A SURVEY OF HEAVY METALS IN WATER, SEDIMENTS, MACROPHYTES AND FISH IN A 30 KM STRETCH OF THE NELSON RIVER SYSTEM, MANITOBA

By

JEFFRAY R. STEPANIUK

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

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ABSTRACT

Total cadmium, copper and lead contents were determined for water, sediment, macrophytes and fish at 28 lotic sites located within the area bounded by $56^{o}19'$ and $56^{o}42'$N, and $93^{o}56'$ and $94^{o}43'$W, on the Nelson River system in northern Manitoba. Samples were obtained during 10 collection periods during the May to September 1988. Atomic absorption spectrophotometry and the standard additions method were used. Results showed generally that metals were least concentrated in water, and most concentrated in sediments. Metal levels in sediments were correlated with particle size and organic matter content. The 35 plant taxa examined showed a wide range in metal content. Interspecific differences were found, and belowground parts tended to show higher values than aboveground portions. Fish muscle tissue tended to show lower metal levels than those seen in macrophytes, and metal per unit dry weight of muscle tissue decreased with increasing size and age of fish. However, levels for many internal organs were higher than in muscle.

While sediment metal levels were correlated with macrophyte contents in some species, in general no consistent relationships between water, sediments, macrophytes and fish could be demonstrated. Metal levels in the study area, however, were comparable to those reported by other workers for relatively unpolluted systems.

ACKNOWLEDGEMENTS

The author wishes to express his gratitude to Dr. E. Pip for her guidance during the study, and to other members of the graduate committee, Drs. J. Stewart, S. Badour, D. Malley, and G. Robinson for their interest and patience during such an imbroglio. I was also aided substantially in processing this paper by the generous guidance of my parents, Eleanor and Gordon.

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INTRODUCTION

I. Economic Development and Ecosystems

Economic development in the north has proceeded with little detailed knowledge of the ecology of natural ecosystems and with a poor ability to predict the impacts of that development, particularly its ecological effects (Hecky and McCullough, 1984). Hydroelectric development is often labelled non-polluting, but it can have very significant side-effects, as has been pointed out by Efford (1975), Penn (1975), Bodaly and Hecky (1979), Baxter and Claude (1980), Newbury and McCullough (1984), Playle and Williamson (1986), and Baker and Davies (1989). Impacts include long term ecological changes, alteration of landscape, loss of both renewable and non-renewable resources (Dickson, 1975), changes in water levels, flows, fluctuations, frequencies and probabilities of occurrence, duration of flows and levels, timing and phasing of construction (Penn, 1975), forest and muskeg inundation and increase in dissolved ions (Duthie and Ostrofsky, 1975), changes in turbidity regimes (Geen, 1975), reduced capacities of the river to assimilate organic wastes resulting in reduction of dissolved oxygen contents (Ruggles and Watt, 1975), decreases in fish catch and relationships between flooding and increased mercury concentrations in fish (Baker and Davies, 1989).

The Nelson River in northern Manitoba represents one of the largest drainage systems in North America providing excellent potential for the development of hydroelectric power. The Nelson River is particularly sensitive to ecological change from flooding. According to Newbury and McCullough (1984), the total area and volumes of materials to be degraded, eroded and redeposited after the impoundment of South Indian Lake indicate that this region will be unstable possibly for the next 50-100 years. The degree of change or instability actually brought about by impoundment, inundation and diversion have been investigated by Hecky and McCullough (1984), and Newbury and McCullough (1984). From Split Lake to Hudson Bay, seven power plants are planned to harness the river's full electric power potential. The Lower Nelson River is non affected not only by these plants but by both Lake Winnipeg regulation and the diversion of the Churchill River into the Nelson River. Development creates both direct and indirect effects on the aquatic environment and the terrestrial shoreline (Didiuk, 1975; Penner et al., 1975).

In Manitoba, following the increase in the water level as a result of the Churchill diversion, large amounts of mercury have unexpectedly entered the aquatic food chain (Bodaly and Hecky, 1979). Unlike the metals of interest here (Cd, Cu and Pb), mercury is methylated. All are, however, increased in bioavailability as a result of hydroelectric development as flooding impacts shorelines, accelerating bank recession, undercutting and slumping. This erosion increases the quantity of various types of clay and other inorganic material, as well as organic detritus carried in suspension by running water. A significant fraction of elements in the water may be associated with suspended material (Penn, 1975). Substances such as metal ions are adsorbed onto such particles.

Clearance and management of tree growth along the right-of-ways is essential for accessibility for maintenance and inspection of power lines (MacLellan, 1982). This normally consists of clear-cutting procedures and herbicidal application commonly with broadcast techniques (MacLellan, 1982). A variety of herbicides have been used in the north by Manitoba

Hydro to discourage weeds and to control tree growth (Pip, 1990). Reservoirs may act as traps for a variety of chemical substances, some returned to the water as a result of changes in pH, redox potential, or water sediment characteristics (Baxter and Claude, 1980).

Substances may additionally be leached from the flooded soils and released by the decay of flooded vegetation. If the area to be flooded has been cleared and the slash burned on site, the ash may also act as a source of inorganic solutes. If the watershed has been clearcut, increased leaching and erosion may contribute further to the total dissolved solids.

Other more local effects include the disturbance of wildlife, removal of vegetation and topsoil for road construction (Penn, 1975), excavation for construction materials from quarries and borrow pits (Penner et al., 1975), access roads and the increased presence and movements of humans and vehicles within the area, and disposal of debris of all kinds - used tires, garbage, and liquid wastes (Baxter and Claude, 1980).

II. Heavy Metal Toxicity

An ubiquitous group of chemicals released into the environment in ever increasing amounts is heavy metals. Heavy metals are natural components of the earth's crust and are present in soil, and surface and ground waters. Their natural concentrations rarely reach toxic levels. Some heavy metals (defined as metals with density > 5 g cm^{3}) such as copper, are required by living organisms for a variety of metabolic and physiological processes (Whitton and Say, 1975). However, even essential metals present in excess amounts can threaten ecosystem structure and function and human health.

Heavy metals cannot be eliminated from a waterbody (Rai et al., 1981). Metals persist in sediments from which they can be slowly released into the water again and pose serious hazards to numerous aquatic organisms. Concern for heavy metal pollution has stimulated research dealing with sources, distribution and effects, and compartmentation and accumulation in various biotic and abiotic components, particularly in aquatic ecosystems (Mathis et al., 1979; Jarvis, 1978; Webb, 1979; Newman and McIntosh, 1983; Pip, 1990; Malley et al., 1989). Research has encompassed natural (Peverly, 1979; Drifmeyer et al. 1980; Pip, 1990), and metal enriched systems (Gale et al., 1973; Burrows and Whitton, 1983; Cornett and Ophell, 1986), and experimental studies (Denny, 1971; DeMarte and Hartman, 1974; Malley et al., 1989).

Heavy metals affect freshwater organisms to varying degrees. Fish have been the most studied, but lower trophic levels and the environment itself have received less attention. At the same time, few studies have been carried out in northern Manitoba of the type undertaken in the United States (e.g., Gale et al., 1973) and in the Soviet Union (e.g., Petkova and Lubyanov, 1969). It is essential to know background metal levels in northern Manitoba in order to assess the impact of increasing human activity in the area. It is equally important to assess any alteration of the quality of aquatic habitats already resulting from the damming of rivers and the associated flooding and impoundment of large volumes of water. The impact of these contributions has been studied very little, and only recently have problems with heavy metal accumulation in soils and water been identified in Manitoba (Van Loon and Beamish, 1977; Williamson, 1983; Canadian Water Quality Guidelines, 1987).

The metals of concern in the present study are Cd, Cu and Pb. These metals were selected because they are common toxicants in the environment and they have been recognized as important contributory agents in the decline of biotic diversity in many natural water systems (Friberg et al., 1971; Mathis and Cummings, 1973; Kneip and Hirshfield, 1975; Jarvis, 1978; Rai et al., 1981). These metals have also been studied for their implications to public health (Manfreda and Sabesky, 1985). Cadmium and copper can all be concentrated in biota. They are of major importance because of plant and animal nutrition problems (Holcombe et al., 1976), and they are concentrated to a considerable degree in aquatic sediments (Jenne et al., 1974).

The toxicity of a variety of metals to aquatic organisms under field conditions is not well understood (Wentzel et al., 1977; Rai et al., 1981) and precultural levels of heavy metals (in sediment cores) in natural systems are needed to evaluate the rate and extent of accumulation of these elements due to man's activities (Iskandar and Keeney, 1974).

High concentrations of all heavy metals are toxic. Trace amounts of copper are essential for some metabolic processes (Sorentino, 1979), but high concentrations are toxic. Excess copper may inhibit growth, photosynthesis, permeability of plasma membranes, and severely inhibit respiration in plants (Davies and Sleep, 1980).

Cadmium and lead, on the other hand, are contaminants that have no known essential function in physiology (Evans et al., 1978) and they are elements of concern because of their potential for toxicity or accumulation in plants and animals (Spehar et al., 1978). In all its forms, cadmium is toxic to living organisms, and at no level of intake does it serve any useful biological function. Studies of cadmium toxicity to algae reported effects including decreased micronutrient utilization, growth inhibition, reduced photosynthetic $^{14}CO_2$ uptake, and changes in mitochondrial structure (Rai et al., 1981).

Lead is a natural constituent in the earth's crust which has been greatly mobilized by human activity. Numerous studies point to its toxic effects on photosynthesis, respiration, and cell division in plants (Rai et al., 1981).

Increasing quantities of these heavy metals resulting from human activities are continually being discharged into the aquatic environment which is particularly sensitive to them. Extent of toxicity of heavy metals in water is determined by chemical form, valency state, organic content, the presence of other heavy metals, suspended matter, oxygen content, pH, salinity, redox potential of the water, hardness, and whether the metal(s) belong to an essential or non-essential group. Research has indicated that many heavy metals in aquatic environments are not magnified along the food chain in predictable ways. The natural pathways of heavy metals are largely controlled by two major processes (Burrell, 1974) which are incorporation on or into various solid phases, and chemical complexation in solution. With reference to submersed and emergent macrophytes, inorganic nutrients are available in aquatic ecosystems either in the dissolved state in the water surrounding the shoot system or from the substratum in which the root system develops (DeMarte and Hartman, 1974).

Hesslein et al. (1980) claims these two compartments are not completely separate because of connecting biological and chemical pathways. An interface exchange of elements occurs at the interface between the water and the substratum as a result of the biological activity of microbial organisms and chemico-physical processes. Metals may be altered or complexed with other compounds, may act synergistically or antagonistically, may settle out to the bottom, may be absorbed by plants and animals, or may be sorbed to sediments (Enk and Mathis, 1977; Rai et al., 1981).

Forstener (1976) shows that in heavily contaminated situations heavy metals usually exist in relatively unstable chemical forms and are therefore highly accessible for biological uptake. Aquatic sediments act as a sink for these substances (Wentzel et al., 1977). Rai et al. (1981) cites one example of a battery industry which dumped cadmium-nickel wastes into a stream feeding the Hudson River. The mud in the stream contained as much as 16.2% cadmium and 22.6% nickel on a dry weight basis.

III. Heavy Metals in Sediments and Biota

Concentrations of heavy metals in water are generally considerably lower than in underlying sediments and in biota. Concentrations of < 100 ng/l of Cd in water have been shown to cause toxicity or lead to bioaccumulation in aquatic organisms (Biesinger and Christensen, 1972; Sangalang and Freeman, 1974; Malley et al., 1989).

Levels of heavy metals in sediments and biota are considerably higher than in water. They are not only more easily detected, but also permit characterization of bioavailability (Namminga et al., 1974). Enk and

Mathis (1977) found that bottom substrates act as a sink for most heavy metal contaminants and that levels in sediments may play a key role in detecting sources of pollution. Consequently, the highest biological contents of certain metals have been found in bottom dwelling organisms (White and Tittlebaum, 1984). Freshwater clams have been found to accumulate significant quantities of cadmium, copper and lead in Lake Winnipeg, with younger individuals showing highest absorption rates (Pip, 1990). Burrows and Whitton (1983) in almost all cases, found that elevated concentrations of metals in water and sediments were paralleled by high tissue contents in animals, and significant positive correlations were demonstrated between metal content in certain taxa and those in their environment.

Much current research is generally directed toward elucidating sublethal effects of low levels of heavy metals (Sprague, 1971; Pickering and Gast, 1972; Balinski and Jonas, 1973; Sangalang and Freeman, 1974; Christensen, 1975). Van Loon and Beamish (1977), and Wilson (1984) reported that fish in contaminated acidic Shield lakes near Flin Flon, impacted by aerial deposition of heavy metals, are adversely affected with respect to growth and reproduction. Lead and cadmium were not detected in fish flesh in significant amounts, but copper levels were significantly higher in whitefish as compared to other species (Wilson, 1984).

Gale _et al_. (1973) pointed out the importance of sampling higher trophic levels in order to determine the extent of dissemination and concentration of heavy metals through food chains.

IV. Heavy Metal Accumulation

In rivers and creeks aquatic macrophytes may cover extensive areas and contribute significant proportions of the primary productivity of the system. It has been suggested that those species of plants capable of accumulating metals to levels above those found in the water would exert some degree of control over metal concentrations in the system (Silvey, 1967). Both field and laboratory studies (Gerloff and Krombholtz, 1966; Cowgill, 1973; Lathwell *et al*., 1973) support this finding. These macrophytes can be significant trace element sinks during the growing season, as well as significant sources to water as they senesce during autumn. Basic questions regarding the dynamics of metal cycling via macrophytes, however, remain unanswered and the results of studies are often contradictory.

Petkova and Lubyanov (1969), Gale *et al*. (1973), Cowgill (1973), Kohler *et al*. (1973), Raghi-Atri (1980), and Heckman (1982) have suggested some aquatic macrophytes may concentrate heavy metals. However, there has been little factual evidence to support or disprove this view as these contentions were based on very limited numbers of samples.

Peverly (1979) has suggested the contrary, that aquatic plants do not accumulate cadmium and lead, but again this sampling program was highly restricted. Conditions under which accumulation may occur have been examined by numerous workers. In chronically metal-contaminated localities, both algae and higher plants have been found to accumulate heavy metals to great levels (Little and Martin, 1974; McIntosh, 1978; Cain *et al*., 1980). Other examples of studies using aquatic plants as biological indicators of metal pollutants include those of Fuge and James (1974), and Haug et al. (1974).

McIntosh (1978) demonstrated not only that aquatic macrophytes were capable of concentrating relatively high levels of particular heavy metals, but also showed that differences in species uptake seemed somewhat related to growth conditions. In his work, macrophyte species growing most rapidly during increased treatments of copper sulfate had the greatest concentration of copper. Increases in copper concentrations in the water were apparently related to the release of the element from dying plants. Sutton and Blackburn (1971) found similar results following application of copper sulfate.

Such varying degrees of heavy metal uptake and accumulation by dissimilar aquatic plant species consequently plays an integral role in aquatic ecophysiology. In waters contaminated with lead and cadmium, bulrush (Scirpus americanus) was shown by Carbonneau and Tremblay (1972) as having the capacity to act as a natural depolluting agent. According to Cain et al. (1980) such metal contents and associated roles of accumulation can be used to help predict the level of metal pollution in a body of water. Contents of some metals in submerged plants, however, were found to be largely independent of concentrations of those elements in the water. Studies of both lead and copper showed that concentration factors depended primarily on the macrophyte species and its selectivity for a particular element. Values for concentration factors were found generally to be in the 100-1000x range.

Vascular aquatic plants have been investigated for their ability to accumulate nutrients from wastewater by Culley and Epps (1973) and radionuclides from water by Abdelmalik et al. (1973). Culley and Epps (1973) developed criteria to judge the utility of various species of aquatic macrophytes for removing nutrients and it was suggested that such plants might also be useful for the removal of certain metals and pesticides. Heavy metal tolerance was the topic of experimental work conducted by McNaughton et al. (1974) near a zinc smelter in Pennsylvania. These workers suggested that cattail is tolerant of heavy metals and there may be a metal precipitating mechanism in the cell wall of the plant. The toxicity and accumulation of cadmium in southern naiad, *Najas guadalupensis*, was the subject of a study by Cearley and Coleman (1973). While control plants accumulated Cd to approximately 7 ug/g ash weight, plants growing in 0.09 mg Cd/l water concentrated the metal to roughly 4000 ug/g.

Symmes (1974) observed that pond lily, *Nuphar variegatum*, accumulated up to 60 ug Cu/g dry weight. But after approximately 5 months from the day of application, the levels in the macrophytes had dropped to approximately 5.0 ug/g. This pattern was also seen in pondweed, *Potamogeton*.

Some workers not only found that individual species of aquatic macrophytes may accumulate heavy metals to varying extents but also found differences in heavy metal concentrations between samples of the same macrophytes collected in midsummer and again in the fall (Petkova and Lubyanov, 1969).

Cowgill (1973) alluded to the role that aquatic plants (from 2 lakes in Connecticut) play in the removal of toxic substances from water allowing other organisms which cannot tolerate these contaminants to survive. Many such elements were concentrated to a great extent. Some elements were concentrated more by submerged species while others were accumulated most by emergent species.

Stanley (1974) examined toxicity of cadmium, copper and lead to water milfoil. Generally, belowground organs were more sensitive than aboveground portions, and growth measured by weight was inhibited more than growth as measured by length.

Allenby (1968) used waterweed, Elodea canadensis, and duckweed, Lemna sp., to demonstrate that there was a decrease in plant contents of copper toward the end of the growing season, and found that there was no correlation between copper contents in these aquatic macrophytes and concentrations found in the surrounding water. Both standing crop and elemental contents were estimated by Boyd (1969) and expressed as the amount of each element bound in the plant tissue per unit area in g/m^2. For copper, a maximum accumulation was attained in and around June or July and possibly the element decrease by August was due to leaching of the ions from submerged macrophyte tissues.

V. Objectives of the Study

The purpose of the present study was to obtain information on levels of cadmium, copper and lead in a range of aquatic sites within the poorly studied Nelson River drainage basin in northern Manitoba impacted to varying degrees by hydroelectric development. Metal concentrations in water, metal contents in sediment and macrophytes. Fish were sampled at a few sites. Sediments were analyzed for organic matter content and were divided into particle size categories. Submerged, floating-leaved, and emergent macrophyte species were studied. Metals were separately analyzed in above and belowground portions of the macrophytes and in tissues of the fish and compared with the total metal contents in sediment and concentrations in water.

MATERIALS AND METHODS

I. Description of Study Area

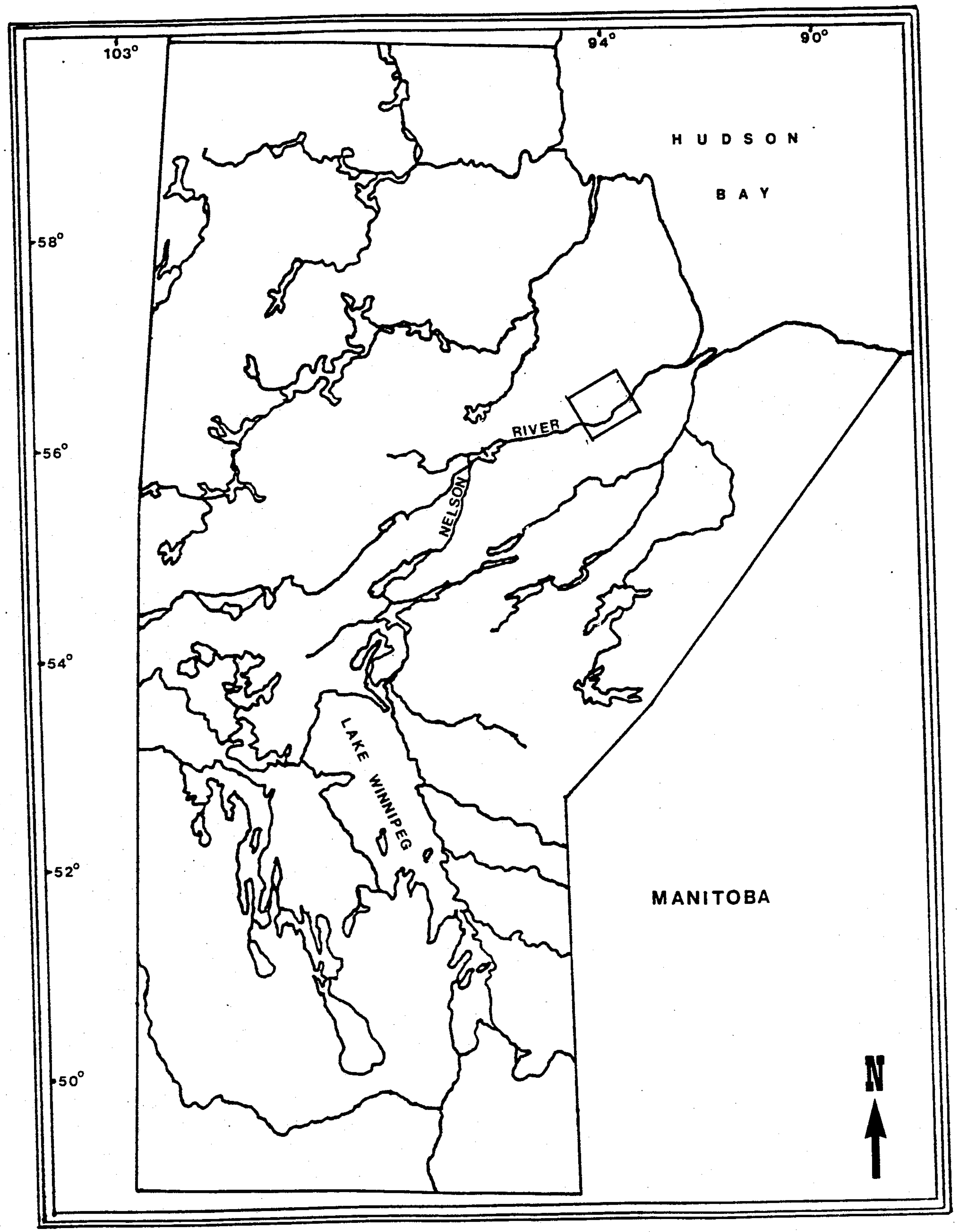
The study area in northern Manitoba was bounded by $56^{\circ}19'$ and $56^{\circ}42'$ N and $93^{\circ}56'$ to 94o43' W (Fig. 1). The area extends from the main portion of the Kettle River Reservoir near Gillam in the west, to Goose Creek, a tributary of the lower Nelson River, in the east. It includes most of the tributaries along both river banks of the lower Nelson River (Fig. 2).

The climate is humid subarctic, consisting of cool, short summers and long, cold winters (Weir, 1960). The annual frost-free period is between 20 and 70 days, and the mean July temperature is $14.8^{\circ}C$. The mean annual precipitation is approximately 32 cm for Gillam (Penner et al., 1975).

Within the study area, the two major physiographic regions are the Precambrian Shield and the Hudson Bay lowlands. The portion that is underlain by the Precambrian Shield contains terrain that is composed of patternless drift plains formed by thick deposits of glacial drift overlying Precambrian bedrock. The relief is very low with extensive bogs in poorly drained depressions (Ritchie, 1962). This type of landform is present in the upriver areas of the study streams.

The Hudson Bay lowlands consist of flat to gently undulating landforms, with surface deposits of marine and glacial clays underlain by horizontally bedded Ordovician and Silurian limestone (Weir, 1960). The

Figure 1: Study area location in northern Manitoba is indicated by the box.


103°
94°
90°
58°
56°
54°
52°
50°
HUDSON
BAY
RIVER
NELSON
LAKE WINNIPEG
MANITOBA
N

predominant surface type is a continuous peat mantle, occupying almost the entire expanse of terrain east of Long Spruce Rapids. Drainage in most areas is poor.

Bedrock is associated with the Nelson River in the study area for approximately half its length. According to Penner et al. (1975), between the Kettle Rapids Generating Station (completed in 1974) and Brooks Creek, the Nelson flows on Precambrian biotite granite gneiss and hybrid gneiss. River bed materials vary from 0-12 m thickness and consist of sands, gravels, and granitic boulders. Between Brooks Creek and Goose Creek, Palaeozoic dolomitic limestone outcrops jut out at several locations at the water's edge, mostly at or just below water levels. In some areas, such as at the Limestone Dam site, the river is entrenched into the sedimentary rock of the Hudson Bay lowland and vertical walls jut out of the river and extend approximately 5.0 meters above the rapids. The limestone bedrock itself overlies the Precambrian rock and gently dips towards Hudson Bay (Ritchie, 1962).

Within the banks of the lower Nelson River, several types of sorted and unsorted materials are present. A coarse granular glaciofluvial deposit composed of cobble and boulders lies on bedrock, near the river edges and extends for hundreds of meters along the shoreline. The deposit width may exceed 700 m. Till may lie either above or below, or on the same horizon as the granular deposits containing fine laminations of sands, silts, and clays. Above this layer, and found in the middle reaches of the Nelson, are layered fine sands and clay-silts that extend up to 20 m thick (Penner et al., 1975).

Scattered along the lower reaches is a 0.5-3.0 m zone of postglacial, marine sandy-silt and/or silty-clay layer which is continually being contorted due to annual temperature fluctuations and changing moisture conditions. This marine deposit extends as far west as the Brooks Creek area. West of the Kettle Rapids area are lacustrine sands, silts, and clays which do not overlap into the marine silts. These sediments have developed a light to dark brown soil horizon at their surface, 10-20 cm thick.

