The Role of Narrow-Leaved Cotton Grass (*Eriophorum angustifolium*) in the Removal of Copper in a Sedge Fen Receiving Acid Mine Drainage

by

David Mark Victor Coombes
B.A. University of Victoria, 1969

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

in the School of Earth and Ocean Sciences

[redacted] We accept this thesis as conforming to the required standard

Dr. Michael Whiticar, Supervisor (School of Earth and Ocean Sciences) [redacted]

Dr. Richard Hebda, Departmental Member (School of Earth and Ocean Sciences) [redacted]

Dr. Derek Ellis, Outside Member (Department of Biology) [redacted]

absent. Dr. Alexander McAuley, Outside Member (Department of Chemistry) [redacted]

Dr. Richard Nordin, Outside Member (Department of Biology) [redacted]

Dr. Raymond Lett, External Member (Geological Branch, Ministry of Employment and Investment) [redacted]

Dr. André Sobolewski, External Examiner (Microbial Technologies)

University of Victoria

Supervisor: Dr. Michael Whiticar

Abstract

A sedge fen on Mount Washington, 23 km west-northwest of Courtenay, British Columbia, was identified as removing copper, iron, aluminum, arsenic and sulphate from a stream, Pyrrhotite Creek, flowing through it.

Samples of the Narrow-Leaved Cotton Grass, Eriophorum angustifolium, a sedge, contained over 1000 ppm. copper.

Production of cotton grass leaf mass was ~109 gm/square metre/summer. Harvesting cotton grass was not feasible as a means of removing copper. Copper into the plants was insignificant compared to the copper being removed from the copper-rich water and retained in the sedge peat soil of the fen.

Processes removing copper from the water of Pyrrhotite Creek appeared to be: Adsorption by organic soil components. Adsorption onto iron oxyhydroxides. Formation of copper and/or copper and iron sulphides (chalcocite, covellite, chalcopyrite, etc.).

Narrow-Leaved Cotton Grass has the potential of being used as cover in contaminated sites as it is extremely adaptable.

Examiners

[redacted]

Dr. Michael Whiticar, Supervisor (School of Earth and Ocean Sciences)

[redacted]

Dr. Richard Hebda, Departmental Member (School of Earth and Ocean Sciences)

[redacted]

Dr. Derek Ellis, Outside Member (Department of Biology)

[redacted]

Dr. Alexander McAuley, Outside Member (Department of Chemistry)

[redacted]

Dr. Richard Nordin, Outside Member (Department of Biology)

[redacted]

Dr. Raymond Lett, External Member (Geological Branch, Ministry of Employment and Investment)

[redacted]

Dr. André Sobolewski, External Examiner (Microbial Technologies)

Abstract

A naturally occurring sedge fen on the northern slope of Mount Washington, 23 km west-northwest of Courtenay, British Columbia, was identified as removing copper, iron, aluminum, arsenic and sulphate from a stream flowing through it.

Initial investigation showed that the Narrow-Leaved Cotton Grass, *Eriophorum angustifolium*, Honck. a plant in the Sedge family, growing in the fen was very high in metals. Copper concentrations in the cotton grass were much higher than usual even in heavily contaminated areas elsewhere in Canada. This suggested that a significant proportion of the copper might be removed by harvesting the cotton grass.

Representative samples of cotton grass leaves, soil and water were taken from the sedge fen at four monthly intervals through the growing season and from a set of nearby "background" sites. The dry mass of cotton grass per square metre of fen surface had a mean value of between 103 to 113 grams per square metre during this season. Copper in this material had a mean copper content of 115 ppm when the leaves were accessible for harvesting. Higher values were found, to an mean copper content of 1174 ppm copper after snowfall. Even the higher value was not high enough, given the low production rate per unit area over a summer, for harvesting cotton grass to be feasible as a means of removing substantial amounts of copper. Moreover, the flux of copper from the water into the cotton grass and subsequently into the fen is insignificant compared to the total amount of copper being removed from the copper-rich water and retained in the sedge peat soil of the fen.

The initial processes removing copper from the water of Pyrrhotite Creek appeared to be (in order of importance): 1. Adsorption of the copper by organic components of the sedge peat soil. 2. Adsorption onto iron oxyhydroxides. 3. Formation of copper and/or copper and iron sulphides (chalcocite, covellite, chalcopyrite, etc.). Although this third process appears to become prominent later in the season, it is likely occurring at depth in the peat soils throughout the year.

This work showed that the Narrow-Leaved Cotton Grass has the potential of being effectively used in physically stabilizing contaminated sites, even heavily contaminated ones, as it grows on dry sites as well as in wetlands, from sea level to high altitudes. It should be considered when planting wetlands to handle wastewater contaminated with toxic metals, and in seed mixtures for meadows on old tailings.

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Acknowledgements

The author is indebted to the following people for assistance during the work on this project. First, Dr. Raymond E.W. Lett, Geological Branch, Ministry of Energy and Mines for his advice, assistance, encouragement and acting as advisor. I am grateful for the comments and advice of his committee, headed by Dr. Michael.J. Whiticar, School of Earth and Ocean Sciences, University of Victoria; Dr. Richard Hebda, Curator of Botany and Adjunct Professor with the School of Earth and Ocean Sciences, University of Victoria; Dr. Derek Ellis, Department of Biology, University of Victoria; Dr. Rick Nordin, Water Quality Branch and Department of Biology, University of Victoria; and Dr. Alex McAuley of the Department of Chemistry, University of Victoria.

Financial aid was provided the Habitat Protection Branch, Ministry of Environment, Lands and Parks, through the good offices of Geoff Chislett and Sylvia von Schuckmann; and by Environment Canada, through the good offices of Alan Redenbach; equipment was provided through the good offices of Dr. Rick Nordin and Mr. Ben Kangasniemi, Water Quality Branch, Ministry of Environment, Lands and Parks; and some was constructed by Alan Thorne, Artificer, with the assistance of Terry Curran, Canadian Hydrographic Service. A truck was made available from the Fisheries Branch through the good offices of Mr. Harvey Andrusak, Director, Fisheries Branch, Ministry of Environment, Lands and Parks.

Comments, a great deal of background data, analytical assistance, advice, and other assistance was provided by Lloyd Erickson and John Deniseger of the Environmental Protection Branch; by Dr. John Kwong, of the National Hydrological Institute (now with Klohn, Crippen); by Dr. André Sobolewski, of Microbial Technologies; Dr. C. Dunn, of the Geological Survey of Canada; and by Dr. Steve Cook, of the Geological Branch, Ministry of Energy and Mines. Mr. Larry Wells, of the Fisheries Branch, Ministry of Environment, Lands and Parks, assisted greatly in converting the various computer files into printable format, including the diagrams and maps.

Surveying the site was done with the assistance of Mr. Michael Taylor, Ms. Robin Hicks and Patrick Smith.

Dr. Adolf Ceska, Conservation Data Centre, Ministry of Environment, Lands and Parks, visited the site, and verified plant identifications.

Last but not least, I would like to thank those volunteers who helped me obtain samples and otherwise investigate the sedge fen. These were: Jane Calvert; Micaéle Maddison; Karen Buschert; Mr. Rick Linden; Henry Ang; Anthony Bohol; Zenaida Coombes; and Lourdes Rooney. They were the ones who got cold, wet, muddy and insect-bitten with me.

Chapter I - Introduction

Acid Mine Drainage

Acid Rock Drainage (ARD) or, the more specific Acid Mine Drainage (AMD), is a problem world-wide. Waste rock, or gangue, and exposed rock surfaces that contain pyrite from mining, quarrying, and construction projects, produce an acidic leachate in most moist environments (Mills, 1997). The amount of acidic leachate produced depends on many factors (Sobolewski, 1997a; Mills,1997), such as: rock type, amount of pyrite present, climate, vegetation type, quantity and chemistry of trace elements in the host rock and overburden. The leachate can dissolve many materials and can accumulate to toxic concentrations metals and metalloids such as arsenic, cadmium and lead, especially in the waters flowing from mine tailings, overburden, and waste rock (Hammer, 1989; Means and Hinchee, 1995; Mills, 1997).

AMD is an extensive problem in the north temperate zone, as that is where the bulk of mining and acid-producing mines are located. Procedures to deal with the problem have included discharge of AMD into lakes, replacement of copper with iron, and the addition of acid neutralizing chemicals (e.g. lime). Replacement produces copper as a valuable by-product, but only works well with high concentrations of very acid leachate and certain metals. Also, there are usually toxic materials and residual acidity in the "spent" solution. Neutralization reduces the volume of toxic waste, and the design and construction of treatment plants for accomplishing this are well-documented. However, there is still the problem of disposing of large quantities of toxic sludge. Both replacement and neutralization provide incomplete solutions so researchers are seeking alternatives. One of the alternatives is to use natural wetlands and the plants growing in them to remediate contaminated water.

