*** +/-0.008	***0.98*** +/- 0.641
1	***4.0*** +/-1.41	***51.5*** +/-2.12	***0.0380*** +/-0.013	***1.15*** +/- 0.070
3	***4.0*** +/-0.00	***89.5*** +/-29.00	***0.0450*** +/-0.021	***1.33*** +/- 0.345
10	***6.0*** +/-0.00	***72.0*** +/-18.38	***0.0850*** +/-0.106	***1.79*** +/- 0.035

Concrete

Distance (M)eters	Total Taxa	Total Individ.	Total Biomass (g)	Diversity Index (H')
0	***4.0*** +/-0.00	***234.5*** +/-74.25	***0.1180*** +/-0.034	***1.44*** +/- 0.069
1	***5.5*** +/-0.71	***134.0*** +/-83.44	***0.0435*** +/-0.005	***1.10*** +/- 0.048
3	***7.0*** +/-4.24	***207.0*** +/-4.24	***0.1325*** +/-0.076	***1.42*** +/- 0.568
10	***7.0*** +/-0.00	***94.0*** +/-4.24	***0.0295*** +/-0.005	***1.65*** +/- 0.012

1 = All values are the mean of that particular sampling location (n=2)

2 = Represents only those individuals acceptable for analysis

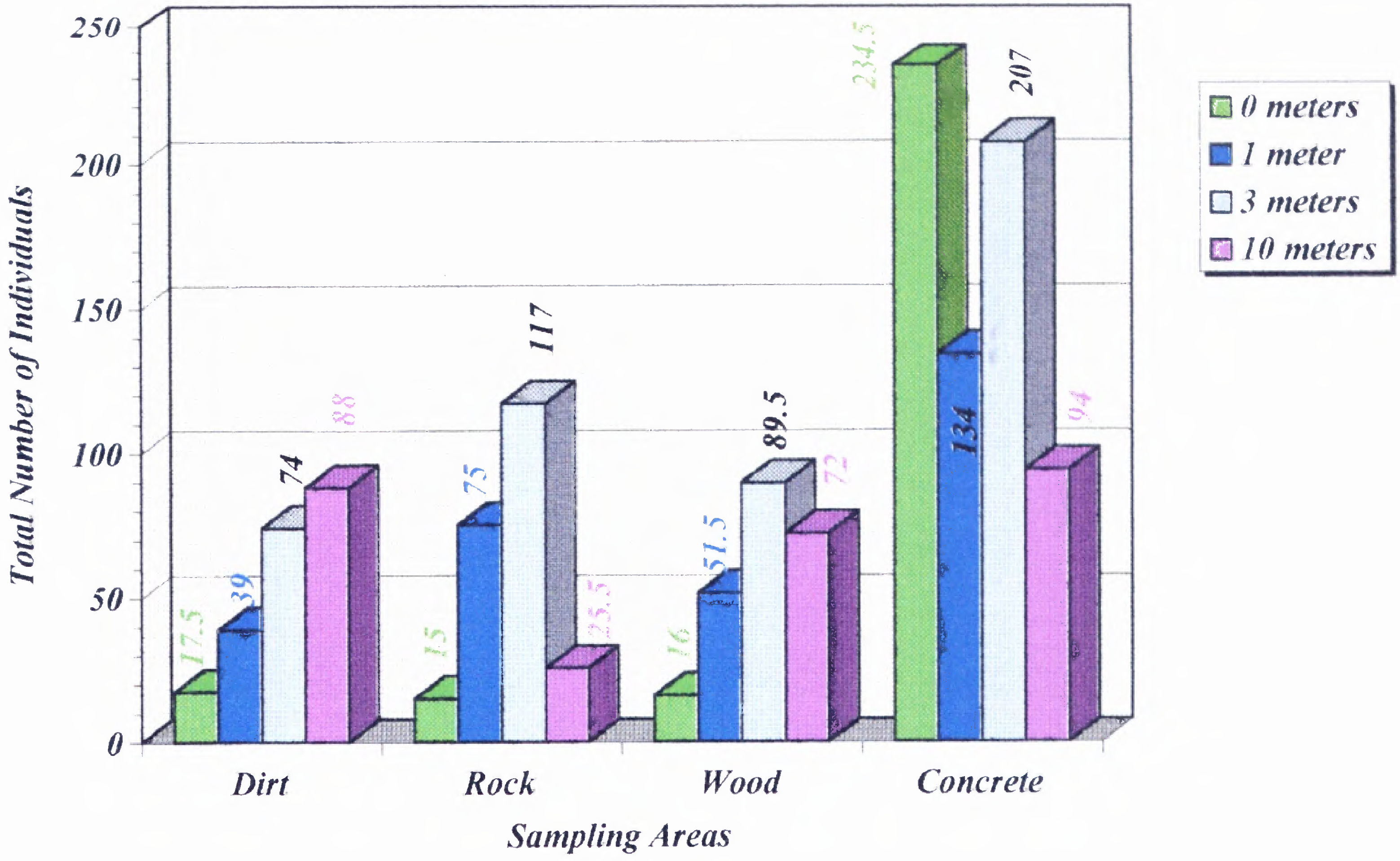

Figure 17 Total number of individuals (mean) for all sampling locations.

4.3.2 Total Number of Individuals

Benthic organisms were collected and counted for all sampling locations. The results from this enumeration can be seen in Figure 17 and Table 7. Figure 17 shows that the Concrete reference bulkhead contained a greater amount of individuals at all locations compared to the other sampling areas. The number of individuals found at the 0-meter location by the Concrete reference bulkhead (234.5 +/- 74.25(SD)) was significantly different (F=16.97, p=.0097) than those found at the other sampling area 0-meter locations. The 0-meter location for the Wood bulkhead contained the lowest number of individuals with 16 +/- 1.41(SD). The total number of individuals for the Rock reference bulkhead and the Wood bulkhead showed no significant difference between or among each other. The Dirt reference area was the only area to show a significant increasing gradient of individuals from 0 to 10-meters (F=12.76, p=0.0163). Although not significant, the Rock reference bulkhead and the Wood bulkhead showed an increasing concentration gradient away from the 0-meter location while the converse was seen at the Concrete reference bulkhead.