A peat layer, 0.2-2.0 m thick overlies the youngest material, consisting of tightly woven mats of roots, leaves, and other organic detritus that forms a humic layer separate from the underlying mineral soil. Most of the terrestrial vegetation is established on this horizon.

Vegetation in the area is predominantly black spruce (Picea mariana), with occasional stands of jackpine (Pinus banksiana) limited to better drained areas. Mixed black and white spruce (Picea glauca), and balsam poplar (Populus balsamifera) forests occupy the banks and the tops of the high till cliffs for the entire length of the Nelson. This dense growth thins on the upland areas to open black spruce stands, lichen, muskeg and fen. Similarly, the open spruce forest thins north-eastward to open fen dominated by sedges (Cyperaceae spp.) and tamarack (Larex laricina) (Penner et al., 1975). The low lying ice scoured zones are characterized by sedges, dwarf birch (Betula glandulosa), alder (Alnus mugosa), willow (Salix sp.), various herbs, and grasses (Penner et al., 1975).

The topography of the lower Nelson River is characterized by 20-40 m high banks, and numerous tributaries drain from the flat wet upland. Within the study area, the slope of the banks at the Nelson itself may vary from between 1:1 to almost 30:1 (Penner et al., 1975). The steeper banks are unstable and sparsely vegetated while the more gently sloping banks are well vegetated and have wide, ice-scoured benches along the shoreline.

The rivers and creeks within the study area are typically shallow and bottomed in the lower reaches with undifferentiated rocks, stones, and gravel (Ritchie, 1962), while the upper regions are dominated by sands and fine soils. The creeks all have pool, riffle, and channel areas, with water depths varying from 15-45 cm in the riffle areas, and depths of 1.5-3.0 m in the pool sections. Deep mud-bottomed beaver ponds are characteristic of the headwater areas.

Creeks may undergo marked seasonal fluctuations with respect to depth, width, and flow rate, some becoming almost intermittent streams. Generally, the small tributaries support large communities of fish and macrophytes. In late summer, when water levels are low, fish and macrophytes persist in pools and remaining riffle areas.

The study area is within the zone of discontinuous permafrost, which is mainly confined to the upland regions and varies from 0.45-1.8 m below the surface (Penner et al., 1975). It occurs as discontinuous blocks and lenses between Kettle Rapids and beyond Goose Creek (Penner et al., 1975). Peat plateaus and domed palsas or peatmounds occur in the drier peat rich areas and increase in density away from the river (Ritchie, 1962). The smaller tributaries reflect the presence of permafrost by their beaded pattern and permafrost may exist within 70 m of the river, especially on the more vegetated banks (Ritchie, 1962). Thickness of permanently frozen ground at Gillam is from 9-12 m (Penner et al., 1975).

In general, the north and south sides of the Nelson River contribute different amounts of stream habitat within the Long Spruce-Conawapa stretch. The proximity of the Angling River drainage basin to the south bank limits the southern drainage area to approximately 205 km^2, while the greater distance to the north of the Weir River allows a northern drainage area of 505 km^2 (Swanson and Kansas, 1987). Hence the smaller drainage area for south shore streams is generally reflected in lower flows, shorter streams, and narrower channels. North shore topography gives tributaries with greater relief and steeper stream gradients than the south side.

Stream discharges are lowest in winter, peak suddenly in spring, maintain a moderate level throughout summer (at least for larger creeks), and decline in fall. However, water level manipulations at the hydro sites often lead to drastically reduced flows in some portions of the system. Differences between upstream and downstream tributary habitats for each of the study streams correspond to different gradients. Increasing gradients near the Nelson River cause greater water velocities, which in turn are associated with greater erosion and greater turbulence. Consequently, peat, silts, glacial tills, and granular deposits which overlie the area (Penner et al., 1975) are transported into the Nelson River.

Generally, upstream habitat with low gradients is characterized by swamp-bog, while downstream study sections of the streams are characterized by riffle-pool sequences due to erosion of softer overburden, down to harder substrates. Upstream habitats usually exhibited negligible flow velocities. Canopy cover in the string bog-slough habitat was minimal as well. In such sections, substrate was almost invariably organic with no gravel, rubble or boulders present. Downstream habitats with riffle-pool sequences contained sand to boulder substrate.

The correspondence between riffle-pool habitat and wooded areas is primarily due to better drainage along stream reaches near the Nelson River (Pennèr et al., 1975). Because riparian zones were more concentrated in "canyon-type" streams, large woody debris was more prevalent. This increased the amount of in-stream cover and promoted cascade habitat through increased roughness and decreased current velocity.

In general, study habitats were seen to progress from continuous downstream riffle to riffle-scour pool sequences to upstream glide-stable pool sequences and finally to swamp-bog on larger streams. A rich productivity in terms of both plant and insect biomass was apparent.

II. Location and Description of Individual Study Sites

A total of 28 sites was investigated during the 1988 season. Site locations are shown in Figure 2; co-ordinates are listed in Table 1. The sites were selected on the basis of as wide a distribution as possible throughout the study area, and on accessibility. Description of the individual sites are as follows:

Kettle River (Site 1)

Between the Long Spruce Reservoir and Gillam, the Kettle River is characterized by a rapid-pool sequence with 2 of 13 major rapids resulting from man-made weirs. Riffle-pool sequences were shallow and macrophytes were more easily sampled. Channel widths range from 15-30 m (Natural Resources Branch, 1988).

Initial impact on the Kettle was the construction of two control structures in 1966. One provides a secondary water source for Gillam near the townsite and the other provides a water source for the Radisson converter station. In 1968 the Butnau River was diverted into the Kettle River. The added runoff has maintained higher flows in the river throughout the summer, causing increased sediment load, bank slumping and erosion (R. Newbury, unpublished data). Thus shallow riffles generally considered to be the most productive sections of the stream have been lost for longer periods of each year, only becoming obvious in late summer and early fall (Department of Natural Resources, Water Resources Branch, 1988).

In 1968, raw sewage was dumped into upstream pools associated with impoundment and construction of the Kettle Rapids Generating Station. Then in 1970 the current chlorinated sewage treatment plant, approximately 50 m downstream of the Gillam townsite weir, became operational (R. Gator, Gillam L.G.D. and G. Swanson, Department of Natural Resources, personal communication).

Additionally, the Kettle River is traversed by the HVDC line to Dorsey from the Radisson Converter Station, the Long Spruce-Radisson 138 kv transmission line from Long Spruce and the Long Spruce rail spur (branch line) and road.

Figure 2: Illustration of study area and location of sampling sites. Numbers representing sampling sites are provided in Table 1.

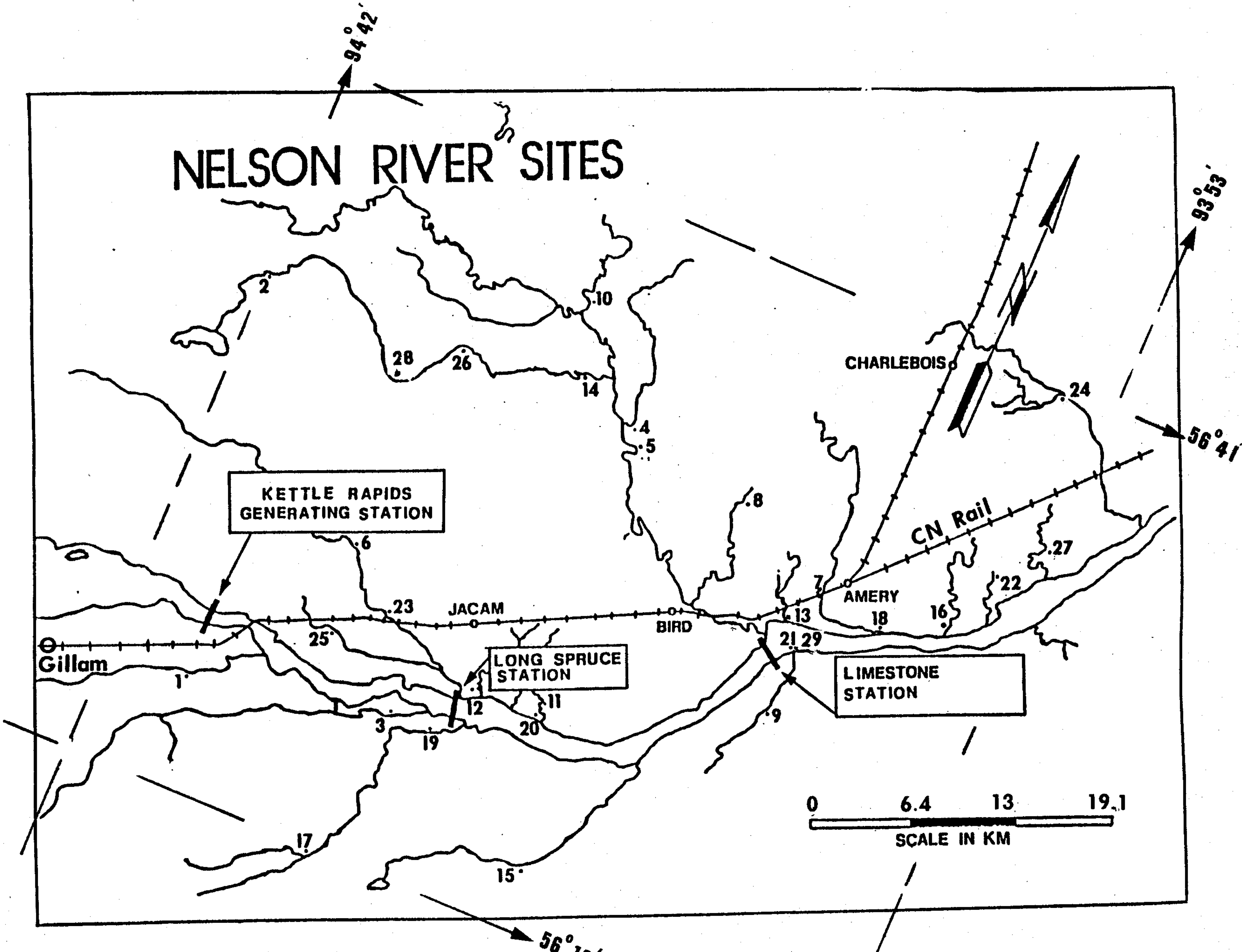

NELSON RIVER SITES
94°42'
93°53'
56°41'
56°19'
KETTLE RAPIDS
GENERATING STATION
LONG SPRUCE
STATION
LIMESTONE
STATION
CHARLEBOIS
CN Rail
AMERY
JACAM
BIRD
Gillam
0
6.4
13
19.1
SCALE IN KM

Table 1: Coordinates of sampling site locations.

Sampling site no.	Sampling site	Latitude ^{o} N (parallels)	Longitude ^{o} W (meridians)
1	Kettle River	56° 21' 20"	94° 35' 42"
2	12 Mile Creek (Camp location)	56° 33' 49"	94° 42' 30"
3	Boots Creek	56° 21' 11"	94° 29' 43"
4	9 Mile Creek	56° 34' 18"	94° 19' 26"
5	Limestone River	56° 33' 22"	94° 19' 16"
6	Sky Pilot Creek	56° 25' 34"	94° 27' 43"
7	Sundance Creek (Upstream)	56° 32' 30"	94° 04' 53"
8	CN Creek	56° 32' 51"	94° 10' 35"
9	Moondance Creek	56° 29' 05"	94° 04' 10"
10	McMillan Creek	56° 37' 00"	94° 25' 21"
11	Leslie Creek	56° 25' 39"	94° 15' 33"
12	Unnamed Creek #1	56° 25' 28"	94° 20' 29"
13	Keeta Creek	56° 31' 25"	94° 06' 18"
14	12 Mile Creek	56° 35' 25"	94° 22' 41"
15	Brooks Creek	56° 20' 30"	94° 11' 50"
16	Beaver Creek	56° 33' 41"	93° 58' 48"
17	Wilson Creek	56° 19' 48"	94° 24' 11"
18	Sundance Creek (Downstream)	56° 32' 07"	94° 00' 21"
19	Long Spruce Quarry	56° 23' 14"	94° 20' 39"
20	Unnamed Creek #2	56° 24' 41"	94° 19' 05"

continued ....

Sampling site no.	Sampling site	Latitude ^{o} N (parallels)	Longitude ^{o} W (meridians)
21	Nelson River	56° 30' 37"	94° 04' 31"
22	Creek 15	56° 34' 28"	93° 56' 28"
23	Small bog near Sky Pilot Creek	56° 25' 12"	94° 25' 55"
24	Goose Creek	56° 41' 41"	93° 56' 42"
25	Small tributary on Sky Pilot Creek	56° 23' 46"	94° 28' 26"
26	12 Mile Creek (Ground water)	56° 34' 10"	94° 26' 05"
27	No Name Creek	56° 36' 00"	93° 53' 30"
28	12 Mile Creek (Cool spring)	56° 32' 43"	94° 30' 01"
29	Moondance Creek (Mouth)	56° 30' 35"	94° 04' 00"

<u>12 Mile Creek</u> (Sites 2, 14, 26, 28)

This is a large tributary of the Limestone River, more than 30 km long (approximately 55 km in length with 13 tributaries), and with channel widths of 10-30 m. Mean water depths range from 0.38 to 0.74 m (Department of Natural Resources, Gillam, Manitoba, 1988). Average width and depth are inversely related to gradient. In general, the habitat consists of relatively deep, fast flowing clear cool water. The riparian zone is not as concentrated, and consequently large woody debris is not as prominent, as in the smaller canyon-like streams such as Moondance, No Name, Beaver, Goose, and Sundance Creeks. Its banks are composed of sandy clay, are slightly undercut, and overhanging stream canopy cover is present. Low gradient sections produce habitat for macrophytes and pond habitat is created by beaver dams in relatively high gradient areas.

Sites 26 and 28 were located in topographically low areas, immediately adjacent to the stream channel where coarse deposits had allowed the impoundment, flow, and movement of ground water. In 1988 infra red thermal image sensing was conducted on 12 Mile Creek to identify areas with frequent coldwater upwellings (personal communication, K. R. Kansas, Department of Natural Resources). Water depth ranged from 5-20 cm at Site 26 and macrophytic growth was absent. Pool depth at Site 28 was slightly deeper (20-50 cm) and aquatic macrophytes were present. No major human disturbances or interferences besides the occasional campsite were encountered.

Boots Creek (Site 3)

This is a smaller Nelson River tributary (<30 km long) which drains into the Long Spruce forebay. Channel widths are <8.0 m and water depths average from 0.2 to 1.0 m (Department of Natural Resources, 1988). In general, upstream habitat consists of a slow flowing, heavily vegetated slough, and riffle-pool sequences become obvious only near the Nelson River. Downstream, the extent of macrophyte communities is largely determined by regional hydrological patterns. Reduced flows in late summer to early fall result in streambed drying. Impacts include the Long Spruce-Radisson HVDC (high voltage direct current) transmission line, a CNR rail spur and an access road.

9 Mile Creek (Site 4)

This is a smaller (< 30 km long) Limestone River tributary located approximately 9 miles (15 km) upstream along the Limestone River from the Nelson. Water depths average 0.2-0.9 m. Water levels may vary drastically from the spring snowmelt period to late summer. Channel widths are narrow, ranging from 3.0-7.0 m, or more where beaver dams in both high and low gradient areas significantly reduce water velocities. Hence as the gradient increases, the average depth and width decreases. A high gradient riffle habitat is present at the mouth of the creek. Reduced flows in late summer to early fall result in streambed drying. The creek's banks, composed of cobble and gravel in the steeper gradient sections and fines and detritus in the lowest gradient sections, are slightly undercut and overhanging vegetation is generally abundant. In-stream vegetation is distributed as patches or strips along the shallow edges of the river. The presence of a well-beaten path, and litter along the creek indicate human traffic in the area (i.e., exploitation of brook trout by natives).

Limestone River (Site 5)

This is a relatively large (approximately 130 km in length and having some 35 feeder streams) tributary of the Nelson River located immediately downstream of the Limestone Dam. Limestone channel widths are 10 m or more and average water depths range from 0.4 to 2.0 m (Fisheries Branch). The river itself is basically a continuous channel where riffles-rapids only become obvious at extremely low flows or at the high gradient riffle habitat present at the mouth. Shoreline vegetation is not as concentrated and consequently large woody debris is not as prominent as in smaller streams. Boulders are most frequent in steeper gradient sections with cobble and gravel in intermediate gradients and fines and detritus in the lowest gradient sections.

The locations of macrophyte communities are largely determined by regional hydrological and sediment patterns. Rooted plants occur as patches or strips along the shallow, more meandering edges of the river. Unsorted rocks, stones, rubble and gravel line the banks and canopy cover is almost non-existent.

There are numerous erosion problems on the Lower Limestone River due to old roads and snow dump sites. In addition, the highway drainage ditch and crossing allow sediment wash-out during the spring. Ground water pollution through diesel fuel and hydraulic fluid spills have also contaminated this river system. Currently there is concern that sewage treatment at the Bird area borrow site may pose additional contamination problems.

<u>Sky Pilot Creek</u> (Sites 6, 23, 25)

This is a tributary of the Nelson River located immediately downstream of the Long Spruce Generating Station. The creek itself is approximately 48 km in length and has 16 tributaries. Channel widths range between 2.0 and 10.0 m. Its banks are composed of unsorted rocks, stones, rubble, gravel, sand or fine soils, are slightly undercut, and stream cover is provided by generally abundant overhanging vegetation. Shoreline vegetation is concentrated and large woody debris is common. High gradient rapid habitat at the mouth is characterized by large boulders and almost no littoral zone. Where riffle and pool sequences are present the water is shallower with dense macrophyte colonization (i.e., Site 25). In general, the low gradient sections upstream (Site 23) produce habitat consisting of slow-flowing sloughs. In addition, pond habitat is created by beaver dams where macrophytes occur in patches.

The creek receives severe angling pressure associated with upstream movements of brook trout in the spring; human traffic is indicated by litter. Furthermore, stream crossings are associated with aggregate removal. Specific problems in this regard include erosion during rainfall into the creek and Limestone Forebay by way of the CNR rail line to Churchill, the highway drainage ditch and the old crossing.

Unnamed Creek #1 (Site 12)

Unnamed Creek #2 (Site 20)

Leslie Creek (Site 11)

These are Limestone Forebay feeder streams on the north shore of the Nelson River. During late summer intermittent flows result in insufficient depths to provide macrophyte habitat in some stretches of the stream channels. Each of these tributaries (10-30 km) is narrow, with 2.0-4.0 m channel widths, and is situated within steep-walled ravines of up to 15 m deep. Creek banks are composed of rocks, stones, gravel, sand, and fine sediments and canopy cover is generally abundant. Upstream low gradient sections produce habitat consisting mainly of slow-flowing sloughs. Human interferences include minimal angling pressure, the CNR to Churchill and the Gillam to Long Spruce access highway.

Sundance Creek (Sites 7, 18)

This is a tributary of the Nelson River (<30 km in length) with narrow (2-6 m) channel widths. It is intermittently contained within steep walled ravines of up to ca. 4 m deep. The presence of erosion-resistant substrate is evident in the exposed bedrock shoreline near the townsite of Sundance and at the lower Limestone Rapids, which has deflected the south-flowing Sundance east, resulting in larger tributaries from the collection of small branches as the stream parallels the Nelson River. According to Swanson and Kansas (1987) the effects of a larger drainage basin on Sundance is theoretically reflected in more consistent flows. However, on the creek, sections of dry streambed were observed during the unusually dry August of 1988. In isolated locations, stream flow was observed to bypass sections of the lower reaches by flowing underground through porous substrates. Streambed deposits in these areas were primarily sand and gravel. Macrophyte communities occurred where there were suitable water depths to sustain growth.

Sundance Creek has been heavily impacted by human activity since 1975. The townsite of Sundance borders Sundance Creek to the south and west, while a gravel pit borders it to the northwest. The gravel pit access crossing has washed out in previous years as evidenced by old culverts downstream of the crossing. The present crossing is not rip-rapped, and high spring flows actively erode the north and south sides. It is additionally possible that the presence of the gravel pit may have reduced or deflected ground water flows and subsequent drying in Sundance Creek.

<u>CN Creek</u> (Site 8)

This is a secondary tributary of the Nelson River which drains into the Limestone River approximately 5 km from its mouth. The creek is approximately 11 km long and has two tributaries. CN Creek channel width ranges between 2 and 6 m and water depths may vary drastically from the spring snowmelt period, periodically flooding its banks. Such faster flowing and prolonged spring spates disperse large amounts of sediment, increasing siltation and turbidity levels. Moderately meandering shorelines produce habitat for a diverse array of aquatic plants along the shallow edges. Ponds created by beaver dams occur intermittently. Where riffle-pool sequences were present the water was shallower.

CN Creek receives severe angling pressure associated with upstream movements of brook trout in the spring. Moreover, there is the presence of a gravel removal road where improper culvert installations have allowed washing out during the larger spring spates.

Moondance Creek (Sites 9, 29)

This is a relatively small (<30 km in length) feeder stream on the south shore of the Nelson River, immediately downstream of the Limestone Generating Station. The majority of the channel length is narrow with 2-6 m widths situated within steep walled ravines of up to 10 m depth. Shoreline vegetation is concentrated and large woody debris is common. Reduced flows in late summer to early fall permit drying of the banks, which are slightly undercut and composed of rocks, gravel, and sandy clays. Moondance Creek is relatively pristine.

McMillan Creek (Site 10)

This is a tributary of the Limestone River located approximately 15 km from its junction with the Nelson. Mean water depths range from 0.42 to 0.94 m, with channel widths between 8 and 15 m (Fisheries Branch, 1985). High water levels are generally maintained throughout the year resulting in an almost continuous channel morphometry, excluding high gradient sections where shallow riffles become obvious only in late summer and early fall. Stream banks are moderately undercut, and overhanging stream canopy cover is abundant. Coldwater upwellings have been identified (Fisheries Branch, 1985) where coarse deposits allow storage and movement of ground water flows out of areas of topographic lows. In-stream vegetation is distributed as patches or strips along the shallow edges. Since the creek is relatively large it has faster flowing and prolonged spring spates, which disperse fine aggregates and detritus from intermediate gradients increasing downstream siltation. McMillan Creek receives moderate angling pressure in the spring and is traversed by an HVDC electrical transmission corridor.

Wilson Creek (Site 17)

Brooks Creek (Site 15)

These are south shore feeder streams of the Nelson River sandwiched between Long Spruce and Limestone Generating Stations. Both tributaries (> 30 km in length) have channel widths between 8.0-20 m. Increasing gradients near the Nelson River cause greater water velocities and increase erosion. Upstream habitat is characterized by swamp-bog, while downstream sections are characterized by riffle-pool-glide sequences. Substrate varies from sand to boulder mixtures and overhanging canopy cover is abundant. Brooks Creek is more of a canyon-type stream flowing through ravines of up to 10-12 m. Macrophyte communities occur in patches where suitable water depths exist. Practically no littoral development is present in faster flowing areas.

Impacts on Wilson Creek include human interference from the 42 km long DC-line with the southwest-northeast direction 30 m wide Long Spruce-Radisson 138 kv transmission line right of way, the CN rail spur, and access highway from Long Spruce. In addition, there is an access road from the highway to Wilson Creek, a temporary bridge over the creek, and a well-beaten path allowing for fishing and recreation.

Keeta Creek (Site 13)

Beaver Creek (Site 16)

Creek 15 (Site 22)

No Name Creek (Site 27)

These are narrow feeder streams of the Nelson River at the Conawapa forebay. Draining from the north bank of the river, they have 2-4 m channel widths, and may, under extremely dry conditions, experience intermittent flows. Shoreline vegetation is dense with woody debris and overhanging brush shelter. Numerous natural barriers lead to diversion of normal flow from natural channels and segments of the channel may lead to blind alleys. Aquatic vegetation is sparse. Substrate consists primarily of sand and gravel deposits. Only Keeta Creek (Site 13) shows evidence of human interference from the Amery rail spur and the Sundance townsite road. Beaver, No Name, and Creek 15 are relatively pristine.

Goose Creek (Site 24)

This is a Nelson River feeder stream located approximately 15 km downstream of the Limestone Generating Station. Channel width is narrow, ranging from 2-7 m. Reduced flows in late summer to early fall are associated with streambed drying. Creek bed substrate is composed of cobble and gravel in the steeper gradient sections and fines and detritus in low gradient segments. Banks are slightly to moderately undercut and canopy cover is patchy. In-stream vegetation is sparsely distributed along the more shallow edges of the creek. Human interference consists of a discontinued CNR rail spur crossing.

Nelson River (Site 21)

The lower Nelson River is characterized by high banks, and numerous tributaries which drain from the flat wet upland. Steeper banks are unstable, sparsely vegetated and have wide, ice-scoured benches along the shoreline. Within the banks several types of sorted and unsorted materials are present.

III. Sample Collection and Preparation

The sampling plan or strategy for this project adopted two approaches: a repetitive sampling of water, sediment, fish, and macrophytes from a series of sampling stations throughout the growing season, and an examination of a number of sites, some remote and accessible only by air, that were visited only once in order to obtain information on metal and content levels over a wider geographical area. The adoption of both intensive and extensive approaches maximized the information that could be gained for metal distributions in the Lower Nelson River region. Larger stream systems were sampled numerous times during the summer period but several of the smaller feeder streams had either dried up or could not be re-visited later in the season.