Over the past few decades, interest in the ability of natural wetlands to remove nutrients, such as nitrogen, potassium, phosphorus, and contaminants, such as heavy metals, from ground and surface waters has intensified. Initially the primary interest was an efficient and cost-effective sewage treatment method. Interest in the possibilities of treating acid mine drainage in wetlands was piqued by studies showing the deposition of metals in bogs and other wetlands (e.g. Fraser, 1961; Huntsman *et al.,* 1978; Lett, 1978; Wieder and Lang, 1982; Sobolewski, 1996). For the past two decades natural wetlands, modified natural wetlands and constructed wetlands have been used with various degrees of success to ameliorate AMD (Hammer, 1989; Gormley *et al.*, 1992; Gopal and Mitsch, 1995; Means and

Hinchee, 1995, Sobolewski, 1997a). This use of wetlands was originally tried on problems in the coalfields of Appalachia and was largely due to the initial observations of Huntsman *et al.* (1978) and Weider and Lang (1982).

Considerable effort has been expended on the layout and design of the constructed wetlands. Substantial work has gone into the defining the optimum composition of the soils and the plant cover. Floating, emergent and submergent aquatic plants have been used and almost all the species used are vascular plants (Mallick *et al.*, 1996; Asola, *et al.*, 1995; Peverly *et al.*, 1995; Outridge and Noller, 1991; Rai *et al.*, 1995). However, some algae and cyanobacteria have been suggested as good candidates (Bender *et al.*, 1994) for inclusion. Cattails, especially *Typha latifolia* L., are the most favoured emergent macrophyte but are not useful at higher elevations and in colder climates.

Many mines in British Columbia produce AMD, e.g.: Britannia, near Squamish; Bell Copper, on Babine Lake; Equity Silver, near Houston, and Mt. Washington Copper, northwest of Courtenay, B.C. (Sobolewski, 1997a). The latter, which has been abandoned for three decades, has one open pit and adjacent waste piles which drain into the headwaters of Pyrrhotite Creek (see Figures 2-2 and 2-3). This creek, in turn, drains into a sedge fen which had been found to remove copper from the water flowing through it (Ferguson, 1985; Deniseger and Erickson, 1991; Erickson and Deniseger, 1994).

The "Branch 126 Sedge Fen" on Mt. Washington was chosen as a site to investigate the role of plants in the amelioration of AMD because: 1) it is accessible; 2) it is well-documented; 3) of extensive environmental monitoring in the area, and; 4) the fen had been demonstrated to retain metals (Erickson and Deniseger, 1994; Deniseger and Pommen, 1995).

Background

Copper in the Tsolum River has been, and probably still is, killing fish (McLean *et al.*, 1996). There are problems with the water quality other than the copper concentration, but, from the fisheries point of view, the principal problem is that copper levels are too high (Deniseger and Pommen, 1995). The discovery that high copper concentrations were the principal problem with the water quality took some time. An abbreviated history follows.

The Canadian Department of Fisheries and Oceans ("DFO") escapement records (Brown *et al.*, 1977; Fish Habitat Inventory and Information Program, 1991; DFO Escapement Records, 1997) show that prior to 1958 there were very large salmon runs in the Tsolum

River of 15,000-100,000 fish. After 1958, logging, gravel mining and over-fishing were blamed for a drop in salmon numbers (McLean, 1985; McLean *et al.*, 1996). Since 1950, chum salmon escapements have been low (except for the 1979-1983 period), pink salmon escapements low since 1960, and coho runs have been in decline since 1975 - with low years in 1955, 1965, 1967-69, 1972-73. The sediment load dropped as gravel mining of the river was banned and as the logging clearcuts were revegetated. Fishing regulations were more strictly enforced, but the salmon runs did not increase as expected from fisheries biologists' experience in other watersheds. There was no recovery of the salmon runs, as can be seen in Figures 1-1a (below) and 1-1b (next page).

Figure 1-1a: **Pink Salmon Tsolum River Escapement**

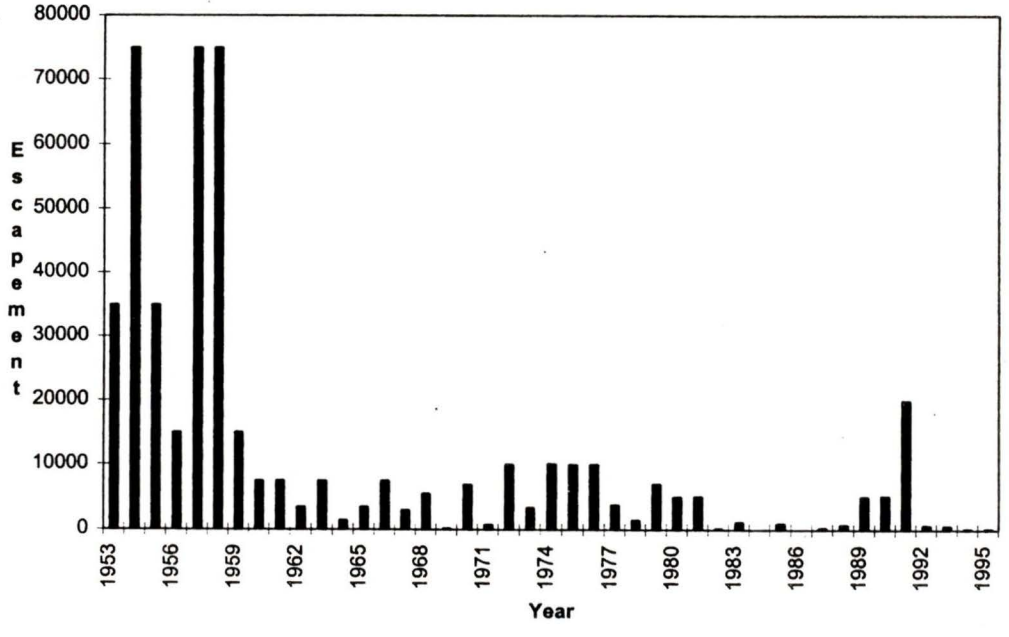

Figure 1-1a: Pink Salmon Escapements in the Tsolum River, 1953-1995 (Fish Information Summary System, 1991; DFO Escapement Records for Area 14N, 1997).

Figure 1-1b: **Coho Salmon Tsolum River Escapement**

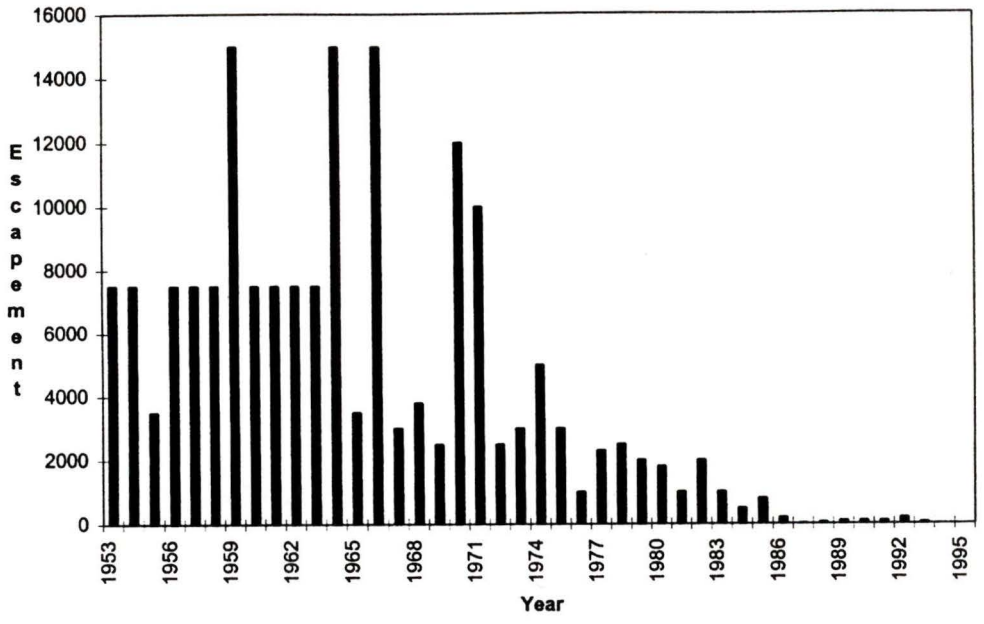

Figure 1-1b: Coho Escapements in the Tsolum River, 1953-1995 (Fish Information Summary System, 1991; DFO Escapement Records for Area 14N, 1997).

In 1968 DFO established a small hatchery at Headquarters Creek on the Tsolum River, the "Tsolum River Hatchery", often referred to as the "Headquarters Creek Hatchery". This hatchery was to study incubation techniques (Bams, 1973a and 1973b; Bams and Crabtree, 1976; Brown *et al.*, 1977; Fish Habitat Inventory and Information Program, 1991) and to improve the poor salmon runs, but without success in the latter goal.