4.3.3 Total Biomass

The total biomass for all taxa at each sampling location, was recorded. Due to the small number of the organisms found and subsequent low weight, all replicates for each sampling location were composited to make a single sample (See Figure 18 and Table 7). Statistical analysis indicated that there was no significant difference in biomass for each sampling location among or between all bulkheads. However it should be noted from Figure 18 that the organisms at the 0-meter location by the Wood bulkhead contained the lowest biomass (0.0085g +/- 0.008(SD)) when compared to the reference bulkheads at

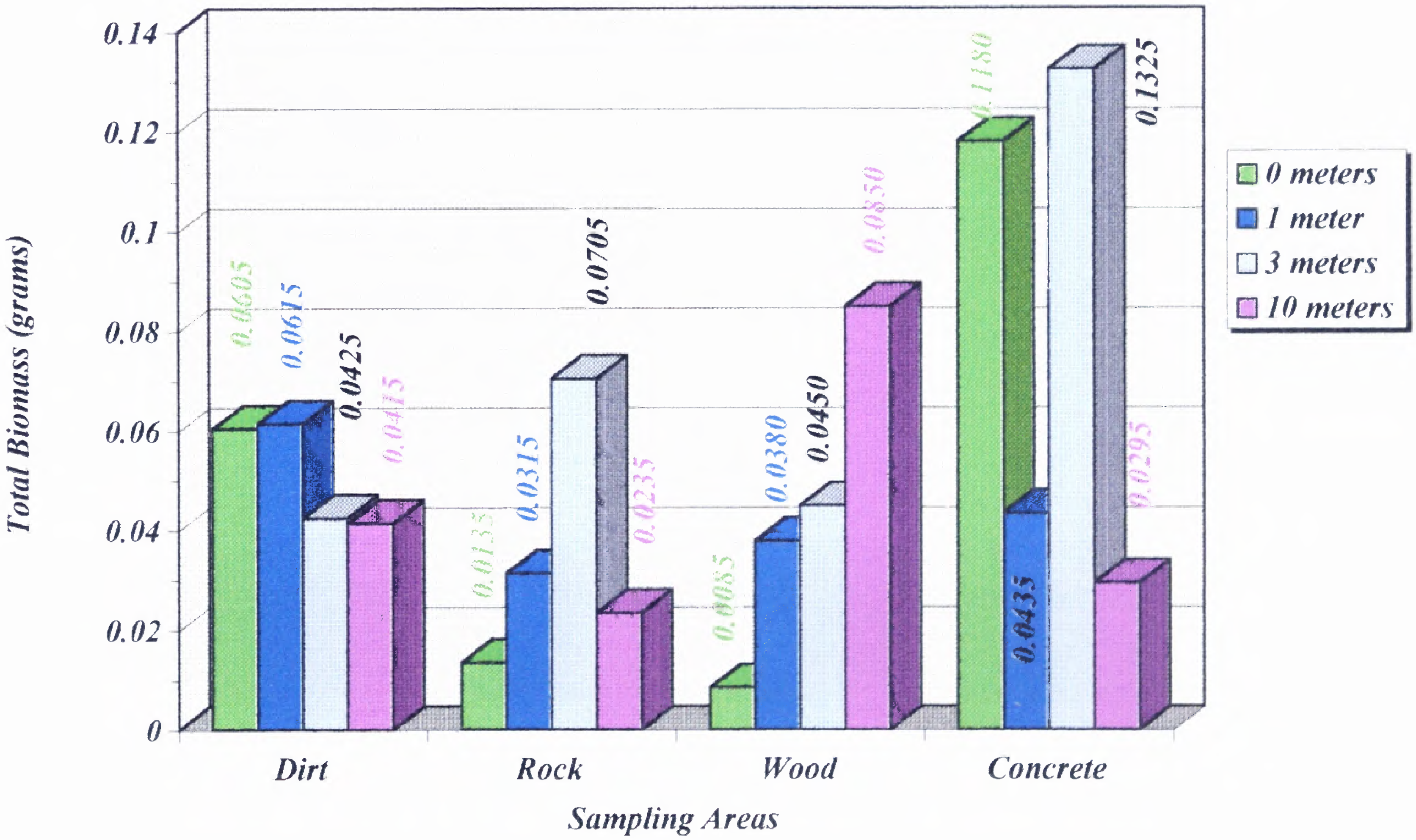

Figure 18 Total biomass (mean) for all sampling locations.
All replicates for each location were composited before analysis.

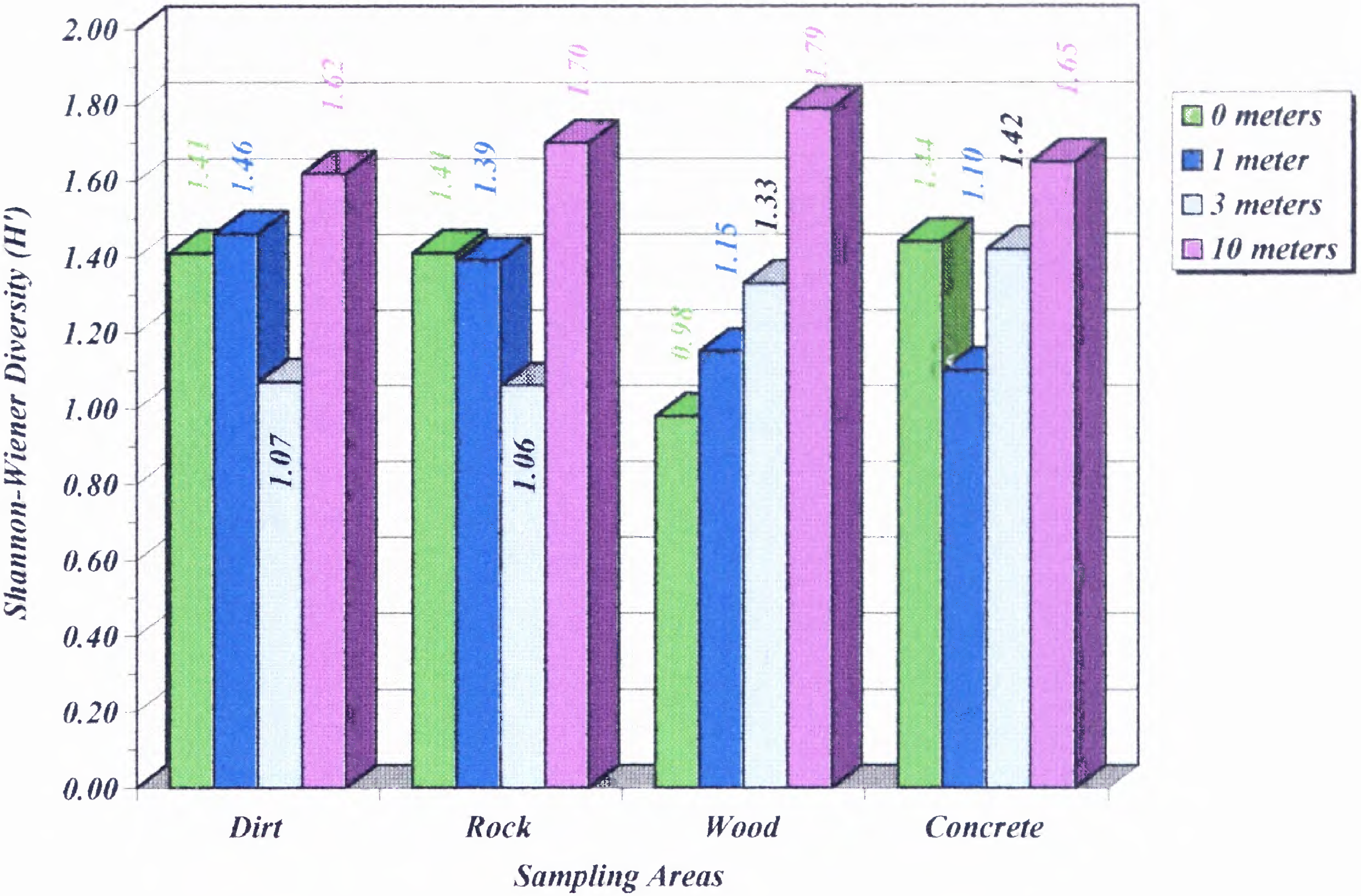

Figure 19 Shannon-Wiener diversity indices (mean) for all sampling locations.

that same location. The location containing the largest biomass was found at the 0 and 3-meter location by the Concrete reference bulkhead with 0.1180g +/- 0.034(SD) and 0.1325g +/- 0.076(SD) respectively. Although not statistically significant the Rock reference bulkhead and the Wood bulkhead show an increase in biomass from 0 to 10-meters while the Dirt and Concrete reference areas show the converse.