Sampling was conducted during the period from May 30 to September 27, 1988. The study area was accessed through Gillam. Sampling locations were reached by transportation available at the time: canoe, motor boat, helicopter or foot. No aquatic macrophyte growth was present prior to the end of May due to ice scour and snow and ice cover. Nineteen of the sites were sampled several (e.g., 3-7) times during the season, while an additional 9 were visited only once.

On each sampling day, water, sediment, and submerged and emergent aquatic macrophytes were harvested at each site visited. Fish sampling was conducted whenever possible.

Fixed sampling areas were marked with stakes or identified with respect to landmarks to permit repeated visits to the same sampling location. In these cases all sample materials were obtained from approximately the same stand locations. Sampling at each site on any given day proceeded in an upstream direction in order not to disturb subsequent study sections.

Water samples were collected in Nalgene 1.0 litre sample bottles at a depth of 10-20 cm below the surface, in the main plume of the river or creek. New bottles were rinsed 3-4 times with creek water. Samples were maintained at $4^{o}C$ for 0.5-4 h until return to base camp where they were frozen at $-20^{o}C$. The possibility of loss of trace amounts of metallic ions on container walls during sample collection, handling, and storage of aqueous solutions was recognized. Nalgene (linear polyethylene) was utilized for collection of field samples because it is the preferred material for this purpose (Subramanian _et_ _al_., 1977; Yost, 1978) on account of its relatively inert characteristics. The degree of success in reconstituting frozen water samples has been previously questioned (Stumm and Morgan, 1970), but investigations have not detected a difference between original and reconstituted samples with respect to these trace metal distributions.

An effort was made to include all macrophyte species encountered at each site on each visit. A number of individual plants were harvested for each species in order to provide composite samples. Macrophyte samples spanned a depth range of approximately 0 to 1.5 metres and were collected by wading and uprooting them by hand or with a small plastic shovel. Samples were washed with stream water at the collection site, packed into plastic bags and stored on ice during transport until return to base camp within 2-5 hours, where they were frozen at $-20^{o}C$. Material harvested included filamentous green algae, charophytes, aquatic bryophytes, and vascular species.

Frozen plant material was subsequently lyophilized using a Labconco freeze-drier equipped with a Model D150 Precision vacuum pump. Dry material was sorted into organs. The season's sampling yielded 382 plant organ samples. Voucher specimens have been deposited in the herbarium of the University of Winnipeg. Where reproductive structures were absent (e.g., many Cyperaceae) species identifications could not be made and the taxa were grouped.

Tissue samples were handled with plastic implements and ground in a stainless steel-plastic mill. Only green parts were used for aboveground portions of the samples. Epiphytic algal coverings were particularly persistent on some older submerged macrophyte portions (e.g., Cyperaceae) and could only partially be removed. Such parts were not used for metal analysis.

Surface sediments (ca. 15 cm^3) were collected within the macrophyte stands using a small plastic shovel. Samples were sieved in the field to remove material larger than 2.0 cm in diameter, since preliminary trials indicated that more than 90% of absorbed metals were associated with smaller particles. Approximately 150-300 g of sediment were placed into plastic sampling bags on ice in coolers and subsequently frozen at base camp. Frozen samples were later lyophilized as for macrophytes.

Approximately 50 fish tissue samples were collected for analysis. Brook trout (Salvelinus fontinalis Mitchill) were collected from McMillan Creek by angling. Whitefish (Coregonus clupeaformis Mitchill), walleye (Stizostedion vitreum Mitchill), northern pike (Esox lucius Linnaeus), goldeye (Hiodon alosoides Rafinesque), and longnose sucker (Catostomus catostomus Forster) were captured from sections of Moondance Creek between Sites 9 and 29 and the Nelson River (Site 21) using a series of gillnets. Each gang or series was composed of six panels of 22.9 m long by 1.8 m deep nets. Mesh sizes used were 3.9 cm, 5.1 cm, 7.6 cm, 9.5 cm, 10.8 cm, and 12.7 cm stretch measure. Each gang was set 2-4 meters deep and allowed to remain overnight.

Fork length and fresh wet weight of all fish were measured in the field, and recorded by species, sex, and age. For age determination otoliths were taken from whitefish and walleye; cleithra were removed from northern pike. Samples of fish axial musculature were analyzed. In the case of brook trout, scales were taken from the left side between the lateral line and the dorsal fin (Power, 1964). Scale samples were preserved between two layers of plastic and stored in scale envelopes containing individual fish information. Scale samples were read directly from plastic scale slides using a microfiche reader at a magnification of 72 times. Samples of fish axial musculature (from the body wall below the dorsal fin), gill tissue, liver, heart, reproductive organs, scales, bone, and brain tissue were removed, frozen and lyophilized, then ground using a porcelain mortar and pestle.

IV. Determination of Sediment Organic Matter and Particle Size Analysis

Organic matter content was determined in sediments because it affects sediment structure, moisture retention, cation exchange capacity, and metal binding properties (Brady, 1974). Approximately 2 g of each lyophilized sediment sample was heated in a porcelain crucible at 550°C in a muffle furnace for 16 h. Samples were cooled to room temperature and the organic matter was determined as the percentage loss of weight on ignition.

Some sediment samples may have been rich in carbonates so the combustion temperature was reduced to 550°C as a precaution (G. Scott, personal communication). To compensate for this lower temperature, a longer muffling time was required. Theoretically, hydrated carbonates can lose small amounts of water and at higher temperatures (>600°C) some calcium carbonate may oxidize to calcium oxide, thereby decreasing the weight (Brady, 1974).

Sediments can be divided into two distinctly different groups (Raudkivi, 1976). Coarse sediments with grains exceeding 0.0625 mm are sands and gravels. Finer sediments with particles smaller than about 0.0625 mm are silts and clays. Grain size particles larger than 2.0 cm were discarded in the field.

For particle size analysis, lyophilized sediment samples were placed in a porcelain mortar and pounded with a rubber hammer using an up and down motion, never a grinding motion to disaggregate them without breaking individual grains. All visible roots and extraneous matter were removed beforehand. Disaggregation was necessary because sand grains may be cemented into aggregates and chemically precipitated materials, which can give erroneous values, due to their increased size (Folk, 1980). The coarse sediments, or grain size particles down to about 4 phi (62.5 um) were analyzed by screening.

Approximately 100 g samples of disaggregated sample were sieved through (Tyler equivalent) #10, #35, #60 and #230. These mesh sizes represented the boundaries between granules, coarse, medium, and fine sand, and mud (composed of silt and clay) (Raudkivi, 1976).

Silts and clays (less than 4 phi) were analyzed by pipette, which utilized differential settling rates in distilled water columns (Folk, 1980). Between 10 and 15 g of the silt and clay fraction retained from dry sieving is an optimal sample size for analysis. With more than 40 g, the individual grains interfere with each other during settling and may flocculate. With less sample, the experimental error in weighing becomes proportionately large (G. Scott, personal communication).

To remove organic matter, the pre-weighed silt and clay fraction was placed into a 600 ml beaker and approximately 50 ml of 6% hydrogen peroxide were added. The mixture was heated gently to simmering. Where necessary to reduce frothing, additions of a few drops of n-amyl alcohol (1-pentanol) were made. Upon completion of digestion, the sample was allowed to cool for 10 min. then 50.0 ml of a 10% purified sodium meta-phosphate (SMP) solution were added as a dispersant (Fisher Scientific Company, Fairlawn, New Jersey). Sample silt and clay contents were then determined by pipette and differential settling rates using methods described by Folk (1980).

V. Determination of Metals by Atomic Absorption Spectrophotometry

a. Extraction of Metals from Water

Water samples in 1.0 l Nalgene bottles were thawed at room temperature, the volume was measured, and the samples were transferred to acid-washed 1 litre beakers. Sample volumes ranged from 800-900 ml. The pH was lowered to 2.8 $\pm$ 0.1 by adding 1.0 N nitric acid and monitoring with a Fisher Accumet model 805 mp pH meter. Following sample acidification, the samples were transferred to 1 litre erlenmeyer flasks, 1.0 ml of a 1% w/v aqueous APCD (ammonium pyrrolidinecarbodithioate) solution (prepared fresh each day) was added, and the mixture was swirled.

Following chelation, samples were allowed to stand for 10 min., then 90.0 ml of MIBK (methyl iso-butyl alcohol) were added to each. The flasks were shaken for approximately 30 sec. The optimum ratio of the organic to aqueous extraction mixture is 10 ml of MIBK per 100 ml of sample water, but the ratio of water to MIBK should not exceed 40:1 by volume (A.P.H.A., 1985). However, the MIBK volume must be sufficient to determine all three analyte elements in one single extraction.

Distilled water was then carefully poured down the side of the flask or introduced below the solvent water interface by means of a pipette in order to raise the upper organic layer into the narrow neck of the flask for aspiration of the organic layer.

The accuracy of trace metal analyses in the creek water samples could not be thoroughly evaluated, since standards prepared in the chemical matrix of natural fresh waters were obtainable. Consequently, in view of the many sources of error, the standard additions technique was used. For this method, two separate additions were performed (for each sample),

Table 2: Grain size scales and conversions.

U.S. standard sieve (Tyler #)	**Millimeters**	**Microns**	**Phi (0)**	**Wentworth size class**
				Granule
10	2.00	2000	-1.0	
				Coarse sand
35	0.50	500	1.0	
				Medium sand
60	0.25	250	2.0	
				Fine sand
230	0.0625	62.5	4.0	
	0.0039	3.9	8.0	Silt
Analysed By Pipette	0.0020	2.0	9.0	Clay

from Folk, 1980

with each addition series bracketing the expected range of analyte metal concentrations. The metal spikes were chosen so as to increase the original trace metal concentrations of the first standard by approximately 50% and the second by a further 50%. Analyte spike concentrations for the standards are given in Table 3. Additions were made prior to acidification of the samples.

The procedural blank in the extraction procedure consisted of the reagents and distilled water, processed in the same manner as the sample unknowns. Reagent (APCD and MIBK) and water volumes for both the procedural control and the spiked addition standards are given in Table 4. Standards and blanks were prepared each extraction day with proportionally increased distilled water and reagent volumes, providing sufficient amounts for repeated aspiration between determinations and unknowns. Because background metal concentrations in the creek water samples were close to detection limits, accuracy was highly susceptible to contamination from glassware, and extreme care was exercised. All glassware was preconditioned by acid leaching (1% nitric acid) and rinsed repeatedly with double distilled water.

Each batch consisted of five unknown creek samples, two reference standards, and a reagent control. This batch size required a total chelation-extraction time from pH adjustment to aspiration of approximately 3-4 hours. Problems associated with instability of the extracted metal-APCD complex were therefore avoided because absorbance readings were determined relatively soon after analyte extraction, reducing detrimental effects caused by complex dissociation.

Table 3: Control, standard, and unknown sample volume ratios for ammonium pyrrolidinecarbodithioate (APCD), methyl iso-butyl alcohol (MIBK), sample water, and analyte metal additions.

	Control*	**No addition**	**1st addition**	**2nd addition**
cadmium	-	-	30 ug	60 ug
copper	-	-	60 ug	120 ug
lead	-	-	150 ug	300 ug
APCD (1% solv.)	2.0 ml	1.0 ml	1.0 ml	1.0 ml
MIBK	180 ml	90 ml	90 ml	90 ml
water volume	300 ml distilled	measured (800-900 mls)	150 ml distilled	150 ml

* Reagent volumes for the control were doubled, permitting: (1) enough organic solvent to aspirate for all three analyte metals, and (2) equilibration of the spectrophotometer before and between all sample readings allowing aspiration of a base-line value.

b. Digestion of Tissue and Sediment Samples

The nitric-perchloric acid digestion method employed in this study was that used by Pip (1990 a,b) for freshwater materials. Where possible, three 1.0 g replicates of powdered freeze-dried sediment, macrophyte and fish tissue samples were extracted. Sediments were sieved to remove material larger than 4.0 mm in diameter (ref. Iskandar and Keeney, 1974).

To each freeze-dried 1.0 g subsample were added 7.5 ml of concentrated nitric acid and 1.5 ml of 70% perchloric acid. To compensate for possible matrix absorption effects, all sediment and tissue samples were processed using the standard additions method. All additions (Table 4) were made prior to the initiation of digestion. Metal standards certified for AAS, Fisher Scientific Company, Fairlawn, New Jersey were used in the additions. Optimum addition quantities for these types of samples with respect to linearity and confidence levels of the results had been previously determined (Pip, unpublished data).

The digestion mixture was heated gently, but not allowed to boil. If either frothing or charring occurred at this stage, the heat was reduced or 1.0 ml of nitric acid was added. Following digestion, 10 ml of 1% nitric acid were added to the beaker and swirled. The residue remaining after the wet ashing procedure was usually negligible and consisted of insoluble salts.

After cooling, the supernatant was filtered using a hand suction pump and Buchner funnel with a Whatman #541 hardened ashless lead-free filter paper. The filtrate and two 2.0 ml filtered rinses of 1% nitric acid were pooled in a graduated cylinder, and made to a volume of 30 ml with 1% nitric acid. All glassware was preconditioned with 1% nitric acid

Table 4: Quantities used in the standard additions and control for tissue and sediment metal determinations.

Beaker	Content description	Distilled H_2O (ml)	Additions (ug) Cd	Cu	Pb
C	Procedural control	2.0	-	-	-
1	Unspiked sample (No addition)	2.0	-	-	-
2	Sample plus first addition	1.51	40	50	100
3	Sample plus second addition	1.02	80	100	200

followed by rinsing with glass distilled water. A procedural control, consisting of all steps and reagents in the extraction protocol, less sample material, was run with each lot of samples processed. On occasion when sample volume permitted, subsamples of plant tissue and sediment were extracted and analyzed in replicate, providing an additional measure of analytical error. Concentrations of metals in the unknowns were calculated by fitting regression lines for the additions for each sample and extrapolating to the intercept on the concentration axis. A typical working curve for such a calculation is shown in Figure 3. In the present study, sediment and tissue results were expressed as microgram per gram dry weight of sample (content), while those for water were expressed as ug/l (concentration).

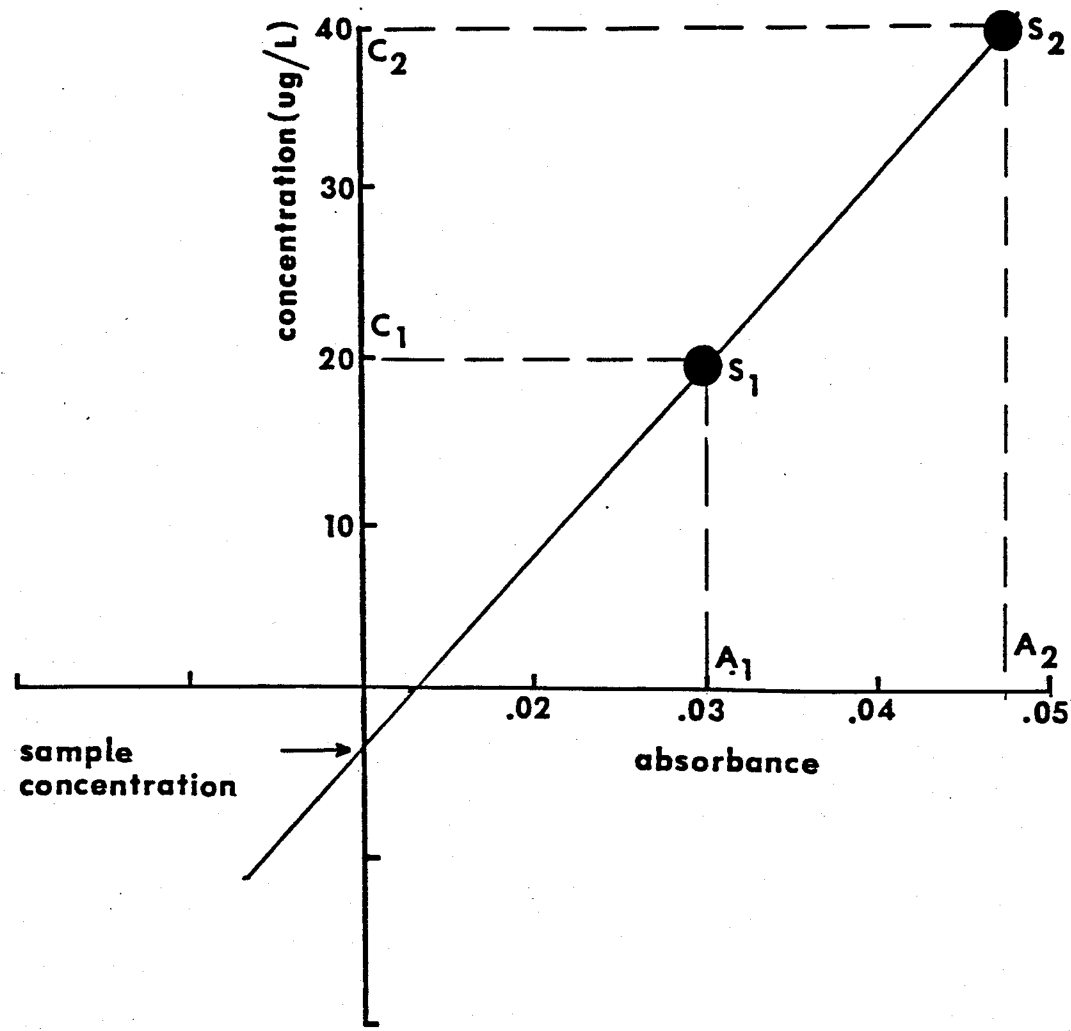
c. Atomic Absorption Spectrophotometry Procedure

Metals were measured using an IL-151 Atomic Absorption Spectrophotometer (Instrumentation Laboratory Inc. Wilmington, Mass.). The burner was allowed to warm 30 min. while distilled water was nebulized in order that the burner head, burner connections and walls of the spray chamber could equilibrate in temperature with each other.

For the metal determinations, the blank, sample and standard solutions were each nebulized into a lean air acetylene flame. The absorbance for Cd, Cu, and Pb was measured at wavelengths of 228.8, 324.7, and 217.0 Å respectively. Each solution was aspirated for sufficient time for a steady value to be achieved on the digital display.

The nebulizer and burner assembly were washed by aspirating pure deionized-distilled water after each batch of samples. Such cleaning and

Figure 3: Typical working curve for the method of additions utilized (C = Concentration, S = Sample, A = Absorbance).



concentration (ug/L)
40
30
20
10
C2
C1
S2
S1
A1
A2
.02
.03
.04
.05
absorbance
sample concentration

inclusion of procedural controls with each sample set ensured that no drift in sensitivity (e.g., change in oxidant: fuel flow rate or variable nebulizer performance) had occurred.

d. Technical, Analytical Considerations

i. 'Total' Metal Content

Most studies dealing with particulate metals in natural water systems concern the total metal content (Tessier et al., 1979), and in accordance with Agemian and Chan (1976), the extraction methods that are the most meaningful for environmental purposes are those which determine 'total' metal content.

The use of total content as a criterion to assess the potential effects of biotic and abiotic contamination unfortunately implies that all forms of a given metal have an equal impact on the environment. However, trace metal partitioning schemes to determine residual and non-residual phases and the selective dissolution of different phases of sediments (such as those reported by Tessier et al., 1979) are beyond the scope of this study.

A persistent problem in dealing with literature values stems from the fact that data are not always directly comparable, as different workers have reported values on the basis of dry weight or ash (e.g., David, 1958; Gale et al., 1973; Mayes and McIntosh, 1975; Wentzel and McIntosh, 1977), or in terms of wet weight (e.g., Mathis and Kevern, 1975; Wolnik et al., 1983). Confusion has additionally arisen through the frequent, inconsistent usage of the terms content and concentration.

VI. Statistical Treatment

Statistical analysis was carried out using SPSS (SPSS Inc., Chicago, Illinois). For assessing differences between/among means, student t-tests and analysis of variance was preferentially applied, provided that F tests indicated that variance distributions were acceptable for parametric tests. In the case of analysis of variance, pre-tests using Cochran's C and Bartlett-Box F were applied. When pre-tests indicated that parametric tests were inappropriate, nonparametric techniques were employed, i.e., Kolmogorov-Smirnov two sample tests and Kruskal-Wallis H corrected for ties. Where proportion data were compared (e.g., sediment particle size), arc sine transformations were used (Sokal and Rohlf, 1987).

Multiple comparisons between means were examined using both Duncan's and Student-Newman-Keuls multiple range tests. For these tests, harmonic means of group sizes were used, and non-empty group means were sorted in ascending order.

Correlation analysis (Pearson r) was carried out using one-tailed probabilities. Appropriate data transformations were made where necessary.

The critical significance level of all statistical tests was $p = 0.05$.

RESULTS

I. Metal Concentrations in Water

For Pb, extremely variable, and some unrealistically high values, caused rejection of the Pb water concentrations. These data are neither presented nor discussed further.

There was also considerable variability among the unfiltered creek water samples with respect to total Cd and Cu levels. It is likely that the highest values obtained reflect contamination of the sample at the time of sampling or during analysis and are not accurate measures of the Cd and/or Cu levels in these waters. Analyte metal concentration values at sampling sites which were visited more than once (N = 20) were often variable. In a total of 104 creek water samples, cadmium and copper concentrations were below detection limits (<0.01 ug/l) in 42 and 20 cases, respectively. However, other values for these metals were occasionally higher than expected, and these are attributed to contamination and/or problems with methodology.

Total Cd concentrations for the 20 sites visited repeatedly encompassed values ranging from below a 0.01 ug/l minimum obtained for Nelson River and 9 Mile Creek, to a 7.46 ug/l maximum for McMillan Creek (Table 5). For Cu the equivalent range was from below 0.01 ug/l obtained during September downstream of the townsite on Sundance Creek (Figure 2) to 25.0 ug/l for Sky Pilot Creek (Table 5). Total Cu concentrations at most sites and times showed a slight elevation over Cd.

For the study area as a whole, no one sampling site showed either the highest or the lowest value for either metal examined.

II. Sediments

a. Total Metal Content of Sediments

Metal contents of surface sediments sampled were not homogeneously distributed among the sites, and as expected from the range of sediment

Table 5: Total cadmium and copper concentration (ug/l) values for unfiltered water samples collected in the Gillam-Limestone locality between May and September 1988. (Maximum values appear in bold numerals.)

Site	Period	Cadmium (ug/l)	Copper (ug/l)
Kettle River	June 16-20	<0.01	4.4
	July 20-27	2.02	21.6
	Aug. 3-7	3.97	14.7
	Aug. 10-16	<0.01	23.2
	Sept. 2-7	<0.01	<0.01
	Sept. 10-14	1.81	<0.01
12 Mile Creek (Camp location)	Aug. 10-16	1.14	3.3
Boots Creek	Aug. 3-7	2.78	21.2
	Aug. 10-16	<0.01	5.4
	Sept. 2-7	<0.01	10.6
	Sept. 10-14	<0.01	<0.01
9 Mile Creek	May 30	5.42	23.9
	June 16-20	0.07	15.5
	Sept. 2-7	2.74	16.7
	Sept. 10-14	1.82	<0.01
	Sept. 22-27	1.14	3.3
Limestone River	June 1-7	4.46	19.8
	June 16-20	<0.01	6.8
	July 20-27	<0.01	15.4
	Sept. 2-7	<0.01	<0.01
	Sept. 10-14	<0.01	5.1
	Sept. 22-27	1.14	1.8
Sky Pilot Creek	June 16-20	<0.01	**25.0**
	July 20-27	0.13	2.8
	Aug. 3-7	4.76	6.8
	Aug. 10-16	2.18	4.1
	Aug. 10-16	<0.01	20.2
	Sept. 2-7	<0.01	17.2
	Sept. 2-7	<0.01	7.6
	Sept. 10-14	<0.01	19.7
	Sept. 22-27	<0.01	<0.01

continued ....

Site	Period	Cadmium (ug/l)	Copper (ug/l)
Sundance Creek (Upstream)	June 16-20	0.14	14.6
	July 20-27	<0.01	2.5
	Aug. 3-7	5.56	9.0
	Aug. 10-16	0.70	10.6
	Sept. 2-7	0.49	8.7
CN Creek	May 30	3.10	7.4
	July 20-27	<0.01	17.2
	Aug. 3-7	3.56	8.3
	Sept. 10-14	1.24	0.8
	Sept. 22-27	2.19	4.3
Moondance Creek	June 23-29	<0.01	16.4
	July 20-27	<0.01	<0.01
	Aug. 3-7	1.57	20.0
	Sept. 2-7	2.06	6.9
McMillan Creek	June 1-7	7.46	16.3
	June 16-20	<0.01	<0.01
	July 20-27	<0.01	7.2
	July 20-27	1.14	4.9
Leslie Creek	June 1-7	0.54	<0.01
	June 16-20	0.49	15.0
	July 20-27	3.23	10.6
	Aug. 3-7	4.76	6.2
	Aug. 10-16	<0.01	10.6
	Sept. 2-7	0.44	7.6
	Sept. 2-7	1.24	2.3
	Sept. 22-27	0.51	<0.01
Unnamed Creek #1	June 16-20	<0.01	<0.01
	July 20-27	2.11	3.8
	Aug. 3-7	2.78	3.0
	Aug. 10-16	<0.01	7.2
	Sept. 2-7	2.85	3.1
	Sept. 2-7	<0.01	2.5
Keeta Creek	Aug. 3-7	3.85	22.5
	Aug. 10-16	1.54	7.4
	Sept. 10-14	0.65	2.5

continued ....