Full-time operations ceased in 1974, but DFO constructed a new facility there in 1979. This was designed as an adult capture and egg take facility, but the low number of returning adults required seining the Tsolum River to obtain sufficient brood stock. Depending on whether the fry were fed or not before release, the initial return rate of adults was very poor (0.010%, for unfed fry) to poor (0.082%, for fed fry). This was 5% to 50% of the return rates for other sites (McLean, 1985).

In 1984, when no adult pink salmon returned, DFO shut down most of the operation. However, the hatchery was used for attempts at enhancement of the Tsolum River salmon runs in 1987, 1988, 1990, 1992, 1993 and 1994 with pink salmon eggs from the Kakweiken

system on the mainland coast (McLean *et al.*, 1996). Now, the facility is closed. McLean and his co-workers (McLean *et al.*, 1996) speculate that the extremely low return rates of adult pink salmon can be attributed to fry mortality from: copper toxicity, low flow; and high predation rates from seals and sea lions downstream.

DFO undertook water quality research in the period 1980-1983 because of the difficulties in reestablishing the salmon stocks. Water testing showed lethal amounts of copper for salmon were present (0.064-0.08 ppm, 0.04 ppm is lethal) in the Tsolum River, especially during the late spring and fall (Kangasniemi and Erickson, 1986).

By 1984 (Kangasniemi and Erickson, 1986; Deniseger and Pommen, 1995), the Ministry of Environment was aware that the Mt. Washington Copper Mine, abandoned since 1967, was adversely affecting water quality, and likely the main source of the problem. Between 1984-1989, Erickson and Deniseger (Erickson and Deniseger, 1987; Deniseger and Erickson, 1989a; Deniseger and Erickson, 1989b) showed that the bulk of the copper contaminating the Tsolum River did not come from the tailings pond, roadway, local deposits, or the mill site. It came from the minesite and specifically the North Pit, of the Mt. Washington Copper Mine. This was established by following the metal-rich water up from the confluence of Murex Creek with the Tsolum River, up Murex Creek to McKay Creek, and up McKay Creek to Pyrrhotite Creek. Pyrrhotite Creek led to the North Pit and was "clean" beyond that point.

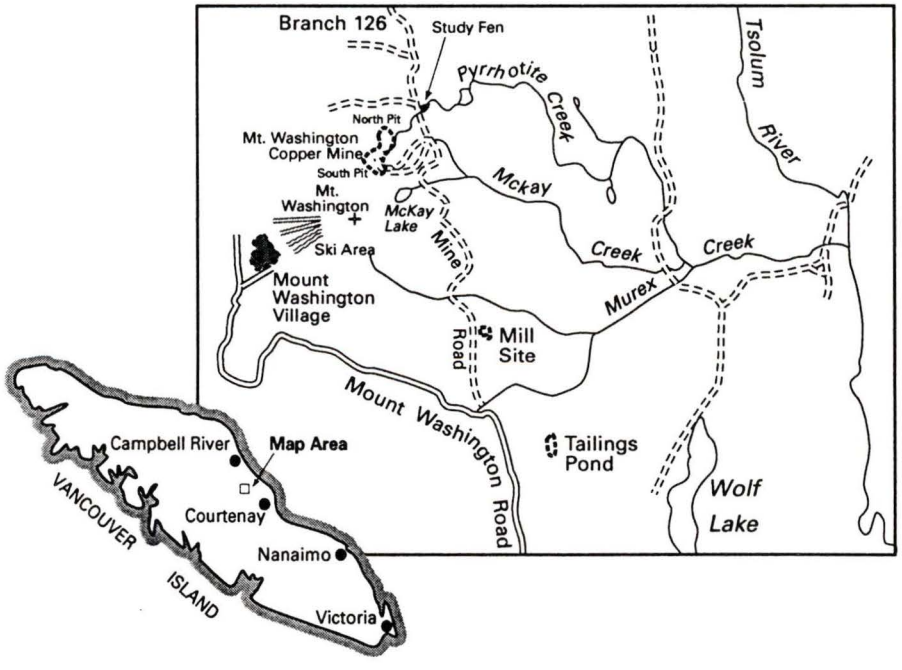

Figure 1-2: Mt. Washington Location and Stream Drainage. See Figure 2-2 and Figure 2-3 for more details.

Based on these initial studies, the B.C. Government passed an Order-in-Council directing the Ministry of Energy, Mines and Petroleum Resources ("EMPR", now part of the Energy and Minerals Division of the Ministry of Energy and Mines) to reduce the impact of the North Pit on water quality in the Tsolum River. The Ministry of Environment and Parks contracted an environmental engineering consulting firm, Steffen Robertson and Kirsten, to recommend a course of action leading to passive long-term reclamation of the site. Using the report submitted (Robertson *et al.*, 1987), EMPR started a program of minesite reclamation in 1988.

The basic concept of the reclamation plan (Robertson *et al.*, 1987) was to keep air and water away from the pyrite-rich waste rock, wall rock, and ore. Iron pyrite in the presence of moisture oxidizes far faster than when it is dry, and if there is sufficient water, then the bacterium *Thiobacillus ferrooxidans* uses the pyrite as an energy source. The presence of this bacteria can increase the oxidation rate one or two orders of magnitude.

At that time, the North Pit had a large amount of broken rock in the pit area, a large waste pile to the west, a much larger heap on the northern edge of the pit, and a small pile to the southeast. The latter two piles are now covered but the pit area can be seen in Plate 1. Keeping water and air away from the pyrite-rich materials was attempted by: diverting water around the site; concentrating, shaping and capping the more highly mineralized waste rock; cleaning material from the pit; and sealing the bedrock against water intrusion (Galbraith, 1991a). To allow reclamation workers to check on the success of these procedures, piezometers were installed to provide sampling access points and ground water levels. Other monitoring stations were established at the minesite and on Pyrrhotite Creek, McKay Creek, Murex Creek and the Tsolum River. These sites were used to monitor pH, water flow, and the concentrations of metals in the streams.

The effluent draining into the sedge fen via Pyrrhotite Creek does not meet Ministry of Environment , Lands and Parks ("MOELP") water quality standards for drinking water, aquatic life (Singleton, 1987; Deniseger and Pommen, 1995; Marr *et al.*, 1996), and other purposes, as can be seen in Table 1-1.

Table 1-1: Comparison of some metal concentrations and other water quality parameters in Pyrrhotite Creek and the Tsolum River in comparison to the provincial water quality criteria*.

Ion or Metal considered (Dissolved)	Provincial Standard (ppm)		Pyrrhotite Ck. (ppm)		Tsolum River (ppm)	
	Drinking Water Continuous/max	Aquatic Life (Fresh Water) Continuous/max	Below Pit Average/ Range	Br.126 sedge fen Average/ Range	Above Murex Creek Average/Range	Below Murex Creek Average/Range
Copper (Cu)	n.a./0.5	0.002/0.004	6.58	6.58/0.4-16.9	0.002/<0.001 -0.030	0.05/0.04-0.06
Aluminum (Al) (see note)	n.a./0.2	≥6.5 pH, 0.05/0.1	6.8	6.8/0.49-16.9	0.057/0.02-0.14	n/a.
Iron (Fe)	n.a./300	n.a./300	1.09	0.73/0.15-4.01	0.23/0.04-0.69	0.08/0.07-0.09
Cadmium (Cd) Depends on $CaCO_3$	n.a./0.005	n.a./ <0.00001	0.004	0.004/0.002-0.010	n/a	<.001
pH	6.5-8.5/?	6.5-9.0/9.5		4.1/3.6-4.7	6.9/6.4-7.5	6.7
Sulphate (SO_4)	n.a./500	n.a./100		134/15.6-356	1.32/1.0-2.2	n/a
Arsenic (As)	n.a./0.025	n.a./0.050		0.002/<0.001 -0.007	n/a	n/a
Lead (Pb) Depends on $CaCO_3$	n.a./0.050 (0.010 proposed)	<0.003 /0.003		0.001/< 0.001-0.001	0.001/<0.001 -0.001	<0.1
Total Phosphorous (P)	n.a./0.10	0.005/0.015 (lakes with salmonids)		n/a	n/a	n/a
Zinc (Zn)	n.a./5.0	n.a./0.03 (gen.)0.014 (phytoplankton.)	0.215	0.215/0.01-0.43	0.01/<0.01-0.01	<0.1
Manganese	n.a./0.05	0.1/1.0	1.11	1.11/0.04-3.4	0.03/<0.01-0.11	0.01-<0.01

(figures in mg/l, ppm by weight)

*In Table 1.1 the Provincial Standards come from "Approved and Working Criteria for Water Quality - 1995" (Nagpal, 1995). Note: The amount of aluminum allowed is a function of the pH.

Copper, aluminum, cadmium, zinc, and manganese concentrations exceed the MOELP standards for drinking water or aquatic life part or all of the time in Pyrrhotite Creek at the fen inlet. The pH is also lower than acceptable to the Ministry. Some of these metals are also present at unacceptably high concentrations in McKay Creek and in Murex Creek, down to its confluence with the Tsolum River. However, only copper exceeds the limits set by MOELP in the Tsolum River (Kangasniemi and Erickson, 1986; Deniseger and Pommen, 1995).