4.3.4 Species Diversity (H′)

Figure 19 and Table 7 show the Shannon-Wiener Diversity Index (H′) for all sampling locations. The data indicate that the Wood bulkhead at the 0-meter location contains the lowest diversity, 0.98 +/- 0.641(SD), while the highest diversity for the same location was seen by the Concrete bulkhead, 1.44 +/- 0.069(SD). However, statistical analysis reveals that there is no significant difference of diversity between or among each sampling area. All sampling areas tend to have an increasing diversity with increased distance away from their 0-meter location.

4.4 Lake Parameters

Water quality analysis was performed to observe the lake conditions during this study. Table 8 shows the summary of the water quality parameters taken for all sampling locations.

4.4.1 Temperature and Conductivity

Temperature and conductivity were found to be consistent throughout all sampling locations with the highest readings being 30°C, 395μmohs/cm and the lowest at 28°C, 385μmohs/cm (See Figures 20, 21 and Table 8). All sampling areas do show slight

Table 8 Water Quality Parameters for all Sampling Locations[1]

Dirt

Distance (M)eters	Temperature (oC)	Conductivity (umohs/cm)	Dissolved Oxygen (mg/L)	pH
0	***30.00*** +/-0.000	***385*** +/-7.071	***7.00*** +/-1.131	***8.095*** +/-0.007
1	***30.00*** +/-0.000	***388*** +/-3.536	***7.88*** +/-0.108	***8.535*** +/-0.049
3	***30.00*** +/-0.000	***392*** +/-2.121	***8.25*** +/-0.354	***8.580*** +/-0.067
10	***30.00*** +/-0.000	***390*** +/-0.000	***9.25*** +/-0.071	***9.030*** +/-0.028

Rock

Distance (M)eters	Temperature (oC)	Conductivity (umohs/cm)	Dissolved Oxygen (mg/L)	pH
0	***28.75*** +/-0.354	***385*** +/-0.000	***6.85*** +/-1.061	***8.515*** +/-0.021
1	***29.25*** +/-0.354	***390*** +/-0.000	***7.20*** +/-0.566	***8.645*** +/-0.064
3	***29.25*** +/-0.354	***390*** +/-0.000	***7.50*** +/-0.424	***8.685*** +/-0.049
10	***29.50*** +/-0.707	***395*** +/-0.000	***9.05*** +/-0.071	***9.060*** +/-0.000

Wood

Distance (M)eters	Temperature (oC)	Conductivity (umohs/cm)	Dissolved Oxygen (mg/L)	pH
0	***29.50*** +/-0.071	***385*** +/-0.000	***7.40*** +/-0.283	***8.660*** +/-0.071
1	***29.75*** +/-0.354	***385*** +/-0.000	***7.50*** +/-0.141	***8.705*** +/-0.064
3	***30.00*** +/-0.000	***385*** +/-0.000	***7.60*** +/-0.000	***8.730*** +/-0.042
10	***30.00*** +/-0.000	***395*** +/-0.000	***8.00*** +/-0.000	***9.050*** +/-0.014

Concrete

Distance (M)eters	Temperature (oC)	Conductivity (umohs/cm)	Dissolved Oxygen (mg/L)	pH
0	***29.00*** +/-0.000	***390*** +/-0.000	***8.45*** +/-0.071	***8.935*** +/-0.021
1	***29.00*** +/-0.000	***390*** +/-0.000	***8.50*** +/-0.000	***8.955*** +/-0.021
3	***29.50*** +/-0.707	***393*** +/-3.536	***8.40*** +/-0.283	***8.985*** +/-0.007
10	***29.50*** +/-0.707	***395*** +/-0.000	***8.15*** +/-0.212	***9.035*** +/-0.007

1 = All values are the mean of that particular sampling location (n=2)

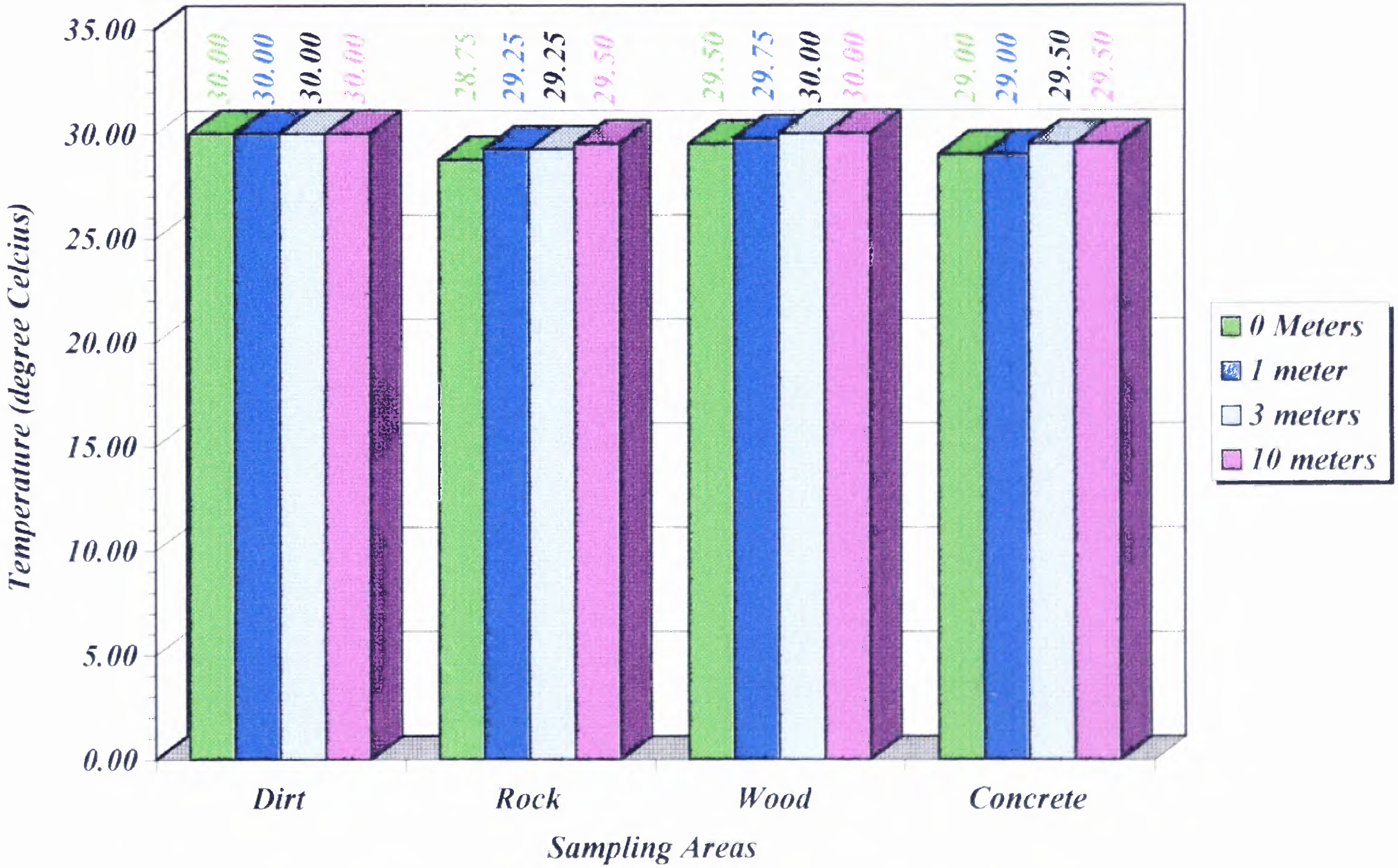

Figure 20 - Temperature readings (mean) for all sampling locations.