Site	Period	Cadmium (ug/l)	Copper (ug/l)
12 Mile Creek	May 30	<0.01	17.2
	June 16-20	<0.01	8.6
	Aug. 10-16	<0.01	11.1
	Sept. 10-14	3.10	6.0
	Sept. 22-27	1.59	4.9
Brooks Creek	June 1-7	<0.01	5.6
	June 16-20	<0.01	<0.01
	Aug. 3-7	2.19	13.7
Beaver Creek	June 23-29	<0.01	22.9
	Aug. 3-7	2.39	<0.01
Wilson Creek	June 1-7	<0.01	7.7
	June 16-20	2.75	11.8
	Aug. 3-7	0.28	9.6
	Aug. 10-16	0.65	<0.01
	Sept. 2-7	2.19	<0.01
	Sept. 2-7	3.97	14.7
	Sept. 10-14	<0.01	3.0
Sundance Creek (Downstream)	June 16-20	3.49	19.5
	July 20-27	2.73	16.7
	Aug. 10-16	2.04	3.1
	Sept. 10-14	1.32	10.7
	Sept. 22-27	2.12	0.7
Long Spruce Quarry	Aug. 3-7	<0.01	<0.01
Unnamed Creek #2	June 16-20	<0.01	<0.01
	Sept. 2-7	<0.01	7.2
	Sept. 10-14	<0.01	20.2
Nelson River	June 1-7	<0.01	5.1
	June 23-29	<0.01	18.9
	June 23-29	0.07	20.1
	Aug. 3-7	0.65	16.3
Creek 15	July 20-27	<0.01	10.3
Small bog near Sky Pilot Creek	June 1-7	2.43	10.6

continued ....

Site	Period	Cadmium (ug/l)	Copper (ug/l)
Goose Creek	June 16-20	6.23	23.4
	July 20-27	1.31	4.1
Small tributary on Sky Pilot Creek	June 1-7	1.09	<0.01
12 Mile Creek (Ground water)	Sept. 10-14	<0.01	1.7
No Name Creek	June 23-29	1.06	<0.01
12 Mile Creek (Cool spring)	Aug. 10-16	1.49	<0.01

Identical sampling periods represent replicate samples.

compositions encountered at many individual sites, differences in total metal contents were also observed in the sediment samples even from a single locality (Table 6). Therefore, no geographical trends were apparent.

The degree of variability was most pronounced for total sediment Pb content (absolute values) and least evident for Cd. Total Cd levels in surficial sediments for the twenty sites visited ranged from a minimum of 0.30 ug/g dry weight for Sundance Creek (downstream of the townsite) to a 9.44 ug/g maximum obtained at Brooks Creek. Of a total 167 samples analyzed for total Cd content, none was found to be below detection limits (0.01 ug/g).

Total Cu content showed a wider range of values. Total levels were lowest (0.2 ug/g dry weight) for McMillan Creek, and highest (14.8 ug/g) for Sky Pilot Creek sediments. Of the 20 sites investigated only Wilson Creek and Limestone River provided levels below the limits of detection (0.1 ug/g).

As with Pb analyses for water samples, there was questionable accuracy with some surface sediments examined providing no guarantee of efficient recovery or sample manipulation. Suspect readings (approximately 2 x the mean) were consequently omitted. Of n = 99 surface samples remaining, total Pb content ranged from a 3.0 ug/g dry weight minimum for Brooks Creek to a maximum of 50.0 ug/g attained at the Kettle River and downstream Sundance Creek locations. Two of ninety-eight determinations were below detection limits (0.4 ug/g).

Lead was the most concentrated analyte found in the sediments sampled. No one site examined showed either the highest or the lowest value(s) for one or more of the heavy metals examined.

An examination of cadmium and copper in water and the corresponding sediments failed to identify any consistent relationships between the latter two phases. Thus the amount of metal in water could not be predicted from the sediment content or vice versa.

Table 6: Total cadmium, copper and lead content (ug/g dry weight) of surface sediments collected in the Gillam-Limestone locality between May and September 1988.

Site	Period	Cadmium (ug/g)	Copper (ug/g)	Lead (ug/g)
Kettle River	June 16-20	3.00	2.6	42.8
	June 16-20	4.06	2.5	50.0
	July 20-27	1.03	10.7	-
	Aug. 3-7	4.02	9.0	-
	Aug. 10-16	1.70	11.1	25.0
	Aug. 10-16	2.31	12.0	50.0
	Sept. 2-7	3.37	5.2	35.7
	Sept. 2-7	4.21	5.1	21.4
	Sept. 10-14	4.45	10.9	-
12 Mile Creek (Camp location)	Aug. 10-16	4.11	5.1	-
	Aug. 10-16	4.15	5.7	-
Boots Creek	Aug. 3-7	1.81	9.9	30.9
	Aug. 3-7	2.60	10.8	28.6
	Aug. 10-16	1.50	8.0	18.0
	Sept. 2-7	0.73	8.0	13.8
	Sept. 10-14	1.46	7.2	18.0
9 Mile Creek	May 30	2.99	3.6	15.5
	May 30	4.45	4.3	14.8
	June 16-20	2.98	3.9	-
	June 16-20	3.85	4.8	-
	Sept. 2-7	2.89	2.9	-
	Sept. 2-7	4.09	3.4	-
	Sept. 10-14	2.68	3.3	23.0
	Sept. 22-27	3.61	4.2	43.3
	Sept. 22-27	3.28	4.4	-
Limestone River	June 1-7	1.74	0.7	15.0
	June 1-7	2.62	<0.1	20.0
	June 16-20	1.39	4.9	27.0
	June 16-20	1.71	4.8	36.5
	July 20-27	4.19	3.8	39.6
	July 20-27	4.10	3.6	36.1
	Sept. 2-7	2.55	7.9	37.1
	Sept. 2-7	3.63	10.1	34.8

continued ....

Site	Period	Cadmium (ug/g)	Copper (ug/g)	Lead (ug/g)
Limestone River	Sept. 10-14	4.73	4.7	38.2
	Sept. 10-14	4.62	4.5	40.0
	Sept. 22-27	4.51	4.5	36.4
Sky Pilot Creek	June 16-20	2.02	7.7	10.0
	June 16-20	2.29	8.5	8.4
	July 20-27	3.28	13.6	49.3
	July 20-27	2.31	14.8	6.1
	Aug. 3-7	0.99	11.0	40.2
	Aug. 3-7	0.65	7.2	-
	Aug. 10-16	0.99	4.5	<0.1
	Aug. 10-16	1.76	5.5	4.1
	Aug. 10-16	3.25	7.5	43.3
	Sept. 2-7	1.85	5.4	40.0
	Sept. 2-7	5.05	1.2	36.4
	Sept. 2-7	1.43	8.8	47.5
	Sept. 2-7	2.20	11.8	-
	Sept. 10-14	4.51	5.5	48.4
	Sept. 22-27	4.51	4.9	43.3
Sundance Creek (Upstream)	June 16-20	1.37	6.4	45.9
	June 16-20	2.39	7.5	-
	July 20-27	1.61	9.0	-
	July 20-27	3.68	11.4	-
	Aug. 3-7	1.58	8.3	33.2
	Aug. 3-7	3.62	7.8	7.1
	Aug. 10-16	2.29	10.8	-
	Aug. 10-16	4.48	8.0	-
	Sept. 2-7	0.87	7.8	28.6
	Sept. 2-7	1.79	6.7	38.8
CN Creek	May 30	1.15	2.9	25.0
	May 30	2.83	0.3	6.5
	July 20-27	3.40	8.9	5.0
	Aug. 3-7	0.97	0.7	<0.1
	Aug. 3-7	2.85	1.6	11.8
	Sept. 10-14	1.28	1.1	33.3
	Sept. 10-14	2.23	0.3	25.4
	Sept. 22-27	1.81	0.8	6.6
	Sept. 22-27	1.88	0.4	14.8
Moondance Creek	June 23-29	1.78	7.0	43.6
	June 23-29	2.55	5.5	44.7
	July 20-27	1.23	11.5	-

continued ....

Site	Period	Cadmium (ug/g)	Copper (ug/g)	Lead (ug/g)
Moondance Creek	July 20-27	2.87	13.9	-
	Aug. 3-7	1.06	7.7	36.5
	Sept. 2-7	1.30	3.2	-
	Sept. 2-7	3.91	1.6	-
McMillan Creek	June 1-7	1.84	1.8	17.0
	June 1-7	5.21	2.7	33.1
	June 16-20	1.10	7.5	14.8
	June 16-20	3.42	10.7	-
	July 20-27	1.12	1.1	36.2
	July 20-27	3.19	0.2	-
	July 20-27	1.34	9.6	-
	July 20-27	1.71	7.6	-
Leslie Creek	June 1-7	3.89	5.3	19.4
	June 16-20	1.65	8.6	-
	June 16-20	1.59	8.0	-
	July 20-27	3.03	13.1	-
	July 20-27	4.68	12.1	-
	Aug. 3-7	1.50	9.1	-
	Aug. 3-7	3.58	11.0	-
	Aug. 10-16	1.27	6.3	-
	Aug. 10-16	1.98	7.3	-
	Sept. 2-7	4.88	5.4	-
	Sept. 2-7	3.16	11.5	-
	Sept. 22-27	2.73	4.2	23.0
Unnamed Creek #1	June 16-20	3.93	5.3	43.3
	July 20-27	4.22	11.2	-
	Aug. 3-7	1.81	10.0	-
	Aug. 3-7	4.88	9.9	-
	Aug. 10-16	1.32	2.7	40.2
	Aug. 10-16	3.30	3.1	40.2
	Sept. 2-7	4.73	13.1	-
	Sept. 2-7	2.19	6.8	-
	Sept. 2-7	7.59	6.7	-
Keeta Creek	Aug. 3-7	4.48	14.8	-
	Aug. 10-16	1.87	12.7	-
	Aug. 10-16	3.14	14.1	-
	Sept. 10-14	2.74	5.2	-
12 Mile Creek	May 30	3.22	7.7	46.9
	May 30	2.86	6.3	33.9

continued ....

Site	Period	Cadmium (ug/g)	Copper (ug/g)	Lead (ug/g)
12 Mile Creek	June 16-20	1.23	6.6	35.7
	June 16-20	1.95	9.0	-
	Aug. 10-16	1.57	8.9	-
	Aug. 10-16	3.32	8.0	-
	Sept. 10-14	4.16	6.1	46.9
	Sept. 22-27	4.27	10.8	-
	Sept. 22-27	3.84	7.8	38.8
Brooks Creek	June 1-7	9.44	4.9	40.0
	June 1-7	4.26	7.1	43.1
	June 16-20	2.04	2.4	25.0
	June 16-20	4.01	0.7	12.6
	Aug. 3-7	1.49	4.5	18.0
	Aug. 3-7	2.98	0.4	3.0
Beaver Creek	June 23-29	1.71	5.3	29.7
	June 23-29	4.11	6.3	-
	Aug. 3-7	0.42	2.6	3.7
	Aug. 3-7	0.31	3.7	23.1
Wilson Creek	June 1-7	0.91	4.3	36.5
	June 1-7	1.86	7.2	36.5
	June 16-20	0.98	11.4	-
	June 16-20	1.53	<0.1	-
	Aug. 3-7	2.06	3.5	40.2
	Aug. 3-7	4.15	1.1	40.0
	Aug. 10-16	2.20	6.5	-
	Aug. 10-16	4.38	6.3	28.6
	Sept. 2-7	1.34	2.7	25.4
	Sept. 2-7	3.09	5.3	40.0
	Sept. 2-7	2.96	7.0	17.7
	Sept. 10-14	4.09	6.8	35.4
Sundance Creek (Downstream)	June 16-20	3.65	10.7	-
	June 16-20	7.61	10.3	-
	July 20-27	1.73	7.9	50.0
	July 20-27	3.41	8.9	40.2
	Aug. 10-16	0.30	3.2	10.8
	Aug. 10-16	2.55	4.4	-
	Sept. 10-14	4.66	10.3	-
	Sept. 22-27	2.79	1.7	-
Long Spruce Quarry	Aug. 3-7	4.17	14.7	-
	Aug. 3-7	4.17	14.4	-

continued ....

Site	Period	Cadmium (ug/g)	Copper (ug/g)	Lead (ug/g)
Unnamed Creek #2	June 16-20	4.56	6.8	-
	Sept. 2-7	1.81	2.1	48.9
	Sept. 10-14	1.85	1.5	-
	Sept. 10-14	3.23	3.4	-
Nelson River	June 1-7	1.52	8.2	-
	June 23-29	0.60	5.5	26.2
	Aug. 3-7	1.76	7.9	31.9
Creek 15	July 20-27	1.65	9.3	29.9
Small bog near Sky Pilot Creek	June 1-7	2.26	2.8	38.4
Goose Creek	June 16-20	4.21	1.5	-
	July 20-27	1.98	11.2	41.1
Small tributary on Sky Pilot Creek	June 1-7	3.98	4.0	36.4
12 Mile Creek (Ground water)	Sept. 10-14	4.01	5.8	-
No Name Creek	June 23-29	1.92	11.1	-
12 Mile Creek (Cool spring)	Aug. 10-16	2.15	11.4	-

"-" Indicates no sample or an unrealistically high value subsequently disregarded.

Identical sampling periods represent replicate samples.

b. Organic Matter Content of Sediments

Organic matter content from the 28 sampling sites encompassed values ranging from a minimum of 0.26% for Site #5 on the Limestone River to a maximum 93.97% for Site 23 in a small bog located near Sky Pilot Creek - (Table 7). Organic content representative of Boots Creek, Sundance Creek (upstream of townsite), Creek 15, and the bog area located near Sky Pilot Creek, was higher than at all other sites. Remaining sites exhibited moderately low values and were not notably different from one another.

A slight (not significant) inverse relationship between total ug/g dry weight Cd content and percent organic matter was apparent. Sampling locations possessing comparatively high organic contents generally exhibited relatively low total Cd levels. No such association was revealed for either total sediment Cu or Pb content.

c. Particle Size Distributions

In general there was considerable variability among and between sampled creek sediments with respect to particle size (diameter) fraction proportions. Intersite proportion particle size component differences, including respective minima and maxima are given in Table 7. Dissimilarities were not related to geographical affinities of the sampling locations, but rather appeared to be a function of individual site conditions and related to factors such as flow rate and local depositional environment.

Relationships among the various particle diameters suggested similar particle size fractions were generally associated with one another. To exemplify, granule ($\geq$ 2.0 mm) proportions were directly related with sediment particulates larger than medium sand (≥ 0.25 mm), whereas more indirect associations were generally apparent with smaller (0.25-0.0039 mm) sediment grain diameters. Particle sizes smaller than, and including fine sand, showed only a positive relationship.

Organic matter content in most cases demonstrated a direct association with sediment fragments smaller than and including the fine sand fraction.

d. Relationships Between Metals and Physical Sediment Characteristics

Heavy metal contents were not homogenously distributed over the various grain size fractions and in some cases large differences in total metal contents were observed for all data considered. A description of the size of the sediment fragments is included in Table 7. Within the grain size spectrum, the finer grained fractions consisting mainly of silt and clay minerals (≤ 0.063 mm in diameter) showed relatively high (not statistical) metal contents. This effect may possibly be the reason for the sometimes large discrepancies observed in metal analysis of the number of sediment samples obtained from the same location in the same creek or river.

As expected considerably more metal was apparently present in the finer samples. Hence sediments comparatively rich in silt and clay contained the largest amounts of heavy metal(s), while a somewhat inverse relationship was apparent for granule (≥ 2.0 mm) sized fractions. No significant associations were indicated for either the coarse or medium sand components of the sediments.

Table 7: Percent organic matter content and particle size proportions in surface sediments at Nelson River sampling sites. Values in parentheses represent particle diameter sizes analyzed. Category minima and maxima are indicated by bold type.

Period	Organic matter content (%)	Granules (≥ 2.0 mm)	Coarse sand (0.5-2.0 mm)	Medium sand (0.025-0.5 mm)	Fine sand (0.063-0.25 mm)	Silt (0.0039-0.063 mm)	Clay (≤ 0.0039 mm)
Kettle River							
June 16-20	6.20	0.009	0.062	0.109	0.605	0.168	0.043
June 16-20	5.93	0.013	0.041	0.072	0.681	0.099	0.094
July 20-27	6.16	0.010	0.154	0.118	0.399	0.257	0.063
Aug. 3-7	7.20	0.002	0.069	0.080	0.568	0.214	0.064
Aug. 10-16	6.47	0.003	0.084	0.071	0.490	0.281	0.068
Aug. 10-16	5.14	0.010	0.073	0.100	0.385	0.315	0.001
Sept. 2-7	5.04	0.003	0.079	0.092	0.548	0.216	0.062
Sept. 2-7	6.00	0.013	0.042	0.398	0.321	0.226	0.009
Sept. 10-14	7.11	0.024	0.140	0.092	0.382	0.289	0.067
12 Mile Creek							
Aug. 10-16	2.34	0.002	0.010	0.482	0.304	0.050	0.059
Aug. 10-16	3.48	0.026	0.035	0.411	0.276	0.091	0.161
Boots Creek							
Aug. 3-7	37.39	0.040	0.145	0.144	0.412	0.155	0.026
Aug. 3-7	36.71	0.010	0.172	0.122	0.435	0.114	0.147
Aug. 10-16	46.82	0.085	0.215	0.161	0.389	0.092	0.026
Sept. 2-7	82.07	0.095	0.250	0.159	0.334	0.063	0.018
Sept. 2-7	83.16	0.080	0.215	0.178	0.412	0.042	0.073

continued ....

Period	Organic matter content (%)	Granules (≥ 2.0 mm)	Coarse sand (0.5-2.0 mm)	Medium sand (0.025-0.5 mm)	Fine sand (0.063-0.25 mm)	Silt (0.0039-0.063 mm)	Clay (≤ 0.0039 mm)
9 Mile Creek							
May 30	4.95	0.001	0.021	0.179	0.534	0.236	0.029
May 30	3.76	0.008	0.072	0.088	0.473	0.352	0.007
June 16-20	0.80	0.057	0.279	0.619	0.041	0.000	0.000
June 16-20	1.32	0.071	0.314	0.578	0.032	0.002	0.003
Sept. 2-7	2.51	0.001	0.017	0.311	0.528	0.132	0.011
Sept. 2-7	1.89	0.024	0.019	0.267	0.588	0.102	0.000
Sept. 10-14	2.23	0.000	0.009	0.280	0.632	0.179	0.027
Sept. 22-27	2,82	0.000	0.003	0.171	0.632	0.179	0.027
Sept. 22-27	2.14	0.002	0.017	0.125	0.742	0.097	0.017
Limestone River							
June 1-7	0.71	0.001	0.003	0.238	0.714	0.045	0.001
June 1-7	0.43	0.002	0.016	0.210	0.684	0.077	0.011
June 16-20	2.36	0.001	0.042	0.178	0.683	0.080	0.012
June 16-20	2.03	0.005	0.081	0.214	0.532	0.071	0.097
July 20-27	0.42	0.003	0.336	0.512	0.147	0.000	0.000
July 20-27	0.26	0.008	0.281	0.564	0.132	0.007	0.008
Sept. 2-7	3.89	0.041	0.089	0.092	0.463	0.282	0.050
Sept. 2-7	2.94	0.012	0.071	0.182	0.364	0.191	0.180
Sept. 10-14	3.77	0.001	0.017	0.024	0.747	0.183	0.029
Sept. 10-14	3.13	0.000	0.004	0.012	0.701	0.216	0.067
Sept. 22-27	4.62	0.002	0.034	0.081	0.669	0.184	0.030

continued ....

Period	Organic matter content (%)	Granules (≥ 2.0 mm)	Coarse sand (0.5-2.0 mm)	Medium sand (0.025-0.5 mm)	Fine sand (0.063-0.25 mm)	Silt (0.0039-0.063 mm)	Clay (≤ 0.0039 mm)
CN Creek							
May 30	16.45	0.020	0.054	0.354	0.433	0.118	0.020
May 30	14.38	0.000	0.113	0.372	0.398	0.139	0.117
July 20-27	9.48	0.116	0.321	0.298	0.113	0.111	0.041
Aug. 3-7	3.28	0.015	0.486	0.420	0.070	0.006	0.003
Aug. 3-7	4.12	0.093	0.368	0.521	0.010	0.003	0.005
Sept. 10-14	0.96	0.006	0.479	0.480	0.032	0.002	0.000
Sept. 10-14	1.63	0.002	0.387	0.412	0.131	0.019	0.049
Sept. 22-27	0.47	0.002	0.208	0.684	0.103	0.000	0.000
Sept. 22-27	1.91	0.110	0.113	0.495	0.312	0.003	0.000
Moondance Creek							
June 23-29	7.31	0.007	0.060	0.171	0.506	0.180	0.073
June 23-29	9.63	0.083	0.050	0.132	0.491	0.164	0.080
July 20-27	9.06	0.071	0.230	0.216	0.313	0.100	0.070
July 20-27	4.68	0.003	0.312	0.114	0.413	0.070	0.088
Aug. 3-7	5.69	0.138	0.266	0.201	0.288	0.066	0.040
Sept. 2-7	13.76	0.033	0.528	0.062	0.019	0.005	0.003
Sept. 2-7	11.72	0.110	0.401	0.162	0.098	0.011	0.210
McMillan Creek							
June 1-7	2.35	0.003	0.063	0.411	0.470	0.470	0.007
June 1-7	4.11	0.006	0.073	0.398	0.412	0.063	0.031
June 16-20	3.47	0.001	0.014	0.055	0.639	0.244	0.048
June 16-20	6.32	0.010	0.023	0.067	0.511	0.310	0.081

continued ....

Period	Organic matter content (%)	Granules (≥ 2.0 mm)	Coarse sand (0.5-2.0 mm)	Medium sand (0.025-0.5 mm)	Fine sand (0.063-0.25 mm)	Silt (0.0039-0.063 mm)	Clay (≤ 0.0039 mm)
McMillan Creek							
July 20-27	1.92	0.003	0.356	0.555	0.073	0.008	0.005
July 20-27	0.96	0.021	0.310	0.447	0.041	0.013	0.160
July 20-27	8.00	0.007	0.149	0.105	0.429	0.255	0.052
July 20-27	11.43	0.011	0.236	0.235	0.329	0.189	0.000
Leslie Creek							
June 1-7	10.76	0.018	0.063	0.146	0.458	0.264	0.051
June 16-20	4.09	0.005	0.099	0.445	0.289	0.150	0.011
June 16-20	6.63	0.091	0.073	0.432	0.247	0.143	0.014
July 20-27	2.65	0.006	0.361	0.386	0.171	0.632	0.014
July 20-27	4.61	0.010	0.263	0.244	0.160	0.321	0.012
Aug. 3-7	4.60	0.027	0.073	0.096	0.364	0.385	0.053
Aug. 3-7	3.24	0.010	0.069	0.100	0.340	0.293	0.180
Aug. 10-16	12.40	0.200	0.119	0.071	0.155	0.576	0.056
Aug. 10-16	11.32	0.009	0.113	0.170	0.233	0.478	0.000
Sept. 2-7	2.90	0.026	0.154	0.084	0.161	0.515	0.056
Sept. 2-7	2.63	0.010	0.059	0.063	0.158	0.642	0.064
Sept. 22-27	4.84	0.005	0.051	0.244	0.464	0.203	0.032
Unnamed Creek #1							
June 16-20	2.46	0.237	0.093	0.281	0.311	0.071	0.007
July 20-27	24.57	0.022	0.199	0.160	0.312	0.258	0.043
Aug. 3-7	14.10	0.134	0.182	0.132	0.285	0.208	0.058

continued ....

Period	Organic matter content (%)	Granules (≥ 2.0 mm)	Coarse sand (0.5-2.0 mm)	Medium sand (0.025-0.5 mm)	Fine sand (0.063-0.25 mm)	Silt (0.0039-0.063 mm)	Clay (≤ 0.0039 mm)
Unnamed Creek #1							
Aug. 3-7	16.23	0.111	0.169	0.200	0.215	0.190	0.115
Aug. 10-16	1.63	0.048	**0.717**	0.026	0.192	0.012	0.005
Aug. 10-16	0.95	0.036	0.632	0.126	0.087	0.006	0.050
Sept. 2-7	15.84	0.047	0.345	0.130	0.170	0.231	0.018
Sept. 2-7	4.36	0.212	0.147	0.098	0.236	0.262	0.043
Sept. 2-7	2.97	0.114	0.121	0.108	0.200	0.311	0.141
Keeta Creek							
Aug. 3-7	2.09	0.020	0.176	0.132	0.449	0.147	0.041
Aug. 10-16	2.39	0.065	0.249	0.180	0.344	0.119	0.042
Aug. 10-16	4.11	0.033	0.199	0.213	0.400	0.103	0.049
Sept. 10-14	4.28	0.006	0.414	0.258	0.219	0.084	0.019
12 Mile Creek							
May 30	11.66	0.010	0.059	0.095	0.434	0.314	0.075
May 30	9.97	0.034	0.039	0.100	0.379	0.291	0.153
June 16-20	3.19	0.061	0.451	0.082	0.245	0.080	0.080
June 16-20	4.21	0.124	0.271	0.374	0.157	0.040	0.034
Aug. 10-16	2.75	0.152	0.275	0.114	0.332	0.044	0.082
Aug. 10-16	7.30	0.230	0.315	0.129	0.228	0.083	0.014
Sept. 10-14	5.94	0.002	0.080	0.083	0.542	0.155	0.135
Sept. 22-27	8.17	0.010	0.100	0.075	0.438	0.284	0.069
Sept. 22-27	7.77	0.028	0.182	0.192	0.428	0.138	0.031

continued ....