Project Rationale

Detailed monitoring (Deniseger and Erickson, 1991) showed that during the summer season, a portion (up to 15%) of the copper in the water of Pyrrhotite Creek flowing out of the minesite was being removed by a small wetland just below a logging spur line "Branch 126". Since this wetland is almost entirely populated by a sedge ally (the "Narrow-Leaved Cotton Grass", *Eriophorum angustifolium,* Honck.) and sedges (*Carex* species), it is a "sedge fen[1]" (Kistritz and Porter, 1993; National Wetlands Working Group, 1993).

In spite of retaining copper, this "Branch 126 Sedge Fen[2]" is thriving (see the photographic plates 2 to 5, 7 to 10) so information obtained should be useful for reclamation efforts in other areas, as the use of wetlands to treat wastewater and mine runoff is increasing at a great rate around the world (*see* D. Hammer, 1989; Means and Hinchee, 1995). The fen is at a moderately high altitude (≈1200 m ASL), where commercial reclamation species (primarily non-native grasses and legumes) do not grow well. Investigating how well this cotton grass, *Eriophorum angustifolium,* grows and its role in removing metals could result in its being used on a commercial scale.

Passive wetland treatment appears to offer considerable cost savings over a lime treatment plant. For the Mt. Washington project, consultants estimated $6 million, with a $0.5 million annual maintenance budget (Golder, 1997a), for a lime treatment plant. M. Galbraith (pers. com.), the engineer in charge of previous reclamation work by the EMPR, considers this low, as to minimize risk, the pipeline and plant would have to be "overbuilt". Golder (1997b) gave an series of estimates (depending on the size, route and other considerations) from $3.3 million to $4.4 million to build a pipeline to carry AMD to a treatment plant. No estimate was given for the cost of a treatment plant, but a plant in the interior of B.C. built to handle 10 kg copper per day cost $840, 000[3]. This proved to require significant upgrading. Annual costs including depreciation of this plant could reach $100,000 (McCandless, pers. com.). An estimate by Golder (1997a) for a passive treatment option was $1.2 million, with a $84,000 per annum maintenance cost.

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[1]Although the committee for the nomenclature of B.C. wetlands has not come down with a specific set of names for all wetlands, the designation "sedge fen" is not in dispute.

[2]Examining all the copper mass balance information available, it appeared that, during the summertime, as much as 60% or more of the copper in Pyrrhotite Creek is apparently removed by all the wetlands on the creek downstream of the fen in question (Deniseger and Pommen, 1995, p. 22).

[3]The plant was built at Samatosum, near Barrière, B.C., for Kinross Gold (McCandless, pers. com.).

From the preceding, it can be seen that, although the exact costs are uncertain, a passive wetland method that works could be very cost-effective in rectifying this situation and many others like it.

Another reason for action on this issue on Mt. Washington is the economic value of the salmon run, estimated to be in the order of $30,000 per annum in 1987. Estimated revenue is $200,000 per annum if the pollution was stopped, and $240,000 per annum if fisheries enhancements were made (Robertson *et al.*, 1987, pp.76-77).

Statement of the Problem

The primary question is: how is the sedge fen removing copper from the AMD? The secondary question is: what is the role of the cotton grass, *Eriophorum angustifolium*, in the removal process? The third question is: is it possible to enhance the removal process?

Several hypotheses were proposed for the copper removal mechanism at the beginning of the project:

A: Given the high copper results in the cotton grass leaves and roots, the bulk of copper is being taken up in the cotton grass plants. The copper could then be converted into other forms, upon the death of the plant, by diagenesis.

B: Bacterial reduction of sulphate in the waste water is providing sulphide ions which precipitate the metal as an almost insoluble sulphide (presence of excess sulphide ion decreases solubility of copper sulphide). The bacteria are using components of the peat in the sedge fen as a nutrient source.

C: Copper ions are being adsorbed and complexed through a variety of physical and chemical processes. The ions are being held by complex ligands formed of peat components, fulvic acids, humic acids and other decomposition products of the peat; and/or adsorbed on the cell walls and other organic and inorganic (mainly iron oxyhydroxide) particle surfaces.

D: Dilution of the effluent is lowering the copper concentration, and the apparent lowering of the copper loading is an result of poor flow data collection and interpretation.

These hypotheses appeared to be the most likely to the investigator, and no others have been seriously suggested.

The emphasis in this paper is to clarify the role of the plants in the wetland. The hypothesis to be tested is set as follows:

"The take-up of copper by the Narrow-Leaved Cotton Grass, *Eriophorum angustifolium*, is the primary factor in the removal of copper from the water of Pyrrhotite Creek in the Branch 126 Sedge Fen."

The following sections provides background on metals in plants, copper in plants, the different factors to be considered, and the plant, *Eriophorum angustifolium* itself. Previous work in the wetland which could concern this study (analytical and physical) will be discussed.

Biogeochemistry

Introduction

In the 1950's and 60's, Dr. H.V. Warren of the University of British Columbia (U.B.C.) demonstrated that terrestrial plants could extract metals from the growth substrate (Warren *et al.*, 1953; Warren and Delevault, 1960; Warren *et al.*, 1966). Most of the subsequent research was done with the idea of using the metal content of plants as a prospecting tool (Warren, 1962; Warren and Delevault, 1965; Warren *et al.*, 1966; Fortescue and Hornbrook, 1969; Hornbrook and Hobson, 1969; Hornbrook and Hobson, 1970; Hornbrook and Allan, 1970; Dunn, 1995). Each plant, especially a shrub or tree, serves as as sampler of a larger area than a small soil pit. The metals content was used to indicate the presence of metalliferous anomalies in the surficial materials which could then be sampled, drilled or tested with geophysical methods for the presence of ore bodies. There are several different facets of this research which are of interest in considering the rate of removal of copper by plants from a substrate.

First, some plants tested simply reflected roughly equivalent proportions of the elements in the soil in the plant tissue (Hornbrook, pers. com.). Second, other plants showed elevated metals content only when the metal concentration in the soil rose above a certain amount

(which varied with the soil chemistry) (Hornbrook and Hobson, 1969). Some elements are toxic to a plant's metabolism, and can cause stress or can be fatal, even in small amounts such as 50 ppm (dry weight) (Jones *et al.*, 1995). Consequently, many plant species have evolved exclusion systems which keep element concentrations below toxic limits. However, if toxic element concentrations in the interstitial soil water saturate plant's rejection systems, the plant levels will increase sharply. Often, plants in this situation will show visible signs of stress, such as chlorosis. Third, some plants concentrate one metal or another to a higher level in the plant than present in the soil or ground water. Some plants may show some colour variations (darker leaves, lighter, chlorosis). (Roberts, 1992; Kruckeberg *et al.*, 1993; Kruckeberg and Reeves, 1995). A fourth situation is where a plant only grows in the presence of large amounts of a particular metal or element[4].

In order to establish which situation applies to the cotton grass *Eriophorum angustifolium* in Branch 126 sedge fen, the distribution of *E. angustifolium* will have to be examined. Also, the concentrations of different elements in background plant, soil and water samples will have to be compared to the concentrations in Branch 126 Sedge Fen samples.

Soil chemistry, apart from the metals present, can determine if a plant is useful as a indicator or a metal accumulator. For example, one cotton grass (*Eriophorum vaginatum* L.) (Goodman and Perkins 1968c) picked up five times more manganese when highly fertilized.

Copper, the element of principal concern, most likely enters all plant roots in a dissociated form (Keller and Fredrickson, 1952; Kabata-Pendias and Pendias, 1992). A large proportion of the copper taken up by plants is in the cell walls of the roots, and another large proportion of this copper is in the cell walls and tissues of plant leaves. Once deposited in these organs, the copper is not usually re-mobilized to any great degree until the organ becomes senescent, and may not be re-mobilized even then (Kabata-Pendias and Pendias, 1992).

Kabata-Pendias and Pendias (1992) note that a considerable portion of the copper present in green tissues appears to be bound in plastocyanin and in some protein fractions. Some plants concentrate copper in reproductive organs, but this varies widely between species, and the reproductive organs of cotton grass do not make up a large proportion of the plants

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[4]Some vetches (*Astralagus* spp.) grow only in the presence of high selenium concentrations and concentrate it in their tissues (found in Alberta, not known from B.C.); some ferns (likely *Polystichum lemonii* Underw., which is found in B.C., Kruckeberg, pers. com.), pinks and some wild cabbages grow only in the presence of high nickel concentrations (Usik, 1969; Kruckeberg and Reeves, 1995); and the mosses *Mielichhoferia, Merceya*, and *Pohlia nutans* indicate copper (Brooks, 1995a; Fraser, 1961).

as may be seen in the diagrams of the fen in the following chapter.