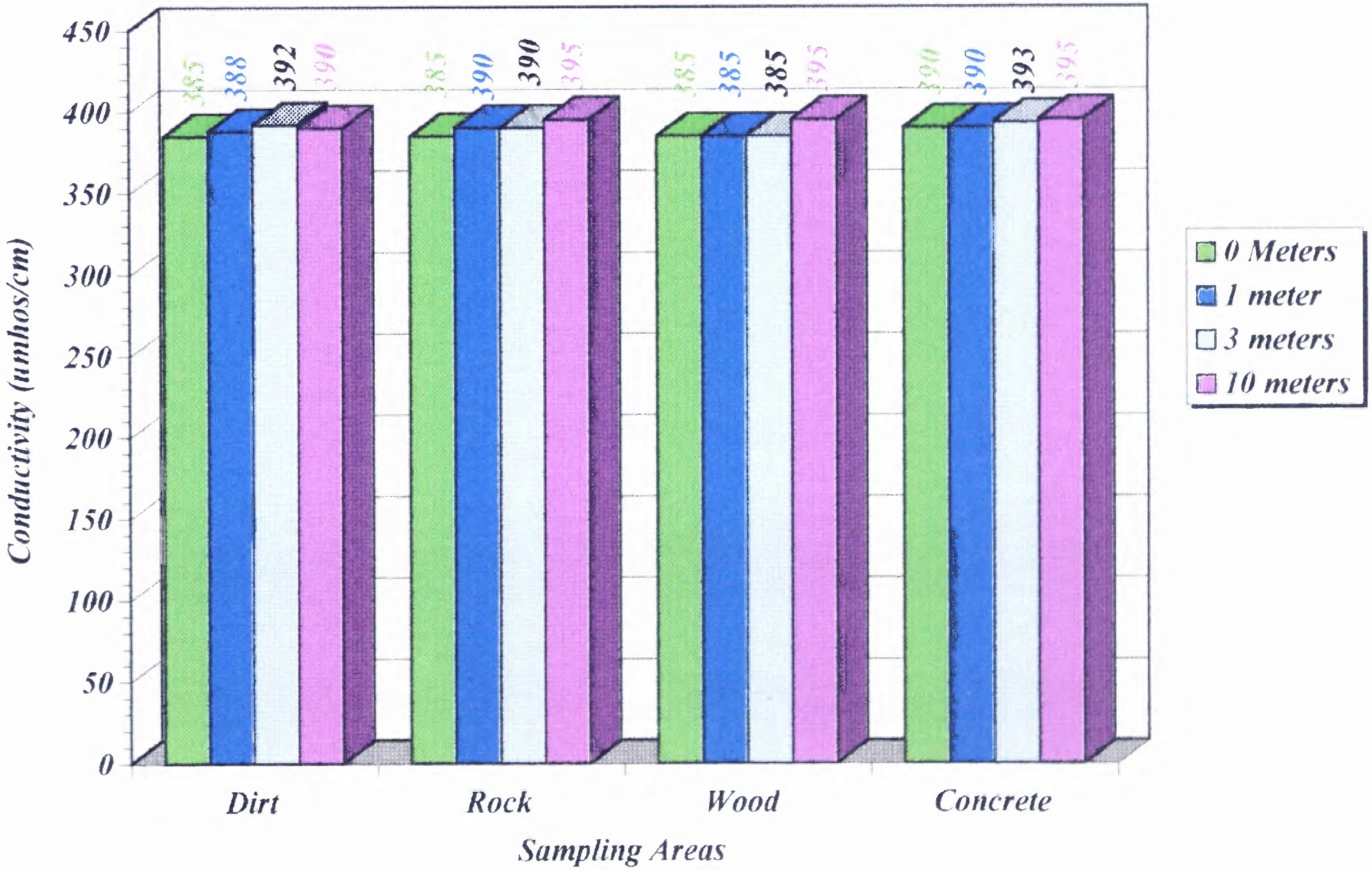

Figure 21 - Conductivity readings (mean) for all sampling locations.