Period	Organic matter content (%)	Granules (≥ 2.0 mm)	Coarse sand (0.5-2.0 mm)	Medium sand (0.025-0.5 mm)	Fine sand (0.063-0.25 mm)	Silt (0.0039-0.063 mm)	Clay (≤ 0.0039 mm)
Brooks Creek							
June 1-7	5.75	0.017	0.158	0.334	0.380	0.093	0.019
June 1-7	6.92	0.020	0.054	0.354	0.433	0.118	0.020
June 16-20	1.27	0.001	0.132	0.606	0.242	0.016	0.002
June 16-20	3.31	0.066	0.158	0.422	0.193	0.009	0.159
Aug. 3-7	3.15	0.003	0.066	0.326	0.475	0.108	0.022
Aug. 3-7	7.32	0.033	0.100	0.311	0.425	0.132	0.010
Beaver Creek							
June 23-29	1.94	0.012	0.240	0.474	0.232	0.024	0.020
June 23-29	3.72	0.033	0.384	0.458	0.107	0.015	0.002
Aug. 3-7	20.30	0.046	0.125	0.175	0.509	0.075	0.070
Aug. 3-7	12.99	0.036	0.240	0.233	0.473	0.079	0.021
Wilson Creek							
June 1-7	9.97	0.011	0.019	0.243	0.446	0.168	0.022
June 1-7	11.38	0.024	0.140	0.092	0.382	0.289	0.067
June 16-20	4.89	0.001	0.038	0.158	0.639	0.123	0.041
June 16-20	2.11	0.002	0.069	0.080	0.568	0.214	0.064
Aug. 3-7	1.76	0.000	0.066	0.578	0.320	0.032	0.005
Aug. 3-7	3.72	0.009	0.062	0.605	0.109	0.168	0.043
Aug. 10-16	1.88	0.001	0.099	0.561	0.300	0.036	0.000
Aug. 10-16	2.00	0.009	0.100	0.493	0.273	0.136	0.000
Sept. 2-7	1.54	0.000	0.113	0.538	0.319	0.026	0.004

continued ....

Period	Organic matter content (%)	Granules (≥ 2.0 mm)	Coarse sand (0.5-2.0 mm)	Medium sand (0.025-0.5 mm)	Fine sand (0.063-0.25 mm)	Silt (0.0039-0.063 mm)	Clay (≤ 0.0039 mm)
Wilson Creek							
Sept. 2-7	2.63	0.063	0.131	0.493	0.237	0.074	0.002
Sept. 2-7	1.93	0.012	0.090	0.331	0.466	0.083	0.018
Sept. 10-14	3.20	0.002	0.020	0.139	0.737	0.079	0.023
Sundance Creek (Downstream)							
June 16-20	11.45	0.23	0.118	0.091	0.348	0.355	0.062
June 16-20	10.38	0.11	0.211	0.090	0.326	0.400	0.010
July 20-27	16.62	0.051	0.355	0.132	0.299	0.120	0.041
July 20-27	20.12	0.004	0.216	0.111	0.222	0.344	0.103
Aug. 10-16	1.21	0.000	0.251	0.629	0.112	0.000	0.000
Aug. 10-16	6.38	0.013	0.263	0.439	0.266	0.010	0.009
Sept. 10-14	3.39	0.403	0.310	0.096	0.142	0.031	0.010
Sept. 22-27	2.73	0.276	0.348	0.121	0.187	0.052	0.016
Long Spruce Quarry							
Aug. 3-7	3.24	0.096	0.334	0.113	0.263	0.149	0.044
Aug. 3-7	3.77	0.093	0.314	0.111	0.243	0.160	0.079
Unnamed Creek #2							
June 16-20	2.55	0.204	0.356	0.309	0.079	0.035	0.018
Sept. 2-7	5.48	0.212	0.155	0.147	0.270	0.176	0.039
Sept. 10-14	1.45	0.124	0.271	0.347	0.157	0.040	0.034
Sept. 10-14	3.42	0.214	0.173	0.271	0.156	0.003	0.180

continued ....

Period	Organic matter content (%)	Granules (≥ 2.0 mm)	Coarse sand (0.5-2.0 mm)	Medium sand (0.025-0.5 mm)	Fine sand (0.063-0.25 mm)	Silt (0.0039-0.063 mm)	Clay (≤ 0.0039 mm)
Nelson River							
June 1-7	11.78	0.097	0.252	0.125	0.348	0.147	0.030
June 23-29	3.03	0.002	0.026	0.063	0.413	0.062	0.007
Aug. 3-7	15.93	0.066	0.158	0.181	0.387	0.173	0.034
Creek 15							
July 20-27	13.02	0.043	0.254	0.255	0.347	0.063	0.037
Small bog near Sky Pilot Creek							
June 1-7	93.97	0.147	0.346	0.215	0.220	0.010	0.003
Goose Creek							
June 16-20	7.44	0.586	0.136	0.072	0.123	0.074	0.009
July 20-27	11.13	0.145	0.037	0.143	0.457	0.191	0.026
Small tributary on Sky Pilot Creek							
June 1-7	11.22	0.021	0.233	0.312	0.273	0.118	0.043

continued ....

Period	Organic matter content (%)	Granules (≥ 2.0 mm)	Coarse sand (0.5-2.0 mm)	Medium sand (0.025-0.5 mm)	Fine sand (0.063-0.25 mm)	Silt (0.0039-0.063 mm)	Clay (≤ 0.0039 mm)
12 Mile Creek (Ground water)							
Sept. 10-14	2.42	0.028	0.182	0.192	0.428	0.138	0.031
No Name Creek							
June 23-29	1.80	0.746	0.145	0.052	0.049	0.000	0.000
12 Mile Creek (Cool spring)							
Aug. 10-16	3.58	0.230	0.315	0.129	0.228	0.083	0.014

N.B. Identical sampling periods represent duplicate samples.

III. Macrophytes

a. Macrophyte Community Composition

The filamentous algae, charophytes, aquatic moss and macrophytes present at the study sites are listed in Table 8. Cyperaceae which lacked reproductive structures could not be identified to specific levels and were pooled. The record for Zosterella dubia at Site 6 (56°25'34" N, 94°27'43" W) represented a substantial northward range extension for this species, which was previously reported in Manitoba from the southeastern portion of the province and the west shore of Lake Winnipeg (Pip, 1980). A voucher specimen has been deposited in the University of Winnipeg herbarium. The taxa which occurred at each site are given in Table 9 while the sites at which each taxon was found are listed in Appendix A.

b. Heavy Metal Content

Sampling and analysis of the many plant species and respective organ types showed major differences in heavy metal contents. Average species and tissue type values were utilized as reference points from which to determine high and low total microgram per gram tissue values. It was realized that these measures of "high" and "low" heavy metal contents do not necessarily give any indication of the effect that the metal has on the physiology of a particular plant taxa, but the value was easily quantifiable and readily allowed comparisons between different macrophyte taxa, tissue types and associated environmental compartments.

Total microgram per gram dry weight cadmium, copper and lead contents were determined for macrophytes collected from 26 lotic sites located within the Gillam-Limestone locality during 10 collection periods between

Table 8: Filamentous algal, charophytes, aquatic moss and macrophyte taxa present in surveyed area. (Family name in brackets.)

(Oedogoniaceae)	Oedogonium sp. Link.
(Vaucheriaceae)	Dichotomosiphon sp. Ernst.
(Zygnemataceae)	Mougeotia sp. Aardh.
(Rivulariaceae)	Gloeotrichia sp. Agardh.
(Charaeceae)	Chara globularis L.
(Equisetaeceae)	Fontinalis antipyretica Hedw.
(Equisetaeceae)	Equisetum fluviatile L.
(Equisetaeceae)	E. pratense Ehrh.
(Equisetaeceae)	E. variegatum Schleich.
(Cyperaceae)	Carex vesicaria L.
(Cyperaceae)	Cyperaceae spp.
(Cyperaceae)	Scirpus microcarpus Pers.
(Gramineae)	Glyceria borealis (Nash) Batch.
(Zosteraceae)	Potamogeton alpinus Balbis.
(Zosteraceae)	P. filiformis Pers.
(Zosteraceae)	P. friesii Rupr.
(Zosteraceae)	P. gramineus L.
(Zosteraceae	P. pectinatus L.
(Zosteraceae)	P. richardsonii (Benn) Rydb.
(Alismataceae)	Sagittaria cuneata Sheld.
(Sparganiaceae)	Sparganium angustifolium Michx.
(Typhaceae)	Typha latifolia L.
(Pontederiaceae)	Zosterella dubia (Jacq) MacM.
(Araceae)	Calla palustris L.
(Callitrichaceae)	Callitriche palustris L.
(Hippuridaceae)	Hippuris vulgaris L.
(Gentianaceae)	Menyanthes trifoliata L.
(Haloragaceae)	Myriophyllum exalbescens Fern.
(Haloragaceae)	Myriophyllum verticillatum L.
(Nymphaeaceae)	Nuphar variegatum Engelm.
(Ranunculaceae)	Caltha palustris
(Ranunculaceae)	Ranunculus aquatilis L.
(Ranunculaceae)	Ranunculus gmelini DC.
(Lentibulariaceae)	Utricularia intermedia Hayne.
(Lentibulariaceae)	U. vulgaris L.

Table 9: Filamentous algal, charophytes, aquatic moss and macrophytes present at individual study sites.

Site	Species present
Kettle River	Glyceria borealis Sagittaria cuneata Potamogeton richardsonii P. gramineus P. filiformis Sparganium angustifolium Myriophyllum exalbescens Callitriche palustris Hippuris vulgaris Ranunculus aquatilis
12 Mile Creek (Camp location)	Equisetum fluviatile Carex vesicaria Potamogeton filiformis P. richardsonii Sparganium angustifolium Sagittaria cuneata Hippuris vulgaris Ranunculus gmelinii
Boots Creek	Equisetum fluviatile Glyceria borealis Sparganium angustifolium Nuphar variegatum Calla palustris * Hippuris vulgaris Ranunculus gmelinii Utricularia vulgaris U. intermedia Myriophyllum exalbescens
9 Mile Creek	Dichotomosiphon sp. Equisetum fluviatile Cyperaceae spp. Sparganium angustifolium Potamogeton filiformis Ranunculus aquatilis Callitriche palustris Hippuris vulgaris

continued ....

Site	Species present
Limestone River	*Equisetum fluviatile* Cyperaceae spp. *Potamogeton gramineus* *P. filiformis* *P. richardsonii* *Sparganium angustifolium* *Hippuris vulgaris*
Sky Pilot Creek	*Oedogonium* sp. *Dichotomosiphon* sp. *Zosterella dubia* *Potamogeton filiformis* *Sparganium angustifolium* Cyperaceae spp. *Hippuris vulgaris*
Sundance Creek (Upstream)	*Oedogonium* sp. *Gloeotrichia* sp. Cyperaceae spp. *Sparganium angustifolium* *Calla palustris* * *Menyanthes trifoliata* *Ranunculus gmelinii*
CN Creek	*Fontinalis antipyretica* Cyperaceae spp. *Sparganium angustifolium* *Hippuris vulgaris* *Menyanthes trifoliata* *Ranunculus gmelinii*
Moondance Creek	*Chara globularis* Cyperaceae spp. *Potamogeton pectinatus* *Scirpus microcarpus* *Sparganium angustifolium* *Hippuris vulgaris*
McMillan Creek	*Equisetum fluviatile* *E. variegatum* Cyperaceae spp. *Potamogeton filiformis* *P. richardsonii* *Hippuris vulgaris*

continued ....

Site	Species present
Leslie Creek	Oedogonium sp. Equisetum fluviatile Cyperaceae spp. Sparganium angustifolium Typha latifolia Callitriche palustris
Unnamed Creek #1	Equisetum fluviatile Cyperaceae spp. Potamogeton alpinus P. gramineus Sparganium angustifolium Calla palustris *
Keeta Creek	Oedogonium sp. Equisetum fluviatile Potamogeton alpinus P. gramineus P. richardsonii
12 Mile Creek	Cyperaceae spp. Potamogeton filiformis P. gramineus Sparganium angustifolium
Brooks Creek	Cyperaceae spp. Potamogeton gramineus Sparganium angustifolium
Beaver Creek	Cyperaceae spp. Sparganium angustifolium Callitriche palustris
Wilson Creek	Equisetum fluviatile Cyperaceae spp. Sparganium angustifolium
Sundance Creek (Downstream)	Equisetum pratense Cyperaceae spp. Calla palustris *
Long Spruce Quarry	Potamogeton friesii P. richardsonii Myriophyllum exalbescens

continued ....

Site	Species present
Unnamed Creek #2	*Potamogeton alpinus* *P. gramineus* *Sparganium angustifolium*
Nelson River	*Mougeotia* sp. *Myriophyllum verticillatum*
Creek 15	Cyperaceae spp. *Ranunculus gmelinii*
Small bog near Sky Pilot Creek	Cyperaceae spp. *Sparganium angustifolium*
Goose Creek	Cyperaceae spp.
Small tributary on Sky Pilot Creek	Cyperaceae spp.
12 Mile Creek (Ground water)	Cyperaceae spp.
12 Mile Creek (Cool spring)	No plant material

May and September, 1988. Aquatic plant growth was either non developed or non existent at Sites 27 (No Name Creek) and 28 (12 Mile Creek - cool spring).

The 35 plant taxa examined, including four filamentous algae, a charophyte, an aquatic moss, three Equisetum spp. (Arthrophyta), 14 Monocotyledoneae and 12 Dicotyledoneae, showed a wide range in metal content. Values are given in Table 10. Metal contents measured in aquatic macrophyte tissues encompassed values ranging from minima below limits of detection, to maxima of 29.10 ug Cd g^{-1}, 19.5 ug Cu g^{-1}, and 81.9 ug Pb g^{-1} dry weight. Of a total 382 samples analyzed spectrophotometrically for total cadmium, copper and lead, reading numbers below limits of detection were 2, 31, and 112 respectively. Although Calla and Caltha palustris were correctly identified, unfortunately ground specimens from sampling sites 3, 7, and 12 were combined.

General trends in the data indicated metal content(s) were quite variable in whole aquatic plants as well as selected organ types. Moreover, total content varied markedly among taxa obtaining different quantities in the individual plant species. A comparison of study metal content quantity for all data considered exhibited a cadmium < copper < lead trend. The degree of variability was by far most pronounced for total ug/g dry weight lead content and least noticeable for total copper.

c. Above and Belowground Heavy Metal Content Comparison

Heavy metal contents of pooled macrophyte communities harvested throughout the season showed great variation within and between above and belowground parts. Sampling and analysis of the many plant species showed

Table 10: Total cadmium, copper and lead (ug/g dry weight) content of filamentous algal, charophyte, aquatic moss, and above and belowground portions of aquatic macrophyte species collected in the Gillam-Limestone locality between May and September 1988.

Species	Plant Part	Sampling period	Cadmium	Copper	Lead
Kettle River					
Sparganium angustifolium	Shoot	Aug. 10-16	2.75	2.8	<0.1
	Shoot	Sept. 2-7	2.33	3.8	14.8
	Shoot	Sept. 2-7	3.42	7.8	20.0
	Shoot	Sept. 10-14	1.93	4.1	7.4
Hippuris vulgaris	Shoot	Sept. 10-14	16.62	1.0	<0.1
Potamogeton gramineus	Shoot	Aug. 10-16	3.47	2.8	19.7
Potamogeton filiformis	Shoot	Sept. 10-14	4.01	6.6	11.8
Potamogeton richardsonii	Shoot	Aug. 3-7	2.93	3.1	6.2
	Shoot	Sept. 10-14	3.23	6.9	28.4
Callitriche palustris	Shoot	Aug. 3-7	8.11	6.5	<0.1
	Shoot	Aug. 10-16	1.90	8.4	11.2
Myriophyllum exalbescens	Shoot	Aug. 3-7	1.20	1.1	<0.1
	Root	Aug. 3-7	<0.01	<0.1	<0.1
	Shoot	Sept. 2-7	4.35	0.2	3.6
	Shoot	Sept. 10-14	2.81	2.9	32.1
Sagittaria cuneata	Shoot	July 20-27	3.08	10.8	34.8
	Shoot	Aug. 3-7	2.63	3.5	<0.1
	Shoot	Aug. 3-7	2.82	0.6	<0.1
	Root	Aug. 3-7	7.98	10.2	<0.1
	Inflorescence	Aug. 3-7	12.89	0.9	<0.1
	Shoot	Aug. 10-16	6.48	6.8	41.7
	Inflorescence	Aug. 10-16	5.27	5.5	33.9
	Shoot	Sept. 2-7	2.66	1.2	<0.1
Ranunculus aquatilis	Shoot	Sept. 10-14	16.56	17.5	32.9
Glyceria borealis	Shoot	June 16-20	2.58	11.7	12.6
	Root	June 16-20	2.55	14.6	39.0
12 Mile Creek (Camp location)					
Sparganium angustifolium	Shoot	Aug. 10-16	3.47	4.9	13.9
	Shoot	Aug. 10-16	6.03	1.5	25.2
	Shoot	Aug. 10-16	3.35	3.2	18.7

continued ....

Species	Plant Part	Sampling period	Cadmium	Copper	Lead
12 Mile Creek (Camp location)					
Equisetum fluviatile	Shoot	Aug. 10-16	2.83	2.7	<0.1
	Shoot	Aug. 10-16	3.09	0.3	<0.1
	Root/Rhizome	Aug. 10-16	13.27	1.2	<0.1
Hippuris vulgaris	Shoot	Aug. 10-16	5.36	7.1	15.6
Potamogeton filiformis	Shoot	Aug. 10-16	3.14	1.4	2.8
	Shoot	Aug. 10-16	9.68	1.3	<0.1
	Shoot	Aug. 10-16	2.47	2.2	<0.1
Potamogeton richardsonii	Shoot	Aug. 10-16	2.16	2.5	6.1
	Shoot	Aug. 10-16	1.97	3.4	15.4
Ranunculus gmelinii	Shoot	Aug. 10-16	4.22	0.3	7.6
Sagittaria cuneata	Shoot	Aug. 10-16	2.47	3.3	<0.1
	Shoot	Aug. 10-16	2.46	1.7	<0.1
Carex vesicaria	Shoot	Aug. 10-16	2.73	1.2	1.9
	Shoot	Aug. 10-16	2.58	0.4	<0.1
	Root/Rhizome	Aug. 10-16	2.80	0.4	<0.1
	Root/Rhizome	Aug. 10-16	2.66	<0.1	2.5
	Seed Head	Aug. 10-16	2.99	0.9	<0.1
Boots Creek					
Hippuris vulgaris	Shoot	Aug. 3-7	4.99	3.6	<0.1
	Shoot	Aug. 3-7	4.48	2.3	1.7
Ranunculus gmelinii	Shoot	Aug. 3-7	2.86	<0.1	<0.1
*Calla palustris	Shoot	Aug. 3-7	2.64	<0.1	<0.1
	Root	Aug. 3-7	29.10	17.0	33.0
Myriophyllum exalbescens	Shoot	Aug. 3-7	8.52	1.3	15.3
Nuphar variegatum	Root/Rhizome	Aug. 3-7	2.73	0.9	<0.1
	Seed Head	Aug. 3-7	2.63	1.2	<0.1
	Seed Head	Aug. 3-7	2.64	0.6	18.1
	Petioles	Aug. 3-7	3.21	0.8	3.6
	Petioles	Aug. 3-7	3.12	1.7	<0.1
	Submerged Leaf	Aug. 3-7	3.55	1.3	2.1
	Submerged Leaf	Aug. 3-7	2.24	<0.1	34.6
Utricularia vulgaris	Shoot	Aug. 3-7	14.18	<0.1	<0.1
Hippuris vulgaris	Shoot	Aug. 10-16	2.55	<0.1	<0.1
	Root/Rhizome	Aug. 10-16	7.22	0.5	<0.1

continued ....

Species	Plant Part	Sampling period	Cadmium	Copper	Lead
Boots Creek					
Glyceria borealis	Shoot	Aug. 10-16	2.76	1.3	2.8
	Shoot	Aug. 10-16	2.56	0.6	16.7
	Root/Rhizome	Aug. 10-16	3.74	2.1	<0.1
	Inflorescence	Aug. 10-16	3.57	2.7	6.3
Nuphar variegatum	Root	Aug. 10-16	2.04	4.1	3.3
	Rhizome	Aug. 10-16	2.08	3.7	6.1
	Rhizome	Aug. 10-16	1.04	3.2	3.3
	Petioles	Aug. 10-16	3.67	3.7	<0.1
	Submerged Leaf	Aug. 10-16	5.89	5.4	45.3
	Floating Leaf	Aug. 10-16	3.50	5.1	37.7
Utricularia intermedia	Shoot	Aug. 10-16	9.45	<0.1	<0.1
Equisetum fluviatile	Shoot	Sept. 2-7	2.11	0.3	3.3
Ranunculus gmelinii	Shoot	Sept. 2-7	2.16	5.3	3.3
	Shoot	Sept. 2-7	1.50	4.3	12.2
*Calla palustris	Shoot	Sept. 2-7	4.70	0.4	<0.1
	Shoot	Sept. 2-7	2.00	2.7	1.5
	Root/Rhizome	Sept. 2-7	4.18	0.3	<0.1
	Root/Rhizome	Sept. 2-7	2.18	0.4	<0.1
Glyceria borealis	Shoot	Sept. 2-7	2.31	0.2	<0.1
	Shoot	Sept. 2-7	1.54	3.3	9.3
	Root/Rhizome	Sept. 2-7	6.53	1.4	3.9
	Inflorescence	Sept. 2-7	1.39	0.1	19.5
Nuphar variegatum	Root	Sept. 2-7	6.45	3.6	5.5
	Rhizome	Sept. 2-7	2.53	4.3	<0.1
	Rhizome	Sept. 2-7	3.03	2.3	<0.1
	Petiole	Sept. 2-7	2.48	<0.1	3.7
Sparganium angustifolium	Shoot	Sept. 10-14	8.54	0.4	<0.1
Equisetum fluviatile	Shoot	Sept. 10-14	2.91	1.7	<0.1
	Shoot	Sept. 10-14	2.27	2.2	2.4
	Root/Rhizome	Sept. 10-14	3.91	2.7	<0.1
*Calla palustris	Shoot	Sept. 10-14	3.24	0.4	3.5
	Shoot	Sept. 10-14	2.64	1.3	10.1
	Root	Sept. 10-14	24.51	1.7	<0.1
Utricularia vulgaris	Shoot	Sept. 10-14	7.25	0.5	<0.1

continued ....

Species	Plant Part	Sampling period	Cadmium	Copper	Lead
9 Mile Creek					
Cyperaceae spp.	Shoot	May 30	1.79	0.5	6.4
	Root/Rhizome	May 30	1.87	1.3	4.5
Equisetum fluviatile	Shoot	Sept. 2-7	2.64	0.2	3.0
Ranunculus gmelinii	Shoot	Sept. 2-7	10.65	<0.1	<0.1
Dichotomosiphon sp.	Whole	Sept. 2-7	5.28	5.3	36.8
	Whole	Sept. 2-7	4.45	4.8	46.6
Sparganium angustifolium	Shoot	Sept. 10-14	5.67	0.8	7.6
Hippuris vulgaris	Shoot	Sept. 10-14	4.02	5.3	16.7
	Shoot	Sept. 10-14	3.30	4.2	25.3
Potamogeton filiformis	Shoot	Sept. 10-14	3.87	5.3	<0.1
Callitriche palustris	Shoot	Sept. 10-14	3.97	7.3	16.7
	Shoot	Sept. 10-14	3.63	5.0	12.6
Potamogeton filiformis	Shoot	Sept. 22-27	2.16	<0.1	3.3
	Shoot	Sept. 22-27	1.85	0.4	16.7
	Root/Rhizome	Sept. 22-27	7.10	<0.1	<0.1
Limestone River					
Cyperaceae spp.	Shoot	June 1-7	1.74	6.2	6.1
	Shoot	June 1-7	3.23	5.2	<0.1
	Root/Rhizome	June 1-7	2.26	10.5	21.9
Equisetum fluviatile	Shoot	June 16-20	1.13	2.6	11.8
	Root/Rhizome	June 16-20	1.13	4.1	29.7
	Cones	June 16-20	0.81	5.1	10.1
	Cones	June 16-20	2.61	4.8	14.8
Cyperaceae spp.	Shoot	Sept. 2-7	2.15	<0.1	<0.1
	Shoot	Sept. 2-7	2.87	<0.1	<0.1
	Root/Rhizome	Sept. 2-7	12.64	1.1	<0.1
Sparganium angustifolium	Shoot	Sept. 2-7	15.79	1.6	<0.1
Equisetum fluviatile	Shoot	Sept. 2-7	3.36	1.3	9.1
	Shoot	Sept. 2-7	3.41	2.8	1.5
Hippuris vulgaris	Shoot	Sept. 2-7	4.50	8.3	21.6
	Root/Rhizome	Sept. 2-7	4.97	6.4	16.8
Potamogeton gramineus	Shoot	Sept. 2-7	4.81	1.2	29.4

continued ....