The form and behaviour of copper in plants can be summarized as follows (after Kabata-Pendias and Pendias, 1992):

1. Copper is mainly complexed with organic compounds of low molecular weight and with proteins.
2. Copper occurs in compounds with no known functions as well as in enzymes having vital functions in plant metabolism.
3. Copper plays a significant role in several physiological processes - photosynthesis, respiration, carbohydrate distribution, nitrogen reduction and fixation, protein metabolism, and cell wall metabolism.
4. Copper influences water permeability of xylem vessels and thus controls water relationships.
5. Copper controls the production of DNA and RNA, and its deficiency greatly inhibits the reproduction of plants (reduced seed production, pollen sterility).
6. Copper is involved in the mechanisms of disease resistance.

Copper in excess of that required for metabolism results in the following:

1. Tissue damage and elongation of root cells,
2. Alteration of membrane permeability, causing root leakage of ions (e.g. K^+, PO_4^{3-}) and solutes,
3. Peroxidation of chloroplast membrane lipids and inhibition of photosynthetic electron transport,
4. Immobilization of copper in cell walls, in cell vacuoles, and in nondiffusible copper-protein complexes.

(Kabata-Pendias and Pendias, 1992).

If cotton grass is similar to the other plants studied, it will have higher levels of copper in the roots and leaves compared to the other plant parts (stems and rhizomes), except for the reproductive parts, in which the concentrations could vary widely (Kabata-Pendias and Pendias, 1992).

Wetland Biogeochemistry

There are more references to the plants and marshes and bogs than those of fens in the literature on remediation wetlands, but fen plants have been studied.

Carex or *Eriophorum* species are not reported as being indicators or hyperaccumulators of copper, although some members of their family, the CYPERACEAE, are indicators and hyperaccumulators (Brooks, 1995a, Brooks, pers. com.).

Carex species were used at the experimental Bell Mine constructed wetland, as well as *Typha latifolia*, as plants suitable for a remediation wetland. The *Carex* species were *Carex aquatilis* Wahl., water sedge; and *Carex laeviculmis* Meinsh., smooth sedge. Copper concentrations (ppm of dry weight) were an average of 13.2 ppm Cu for the *Carex* leaves, 26.5 ppm for the *Carex* roots, 5.0 ppm for the *Typha latifolia* leaves and 170 ppm for the *Typha latifolia* roots (Gormley *et al.*, 1992).

Other constructed wetlands built to remove metals are often planted with cattails, *Typha* spp., primarily *Typha latifolia,* which is the species found throughout B.C. Examples of these wetlands can be found in Hammer (1989) and in Cooper and Findlater (1990). However, in B.C. this species is found from low to middle elevations, and not at the higher elevations of the project area. It is not a hyperaccumulator. The value of the cattail in remediation wetlands is largely due to its ability to thrive under a variety of conditions, its high growth rate, and its ability to trap sediment.

Initial analyses (see Chapter 3) of the cotton grass leaves and roots in the Branch 126 Sedge Fen revealed that some plants had up to 3300 ppm copper in their leaves and one sample of roots and leaf bases contained 6240 ppm copper by dry weight. The amounts found in these plants far exceeded those reported to date from any plants in B.C. or in Canada (C. Dunn, pers. com.). High values noted in the literature were in a grass (creeping red fescue, *Festuca rubra* L.) and in a lotus (birdsfoot trefoil, *Lotus corniculatus* L.) at Bell Mine (Jones *et al.*, 1995). Samples of both gave a maximum concentration of 800 ppm. Unnamed legumes in the yard of Gibraltar Mine had a maximum concentration of 1884 ppm (Gormley *et al.*, 1992; Jones *et al.*, 1995).

No studies on cotton grass heavy metal or transition metal uptake were found in the literature, other than Goodman and Perkins (1968c), and only a few on "true" sedges, members of the genus *Carex* (closely related to the genus *Eriophorum*, the cotton-grasses), therefore any information covering these plants' metal uptake and possible remediation uses is new.

Goodman and Perkins documented the behaviour of two species of cotton grasses (*Eriophorum angustifolium* and *E. vaginatum*) when subjected to various fertilization treatments (Goodman and Perkins, 1959; 1963; 1968a; 1968b; 1968c). Gebauer *et al.* (1995) looked at the flooding regime, nutrients and the level of soil oxygen influencing the growth of the same two species. Cotton grasses are circumpolar, and the species, *Eriophorum angustifolium*, the "Narrow-Leaved Cotton Grass[5]" which is found at the Branch 126 sedge fen, is ubiquitous at higher altitudes, but can be found down to the seashore (Pojar and McKinnon, 1994, p. 407).

Some other information on cotton grasses was noted. Goodman and Perkins (1968b, 1968c) found that potassium was a limiting factor in the growth of *Eriophorum vaginatum* and Glaser (1987) noted that *Eriophorum spissum* was only found in low nutrient "poor fens" on the verge of becoming bogs. Mitsch and Grosselink (1993, p. 394) noted that: "Many bog plants have adaptations to the low nutrient supply that enable them to conserve and accumulate nutrients. Some bog plants, notably cotton grass (*Eriophorum* spp.). translocate nutrients back to perennnating organs prior to litterfall in the autumn to provide nutrient reserves for the following year's growth and seedling establishment." Gebauer *et al.* (1995) studied this allocation in *E. angustifolium* and compared it to *E. vaginatum.* They also noted that *E. angustifolium* grew best when the soil was anoxic, and were able to determine the proportions of vegetative mass of the plants in leaves, rhizomes, and roots.

Although the narrow-leaved cotton grass is not known to indicate high copper concentrations in water or soil, there are many varieties of plant species which have not separated sufficiently from their parent taxon to be considered separate species, but which have very greatly different capabilities. For instance, there are metal-tolerant varieties (Brooks, 1995a). Some of these are palaeo-endemic varieties which may have been widespread. They are now found in restricted areas because they are resistant to metal poisoning. Others are neoendemic varieties which are derived from widespread species and are evolving to utilize or resist the toxic effects of high metals concentration.

Wetland plants growing in iron-rich water often develop an iron plaque on the roots. This can affect the uptake of nutrients and elements into the plant, and can also serve to provide adsorption sites for many elements (Otte *et al.*, 1995; St.-Cyr and Campbell, 1996). The plants of Branch 126 Sedge Fen will have to be examined for iron plaque formation.

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[5]Also known as the "Many-Spiked Cotton Grass", *Eriophorum polystachion* L. (Hitchcock and Cronquist, 1973).

Apart from the use as a prospecting tool, hyperaccumulators have been suggested as tools in "green remediation" (Chaney and Angle, 1993). According to Brooks (1995a), plants suitable as tools for "green remediation" should:

(1) have an appreciable biomass,

(2) be able to tolerate a cool climate since there is an urgent need for remediation in temperate zones,

(3) be easy to grow.

Using an hyperaccumulator as a green remediation tool would require that the plants be grown for a season, then harvested, burnt, and the residue smelted to recoup some of the costs. Since little or no sulphur is given off in the burning and smelting, pollution is lower than from traditional ore processing (Brooks, 1995a).

Wetlands Soil Chemistry

The nature of the wetland will have a great influence on the soil geochemistry. General classes are bogs, fens, marshes, carrs and swamps (Kistritz and Porter, 1993; National Wetlands Working Group, 1993). Typically, *Sphagnum* spp. dominate bogs. Sedges and sedge allies dominate fens. Herbaceous plants dominate marshes. Shrubs dominate carrs, and trees with open water areas dominate swamps. The source of water may be surface flow, meteoric, or groundwater, and this water may be high or low in minerals. Few generalizations can be made and they cannot be counted on to apply to a particular wetland. To use pH as an example, ombrotrophic bogs tend to be acidic, and they are usually around a pH of 4. Sjörs related wetland types and associated pH in the following listing: Bogs, 3.7-4.2; Extreme poor fen, 3.8-5; Transitional poor fen, 4.8 - 5.7; Intermediate fen, 5.2 - 6.4; Transitional rich fen, 5.8 - 7; Extreme rich fen, 7 - 8.4 (Shotyk, 1988). However, pH differences between seasons can be as much as two pH units. Minimum pH levels occur in May-June, and maximum pH in September. The pH varies horizontally and vertically in bogs and other wetlands (Shotyk, 1988). Using the pH as a guide, since the wetland pH results (see Chapter IV) range from 4-1 to 5.7, this wetland ranges from being a bog to an intermediate fen. However, nutrients are in good supply (see soil analyses in Appendix 2-3) any *Eriophorum angustifolium,* prefers richer soils to other cotton grasses such as *E. spissum* (Glaser, 1987); so this sedge fen is an intermediate fen.