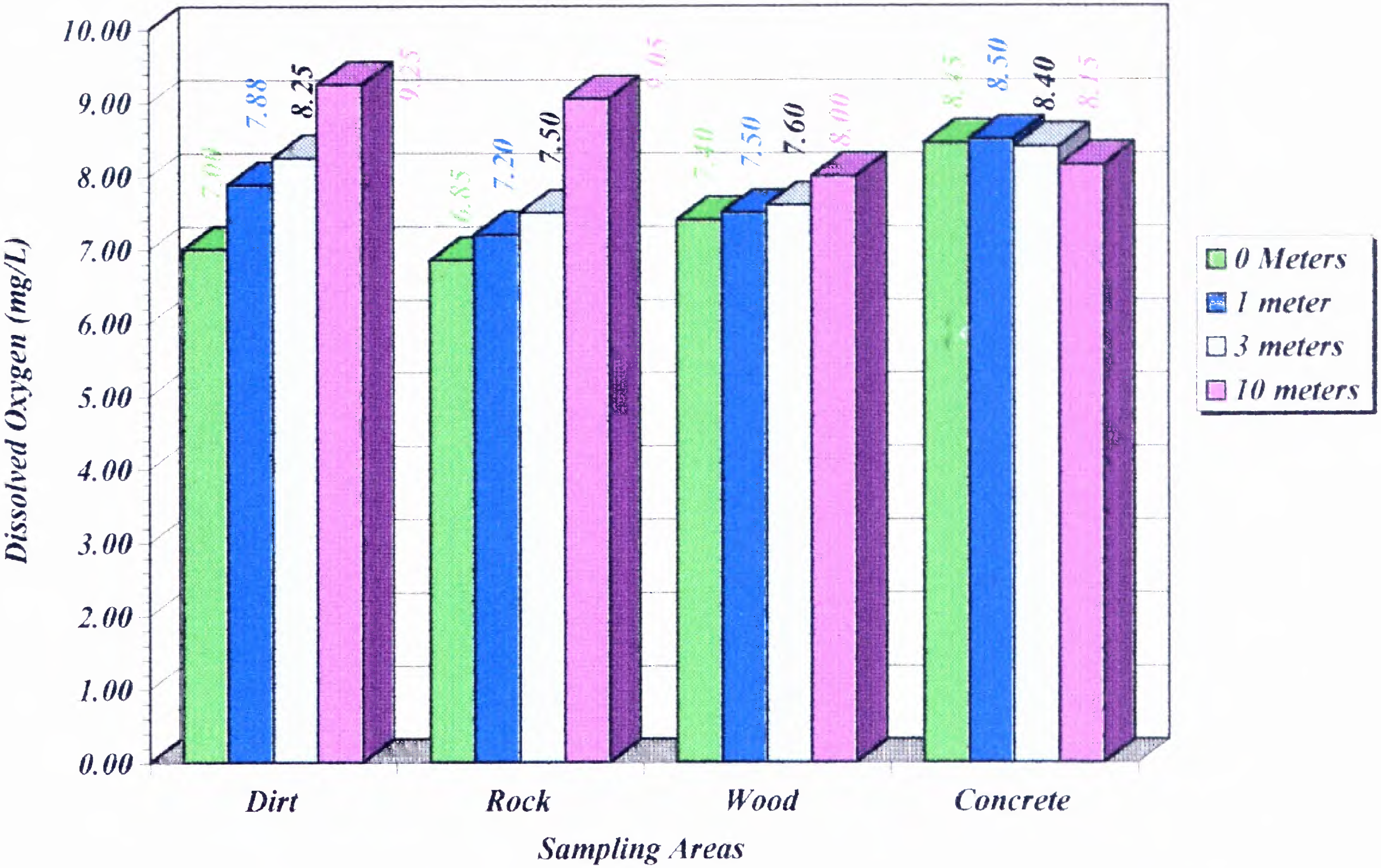

Figure 22 - Dissolved oxygen readings (mean) for all sampling locations.

gradient increases away from their 0-meter locations. There was no statistical significance among or between all bulkheads for comparison of temperature or conductivity among or between all sampling areas.

4.4.2 Dissolved Oxygen

Dissolved oxygen (DO) readings, seen in Figure 22 and Table 8, show an increasing gradient from 0 to 10-meters by the Dirt, Rock and Wood sampling areas. The Concrete reference bulkhead showed a slight decrease in gradient as we sampled further away from the bulkhead. The Rock reference bulkhead 0-meter location contained the lowest DO reading of 6.85 mg/L +/- 1.061(SD) with the highest being recorded at the Dirt reference area 10-meter location with 9.25 mg/L +/- 0.071(SD). The only significant difference in DO readings was found at the 10-meter location by the Dirt reference area (9.25 +/- 0.071(SD)) compared to the 10-meter location by the Wood bulkhead (8.00 +/- 0.000(SD), F=57.55, p=0.0010).

4.4.3 pH

Water pH readings showed significance at all bulkheads from 0 to 10-meters. See Figure 23 and Table 8. The readings for each bulkhead at 0 and 10-meters are as follows; Dirt reference area at 0 m = 8.095 +/- 0.007(SD), 10 m = 9.030 +/- 0.028 (SD) (F=179.75,p=0.0001); Rock reference bulkhead at 0 m = 8.515 +/- 0.021(SD), 10 m = 9.060 +/- 0.000(SD) (F=63.05, p=0.0008); Wood bulkhead at 0 m = 8.660 +/- 0.071(SD), 10 m = 9.050 +/- 0.014(SD) (F=22.99, p=0.0055); Concrete reference bulkhead at 0 m = 8.935 +/- 0.021(SD), 10 m = 9.035 +/- 0.007(SD)(F=15.13, p=0.012). The Concrete reference bulkhead obtained the highest pH readings for all 0, 1 and 3-meter locations.

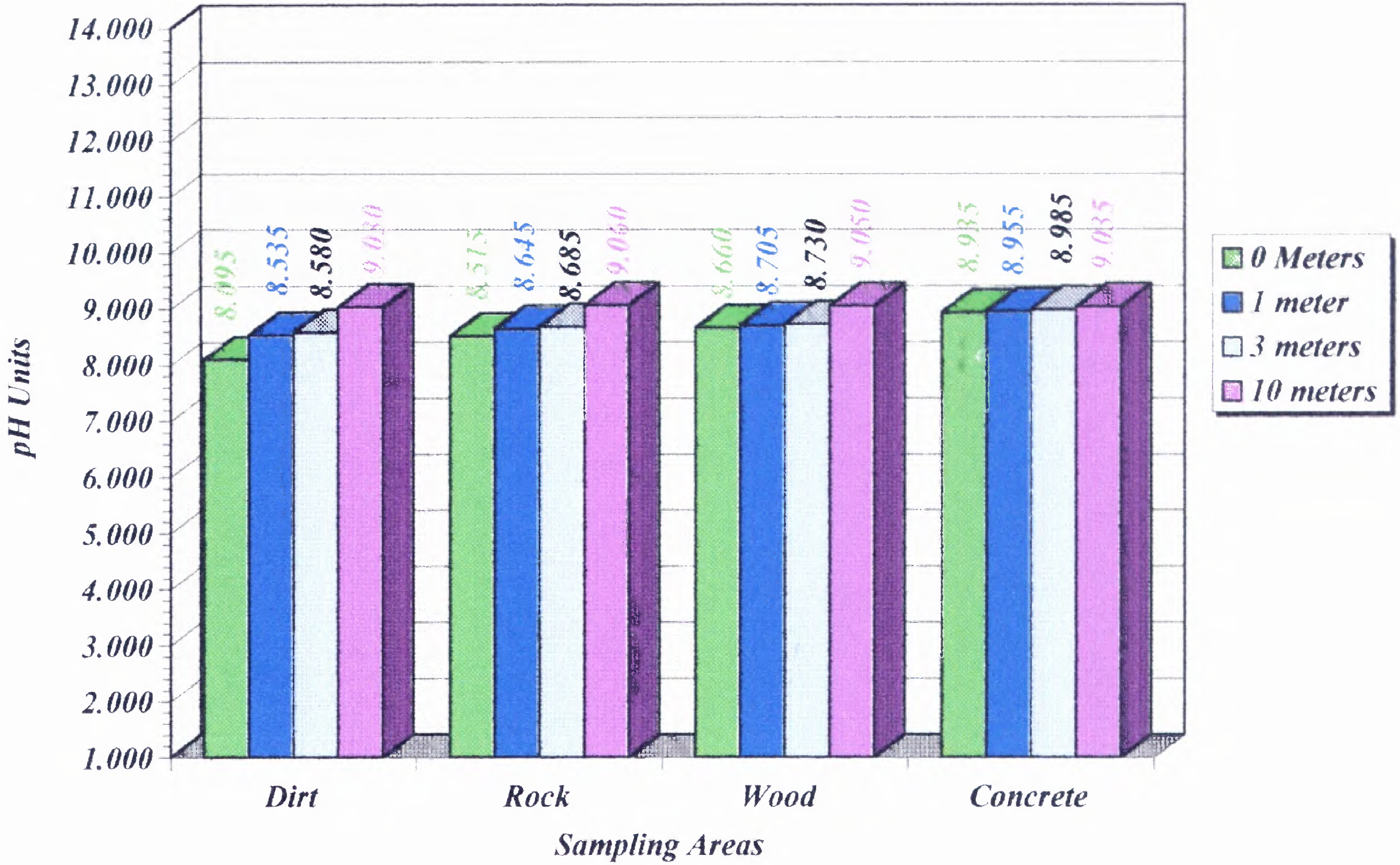

Figure 23 - pH readings (mean) for all sampling locations.

locations. Its 10-meter pH (9.035 +/- 0.007(SD)) was surpassed by the 10-meter pH at the Rock reference bulkhead (9.060 +/- 0.000(SD)). The lowest pH was found at the 0-meter location by the Dirt reference area (8.095 +/-0.007(SD)) and the highest pH at 0-meters was found at the Concrete reference bulkhead (8.935 +/- 0.021(SD)). The Wood bulkhead pH readings at all locations were not significantly different from the other pH values taken and as a result can not be inferred as causing any significance towards accelerating the leaching of chromium, copper and arsenic from the CCA-treated wood.