Species	Plant Part	Sampling period	Cadmium	Copper	Lead
Limestone River					
Potamogeton filiformis	Shoot	Sept. 2-7	5.34	<0.1	<0.1
	Shoot	Sept. 2-7	3.59	1.9	<0.1
Hippuris vulgaris	Shoot	Sept. 10-14	3.55	6.1	2.8
	Shoot	Sept. 10-14	3.19	5.4	2.8
	Root/Rhizome	Sept. 10-14	0.22	<0.1	<0.1
	Root/Rhizome	Sept. 10-14	<0.01	<0.1	<0.1
Potamogeton filiformis	Shoot	Sept. 10-14	3.33	5.2	20.0
Potamogeton richardsonii	Shoot	Sept. 10-14	3.14	4.9	37.6
Sparganium angustifolium	Shoot	Sept. 22-27	15.25	2.0	<0.1
Hippuris vulgaris	Shoot	Sept. 22-27	2.35	8.9	16.7
	Shoot	Sept. 22-27	2.21	7.3	18.8
	Root/Rhizome	Sept. 22-27	5.84	2.4	<0.1
Potamogeton filiformis	Shoot	Sept. 22-27	12.35	7.9	<0.1
	Shoot	Sept. 22-27	3.41	0.7	<0.1
	Shoot	Sept. 22-27	3.12	2.2	2.8
Sky Pilot Creek					
Hippuris vulgaris	Shoot	June 16-20	3.19	8.2	40.4
Zosterella dubia	Shoot	June 16-20	3.69	7.9	41.8
Sparganium angustifolium	Shoot	July 20-27	2.29	2.9	<0.1
	Shoot	July 20-27	2.14	2.3	6.6
Potamogeton filiformis	Shoot	July 20-27	2.10	4.1	3.3
Sparganium angustifolium	Shoot	Aug. 3-7	2.62	17.9	51.1
	Shoot	Aug. 3-7	1.99	18.4	27.7
Sparganium angustifolium	Shoot	Aug. 10-16	2.76	1.0	<0.1
Hippuris vulgaris	Shoot	Aug. 10-16	7.52	0.9	<0.1
Potamogeton filiformis	Shoot	Aug. 10-16	2.09	6.2	12.2
	Shoot	Aug. 10-16	1.87	4.6	3.3
	Root/Rhizome	Aug. 10-16	5.96	11.6	14.4
Sparganium angustifolium	Shoot	Sept. 2-7	5.85	1.4	62.8
	Shoot	Sept. 2-7	2.09	13.3	25.0
Hippuris vulgaris	Shoot	Sept. 2-7	3.28	7.9	40.5

continued ....

Species	Plant Part	Sampling period	Cadmium	Copper	Lead
Sundance Creek (Upstream)					
Oedogonium sp.	Whole	Sept. 2-7	3.68	<0.1	3.2
Cyperaceae spp.	Shoot	Sept. 10-14	1.95	7.4	20.0
Dichotomosiphon sp.	Whole	Sept. 10-14	4.41	8.4	43.3
	Whole	Sept. 10-14	4.14	7.8	24.3
Oedogonium sp.	Whole	June 16-20	8.47	0.6	<0.1
Gloetrichia sp.	Whole	June 16-20	8.47	0.6	<0.1
Sparganium angustifolium	Shoot	July 20-27	3.32	8.5	27.8
	Seed Head	July 20-27	9.41	**19.5**	<0.1
Ranunculus gmelinii	Whole	July 20-27	11.63	17.4	<0.1
Ranunculus gmelinii	Whole	Aug. 3-7	2.48	5.1	2.3
Sparganium angustifolium	Shoot	Aug. 10-16	2.44	1.0	<0.1
	Shoot	Aug. 10-16	2.15	3.1	<0.1
Menyanthes trifoliata	Shoot	Aug. 10-16	3.40	0.3	<0.1
	Root/Rhizome	Aug. 10-16	1.23	**0.2**	3.3
Cyperaceae spp.	Shoot	Sept. 2-7	3.25	1.5	<0.1
	Root/Rhizome	Sept. 2-7	6.25	<0.1	<0.1
*Calla palustris	Shoot	Sept. 2-7	9.46	2.1	18.4
CN Creek					
Cyperaceae spp.	Shoot	May 30	1.59	2.9	<0.1
	Shoot	May 30	1.61	3.5	1.9
	Root/Rhizome	May 30	2.35	1.7	3.3
	Root/Rhizome	May 30	2.39	1.7	<0.1
Fontinalis antipyretica	Whole	May 30	3.96	4.7	1.4
	Whole	May 30	3.95	4.1	4.9
Sparganium angustifolium	Shoot	July 20-27	2.85	0.7	18.1
Hippuris vulgaris	Shoot	July 20-27	2.24	4.9	25.4
	Shoot	July 20-27	1.73	4.4	5.3

continued ....

Species	Plant Part	Sampling period	Cadmium	Copper	Lead
CN Creek					
Fontinalis antipyretica	Whole	July 20-27	6.75	6.3	9.4
Sparganium angustifolium	Shoot	Aug. 3-7	4.06	1.7	<0.1
	Root/Rhizome	Aug. 3-7	9.32	5.8	<0.1
Hippuris vulgaris	Shoot	Aug. 3-7	5.78	0.6	40.1
Ranunculus gmelinii	Shoot	Aug. 3-7	6.63	3.7	8.9
Menyanthes trifoliata	Shoot	Aug. 3-7	1.68	<0.1	<0.1
	Root/Rhizome	Aug. 3-7	1.84	0.7	<0.1
Cyperaceae spp.	Shoot	Sept. 10-14	2.63	4.4	<0.1
Moondance Creek					
Potamogeton pectinatus	Shoot	June 23-29	1.92	9.6	25.0
	Shoot	June 23-29	4.11	10.6	33.1
Scirpus microcarpus	Shoot	June 23-29	1.66	2.9	10.1
	Shoot	June 23-29	3.70	1.8	12.6
	Root/Rhizome	June 23-29	2.08	5.3	20.4
Chara globularis	Shoot	July 20-27	6.59	0.7	58.7
Sparganium angustifolium	Shoot	Aug. 3-7	2.22	9.9	24.9
	Root/Rhizome	Aug. 3-7	4.87	6.0	50.0
Hippuris vulgaris	Shoot	Aug. 3-7	2.79	10.6	18.9
	Root/Rhizome	Aug. 3-7	1.66	6.6	15.6
Cyperaceae spp.	Shoot	Sept. 2-7	1.92	3.4	1.8
	Shoot	Sept. 2-7	1.41	3.3	3.4
	Shoot	Sept. 2-7	2.75	3.5	<0.1
	Root/Rhizome	Sept. 2-7	3.57	4.5	1.5
	Root/Rhizome	Sept. 2-7	1.73	4.5	3.3
McMillan Creek					
Cyperaceae spp.	Shoot	June 1-7	3.43	1.4	<0.1
	Root/Rhizome	June 1-7	9.28	<0.1	<0.1
Equisetum variegatum	Shoot	June 1-7	1.56	3.0	14.8
	Shoot	June 1-7	3.25	3.4	28.0
	Root/Rhizome	June 1-7	1.87	3.9	11.8

continued ....

Species	Plant Part	Sampling period	Cadmium	Copper	Lead
McMillan Creek					
Cyperaceae spp.	Shoot	June 16-20	1.28	12.4	25.4
	Root/Rhizome	June 16-20	3.23	11.4	14.8
Cyperaceae spp.	Shoot	July 20-27	2.29	6.4	<0.1
	Shoot	July 20-27	2.58	4.3	20.0
	Root/Rhizome	July 20-27	5.07	6.6	<0.1
Equisetum fluviatile	Shoot	July 20-27	2.38	5.2	<0.1
	Root/Rhizome	July 20-27	9.55	1.1	<0.1
Hippuris vulgaris	Shoot	July 20-27	3.22	6.4	50.3
	Shoot	July 20-27	3.06	1.6	43.3
	Shoot	July 20-27	2.02	9.6	41.8
	Shoot	July 20-27	4.63	4.7	59.9
	Shoot	July 20-27	3.51	7.5	57.4
	Shoot	July 20-27	8.85	<0.1	<0.1
	Shoot	July 20-27	3.68	5.2	55.5
	Shoot	July 20-27	3.74	10.4	34.0
	Shoot	July 20-27	3.08	11.9	25.4
Hippuris vulgaris	Root/Rhizome	July 20-27	4.81	18.5	24.7
	Root/Rhizome	July 20-27	2.43	1.6	16.0
	Root/Rhizome	July 20-27	12.63	1.5	<0.1
Potamogeton filiformis	Shoot	July 20-27	1.94	1.3	79.3
	Shoot	July 20-27	4.48	2.2	<0.1
	Shoot	July 20-27	5.70	<0.1	7.5
	Shoot	July 20-27	9.07	7.6	16.5
	Shoot	July 20-27	3.70	7.7	18.0
	Shoot	July 20-27	1.72	0.8	4.1
	Shoot	July 20-27	3.88	0.5	6.5
	Root/Rhizome	July 20-27	4.26	1.0	22.9
Potamogeton richardsonii	Shoot	July 20-27	1.26	4.9	51.4
	Root/Rhizome	July 20-27	5.45	1.6	79.7
	Petioles	July 20-27	3.91	4.3	32.6
Ranunculus gmelinii	Shoot	July 20-27	4.17	<0.1	11.8
	Shoot	July 20-27	3.52	5.1	25.6
	Shoot	July 20-27	2.14	7.3	24.6
	Shoot	July 20-27	3.77	8.9	29.7
Leslie Creek					
Cyperaceae spp.	Shoot	June 1-7	3.68	0.8	8.4
	Root/Rhizome	June 1-7	7.36	7.5	<0.1

continued ....

Species	Plant Part	Sampling period	Cadmium	Copper	Lead
Leslie Creek					
Sparganium angustifolium	Shoot	June 16-20	1.43	<0.1	31.3
	Root	June 16-20	8.01	4.3	81.9
Typha latifolia	Shoot	June 16-20	1.86	4.7	25.3
	Shoot	June 16-20	2.79	4.7	8.7
	Root	June 16-20	6.06	5.3	40.0
	Rhizome	June 16-20	2.26	2.9	14.2
Sparganium angustifolium	Shoot	July 20-27	3.38	6.3	11.6
	Shoot	July 20-27	3.16	4.2	20.0
	Root/Rhizome	July 20-27	12.76	17.3	9.8
	Inflorescence	July 20-27	5.45	7.3	34.5
Callitriche palustris	Whole	July 20-27	3.29	6.3	51.1
	Whole	July 20-27	3.23	5.9	69.2
Cyperaceae spp.	Shoot	Aug. 3-7	2.77	0.5	<0.1
	Shoot	Aug. 3-7	2.67	0.3	2.8
	Shoot	Aug. 3-7	2.65	1.0	<0.1
	Root/Rhizome	Aug. 3-7	5.35	1.1	<0.1
	Root/Rhizome	Aug. 3-7	8.64	1.0	20.0
Cyperaceae spp.	Shoot	Aug. 3-7	3.45	0.6	<0.1
	Root/Rhizome	Aug. 3-7	0.83	7.7	19.0
	Seed Head	Aug. 3-7	4.76	2.5	<0.1
Calla palustris	Shoot	Aug. 3-7	4.94	6.0	1.0
Sparganium angustifolium	Shoot	Aug. 10-16	1.43	4.9	3.3
Equisetum fluviatile	Shoot	Aug. 10-16	2.11	5.6	14.8
Callitriche palustris	Whole	Aug. 10-16	2.61	8.5	23.9
	Whole	Aug. 10-16	2.74	6.9	16.5
Cyperaceae spp.	Shoot	Sept. 2-7	2.41	1.7	<0.1
	Shoot	Sept. 2-7	1.29	1.0	5.3
	Root/Rhizome	Sept. 2-7	4.09	8.5	1.0
	Root/Rhizome	Sept. 2-7	8.26	5.9	42.4
Sparganium angustifolium	Shoot	Sept. 2-7	6.90	1.4	<0.1
Oedogonium sp.	Whole	Sept. 22-27	3.96	7.4	13.6

continued ....

Species	Plant Part	Sampling period	Cadmium	Copper	Lead
Unnamed Creek #1					
Cyperaceae spp.	Shoot	June 16-20	3.48	7.1	38.3
Cyperaceae spp.	Shoot	July 20-27	1.72	1.0	1.7
	Root/Rhizome	July 20-27	2.36	2.0	7.0
Sparganium angustifolium	Shoot	July 20-27	4.00	4.1	30.1
	Inflorescence	July 20-27	2.94	3.6	9.4
Equisetum fluviatile	Shoot	July 20-27	2.33	0.7	3.3
	Root/Rhizome	July 20-27	4.75	2.5	1.0
Potamogeton alpinus	Shoot	July 20-27	2.26	7.1	3.3
	Inflorescence	July 20-27	6.85	17.4	9.9
Sparganium angustifolium	Shoot	Aug. 3-7	3.49	4.4	21.5
Cyperaceae spp.	Shoot	Aug. 3-7	2.19	1.2	<0.1
	Root/Rhizome	Aug. 3-7	1.54	3.5	1.1
Equisetum fluviatile	Shoot	Aug. 3-7	2.59	3.1	25.4
	Root/Rhizome	Aug. 3-7	3.66	7.6	7.5
Sparganium angustifolium	Shoot	Sept. 2-7	1.71	8.0	9.8
	Seed Head	Sept. 2-7	1.66	8.0	1.0
Potamogeton gramineus	Shoot	Sept. 2-7	2.83	5.9	10.9
	Seed Head	Sept. 2-7	3.62	13.1	29.6
*Calla palustris	Shoot	Sept. 2-7	4.07	2.2	1.0
	Seed Head	Sept. 2-7	3.32	8.9	<0.1
	Roots	Sept. 2-7	7.70	7.6	5.1
Keeta Creek					
Equisetum fluviatile	Shoot	Aug. 3-7	0.98	5.5	14.8
Potamogeton alpinus	Shoot	Aug. 3-7	1.56	7.5	1.0
	Seed Head	Aug. 3-7	6.52	5.5	<0.1
Equisetum fluviatile	Shoot	Aug. 10-16	2.59	5.0	1.0
Potamogeton gramineus	Shoot	Aug. 10-16	2.30	5.6	3.3
Potamogeton richardsonii	Seed Head	Aug. 10-16	2.65	5.7	1.0
Equisetum fluviatile	Shoot	Sept. 10-14	4.10	4.1	44.9
Oedogonium sp.	Whole	Sept. 10-14	5.28	5.1	25.8

continued ....

Species	Plant Part	Sampling period	Cadmium	Copper	Lead
12 Mile Creek					
Cyperaceae spp.	Shoot	May 30	2.42	4.6	11.0
	Shoot	May 30	2.23	5.2	14.6
	Root/Rhizome	May 30	3.58	6.5	1.0
	Root/Rhizome	May 30	4.21	5.7	1.0
Cyperaceae spp.	Shoot	June 16-20	2.21	9.9	25.4
	Shoot	June 16-20	2.52	9.2	20.0
	Root/Rhizome	June 16-20	2.47	9.9	<0.1
Cyperaceae spp.	Shoot	Sept. 10-14	2.56	0.2	<0.1
	Shoot	Sept. 10-14	2.26	<0.1	1.0
	Root/Rhizome	Sept. 10-14	3.08	0.2	1.0
	Root/Rhizome	Sept. 10-14	2.73	<0.1	<0.1
Sparganium angustifolium	Shoot	Sept. 10-14	4.22	<0.1	<0.1
Potamogeton gramineus	Shoot	Sept. 10-14	2.54	3.6	16.7
	Shoot	Sept. 10-14	2.69	2.2	14.6
Potamogeton filiformis	Shoot	Sept. 10-14	2.77	<0.1	6.3
Sparganium angustifolium	Shoot	Sept. 22-27	7.41	4.4	15.0
Potamogeton gramineus	Shoot	Sept. 22-27	4.11	5.4	21.4
Brooks Creek					
Cyperaceae spp.	Shoot	June 1-7	2.59	4.7	4.0
	Shoot	June 1-7	2.61	2.0	4.6
	Root/Rhizome	June 1-7	2.27	2.6	<0.1
Potamogeton gramineus	Shoot	June 16-20	3.35	12.3	30.1
	Shoot	June 16-20	3.39	10.9	40.0
Cyperaceae spp.	Shoot	Aug. 3-7	2.98	4.7	28.6
	Root/Rhizome	Aug. 3-7	16.14	18.0	1.0
Sparganium angustifolium	Shoot	Aug. 3-7	3.86	8.6	37.9
Beaver Creek					
Cyperaceae spp.	Shoot	June 23-29	2.16	0.6	1.0
	Shoot	June 23-29	1.88	<0.1	7.9
	Root/Rhizome	June 23-29	2.03	1.7	9.3

continued ....

Species	Plant Part	Sampling period	Cadmium	Copper	Lead
Beaver Creek					
Sparganium angustifolium	Shoot	Aug. 3-7	7.77	9.3	1.0
Callitriche palustris	Whole	Aug. 3-7	4.28	10.9	54.6
Wilson Creek					
Cyperaceae spp.	Shoot	June 16-20	2.05	10.4	21.1
	Root/Rhizome	June 16-20	1.89	5.4	23.9
Equisetum fluviatile	Shoot	June 16-20	2.85	6.8	31.2
	Root/Rhizome	June 16-20	3.97	4.7	34.7
Sparganium angustifolium	Shoot	Aug. 3-7	3.41	5.5	5.8
	Shoot	Aug. 3-7	4.71	0.3	10.1
Sparganium angustifolium	Shoot	Aug. 10-16	4.15	7.3	8.4
Sparganium angustifolium	Shoot	Sept. 2-7	6.18	6.9	34.5
Cyperaceae spp.	Shoot	Sept. 10-14	2.25	0.8	<0.1
	Shoot	Sept. 10-14	2.69	1.4	10.1
Sundance Creek (Downstream)					
Cyperaceae spp.	Shoot	June 16-20	2.14	10.6	37.7
	Root/Rhizome	June 16-20	2.29	7.1	25.4
Cyperaceae spp.	Shoot	July 20-27	1.17	8.2	18.0
	Root/Rhizome	July 20-27	1.87	6.0	2.1
Cyperaceae spp.	Shoot	Aug. 10-16	1.68	6.9	25.0
	Root/Rhizome	Aug. 10-16	5.30	4.6	9.2
Equisetum pratense	Shoot	Aug. 10-16	2.38	7.3	21.7
Cyperaceae spp.	Shoot	Sept. 10-14	2.38	3.9	1.5
	Root/Rhizome	Sept. 10-14	2.48	3.9	1.5
Calla palustris	Shoot	Sept. 10-14	2.97	<0.1	1.8
	Shoot	Sept. 10-14	6.70	1.0	12.3

continued ....

Species	Plant Part	Sampling period	Cadmium	Copper	Lead
Long Spruce Quarry					
Potamogeton richardsonii	Shoot	Aug. 3-7	2.80	7.3	25.4
	Seed Head	Aug. 3-7	6.10	17.1	<0.1
Myriophyllum exalbescens	Shoot	Aug. 3-7	1.95	5.8	1.0
Potamogeton friesii	Shoot	Aug. 3-7	2.41	5.3	20.0
Unnamed Creek #2					
Sparganium angustifolium	Shoot	Sept. 2-7	2.81	3.2	1.0
	Seed Head	Sept. 2-7	1.64	3.9	<0.1
Potamogeton gramineus	Shoot	Sept. 2-7	3.68	2.0	<0.1
	Seed Head	Sept. 2-7	4.84	3.1	1.0
Potamogeton alpinus	Shoot	Sept. 10-14	6.45	1.5	<0.1
Nelson River					
Mougeotia sp.	Whole	June 23-29	5.53	2.9	58.3
Myriophyllum verticillatum	Shoot	Aug. 3-7	3.50	5.0	1.0
	Shoot	Aug. 3-7	3.33	4.2	1.4
	Root/Rhizome	Aug. 3-7	9.31	0.7	5.6
Creek 15					
Cyperaceae spp.	Shoot	July 20-27	4.42	2.0	<0.1
	Root/Rhizome	July 20-27	4.94	1.9	1.0
Ranunculus gmelinii	Shoot	July 20-27	4.42	3.9	46.3
Small bog near Sky Pilot Creek					
Cyperaceae spp.	Shoot	June 1-7	4.49	2.2	<0.1
Sparganium angustifolium	Shoot	June 1-7	3.31	0.2	<0.1

continued ....

Species	Plant Part	Sampling period	Cadmium	Copper	Lead
Goose Creek					
Cyperaceae spp.	Shoot	July 20-27	1.94	1.5	14.6
	Root/Rhizome	July 20-27	1.80	3.8	16.7
Small tributary on Sky Pilot Creek					
Cyperaceae spp.	Shoot	June 1-7	3.71	1.3	7.2
	Root/Rhizome	June 1-7	2.90	8.4	20.0
12 Mile Creek (Ground water)					
Cyperaceae spp.	Shoot	Sept. 10-14	2.37	3.9	1.0
	Root/Rhizome	Sept. 10-14	3.19	1.3	1.7

No plant material collected at sampling locations 27 and 28.

* Although Calla and Caltha palustris were correctly identified, some confusion occurred between ground specimens during processing and results were combined for sampling locations 3, 7, and 12.

cadmium levels were generally (not statistically) higher in belowground (N = 86) organs (roots/rhizomes) relative to aboveground (N = 276) tissues (shoots, inflorescences, and cones). Levels for belowground parts copper contents were, on average, slightly elevated (not statistically) relative to aboveground part concentrations. Comparative data for the content of lead in aquatic plant organs revealed much greater aboveground parts contents. Respective total ug/g dry weight total Cd, Cu and Pb parts contents for the different species are listed in Table 10.

Three of 10 species sampled more than five times showed significant differences in metal content between above and belowground parts (Table 11). Metal contents were generally slightly elevated in belowground parts. Exceptions were Cyperaceae spp. and Nuphar variegatum. The latter contained cadmium and lead elevated in aboveground levels comparted with belowground parts; in Cyperaceae spp. aboveground parts showed an elevated lead content. Kilmogorov-Smirnov and t-test results (as appropriate) showed significantly different above and belowground cadmium tissue levels for the taxa Equisetum fluviatile ($z = 1.82$, $n = 26$, $p = 0.003$), and Cyperaceae spp. ($z = 1.62$, $n = 86$, $p = 0.01$), with significantly higher cadmium contents in belowground parts. Hippuris vulgaris showed lead levels to be significantly greater in aboveground organs.

d. Metal Content of Macrophyte Organs

Cadmium, copper and lead contents of assorted plant parts (i.e., shoot, root, inflorescence, seed head, petiole, submerged leaf, floating leaf, cones) tended to be different among species and within plants. Generally, higher contents were found in belowground tissues. Reproductive parts also tended to exhibit slightly elevated metal levels. Noticeable was that Nuphar variegatum showed elevated levels of lead in submerged and floating leaves.

Shoots of Ranunculus aquatilis showed the highest cadmium and copper contents, and this species was sixth with respect to lead relative to other aboveground organs. Chara globularis shoots yielded the highest aboveground lead value, were eighth in terms of cadmium content, but accumulated little copper. Oedogonium, Dichotomosiphon, Mougeotia, and Gloeotrichia ranked high for cadmium and lead but lower for copper. Similarly, while Utricularia vulgaris and Utricularia intermedia tended to show high cadmium values, these species were among the lowest ranked for copper and lead. Although taxa with finely divided submerged leaves tended to rank high for cadmium, this was not a constant factor as, for example, the Myriophyllum species ranked less highly.

Belowground parts showed few consistent trends. Potamogeton richardsonii exhibited a remarkably higher content of lead than was present in all other 33 species of aquatic plants. Roots of Myriophyllum exalbescens were uniformly low in all three study metals.

e. Individual Species

In subsequent comparisons individual macrophyte species were examined for metal differences between organs. Statistically significant mean total cadmium, copper and lead differences among plant parts are listed in Table 12. Both Equisetum fluviatile and Cyperaceae spp. demonstrated

Table 11: Kolmogorov-Smirnov and t-test results showing significant differences in mean total ug cadmium and lead/g (dry weight) content between above and belowground parts for individual macrophyte species.

Species	**Metal**	**Part type demonstrating significantly higher metal content**	**t,z**
Equisetum fluviatile	Cd	belowground	$z = 1.82$ $n = 26$ $p = 0.003$
Cyperaceae spp.	Cd	belowground	$z = 1.62$ $n = 84$ $p = 0.01$
Hippuris vulgaris	Pb	aboveground	$t = 3.09$ $n = 37$ $p = 0.005$

Table 12: Anova, Duncans, Kruskal-Wallis, Kolmogorov-Smirnov and t-test results for significant mean total cadmium, copper and lead content (ug/g dry weight) differences among individual macrophyte plant parts. Parametric or non-parametric test was chosen as required by the data set.