Fulvic and humic acids[6] in wetlands can serve as ligands and form complexes with the transition metals such as copper (Lett, 1978). At the Mt. Washington site, dissolved copper

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[6]When NaOH solution is used to extract material from peat and other plant material remains, humic acid is the amorphous material which comes out of the extraction solution when the base is neutralized with HCl, while fulvic acid remains in solution. Both are organic polymers, but humic acid has a higher molecular weight than fulvic acid. Both have phenolic and carboxylic acid residues (Lett, 1978).

is high in the water of the background area (avg. 0.002 ppm), but most of this is not bioavailable as it is in dissolved fulvic and humic complexes (Deniseger and Pommen, 1995). These organic acids can also affect transition metal adsorption onto iron, aluminum and silicon hydroxides and oxyhydroxides (Düker *et al.*, 1995; Tessier *et al.*, 1996).

Many metals can concentrate in wetlands. With these following past examples it can be seen that it is possible to use wetlands to our advantage in removing toxic metals from solution.

The first iron ores exploited in northern Europe and in North America were bog iron deposits. Bog iron ores form where reduced iron, originally formed in reducing conditions and then dissolved in ground water, is oxidized and precipitates as lenses in wetlands. Decaying vegetation of the wetland causes the reducing conditions (Craig *et al.*, 1988).

In the Late Neolithic period of Europe, copper bogs were the major source of copper, and copper bogs were mined in Wales in the early 19th century (Brooks *et al.*, 1995; Fraser, 1961). Lett (1978) investigated a copper-rich bog in the Cascades, which was receiving copper-enriched ground water and found that copper is retained in a number of forms. The largest reservoir of copper was bound by chemical and physical adsorption onto soil organic matter, largely on fulvic and humic complexes. The next most abundant reservoir of copper was bound to proteins which were part of the preserved cell wall membranes of the decomposing plant fragments. Finally, there was a variety of authigenic mineral grains, mainly sulphides: chalcopyrite; chalcopyrite-covellite; covellite; and native copper-cuprite grains. In west-central B.C., chalcocite was the major form of retained copper in a wetland marginal to a lake, although the nearby constructed wetlands held most of the retained copper in organic reservoirs, with the next largest reservoir of copper adsorbed onto iron oxides (Sobolewski, 1996).

Zinc in a New York bog has been reported at values up to 8.8% (Cannon, 1955) dry weight. Fletcher *et al.* (1995) reported a twenty fold increase of platinum and associated metals in organic seepage soils, compared to non-seepage soils on nearby slopes, in the Tulameen area of southern British Columbia. Many other metals have been reported in the literature as being concentrated in wetlands including manganese, cobalt, lead, uranium, arsenic and nickel (Rose *et al.*, 1979; Levinson 1980; Sobolewski, 1997c) .

Previous work specific to Branch 126 sedge fen

There has been a little previous research done on the Branch 126 Sedge Fen. The Environmental Protection Branch of Environment Canada did some unpublished research on the plants of the wetland (Ferguson, 1985). Erickson, Deniseger and their co-workers monitored the concentrations of metals flowing into and out of the wetland (Deniseger, 1995; Deniseger and Pommen, 1995; Erickson and Deniseger 1987; Erickson and Deniseger 1994). Deniseger and Kwong (1996) examined this and the downstream wetlands as sources of organic carbon and as sediment sinks.

Hay bale weirs were built to increase retention time through the fen of the contaminated water flowing from the minesite through the fen with the intent to increase the amount of copper retained (Sobolewski, 1996).

Erickson and Deniseger built the initial hay bale weirs (see Plate 2) and a concrete weir at the wetland outlet in 1991. In 1992, Erickson, Deniseger and the author extended and repaired these hay bale weirs (see Plate 3) to the extent marked on the outline of the sedge fen in Figure 2-4. Hay bales were used because: they create a reducing environment as the hay decomposes; they can filter out solid matter, such as sediment; and they are easily installed. Since then, the wetland has been relatively unmodified with the minor exception of a V-notch weir the author built at the outlet in 1995. This was a modification of the outlet weir lip and not designed to impede the flow or appreciably change the water level in the fen.

Chapter II - Description of the Study Site

Location

The study site is located 23 km west-northwest of Courtenay's town centre, on Vancouver Island, British Columbia (see Figure 2-1). The study site is on the north side of Mt. Washington, an eastern outlier of the Insular Ranges of Vancouver Island with a summit elevation of 1608 m. The mine site is approximately 1 km north-northwest of the summit of Mt. Washington, and the Branch 126 sedge fen is about 1.1 km just east of due north of the Mt. Washington mine site's North Pit. The fen is bisected by Pyrrhotite Creek, and lies about 2.5 km due north of the summit of Mt. Washington.

Topography and Landforms

The summit area of Mt. Washington is fairly precipitous, with three subdued arêtes running from it: one to the south-southeast, known as the "South Arm"; one to the north-northwest, known as the "West Arm"; and one to the east-northeast, known as the "East Arm". McKay Lake is a cirque lake in the cirque between the latter two arêtes, and the minesite is on the slope facing to the northeast of the arête running to the north-northwest (see Figures 2-2 and 2-3, and Figure 2-8).

Elevation of the minesite is between 1270 m and 1350 m, while the sedge fen is at approximately 1200 m.

History

Native peoples may have used this area to hunt for marmots (David Routledge, pers. com.), but no archaeological sites have been found.

Early prospectors found gossans and evidence of copper mineralization. Malcolm McKay staked claims in this area before the Second World War, some of which, the "Domineer" group, cover the minesite area. During the war, H. K. Springer and Associates and Cominco looked at the property. In 1951, Noranda investigated the area. The area of the minesite was first accessible by road in 1955 (inspection from the aerial photographs), and Gordon C. Murray formed the Mount Washington Copper Co. This company, in partnership with Noranda and then Cominco, "proved up" some reserves. These were 600,000 tons of ore

grading 1.4% copper, with some gold and silver (Mamen, 1965). Roads were built from Duncan Bay and along the Oyster River to facilitate the removal of timber, and with the start of logging in the lower elevation areas north of Mt. Washington, it was feasible to construct a route for diamond drilling crew access into the mineralized area. This road passed by the southern end of the sedge fen, and some overburden was emplaced onto the southern margin of the fen as road fill. Further road construction occurred to the south of the fen, as the diamond drilling outlined the areas of economic mineralization. To minimize travel time, a road was constructed from the proposed minesite to the Dove Creek Mainline, an offshoot of the Comox Logging Road. The Dove Creek Mainline has now been replaced by the Mount Washington Road, the main access to the developed ski area on Mt. Washington (which extends from the summit of Mt. Washington to approximately 2 kilometres south of that point, see Figures 2-2 and 2-3).