CHAPTER 5

DISCUSSION

5.1 Sediment Concentrations

Sediment chromium analysis revealed no significant differences among or between all sampling areas. One sampling location, Dirt at 0-meters, contained the highest concentration of chromium compared to all of the other 0-meter locations. This "peak", although not significant, suggests that there may be potential contamination at this reference location by a source outside of our sampling area. The other three bulkhead 0-meter chromium concentrations were uniform and there was no significant difference of chromium by the Wood bulkhead compared to the other reference sampling areas.

Zero-meter sediment copper concentrations were very enigmatic. Levels of copper found in the sediments were higher than anticipated at all sampling locations but were much lower adjacent to the Wood bulkhead. These unusually high copper concentrations suggest that the sediments may be getting contaminated with large amounts of copper from an outside source. Researching the possible cause of this contamination led to the finding that the Pines Lake Association annually adds approximately one metric ton of copper sulfate ($CuSO_4$) to the lake every summer as a eutrophication preventative. This practice has been in place for approximately 10 years, and since there is very little flow of water through the lake, the copper accumulates in the sediments. It seems that the annual introduction of $CuSO_4$ to the lake may have elevated background copper levels to a point that any potential leaching of copper from the CCA-treated wood bulkhead has been greatly overshadowed. Our results would then be showing us the consequence of a ten year application of approximately 1 metric ton per year of $CuSO_4$ addition.

The data seems to imply that the addition of pressure-treated wood to a lake can actually decrease the amount of copper in the sediment; if looking at the concentration of copper adjacent to the Wood bulkhead compared to other reference locations. An explanation why there are significantly lower copper concentrations adjacent to the Wood bulkhead has been found. During the construction of the wood bulkhead the original sediment was removed. This removal may have "erased" $CuSO_4$ accumulation in those nearby sediments. Copper concentrations in sediment samples at 1, 3, and 10 meters away from the Wood bulkhead were also lower than those for its respective reference bulkheads possibly due to the release and spreading of "virgin" soil during construction. The release of soil, when washed into the lake, could have masked the existing sediment concentrations at those sampling locations. Therefore, it appears that copper accumulation in the lake from the addition of $CuSO_4$ is of greater concern than the addition of a CCA treated wood bulkhead.

Arsenic sediment concentrations showed no significant differences between all sampling areas but there were two locations that were higher than the rest. The Dirt 0-meter reference location contained the highest concentration of arsenic. This location also contained the highest concentration of chromium. With no development or noticeable contamination at or near this area it is difficult to assume that this location has been affected by some form of contaminant migration but rather that this metal may be inherent in the local sediments and should be investigated further. An increase of arsenic adjacent to the Wood bulkhead, although not as high or statistically different from the Dirt reference area, could also be attributed to this potential inherent quality. Arsenic levels that were buried in the sediments could have surfaced during the construction of the bulkhead. Although statistically insignificant, it could be attributed to leaching from the CCA-treated wood due to low levels of arsenic found at its neighboring 0-meter reference locations.

. All 0-meter locations at each sampling area had a lower percentage of fines than at 10-meters. This agreed with studies performed by Weis et al (1993) in that percent fines were relatively lower adjacent to the 0-meter locations and conversely increased with increasing distance away. They also noticed that metal concentrations adjacent to a CCA bulkhead were higher than those found at the other locations. Although we noticed a similar trend at the Wood bulkhead in this study, we could not statistically prove that the increase in metal concentrations at the 0-meter location was caused by leaching of metals from the pressure treated wood bulkhead. This trend could also be seen at the other reference sampling areas for chromium and arsenic. Copper concentrations were increased at all sampling locations and a gradient was not seen. The annual addition of $CuSO_4$ appears to have increased sediment copper concentrations throughout the entire lake.

Percent total carbon was observed to be highest at the 0-meter location by all sampling areas and at the 1-meter location by the Dirt reference area. During the study it was noticed that wave action caused leaves, sticks and other organic debris to collect at the 0-meter locations. The large amount of organic matter found justifies the noticed increase in percent total carbon at these areas. Conversely, as we sampled further away from the 0-meter locations we noticed a decrease in the amount of organic material found. Occasionally a sample would contain some leaves or organic debris not found at another location which accounts for the inconsistency in the results. Increased percent total carbon values at 0-meter locations did coincide with increased sediment and benthic organism metal concentrations but could not be statistically proven.

5.2 Benthic Organism Metal Concentrations

Due to low biomass obtained from our samples it was necessary to composite both replicate samples prior to analysis to obtain a larger weight. Unfortunately, the compositing of replicates made us unable to perform statistical analysis ($n = 1$). Therefore, differences among benthic organism metal concentrations could not be statistically proven. The available data does show that the highest benthic organism copper and arsenic concentrations were at the Wood bulkhead 0-meter location. Benthic organism chromium concentrations were found to be consistent with those obtained from the reference areas and were not statistically significant. The potential for leaching and bioaccumulation of copper from the Wood bulkhead, although statistically insignificant, should not be discounted. It was noted that benthic organisms living at the Wood 0-meter location appeared to have increased levels of copper in their tissues compared to the other locations even though this location had the lowest amount of sediment copper. The data would then suggest that copper leached from the Wood bulkhead is more readily bioaccumulated than copper obtained from $CuSO_4$. Increased benthic organism arsenic concentrations are also present at the Wood bulkhead 0-meter location, indicating that this metal may be leaching from the Wood and being taken up by the local benthic organisms. Another study needs to be done where a greater number of benthic organisms can be obtained, perhaps from a lake without added $CuSO_4$, and statistical analysis performed.

5.3 Benthic Organism Community Structure

The total number of taxa found at the 0-meter location in each sampling area was very similar and showed no significant difference. Except for the Rock reference bulkhead 3-meter location, it was observed that all sampling areas had increasing gradients of taxa away from their 0-meter location. There is no significant effect on total taxa living adjacent to a CCA-treated wood bulkhead.

Total individuals were found to be lowest at the 0-meter locations by the Dirt, Rock and Wood sampling areas with the largest amount at the Concrete reference bulkhead 0-meter location. The increase of individuals seen at the Concrete reference bulkhead 0-meter location was significantly different from the other 0-meter locations. This could be attributed to the lack of submerged aquatic vegetation and sustainable food source found at the Dirt, Rock and Wood sampling areas compared to the Concrete reference sampling area.