Species	Metal	z, x^2, F, t	Tissue types contributing significant differences ($p \leq 0.05$)
Equisetum fluviatile	Cd	$x^2 = 8.17$ n = 26 p = 0.016	shoots < rhizomes and roots
Cyperaceae spp.	Cd	z = 1.62 n = 84 p = 0.01	shoots < rhizomes and roots
Nuphar variegatum	Cu	F = 5.61 n = 17 p = 0.01	*roots and rhizomes > seed heads *submerged leaf > roots and rhizomes, seed heads
Hippuris vulgaris	Pb	t = 3.09 n = 37 p = 0.005	shoots > rhizomes and roots

* Duncans new multiple range test.

significantly lower ug Cd g^{-1} contents in shoot tissues. Analyses of variance showed Cu contents in Nuphar variegatum roots and leaves (submerged and floating) to be significantly greater than levels in seed heads. Total Pb was detected in relative greater amounts in shoot tissues of Hippuris vulgaris, relative to rhizomes and roots.

Examining only aboveground organs revealed significant interspecific differences among aquatic macrophyte taxa. Such trends were seen for mean total aboveground tissue cadmium ($x^2 = 67.09$, $n = 276$, $p < 0.001$), copper ($x^2 = 55.30$, $n = 276$, $p = 0.002$) contents using Kruskal-Wallis tests (Table 13). Sparganium angustifolium, Hippuris vulgaris, Ranunculus aquatilis and Utricularia vulgaris each showed significantly higher mean total aboveground cadmium tissue contents than remaining species. Ranunculus aquatilis showed significantly higher values with respect to mean total cadmium content than numerous other taxa, whereas Hippuris vulgaris and Potamogeton richardsonii showed higher mean total lead levels.

f. Growth Form

All macrophytes were classified according to growth form: submerged, submerged with floating leaves, or emergent. Examination of metals in aboveground parts pooled over all sites and times indicated significant differences among the growth forms only for cadmium ($x^2 = 8.47$, $n = 276$, $p = 0.014$) (Table 14). Student-Newman-Keuls (SNK) tests revealed that emergent growth forms showed significantly higher values of Cd than did submerged species.

Table 13: Aquatic macrophyte taxa showing significant differences for mean metal contents in aboveground tissues (ug/g dry weight) using Kruskal-Wallis tests (ranked according to decreasing significance).

Parameter	Macrophyte species significantly different		From species
CADMIUM			
$x^2 = 67.09$	Sparganium angustifolium	>	Cyperaceae spp.
n = 276	Hippuris vulgaris	>	Cyperaceae spp.
p = <0.001			
	Ranunculus aquatilis	>	Utricularia vulgaris
			Chara globularis
			Callitriche palustris
			Potamogeton alpinus
			Sagittaria cuneata
			Hippuris vulgaris
			*Calla palustris
			Ranunculus gmelinii
			Sparganium angustifolium
			Potamogeton filiformis
			Myriophyllum exalbescens
			Zosterella dubia
			Potamogeton gramineus
			Myriophyllum verticillatum
			Nuphar variegatum
			Potamogeton pectinatus
			P. richardsonii
			Scirpus microcarpus

continued ....

Parameter	Macrophyte species significantly different		From species
	Ranunculus aquatilis		Equisetum fluviatile Cyperaceae spp. Equisetum variegatum Potamogeton friesii Glyceria borealis Carex vesicaria Equisetum pratense Typha latifolia Menyanthes trifoliata
	Utricularia vulgaris	>	Potamogeton alpinus Sagittaria cuneata Hippuris vulgaris *Calla palustris
	Utricularia vulgaris	>	Ranunculus gmelinii Sparganium angustifolium Potamogeton filiformis Myriophyllum exalbescens Potamogeton gramineus Nuphar variegatum Potamogeton richardsonii Equisetum fluviatile Cyperaceae spp. Equisetum variegatum

continued....

Parameter	Macrophyte species significantly different		From species
	Utricularia vulgaris	>	Glyceria borealis Carex vesicaria Menyanthes trifoliata
COPPER $x^2 = 59.57$ n = 276 p = 0.0007	Ranunculus aquatilis	>	Potamogeton richardsonii Potamogeton gramineus Hippuris vulgaris Sparganium angustifolium Sagittaria cuneata Ranunculus gmelinii Cyperaceae spp. Equisetum fluviatile Glyceria borealis Potamogeton filiformis Myriophyllum exalbescens *Calla palustris Nuphar variegatum Carex vesicaria Utricularia vulgaris Menyanthes trifoliata

continued ....

Parameter	Macrophyte species significantly different		From species
LEAD			
	Hippuris vulgaris	>	Cyperaceae spp.
$x^2 = 55.30$ n = 276 p = 0.0023	*Potamogeton richardsonii*	>	*Potamogeton filiformis* Cyperaceae spp. **Calla palustris*

* Although *Calla* and *Caltha palustris* were correctly identified, some confusion occurred between ground specimens during processing and results were unfortunately combined for locations 3, 7, and 12.

Table 14: Mean total cadmium, copper and lead (ug g^{-1} dry weight) content of aboveground portions of macrophyte growth forms.

Macrophyte growth form	**N**	**Cadmium** $\bar{x}$ **(S.E.)**	**Copper** $\bar{x}$ **(S.E.)**	**Lead** $\bar{x}$ **(S.E.)**
Submerged	195	3.43(0.16)	3.9(0.3)	12.3(1.0)
Submerged with floating leaves	30	3.80(0.28)	4.8(0.8)	13.4(2.5)
Emergent	51	4.41(0.42)	4.0(0.5)	17.6(4.5)

A less striking result was the variablity of metal contents at different sampling periods (Table 10). During the end of June and through July (periods 4-5) copper and lead were apparently accumulated to greater extents in macrophytes with floating leaves than in completely submerged growth forms. Thus while overall seasonal differences were more apparent for cadmium, midseason differences emerged for copper and lead.

g. Correlations Among Metals in Aboveground Tissues

Correlations among the three study metals were examined for individual taxa in aboveground tissues. For each taxon data from all sites and times were pooled. Both positive and negative significant correlations were found with respect to metal pair combinations (Table 15). Of the 35 plant species examined, 14 allowed statistical examination. Significant correlations were indicated for each of the three metal pair combinations. Both positive and negative correlations were apparent for cadmium-copper and cadmium-lead combinations, whereas only a positive relationship was observed between copper and lead. Significant positive copper-lead relationships were evident for the taxa: *Equisetum fluviatile*, *Potamogeton alpinus*, *P. gramineus*, *Sagittaria cuneata*, *Sparganium angustifolium*, *Ranunculus gmelinii*, *Hippuris vulgaris*, and Cyperaceae spp. The emergents, Cyperaceae spp. and *H. vulgaris*, each exhibited a significantly negative correlation between cadmium and copper. *H. vulgaris* also showed a significantly negative cadmium-lead correlation, making it the only sampled macrophyte representative of three significantly correlated metal pair combinations. *Calla palustris*

Table 15: Significant seasonal correlations among cadmium, copper and lead microgram per gram dry weight contents in aboveground parts of individual taxa where n ≥ 5. Data pooled for all sites and times.

Metal pair	Species	Statistical significance
Cd–Cu	**Cyperaceae spp.**	**(r = −0.254, n = 51, p = 0.039)**
	Potamogeton filiformis	(r = 0.362, n = 24, p = 0.045)
	P. richardsonii	(r = 0.818, n = 10, p = 0.002)
	Hippuris vulgaris	**(r = −0.485, n = 28, p = 0.004)**
	Nuphar variegatum	(r = 0.811, n = 10, p = 0.002)
Cd–Pb	**Calla palustris*	(r = 0.727, n = 11, p = 0.006)
	Hippuris vulgaris	**(r = −0.323, n = 28, p = 0.047)**
Cu–Pb	***Equisetum fluviatile***	**(r = −0.468, n = 19, p = 0.022)**
	Cyperaceae spp.	(r = 0.720, n = 51, p < 0.01)
	Potamogeton alpinus	(r = 0.918, n = 5, p = 0.014)
	P. gramineus	(r = 0.572, n = 12, p = 0.026)
	Sagittaria cuneata	(r = 0.850, n = 9, p = 0.002)
	Sparganium angustifolium	(r = 0.306, n = 47, p = 0.016)
	Hippuris vulgaris	(r = 0.355, n = 28, p = 0.032)
	Ranunculus gmelinii	(r = 0.579, n = 11, p = 0.031)

Bold type represents an inverse correlation.
* *Calla* and *Caltha palustris* combination.

represented the only other significant cadmium-lead relationship besides H. vulgaris. Potamogeton filiformis, P. richardsonii, and Nuphar variegatum showed significantly positive cadmium-copper correlations. No significant correlations were found for either the submerged Myriophyllum exalbescens, or the emergent Glyceria borealis.

In subsequent comparisons aboveground tissue metal contents in sampled macrophytes were compared in order to determine whether any relationships existed. All data was considered. Both significant positive and negative correlations existed for each metal (Table 16). Of 35 aquatic plant species sampled, 8 permitted statistical evaluation ($n \geq 5$). Significant correlations for mean total cadmium, copper and lead contents were observed for 3, 7 and 4 taxa respectively. Table 17 summarizes these relationships.

IV. Fish

Fish (N = 49) were collected in conjunction with the Department of Natural Resources (Fisheries Branch) from three of the twenty-eight sampling sites: Moondance Creek, McMillan Creek, and the Nelson River. Six species {Salvelinius fontinalis (Mitchill), Coregonus clupeaformis (Mitchill), Stizostedion vitreum (Mitchill), Esox lucius (Linnaeus), Hoidon alosoides (Rafinesque), and Catostomus catostomus (Forster)} were represented. Times of collection included May 30 and August 3-7. Tail fork lengths, wet weights, age, and mean total metal levels of axial musculature are given in Appendix B. Sufficient numbers of samples were available for E. lucius and C. clupeaformis from sections of Moondance Creek between Sites 9 to 29 to allow statistical testing. Metal content

Table 16: Significant seasonal correlations between macrophyte species (aboveground portions) with respect to mean total cadmium, copper and lead contents. All data considered.

Parameter	Correlated components		Statistical significance
Cd	*Potamogeton filiformis*	– *P. richardsonii*	(r = -0.896, n = 5, p = 0.020)
	P. filiformis	– *Sparganium angustifolium*	(r = 0.698, n = 9, p = 0.018)
	P. gramineus	– *S. angustifolium*	(r = 0.691, n = 7, p = 0.043)
Cu	Cyperaceae spp.	– *S. angustifolium*	(r = 0.721, n = 8, p = 0.022)
	Cyperaceae spp.	– *Equisetum fluviatile*	(r = 0.923, n = 6, p = 0.004)
	S. angustifolium	– *H. vulgaris*	(r = 0.573, n = 13, p = 0.02)
	S. angustifolium	– *P. gramineus*	(r = 0.920, n = 7, p = 0.002)
	H. vulgaris	– *P. filiformis*	(r = -0.988, n = 11, p = 0.002)
	H. vulgaris	– *P. richardsonii*	(r = -0.913, n = 5, p = 0.015)
	P. filiformis	– *P. richardsonii*	(r = 0.920, n = 5, p = 0.013)
Pb	Cyperaceae spp.	– *S. angustifolium*	(r = 0.863, n = 8, p = 0.003)
	S. angustifolium	– *H. vulgaris*	(r = 0.578, n = 12, p = 0.025)
	H. vulgaris	– *Ranunculus gmelinii*	(r = 0.832, n = 5, p = 0.04)

Table 17: Significant correlations among metal levels in individual macrophyte taxa. All data considered.

Significantly correlated components		**Metal** Cd	Cu	Pb
Equisetum fluviatile	- Cyperaceae spp.		+	
Cyperaceae spp.	- *E. fluviatile*		+	
	- *Sparganium angustifolium*		+	+
Sparganium angustifolium	- Cyperaceae spp.		+	+
	- *P. filiformis*	+		
	- *P. gramineus*	+	+	
	- *H. vulgaris*		+	
Potamogeton filiformis	- *S. angustifolium*	+		
	- *P. richardsonii*	-	+	
	- *H. vulgaris*		-	
Potamogeton gramineus	- *S. angustifolium*	+	+	
Potamogeton richardsonii	- *P. filiformis*	-	+	
	- *H. vulgaris*		-	
Ranunculus gmelinii	- *H. vulgaris*			+
Hippuris vulgaris	- *S. angustifolium*		+	+
	- *P. filiformis*		-	
	- *P. richardsonii*		-	
	- *Ranunculus gmelinii*			+

of axial musculature is summarized for these two species in Table 18. Comparing mean total metal contents in axial musculature of the carnivorous Northern pike and the ominvorous whitefish revealed no significantly increased metal content at the higher trophic level, although mean Cd, Cu and Pb contents were slightly enhanced in the carnivorous Northern pike relative to whitefish tissue samples. The order of metal accumulation for both species was lead > cadmium > copper.

Northern pike and whitefish samplings were additionally examined for significant correlation patterns among metals in axial muscle tissue. A significantly positive ($r = 0.399$, $n = 28$, $p = 0.018$) correlation between cadmium-copper was found for the carnivorous northern pike (E. lucius), but no other metal pairs were correlated. In the omnivorous whitefish (C. clupeaformis), none of the metal pairs were significantly associated.

Metal content of axial musculature was examined for correlations with fork length, wet weight, and age. Significant relationships are summarized in Table 19. In E. lucius, as wet weight increased, axial muscle tissue lead content decreased per unit weight. No significant trends were found for either total cadmium or copper content and increasing age (weight and length). For C. clupeaformis, both cadmium and copper contents decreased with increasing tail fork length. Copper also showed an inverse relationship with weight and age.

In addition to axial musculature, in two brook trout (Salvelinus fontinalis), gill tissue, liver, heart, reproductive organs, scales, bone and brain tissue were analyzed (Table 20). Mean metal contents varied substantially within and between the tissue types. Mean total cadmium contents of brook trout tissues encompassed values ranging from minimum

Table 18: Mean weight, length, age, and total axial musculature cadmium, copper and lead content (ug/g dry weight) of Esox lucius (Northern Pike) and Coregonus clupeaformis (Whitefish) collected from sections of Moondance Creek.

		Total metal content x, (S.E.) (ug/g dry weight)					
Species	N	Cd	Cu	Pb	Weight (grams)	Length (mm)	Age (years)
Esox lucius	28	2.90(0.19)	1.69(0.25)	4.74(0.21)	995.7(77.2)	515.7(9.3)	8.2(0.4)
Coregonus clupeaformis	14(13)*	2.49(0.29)	1.16(0.24)	4.28 (1.11)	995.6(119.6)	392(12.6)	10.2(0.6)

* N for whitefish weight, length, and age measurements only.

Table 19: Significant correlations between axial musculature metal content and wet weight, length and age of *Esox lucius* and *Coregonus clupeaformis*.

Species	Correlated parameters	Statistical significance
Esox lucius	Pb - weight	(r = -0.374, n = 28, p = 0.025)
Coregonus clupeaformis	Cd - length	(r = -0.747, n = 13, p = 0.002)
	Cu - weight	(r = -0.515, n = 13, p = 0.036)
	Cu - length	(r = -0.527, n = 13, p = 0.032)
	Cu - age	(r = -0.654, n = 13, p = 0.008)

Table 20: Mean total metal content (ug/g dry weight) of Brook trout (<u>Salvelinus</u> <u>fontinalis</u>) organs.

Tissue type	**Sample No.***	**Mean total metal content (ug/g dry weight)**		
		Cadmium	**Copper**	**Lead**
axial musculature	1	2.82	3.1	2.4
	2	3.11	2.8	0.0
brain	1	5.46	6.3	29.7
	2	2.92	2.6	2.4
liver	1	3.03	**107.0	202.5
	2	2.69	7.9	136.7
reproductive organs	1	2.11	71.0	122.6
	2	4.28	14.4	39.2
gills	1	2.96	4.7	23.8
	2	3.89	6.6	28.0
heart	1	6.66	23.5	52.3
	2	12.71	18.1	0.0
bone	1	5.11	3.3	30.3
	2	6.62	2.2	27.0
scales	1	1.62	9.9	69.2
	2	2.21	7.1	33.1

* Tail fork length, wet weight, age, and sex of above sample fish.

Species	Length (mm)	Wet weight (g)	Age (y)	Sex
Brook trout #1	450	1450	11	female
Brook trout #2	430	971	8	male

** Experimental error.

levels for scales (x = 1.92) and axial musculature (x = 2.97), to maxima of x = 9.69 for heart tissue, x = 5.87 for bone, and x = 4.19 for brain tissue. Mean copper and lead contents encompassed much wider ranges (Cu, 2.75 - 57.5, Pb 1.2 - 170). Cadmium, copper and lead were all associated largely with portions that are not normally consumed by humans (i.e., liver, brain, reproductive organs, heart), while the flesh was less contaminated.

V. Metal Compartmentation

a. Component Contents

A summary of component contents per unit dry weight excluding water samples (sites, harvesting times and species pooled) are given in Table 21. Water showed the lowest metal concentrations. Although strict statistical comparisons would be invalid it appeared that from overall data total metal contents in fish axial musculature were exceeded by contents in both macrophytes and the underlying sediments. Sediments appeared to be a sink for copper and lead, showing greater quantities than the levels in macrophyte and fish tissues. However, cadmium showed higher amounts in pooled macrophyte tissues, being greater than in either the fish or sediments.

Table 21: Average total (ug/g dry weight) contents of cadmium, copper and lead in sediment, macrophyte and fish tissue samples. All data considered.

Parameter (ug/g dry weight)	N	$\bar{x}$ (S.E.)		
		Cd Cadmium	**Cu Copper**	**Pb Lead**
Water (ug/l)	102(100)*	1.29(0.16)	9.53(1.03)	-
Sediment (ug/g)	167(101)*	2.72(0.14)	6.55(0.30)	33.33(3.59)
Macrophyte (ug/g)	382(381)*	4.03(0.16)	4.83(0.53)	13.42(1.03)
Fish (ug/g)	49	2.81(0.14)	1.52(0.18)	4.55(0.76)

* N for water copper samples.

* N for sediment and macrophyte lead samples.

DISCUSSION

Results from the present survey showed that Cd and Cu concentrations in the creek and river waters ranged from below detection limits (<0.01 ug/l) to 7.5 ug l^{-1} and from <0.01 ug/l to 25.0 ug l^{-1} respectively (Table 5). Many values appeared similar to those reported for other studies of Canadian waters (Spear and Pierce, 1979; Canadian Water Quality Guidelines, 1987).

Canadian water quality guidelines provide 'acceptable' limits for waters destined for particular uses, and to protect aquatic life. Unpolluted freshwater in Canada generally contains less than 1.0 ug/l total cadmium (Friberg et al., 1974; Williamson, 1983). Total copper concentrations should not exceed 6 ug/l to protect aquatic life. A Canadian water survey indicated median cadmium concentrations in distributed river waters are less than or equal to 10 ug/l (Canadian Water Quality Guidelines, 1987). Spear and Pierce (1979) reported that total dissolved copper levels in Canadian surface waters rarely exceed 5 ug/l, and for unpolluted U.S. surface waters common concentrations are generally in the vicinity of 1-10 ug/l. Concentrations greater than these background levels can most likely be attributed to anthropogenic sources (McNeely et al., 1979).

The Cd concentrations encompassed levels found by Cowgill (1974) (1.4-1.8 ug/l), McIntosh et al. (1978) (0.5-2.5 ug/l), Meranger et al. (1979) (0.27-1.13 ug/l), and Webb (1979) (<1.0-2.7 ug/l). Copper levels ranged from being intermediate to enhanced when compared with those of McNeely et al. (1979) (well below 20 ug/l), Spear and Pierce (1979) (rarely exceeding

5 ug/l), Demayo and Taylor (1981) (2.0 - 6.0 ug/l), and Williamson (1983) (up to 5.6 ug/l).

Values in this study were elevated when compared to those determined by Friberg et al. (1971) (<0.1 ug/l) in areas not known to be polluted, but were almost an order of magnitude greater than concentrations found by Williamson (1983) (0.012 - 0.051 ug/l), and Malley et al. (1989) (0.016 ug/l).

Where higher levels have been reported they are generally from areas with anthropogenic influences. Rowley (1975) investigated water pollution in the vicinity of Flin Flon, Manitoba and found total cadmium and copper concentrations in Thompson and Schist Lakes (approximately 15 km from Flin Flon) to range between 0.02-0.16 m Cd/l and 0.014-3.1 m Cu/l respectively. Sergy and Fallis (1978) confirmed these findings.

Some total unfiltered analyte concentrations were quite pronounced (i.e., > 5.0 ug Cd/l and> 10.0 ug Cu/l) in creek samples from the surveyed area (Table 5). In some cases, higher cadmium and copper levels were obtained during the earlier part of the season when water flows were increased and rates of runoff and leaching were greatest. Shapiro (1964) suggested metals tend to be associated with suspended and colloidal materials in natural waters, and values in spring generally reflect diffuse sources of eroding sediment. Such a pattern has also been observed elsewhere by Brown (1974) and Blachford and Ongley (1981). Thus, differences in metal concentrations between sites and sampling periods could possibly be attributed to increased sediment concentrations and a larger component of fine-grained material suspended within the water column due to fluctuations in stream runoff, unstable flow rates, channel sizes, amounts of bottom scour, and rates of erosion. Williams et al. (1973) reported that during periods of increased flow of the Ohio River at Cincinnati, increased turbulence caused resuspension of ooze material and a corresponding rise in the metal content of suspended material in the water column. These periods were directly associated with the destruction of plankton communities, and fish kills in severe cases.

No significant relationship between cadmium and copper was apparent for water sample analysis in the present survey (Table 5) suggesting these metals were entering the system independently of each other, and were not traceable to any common source.

Sediments constitute sinks for trace metals in aquatic environments (Iskander and Keeney, 1974; Mathis and Kevern, 1975; Ward et al., 1976; Enk and Mathis, 1977; Wong et al., 1978; Mathis et al., 1979; White and Tittlebaum, 1984), and more recently there has been a growing awareness of the role that sediments play in the dynamics of river systems (Peverly, 1979; Hesslein et al., 1980; Salomons and Forstner, 1984). Aquatic sediments are thus important for the assessment of contamination of water bodies.

Because the surveyed area was so heterogeneous in terms of surficial deposits and flow dynamics which differed at the various sampling sites, both physical sediment characteristics and sediment metal contents showed a wide range of values. Local variations at individual sites were commonly encountered. For the study area as a whole, total cadmium, copper and lead contents of the sediment samples ranged from 0.3-9.44 ug Cd/g, 0.. 14.8 ug Cu/g, and 3.0-50.0 ug Pb/g respectively (Table 6). These dry weight contents approach values characteristic of "unpolluted" systems, and may therefore be regarded as base line data for this region. Dhar (1973) suggested such variability of metal contents in sediments is probably a normal phenomenon due to stream turbulence and fluctuation in seasonal sediment distribution patterns.

Sediments consistently contained substantially more cadmium than water samples (Table 5). Ranges (Table 6) agreed well with background content values reported for other nonindustrialized regions [i.e., Fulkerson et al., 1973 (up to 6.0 ug/g), Mathis and Kevern, 1975 (2.5-5.3 ug/g), Wentzel and McIntosh, 1977 (1.0-4.0 ug/g), Yost, 1978 (up to 3.0 ug/g), Webb, 1979 (<7.0 ug/g), and Pip, 1990b (<7.0 ug/g) on a dry weight basis.

Total (ug/g) copper contents from the study sites (Table 6) were almost identical to those observed in Illinois River sediments in unpolluted areas; these ranged from approximately 3.5-11.2 ug/g (dry weight) (Mathis and Cummings, 1973). Generally the average copper value for the present survey was less than 7.0 ug/g. Slightly higher values were found by Spear and Pierce (1979) (12-57 ug/g), and Pip (1990b) (ranging from 15-43 ug/g) in Canadian freshwater sediments.

Lead was the most concentrated metal found in the sediments (Table 6). Preponderance of lead has also been noted in other sediments by Namminga et al. (1974). In the present study, total values ranged between 3.0 and 50.0 ug/g (Table 6). Such total dry weight contents are similar to numerous other studies including those by Ward et al. (1976) (15-20 ug/g), McDuffie et al. (1972) (up to 24 ug/g), and Pip (1990b) (18-61 ug/g).

Examination of physical sediment characteristics revealed similar particle size fractions were positively (although not statistically) related with one another, while unlike diameter size fractions showed reversal of this trend. Such trends have been previously reported by Raudkivi (1976). Moreover, a number of studies have shown a relationship between heavy metals and various sediment parameters (McDuffie et al., 1972; Nriagu and Coker, 1980). The nature of the substrate itself seems to play an important role in the holding capacity of sediments and Stanley (1974) suggested that the degree of such metal adsorption is greatly influenced by ambient conditions and sediment type. Particle size distributions are therefore extremely important because fine sediments have adsorption capacities higher than that of coarse samples. From survey results it was evident that fine sediments were more effective at binding the metals than were sands and gravels. Within the grain size spectrum examined, the fine grained fractions, consisting mainly of silts and clays, showed (although not statistically) the highest metal contents (Tables 6 and 7). Large total surface area in fine-textured sediments is associated with physical and chemical adsorption contributing to enhanced levels of heavy metals in sediments (Oliver and Kinrade, 1979). Salomons and Forstner (1984) suggest such trends are especially marked in less contaminated material, where a general decrease of metal content is found with increasing particle diameter, and this was seen in the present survey as well (Tables 6 and 7).