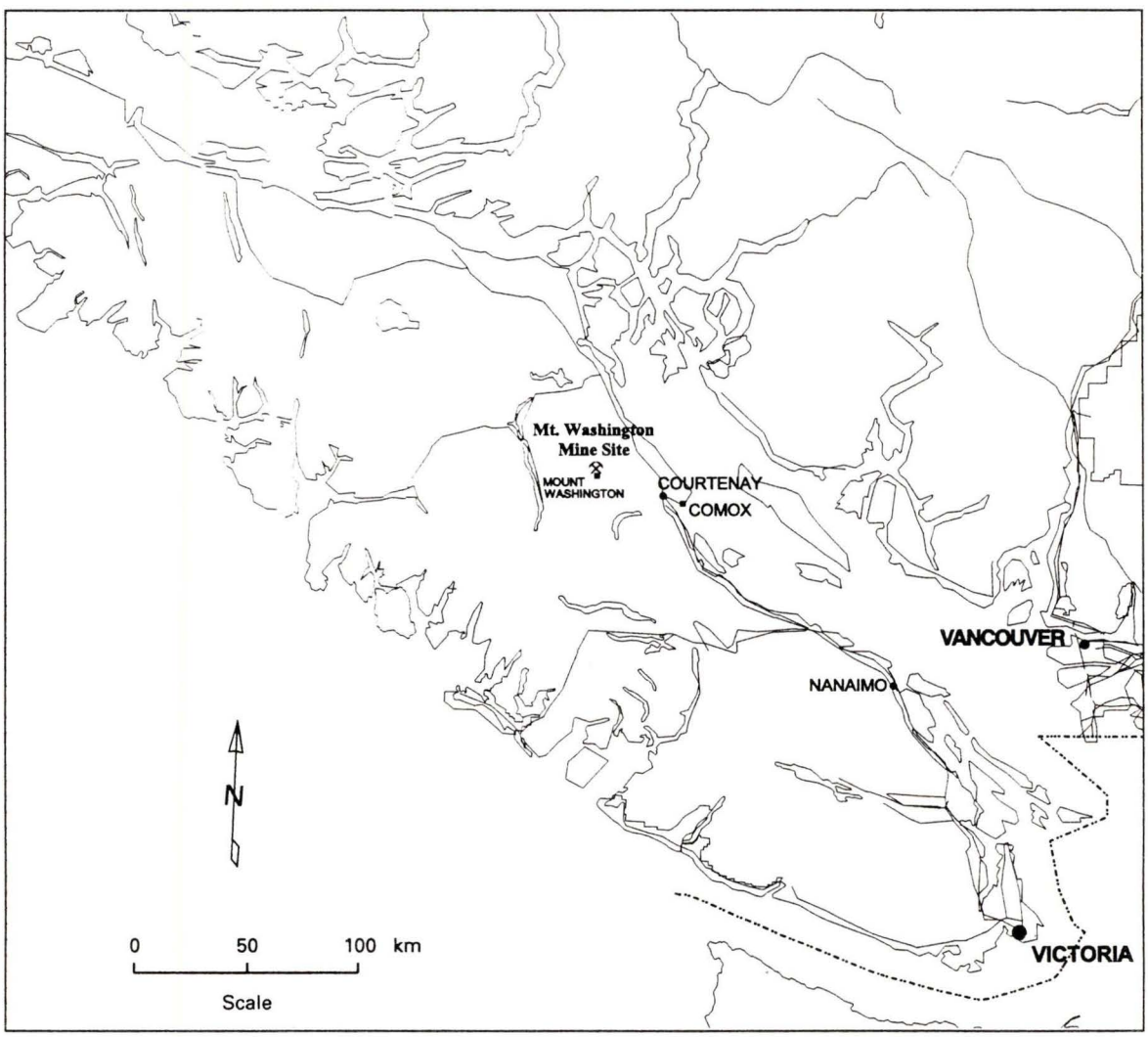

Figure 2-1: Location of Mt. Washington Copper Mine on Vancouver Island

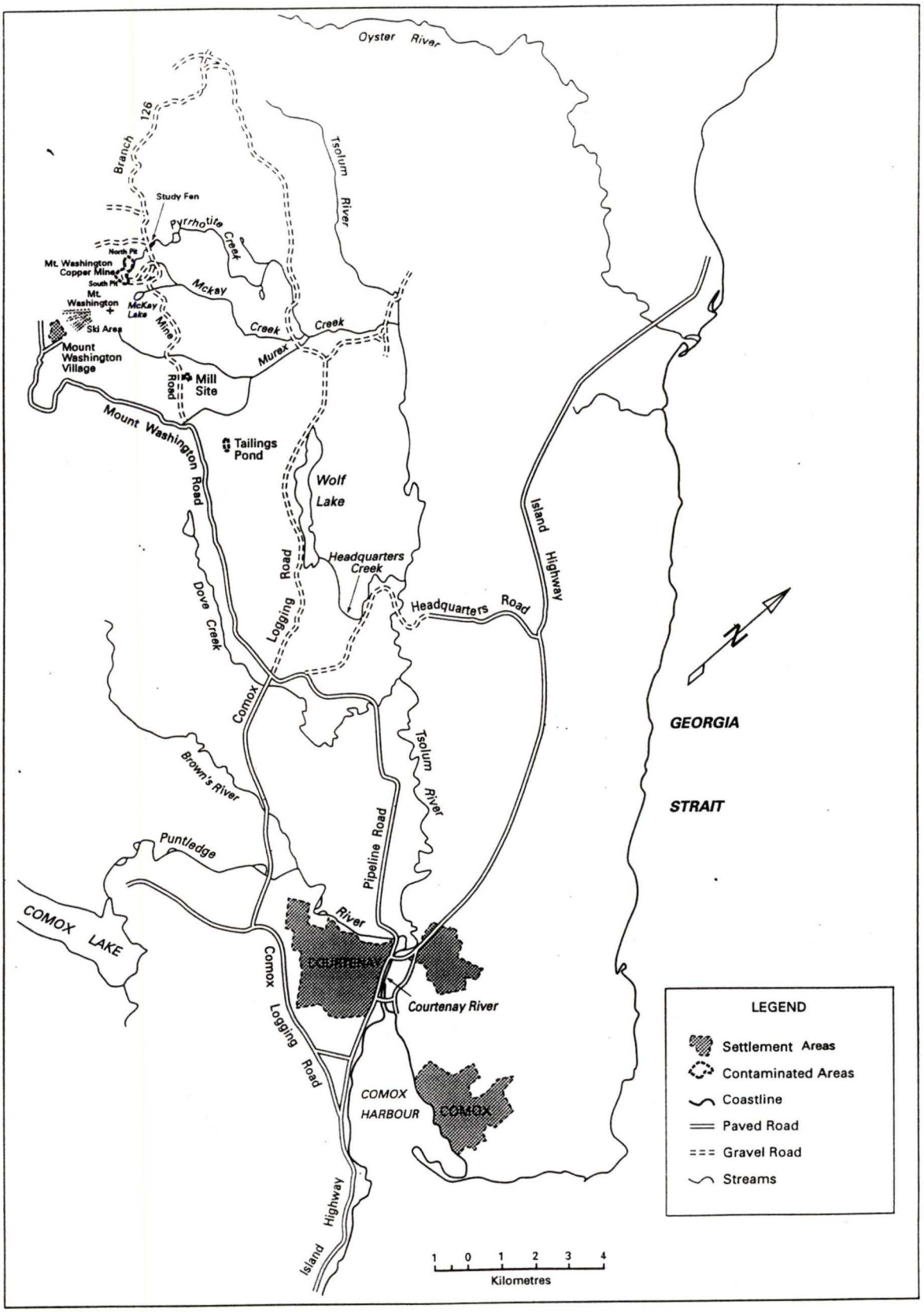

Figure 2-2. Overview: Courtenay - Mt. Washington Area

A mill site and tailings impoundment were set up along the Mount Washington Mine Road (see Figures 2-2 and 2-3), and these were ready for operation by the winter of 1964. The mine was opened Dec. 5, 1964 and run as a joint operation of two companies: Mt. Washington Copper Co. which mined the property; and Cumberland Milling Co. which ran the mill (Mamen, 1965). 381,773 tonnes of ore were mined from 1964 to 1966; and 359,330 tonnes were milled from 1965 to 1967, producing 7,235,180 g of silver, 130,788 g of gold, and 3,548,191 kg of copper (Minfile 92F-116). After all operations at the mine ceased by the summer of 1967, the roads were used by the forest companies to access their holdings for timber harvesting. The block to the southeast of the sedge fen was logged around 1977. Some trees in the southern margin of the fen were cut at that time, but not all were harvested and some were left at the site. Harvesting for timber required at the mine site had been done from 1955 to 1965, and some trees may have been taken from the southern margin of the fen in that period (personal observation, inspection of the aerial photographs, and Robertson *et al*,1987).