Zero-meter sampling locations showed no significant differences in biomass among all sampling areas at that location. However, although not significantly different, the lowest biomass was recorded at the Wood bulkhead 0-meter location while the largest was seen at the Concrete reference bulkhead 0-meter location. The differences in biomass might be attributed to the quantity of available food located at these sampling locations for the benthic organisms. As mentioned earlier, the increase in submerged aquatic vegetation found at the Concrete reference bulkhead could explain why the total biomass at this location was much larger than the other 0-meter locations. Since the Wood bulkhead 0-meter location contained the lowest total biomass, it is possible, although questionable, that this biomass was influenced by the presence of a CCA treated wood bulkhead.

Overall Shannon-Wiener diversities were not significantly different from one another. When comparing 0-meter diversity indices it was observed that the Wood bulkhead had the lowest diversity for all 0-meter locations with the highest diversity found at the Concrete reference bulkhead. If we look back at the data gathered for all 0-meter locations we can notice a slight trend, although not statistically significant, at the Wood bulkhead. It has been shown that benthic organism metal concentrations at the Wood bulkhead contained the highest concentrations of copper, arsenic, and to some degree chromium, at its 0-meter location compared to the reference bulkheads at that same location. The accumulation of these metals may have resulted in the decreased diversity found. Conversely, the amount of metals found in benthic organisms at the 0-meter location by the Concrete reference bulkhead was the lowest compared to all other locations. It can also be reiterated that the presence of a food source at the Concrete reference bulkhead compared to the lack of a food source at the other sampling areas was a limiting factor in determining the overall diversity at these locations. Analysis of the data, although not statistically proven, could then be interpreted as showing a reduction in benthic organism diversity due to exposure to a CCA-treated wood bulkhead.

5.4 Lake Parameters

There were no significant differences in temperature, conductivity and dissolved oxygen when we compared the Wood bulkhead 0-meter location to the other reference 0-meter locations. The pH data showed that there were significant differences among each sampling area from 0 to 10-meters. It was observed that the Wood bulkhead 0-meter location contained the second highest pH, 8.66, when compared to all other 0-meter locations. This pH is higher than recorded in the study performed by Warner and Solomon (1990) in which they showed an increase in leaching of CCA toxicants from treated wood when exposed to pH levels of 3-4 pH units. Aceto and Fedele (1994) performed similar studies looking at the leaching of chromium, copper and arsenic after exposure to acid rain. They observed that under optimal conditions CCA treated wood leached the greatest amount of toxicants when exposed to rain water with a pH around 3-4. They also observed that the wood lost the greatest percentage of the three metals within the first 48 hours of exposure. Thus, the pH levels recorded in this study most likely posed an insignificant effect on the rate of CCA metal leaching from the pressure-treated wood.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, we could not statistically prove a negative impact due to exposure to a CCA-treated wood bulkhead upon the local sediments, benthic organisms and benthic community structure in this lake environment. The data does show that there were higher levels of copper and arsenic in the sediments at the Wood bulkhead 0-meter location. Benthic organisms at the same location contained concentrations of chromium, copper and arsenic greater than any of the other reference sampling areas at the same sampling location. Unfortunately, due to small benthic organism sample size ($n = 1$) the results could not be analyzed statistically. Furthermore, benthic organism community structure data reveals a lower total biomass and Shannon-Wiener diversity at the Wood bulkhead 0-meter location than at any other 0-meter location. This data might suggest, although statistically unproved, that the presence of a Chromated Copper-Arsenate treated wood bulkhead in a lake environment may have an impact on the local benthic organisms and benthic community structure.

I recommend that a follow-up study be performed to obtain more sediment and benthic organism samples. A greater number of sediment samples and increase in benthic organism biomass collection may help to statistically clarify whether the addition of a Chromated Copper-Arsenate treated wood bulkhead causes a negative impact upon the local sediments, benthic organisms and benthic community structure. I also recommend that future studies be performed to better assess the impact of $CuSO_4$ application and its potential effects on the benthic community. Further investigations can be performed to see if there is a significant impact to the local benthic community upon exposure to a CCA-treated wood bulkhead in a freshwater environment once a baseline for benthic organism exposure to $CuSO_4$ has been established. This study could be run parallel with another freshwater lake that did not have $CuSO_4$ added to the water and then compare both data sets to see which exposure is more detrimental.

APPENDIX A

MAP OF PINES LAKE, WAYNE, NJ

Figure 1a shows the location of Pines Lake in Wayne, NJ and Figure 1b shows the areas sampled for this study.

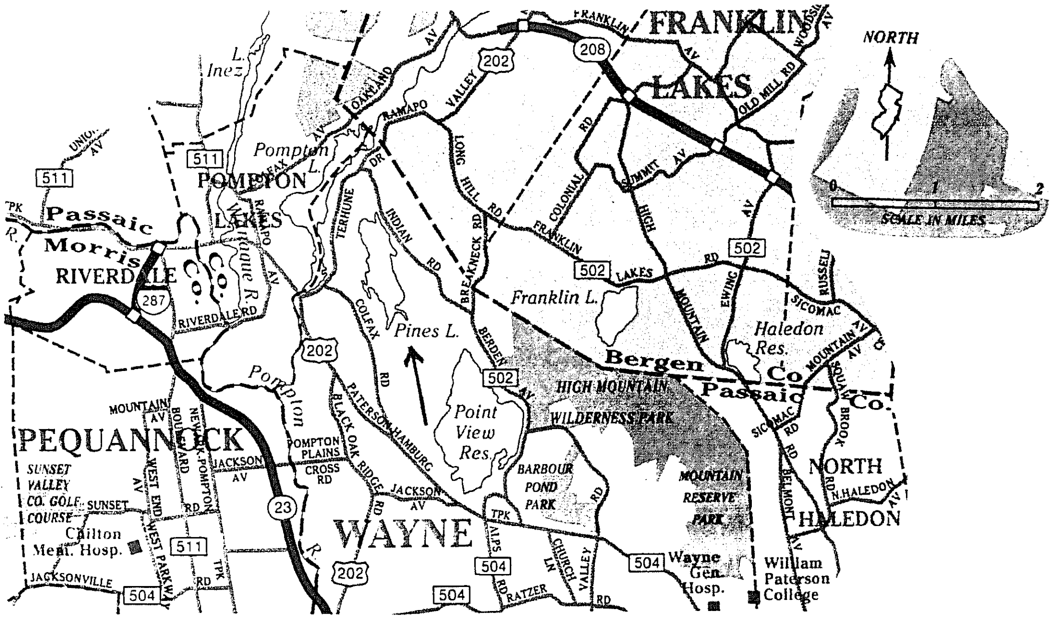

Figure 1a Map of Wayne, NJ showing Pines Lake (at arrow).