Gibbs (1977) and Oliver and Kinrade (1979) reported high correlation coefficients between percentages of silt and clay and metal content. Hutchinson et al. (1975) considered clay minerals to be the most important grain size component for transport of metals, reporting significant positive correlations between contents of both copper and lead, and the clay size parameter. According to Folk (1980), these fine grained materials have the most potential for interaction with metals because typical clay sized sediments have surface areas at least an order of magnitude greater than sand-sized sediments.

Interestingly, cadmium appeared inversely (not statistically) related with organic matter. Fulkerson et al. (1973) and Iskander and Keeney (1974) found similar results but in their research relationships were significant. Fulkerson et al. (1973) found that in river bottom sediments, most of the cadmium was associated with larger particles which were predominantly quartz or dolomite, as opposed to finer particles and organic detritus. Iskander and Keeney (1974) similarly reported no consistent relationships between organic components and contents of cadmium, copper or lead.

While aquatic macrophytes constitute a large proportion of the primary production of freshwater ecosystems, the literature is fragmentary with regard to their response to metals (Peverly, 1979). Although organisms of economic value such as fish have been intensely studied by numerous workers, macrophytes have received relatively little attention regarding metal uptake (Sutton and Blackburn, 1971), and the role they play in trace metal cycling (Mayes and McIntosh, 1975). A smaller number of researchers have studied metal content in various macrophytes (Allenby, 1968; Cowgill, 1974; Gale et al., 1974; Harding and Whitton, 1977; Kimball and Baker, 1982; Pip, 1990b) and it has been suggested that such organisms are also potentially useful indicators of pollution trends (Adams et al., 1971; Peverly, 1985).

Analyte metal contents in macrophyte tissue generally exhibited a cadmium < copper < lead trend (Table 10). Total contents measured encompassed values ranging from minima of: 0.22 ug Cd/g, 0.2 ug Cu/g, and 1.0 ug Pb/g, to maxima of 29.10 ug Cd/g, 19.5 ug Cu/g, and 81.9 ug Pb/g dry weight (Table 10). In some cases, values showed great deviation from the normal distribution and may be nonrepresentative because of indeterminate factors, but for the most part values were comparable to those reported for macrophytes by other workers: Reimer and Toth (1968), Petkova and Lubyanov (1969), Cowgill (1974), Behan et al. (1979), and Pip (1990b). Generally, for copper, average contents were slightly lower than those listed by Taylor and Crowder (1983) (9-17 ug/g) and Boyd (1970) (37 ug/g). Lead levels were comparable to those found by Rolfe et al. (1977) (2.5-51 ug/g), those of Pip (1990b) (highest mean 28.0 ug/g in *Najas flexilis*) and Wong et al. (1978), who found mean levels of 30.0 ug Pb/g for *Potamogeton* spp.

Individual macrophyte species were found to differ considerably in their metal accumulation in the roots and aboveground tissues (Table 10). This is in agreement with evidence in the literature suggesting plants can accumulate metals in different tissues to varying degrees (Baker, 1981). Intra-specific variation seen in the present study has also been observed in macrophytes by other workers: Welsh and Denny (1976), Boggess and Wixson (1977), Pip (1990b). Nriagu and Coker (1980) suggested variations in metal contents of aquatic macrophytes occur with respect to age or size differences for a given species. Different taxa do not respond in the same manner to environmental factors. Generally, significantly higher cadmium and copper contents were measured in the roots and rhizomes, relative to corresponding aboveground portions of the macrophytes sampled (Table 10). Similar patterns have been found by others (Hutchinson et al., 1973; Kneip et al. 1974; Stanley, 1974; Welsh and Denny, 1976; Boggess and Wixson, 1977; Wong et al., 1978; Behan et al., 1979; Raghi-Atri, 1980; Taylor and Crowder, 1983; Pip, 1990b. Mayes et al. (1977) has suggested that both the organ types may be important as sites of metal absorption. Hutchinson et al. (1975) showed that roots of an Equisetum spp. were uniformly higher in cadmium, copper and lead content than were the stems. Similar results were found for Equisetum spp. in the current survey, particularly for Equisetum fluviatile (Tables 10 and 11). Glyceria borealis in the present study had higher average metal contents in belowground portions (Table 10). Similarly, Glyceria maxima was found by Raghi-Atri (1980) to have considerably greater quantities of cadmium in roots and rhizomes relative to those in leaf tissue. On average, total cadmium, copper and lead contents in Myriophyllum exalbescens root tissue tended to be higher than contents measured in the shoots (Table 10). Similar results for this same species were found by Pip (1990b).

In contrast, Cowgill (1974) found that Nuphar spp. in copper was contained in greatest quantities in the flowers and the leaves. This finding was similar to the patterns for copper and lead in Nuphar variegatum in the present study, where both these metals showed elevated levels in submerged and floating leaves (Table 12). A similar report was put forward by Hutchinson et al. (1973), who found the highest contents of cadmium, copper and lead in the large floating leaves of Nuphar variegatum. Mathis and Kevern (1975) found comparable results.

Seed heads and inflorescences tended to accumulate less of each metal than roots and rhizomes (Table 10). Various studies by Boggess and Wixson (1977), Behan et al. (1979), Taylor and Crowder (1983) have given similar results. For example in Typha latifolia, Taylor and Crowder (1983) found belowground tissues to contain greater copper content (ug/g) ranges than those observed in reproductive tissues. Behan et al. (1979) found only small differences in lead quantities between shoots and fruits, where roots exhibited much greater values. Concurrent with the general trend, however, copper contents in the taxa Potamogeton richardsonii, Calla palustris, and Carex vesicaria, and lead contents in Sagittaria cuneata and Nuphar variegatum were higher in reproductive than in non-reproductive organs (Table 10). Cowgill (1974) similarly found an exception to the general trend, where lead contents were largely concentrated in the flowers of Pontederia spp. No explanatory literature findings was available to support or dispute such findings.

Significant interspecific differences as well were revealed among macrophytes harvested from the surveyed area with respect to each of the three metals studied (Table 13). Sparganium angustifolium, Hippuris vulgaris, Ranunculus aquatilis, and Utricularia vulgaris each showed significantly higher mean total cadmium in aboveground tissue than the other species examined. Ranunculus aquatilis showed significantly higher values than numerous other species with respect to mean copper content as well. Taxa showing significantly higher lead levels were Hippuris vulgaris and Potamogeton richardsonii. Other workers who observed interspecific differences in metal contents were Petkova and Lubyanov (1969), Hutchinson et al. (1975), Welsh and Denny (1976), Boggess and Wixson (1977), and Kovacs (1978). Alternatively, Cowgill (1974) in her study of Linsley Pond found no differences in total cadmium or copper between aquatic macrophyte species examined. Similarly, no interspecific differences were found by Pip (1990b) among ten species, although only submerged taxa were examined.

No statistically valid seasonal metal accumulation patterns were indicated due to insufficient sample sizes at any one time. Values reflecting total amounts of copper and lead in some macrophyte samples were, however, highest by early August, and had tended to decrease by the beginning of September (Table 10). In midseason, macrophytes had generally appeared to achieve higher burdens of copper and lead, since at this time standing crop is also greatest (Table 10). The relationship between accumulation and periods of production has been previously suggested by Bailey and O'Neill (1972). Decreased contents towards the end of the growing season have been suggested by Welsh and Denny (1976) to represent rapid metal releases from decomposing macrophyte tissues. Boyd (1969), Sutton and Blackburn (1971), and Mayes and McIntosh (1975) demonstrated similar findings for the metals copper and cadmium. Cowgill (1974) suggested that lead and cadmium appeared to accumulate with increasing age in aquatic species examined in Linsley Pond. Observations of heavy metal contents tending to follow seasonal growing patterns (increasing during the period of most active growth in spring to a midseason maximum, then declining to more or less stable levels progressively) have been reported for Myriophyllym spp. (Newman and McIntosh, 1983) and Potamogeton spp. (Welsh and Denny, 1976; Mayes et al., 1977; Pip, 1990b). No trend seemed apparent for total tissue contents of cadmium (Table 10). Pip (1990b) recently reported cadmium showed a distinct tendency to increase steadily with time during the growing season in aboveground tissues, and contents present in Elodea canadensis were shown by Mayes *et al*. (1977) to decrease throughout the year. No seasonal metal accumulation patterns in macrophyte tissues are reported by Boyd (1969), Peverly (1979), Welsh and Denny (1980), and Kimball and Baker (1982), although sample sizes were small and many were below the level of detection.

Significant differences among growth forms were found only for mean total cadmium. Emergent growth forms demonstrated significantly higher values than either the submerged or floating leaved species (Table 14). No comparative literature findings were available to support this result. In opposition, Cowgill (1973) noted that the two submerged species *C. demersum* and *P. praelongus* both contained greater quantities of cadmium than those of *Nuphar advena* which had floating leaves, and comparing available data for distributions of copper, she found no consistent differences among submerged, floating leaved, and true emergent plants. Peverly (1985) noted that non-rooted submersed species contain higher tissue contents compared with values in emergent plant species.

Analysis of aboveground shoots showed significant relationships between each of the metal pair combinations (Table 15). Supporting literature for metal pair correlations is fragmentary. Pip (1990b) found cadmium and copper to be significantly inversely correlated in two *Potamogeton* spp. growing in Shoal Lake (Manitoba-Ontario). Copper-lead and cadmium-lead levels were correlated as well (Table 15). Cadmium and copper in macrophytes from the Gillam locality showed both positive and negative correlations for various species, suggesting that no generalizations could be made for macrophyte communities as a whole (Tables 16 and 17).

Considerably more literature exists with respect to fish (Boggess and Wixson, 1977; Florence, 1982). Depending upon their availability for uptake by biota, heavy metals accumulated may produce numerous effects depending on the metal in different species (Sprague, 1971; Pagenkopf and Newman, 1974; Sangalang and Freeman, 1974). At relatively low levels, metals have been found to disrupt energy production and oxygen uptake (Hillibran, 1971), affect intestine, kidney and other tissues (Eisler, 1971), early life stages (McKim et al., 1975; Sauler et al., 1976), coagulation of mucus on gill surfaces and respiratory activity (Morgan and Kuhn, 1974), and hormone metabolism (Freeman and Sangalang, 1976).

Generally, mean contents reported from this survey for axial musculature (Table 18 and Appendix B) were intermediate to slightly elevated compared to those given by Mathis and Cummings (1973), Hutchinson et al. (1975), and Sergy and Fallis (1978).

In *E. lucius* in the survey area, as wet weight increased, axial muscle tissue lead content decreased per unit weight (Table 19). This is in contrast to the findings of Pagenkopf and Newman (1974), who showed older fish have higher lead levels in bone. Fulkerson et al. (1973) found similar results, in that the oldest (largest) northern pike sampled contained 2-3 times more cadmium in muscle and liver tissue than did young fish. No significant trends were apparent for either cadmium or copper in *E. lucius* in the present survey (Table 19). There was no correlation between age (weight and length) and muscle content, an observation also reported by other investigators (Mathis and Kevern, 1975). For example, Sergy and Fallis (1978) found there to be no discernible relationship between fish size and the concentration of heavy metals in analyzed tissues.

For whitefish analyzed, contents of both cadmium and copper in muscle decreased with increasing tail fork length (age) (Table 19). These data are particularly important in terms of comparative sensitivity of different life stages. While examining tissue metal contents in freshwater mussels (Anodonta sp.), Pip (1990a) showed contents of copper and lead decreased as animal size increased, and suggested that smaller individuals take up metals at greater rates (or dispose of them more slowly) than do larger clams of the same species. Christensen (1975) evaluated biochemical responses of brook trout embryos to cadmium and lead. Results indicated greater biochemical stress was produced when the growing organism is undergoing dramatic changes in metabolism and morphology from embryo to fry. During the period there is a loss of the protective embryonic casing, the beginning of use of newly-developed gill tissue which can absorb toxicants, the beginning of ingestion of food from the external environment, and this is the time of conversion from an immobile to mobile state requiring new energy requirements.

Comparing mean metal contents in muscle tissue of the carnivorous northern pike and the omnivorous whitefish revealed no significant indication of increased metal contents at higher trophic levels. Other workers (Mathis and Cummings, 1973; Boggess and Wixson, 1977; Rolfe et al., 1977; Sergy and Fallis, 1978; Burrows and Whitton, 1983; Wong, 1985) have found similar results. Each of these authors has pointed out that in aquatic ecosystems there are little data to support the simplistic assumption of stepwise heavy metal biomagnification through the food web.

Rather, the data suggest that larger organisms higher up the food chain have the greatest control over uptake. Mathis and Cummings (1973) recognized some overlap in metal content of muscle tissue between carnivorous and omnivorous groups, and when compared statistically, there were no significant differences for lead and cadmium. Omnivorous fish, however, exhibited higher mean copper values. This was not the case with any of the three metals studied in this project. For each metal, mean total levels were somewhat greater in Northern pike (Table 18 and Appendix B). Burrows and Whitton (1983) found comparisons of carnivorous species with other taxa revealed no indication of increased metal contents at higher trophic levels. Furthermore, Sergy and Fallis (1978) found few interspecific differences in quantities of heavy metals in muscle tissues of pike and whitefish.

In addition to axial muscle tissue in two brook trout, gill tissue, liver, heart, reproductive organs, scales, bone and brain tissue were analyzed. Mean metal contents varied substantially within and between the tissue types (Table 20). Cadmium, copper and lead were highest in portions that are not normally consumed by humans (i.e., liver, brain, reproductive organs, heart) while muscle tissue was less contaminated. Mean levels found for this study were of the same tissue ratios and magnitude as those found by Hutchinson et al. (1975).

Webb (1979) has also found that liver and kidney were the principle organs involved in heavy metal storage. Yost (1978) found cadmium contents in fish livers to be significantly elevated. No evidence was found of elevated contents in edible flesh (Table 20). Mathis and Kevern (1975) reported heavy metals accumulate in fish, with liver, kidneys and intestines containing the highest contents. Both Dhar (1973) and Enk and Mathis (1977) supported these findings. Similarly, Benoit (1976) and Sangalang and Freeman (1979) found that fish usually accumulate less cadmium in axial muscle tissue than in most other tissues and organs. Results for Gillam-Limestone fish samples gave similar results (Table 20). Hutchinson et al. (1975) also found metal levels in muscle tissue were lower than those in other parts of the fish sampled.

Analysis of bone tissue showed lead was present to a greater extent than cadmium and copper (Table 20). This supported the results of Pagenkopf and Newman (1974) who showed that older fish have higher lead levels in bone. Heart tissue contents of the two sampled brook trout from the study area also showed elevated cadmium, copper and lead contents. Analysis of cadmium and lead in caged channel catfish and green sunfish by Mathis et al. (1979) indicated that contents were quite variable in whole fish as well as in selected organs, but heart tissue tended to have higher contents.

Comparisons between metal composition values among biotic and abiotic compartments sampled demonstrated variability with respect to mean total heavy metal accumulation and content (Table 21). Sediment appeared to be a sink for copper and lead, showing greater quantities than those levels contained in macrophyte and fish tissues. These results are consistent with findings of other workers (Iskandar and Keeney, 1974; Namminga et al., 1974; Harding and Whitton, 1977; Wentzel and McIntosh, 1977; Tessier et al., 1979; Salomons and Forstner; 1984; Cornett and Ophel, 1986; Pip, 1990b).

Hesslein *et al*. (1980) suggested that the major sink for metal isotopes lost from the water column are the sediments, and that sediments play an important role in the dynamics of aquatic systems. A similar viewpoint had been advanced by Jones and Bowser (1978). Aside from water, fish muscle tissue appeared to show the least metal concentrating ability of all (Table 21). Kneip and Lauer (1974), Namminga *et al*. (1974), and Hutchinson *et al*. (1975) have found similar trends.

Mathis and Kevern (1975) examined similar environmental compartments to those of the present survey for cadmium and lead, and found concentrations in water, fish, macrophytes and sediments to be generally similar to contents found in this project (Table 21), and compartment ordering from lowest to highest metal content was identical (water < fish < aquatic macrophyte < bottom sediments). Mathis and Cummings (1973), Wentzel and McIntosh (1977), Spehar *et al*. (1978), Eyrest and Pugh-Thomas (1978), Pip (1990b), found comparable metal distribution patterns.

CONCLUSIONS

Metal levels found from the study area (for the different components) were generally comparable to those reported by others, for unpolluted areas. Water levels reported here were higher than reported in most studies of unpolluted areas. Collection bottles pre-washed with acid may have reduced levels of contamination. While many environmental monitoring programs sample only water, or only sediment, this study suggests that both have to be measured, as neither one is a predictor of levels in the other.

The higher contents found in roots and rhizomes, was expected in view of the contact of these structures with the sediments (where levels are generally higher), while interspecific differences have been a point of much contention in the literature, the present study clearly indicates that such differences do exist.

In regards to seasonal flux of heavy metal(s) contents, the apparent tendency of cadmium to increase during the season in macrophytes further confirms the results of other workers (Pip, 1990a). Additionally, because cadmium may have higher average contents at the end of season, and copper and lead appeared higher in midseason, this may suggest that the ways these metals are taken up and accumulated are different. Obviously then, no one sampling time will give an accurate representation of the metal burden tied up in macrophytes for all three metals.

While some workers have suggested that metal levels in macrophytes reflect the levels in the environment, the present survey indicated that such an approach is too simplistic and other factors are probably also operating. Only six species were correlated with sediment levels, but some of these correlations were inverse. Thus no generalizations can be made regarding macrophyte metal content from a knowledge of what the sediment levels are.

The relationship of metal content to growth form may reflect, in some measure, passive uptake by the plant in the course of transpiration. Submerged forms, which do not transpire, contained the lowest metal levels.

In regard to fish tissue analysis, smaller concentrations of metals per unit muscle tissue weight in larger fish suggested that uptake and retention are greatest in younger fish. Similar patterns have been reported for invertebrates. At present, environmental monitoring programs in Manitoba often sample the largest fish for metal analysis, and these fish will be expected to give the smallest values. For a more realistic assessment, younger fish, and or internal organs of older fish, should be sampled and analyzed. The lowest degree of bioaccumulation of metals occurred in muscle tissue. Unfortunately, because of their economic value, fish are often the only components of a system that are examined for contamination, and because they also are likely to give the lowest values, a contaminated system may be overlooked for some time.

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Appendix A: Study sites at which each macrophyte taxon occurred.

Site	Species present
Oedogonium sp.	Sky Pilot Creek Sundance Creek (Upstream) Leslie Creek Keeta Creek
Dichotomosiphon sp.	9 Mile Creek Sky Pilot Creek
Mougeotia sp.	Nelson River
Gloeotrichia sp.	Sundance Creek (Upstream)
Chara globularis	Moondance Creek
Fontinalis antipyretica	CN Creek
Equisetum fluviatile	Boots Creek 9 Mile Creek Limestone River McMillan Creek Leslie Creek Unnamed Creek #1 Keeta Creek 12 Mile Creek (Camp location) Wilson Creek
Equisetum pratense	Sundance Creek (Downstream)
Equisetum variegatum	McMillan Creek
Carex vesicaria	12 Mile Creek (Camp location)
Cyperaceae spp.	12 Mile Creek 9 Mile Creek Limestone River Sky Pilot Creek Sundance Creek (Upstream) CN Creek Moondance Creek

continued ....

Site	Species present
Cyperaceae spp.	McMillan Creek Leslie Creek Unnamed Creek #1 Brooks Creek Beaver Creek Wilson Creek Sundance Creek (Downstream) Creek 15 Small bog near Sky Pilot Creek Goose Creek Small tributary on Sky Pilot Creek 12 Mile Creek (Ground water)
<u>Glyceria</u> <u>borealis</u>	Kettle River Boots Creek
<u>Potamogeton</u> <u>alpinus</u>	Unnamed Creek #1 Keeta Creek Unnamed Creek #2
<u>Potamogeton</u> <u>filiformis</u>	Kettle River 12 Mile Creek 9 Mile Creek Limestone River Sky Pilot Creek McMillan Creek 12 Mile Creek (Camp location)
<u>Potamogeton</u> <u>friesii</u>	Long Spruce Quarry
<u>Potamogeton</u> <u>gramineus</u>	Kettle River 12 Mile Creek Limestone River Unnamed Creek #1 Keeta Creek Brooks Creek Unnamed Creek #2
<u>Potamogeton</u> <u>pectinatus</u>	Moondance Creek

continued ....

Site	Species present
Potamogeton richardsonii	Kettle River Limestone River McMillan Creek Keeta Creek 12 Mile Creek (Camp location) Long Spruce Quarry
Sagittaria cuneata	Kettle River 12 Mile Creek (Camp location)
Scirpus microcarpus	Moondance Creek
Sparganium angustifolium	Kettle River 12 Mile Creek Boots Creek 9 Mile Creek Limestone River Sky Pilot Creek Sundance Creek (Upstream) CN Creek Moondance Creek Leslie Creek Unnamed Creek #1 12 Mile Creek (Camp location) Brooks Creek Beaver Creek Wilson Creek Unnamed Creek #2 Small bog near Sky Pilot Creek
Typha latifolia	Leslie Creek
Zosterella dubia	Sky Pilot Creek
*Calla palustris	Boots Creek Sundance Creek (Upstream) Unnamed Creek #1 Sundance Creek (Downstream)

continued ....

Site	Species present
Callitriche palustris	Kettle River 9 Mile Creek Leslie Creek Beaver Creek
Hippuris vulgaris	Kettle River Boots Creek 9 Mile Creek Limestone River Sky Pilot Creek CN Creek Moondance Creek McMillan Creek 12 Mile Creek (Camp location)
Menyanthes trifoliata	Sundance Creek (Upstream) CN Creek
Myriophyllum exalbescens	Kettle River Boots Creek Long Spruce Quarry
Myriophyllum verticillatum	Nelson River
Nuphar variegatum	Boots Creek
Ranunculus aquatilis	Kettle River 9 Mile Creek
Ranunculus gmelinii	Boots Creek Sundance Creek (Upstream) CN Creek 12 Mile Creek (Camp location) Creek 15
Utricularia intermedia	Boots Creek
Utricularia vulgaris	Boots Creek

* Although *Calla* and *Caltha palustris* were correctly identified, some confusion occurred between ground specimens during processing and results were unfortunately combined for locations 3, 7, and 12.

Appendix B: Gillam-Region catch composition from angling and gillnet sets in 1988. Wet weight is to nearest 10 g.

Species	Site	Time	Metal content of axial muscle (ug/g dry weight) Cd	Cu	Pb	Wet weight (g)	Length (mm)	Age (years)
Esox lucius	Moondance Creek (Site 9)	Aug. 3-7	1.09	1.0	20.5	400	450	6
			0.38	2.1	4.4	600	520	9
			0.96	1.1	15.8	400	450	5
			2.62	0.2	1.3	550	510	6
			2.83	0.5	15.8	550	480	6
			3.56	0.1	6.1	950	580	8
			3.89	2.1	18.0	900	500	6
			2.79	0.9	<0.0	1130	560	9
			1.72	0.0	3.5	1070	515	10
			2.78	0.9	0.0	790	484	5
			2.78	0.2	0.4	1470	544	10
			3.34	4.2	2.8	1190	548	9
			2.59	2.0	<0.0	1600	598	11
			3.45	4.3	<0.0	740	504	10
			2.54	2.8	2.8	1800	610	12
			3.81	3.3	3.7	1130	490	9
			4.34	2.1	4.2	900	480	9
			2.99	0.7	15.6	1000	530	12
			2.82	2.5	<0.0	900	510	7
			4.98	4.9	<0.0	680	445	6
			4.29	2.5	<0.0	1130	518	8
			2.41	0.5	3.4	900	490	6
			3.15	3.2	<0.0	790	490	5
			2.37	1.8	2.8	1900	600	11
			3.21	0.3	<0.0	680	456	6
			2.66	1.2	5.2	730	442	7
			2.72	0.8	3.0	1750	580	13
			4.18	1.0	3.3	1250	555	11
Coregonus clupeaformis	Moondance Creek (Site 9)	Aug. 3-7	0.52	0.8	6.0	1250	500	13
			0.41	1.0	5.3	1250	500	12
			4.17	1.7	16.8	450	320	7
			3.38	0.1	3.5	1130	390	12
			2.89	0.0	2.4	1300	438	18
			3.14	1.0	7.1	900	386	8
			2.94	0.5	5.0	2100	426	13
			2.45	1.4	0.0	790	378	12
			3.63	2.8	0.0	400	292	5
			3.15	2.3	3.3	570	340	7
			1.97	2.5	0.0	900	365	7
			2.11	1.5	2.8	1300	412	12
			1.71	0.0	2.8	600	350	7
			2.45	0.6	5.3	-	-	-

continued ....

Species	Site	Time	Metal content of axial muscle (ug/g dry weight) Cd	Cu	Pb	Wet weight (g)	Length (mm)	Age (years)
Hiodon alosoides	Nelson River (Site 21)	Aug. 3-7	5.10	0.3	10.2	230	256	-
			3.09	0.3	1.9	230	252	-
			2.77	3.7	7.4	300	268	-
Salvelinus fontinalis	McMillan Creek (Site 10)	Aug. 3-7	2.82	3.1	2.4	1450	450	11
			3.11	2.8	0.0	970	430	8
Catostomus catostomus	Nelson River (Site 21)	May 30	1.74	0.4	8.7	400	390	6
Stizostedion vitreum	Nelson River (Site 21)	Aug. 3-7	2.64	0.5	0.0	570	370	9