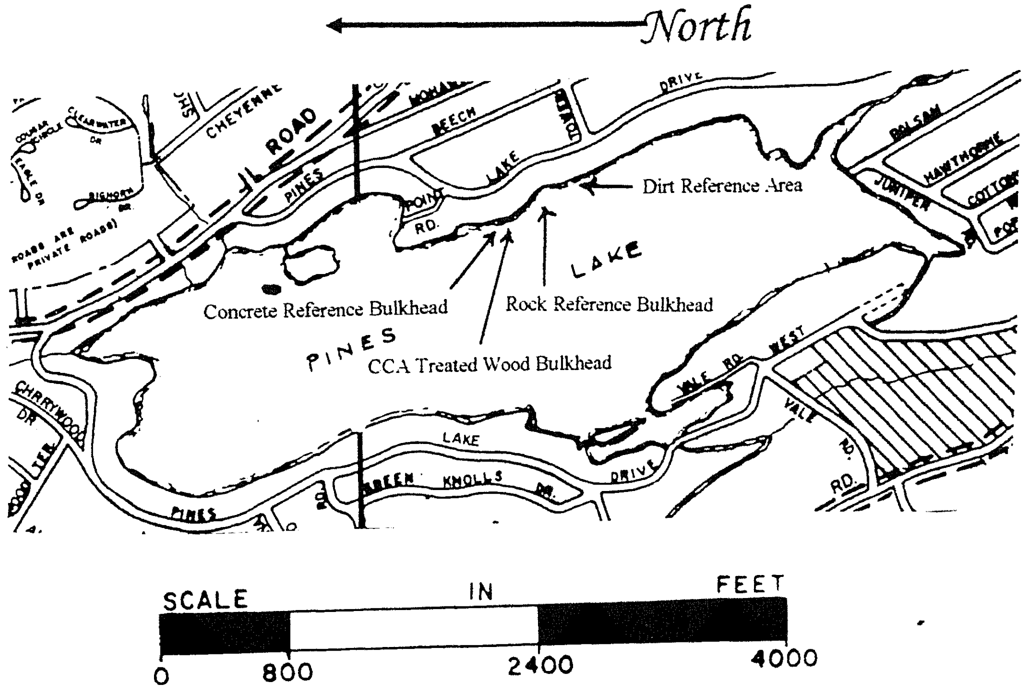

Figure 1b Map of Pines Lake showing all sampling areas and locations.

APPENDIX B

PICTURES OF SAMPLING AREAS

Figures 2a, 2b, 2c and 2d show the “Dirt”, “Rock”, “Wood”, and “Concrete” sampling areas respectively.

Figure 2a Picture showing "Dirt" reference area.

Figure 2b Picture showing "Rock" reference bulkhead

Figure 2c Picture showing "Wood" (CCA) bulkhead.

Figure 2d Picture showing "Concrete" reference bulkhead

APPENDIX C

ATOMIC ABSORPTION SPECTROPHOTOMETER

Figures 3a and 3b show the Atomic Absorption Spectrophotometer used in this study.

Table 9 lists the Atomic Absorption settings used during metal analysis.

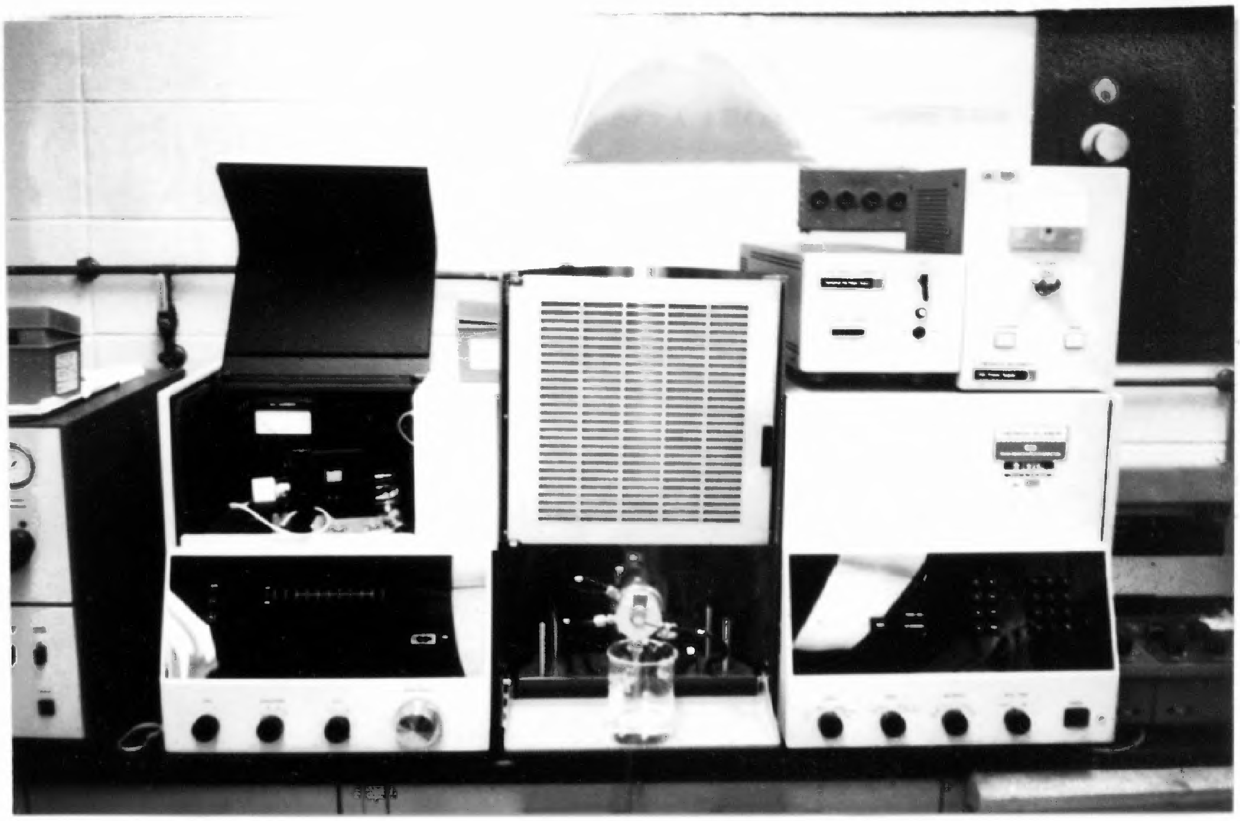

Figure 3a Picture of Perkin Elmer Model 603 Atomic Absorption Spectrophotometer

Figure 3b Picture of Perkin Elmer Model 603 Atomic Absorption Spectrophotometer with Cold Vapor Generator Setup for Arsenic Analysis via Hydride Generation

Table 9 Atomic Absorption Spectrophotometer and Hollow Cathode Lamp Settings

Element	**Wave-length**[1]	**mAmps**	**Fuel**[2]	**Gain**	**Interval**	**Slit**	**Scan Speed (sec)**	**Mode**	**EDL**[4]	**Chart Speed**
Chromium	3597A	28	55/75	4/7	1	4	1	cont.[3]	N/A[5]	N/A
Copper	3247A	16	40/75	5/7	1/2	4	1	cont.	N/A	N/A
Arsenic	1937A	N/A	20/40[6]	4/7	1	4	1	cont.	8watts	5mm/ min

1 - Wavelength is in Angstroms

2 - Fuel is represented as ml per minute of Argon gas/ ml per minute of air

3 - Cont. = continuous

4 - EDL = External power supply (Amplifier for use in arsenic determination)

5 - N/A = Not applicable

6 - Argon was also used as the carrying agent at a rate of 1 lpm

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