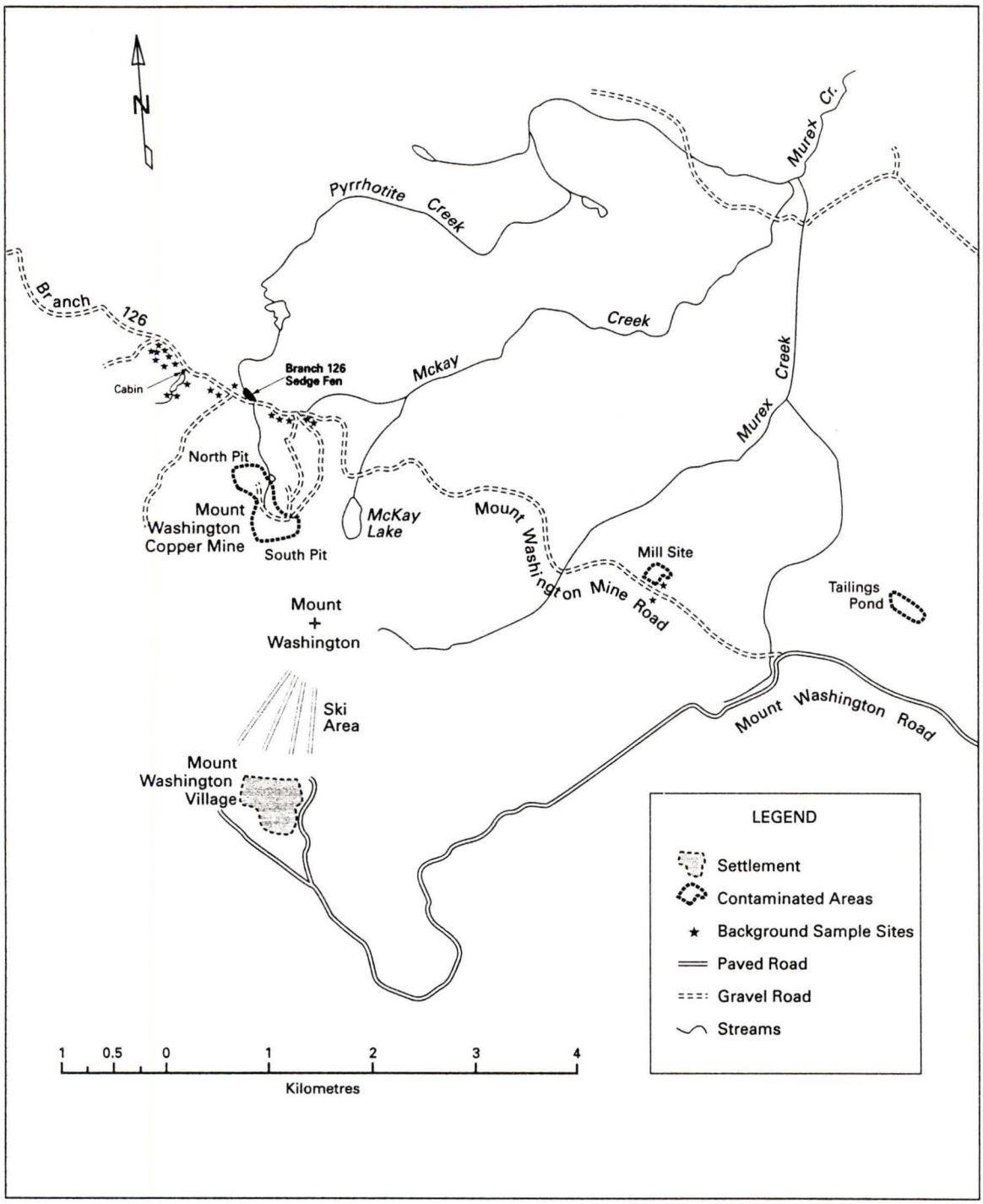

Figure 2-3. Mount Washington Area, showing the mine site, Branch 126 Sedge Fen, and the locations of the background sample sites.

When the rehabilitation of the minesite was attempted, the mine road to the ski access road, labeled "Mount Washington Road" in Figure 2-3, was improved. From 1988 to 1994,

Murray Galbraith of the Resource Management Branch of the Ministry of Energy, Mines and Petroleum Resources worked on the site to reduce copper loading in Pyrrhotite Creek. Weirs were installed to serve as flow measurement sites and monitoring points for the water chemistry. The weir referred to as the Branch 126 weir was built on Pyrrhotite Creek just south of the road crossing in an area of bedrock in 1988 (British Columbia Acid Mine Drainage Task Force, 1992; Galbraith, 1991a; Galbraith, pers. com.).

At the minesite, mining waste was gathered, compacted, and covered with till borrowed from a site about a kilometre away, first. Later, the "hottest" [both literally from oxidation of the pyrite (which increases the temperature perceptibly) and due to metal concentrations from the leachate] materials left were covered with concrete, or with geotechnical fabric and asphalt emulsion to keep water and air out. Water was diverted and instrumentation installed to monitor the site (later removed). This work was done to apply the recommendations in the report by Robertson *et al.* (1987).

In 1990, the bridge over Pyrrhotite Creek was replaced (Galbraith, 1991a; Galbraith, 1993). Hay bale weirs were added to the fen in 1991, then expanded and repaired in 1992 as previously noted (see Plates 2 and 3).

A log crib was built and filled with hay, to test the possibility of using a tiered set of reaction cells to remove metals and raise pH. These cells were expected to become anoxic, and the growth of sulphate reducing bacteria would then produce sufficient hydrogen sulphide to precipitate much of the copper.

The results of the work on the minesite were unsatisfactory, as the copper loadings in Pyrrhotite Creek remain high, as previously noted (Deniseger and Pommen, 1995). The log crib of hay bales became plugged with iron compounds, and the contaminated water simply flowed over the reaction beds, rather than through them, as planned (Galbraith, pers. com. and personal observation).

Branch 126 Sedge Fen Topography

The sedge fen (including the stream channel area) is approximately 4200 m^2 in area (see Figure 2-4), has a maximum depth of 2.4 m (see Figure 2-6a) and a mean depth overall of 0.5 m. Its volume of peat (excluding the southeast arm, which is not involved in metals uptake so far as could be determined) was calculated at 2,062.3 m^3. As this would include the water contained in the channels, rounding this figure off to 2000 m^3 is justified. From the southern end, which has a steeper profile than the body of the fen (see Figure 2-4), due to the presence of an alluvial fan (laid down by Pyrrhotite Creek), the surface is slightly

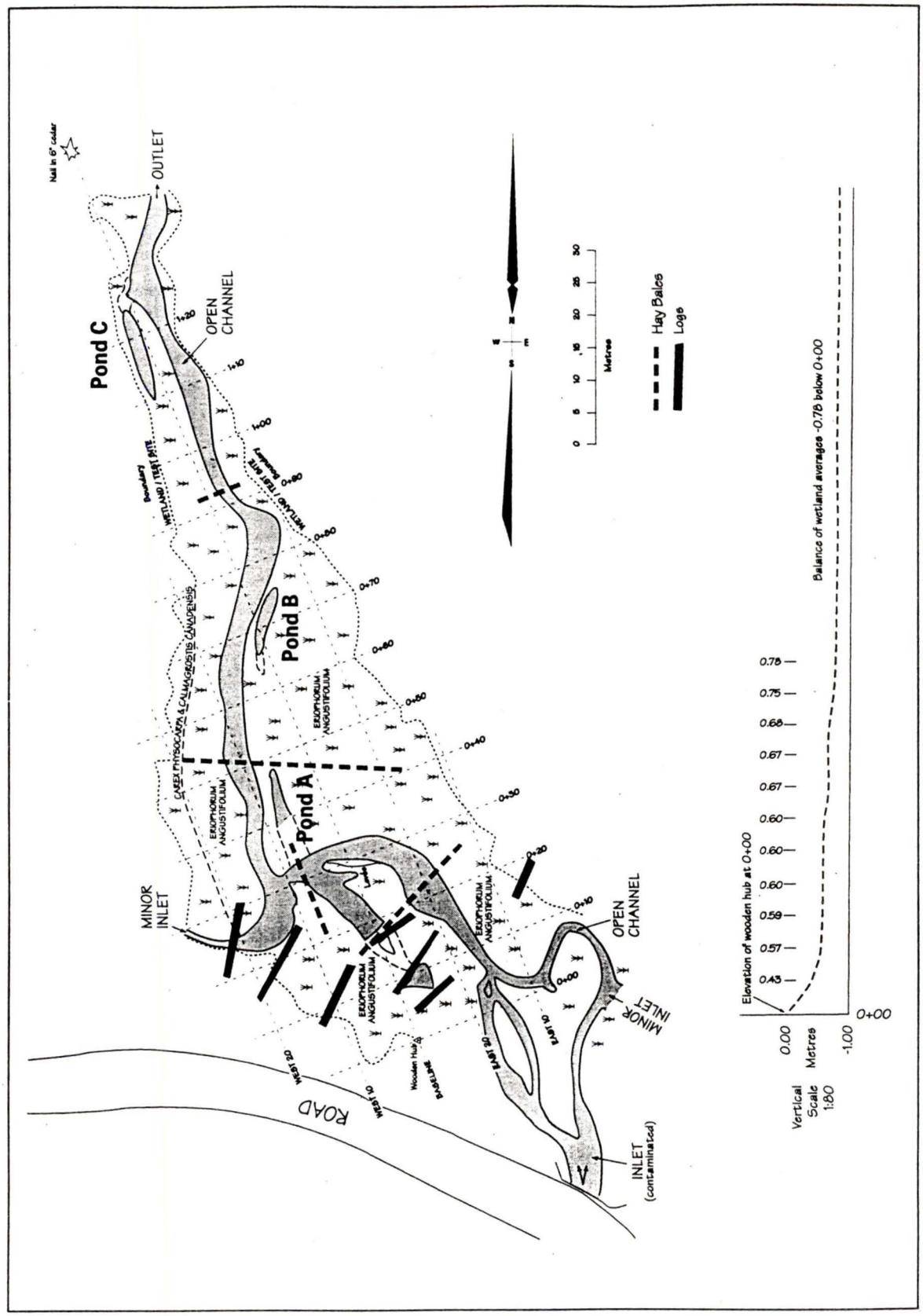

Figure 2-4: Branch 126 Sedge Fen Topography

domed (the crest of the fan), dropping slightly to the east and west. Going down the baseline, the surface of the fen drops almost 0.5 m in the first 5 metres, another 0.1 m from there to the south bank of the main channel (a distance of 25 metres), and another 0.18 m in the 25 metres from the south bank into the centre of the fen. From that point, to the end of the fen, there was less than a centimetre drop. There are very slight levées along the banks of the main channel, which are barely 2 cm above the dry season water level. There are some shallow (8 to 20 cm deep) ponds in the fen soil surface, which can be seen in various of the outlines. These ponds are marked as ponds A, B, and C on Figure 2-4. The hay bale weirs were approximately 30 cm above the surface of the fen shortly after installation. See Figure 2-4 for the locations of these hay bale weirs, and Plate 3 for the photograph which shows them best, taken in October, 1992. Currents in the fen were measured in August 1994, and these are shown in Figure 3-3. This was a middle stage (between freshet and drought conditions) when the currents were most complex. In drought conditions, only the channel had any current, and in flood conditions, the water flows over the entire fen evenly, from south to north (see Plate 6, of the fen in June, 1995).

North of the widest part of the fen, the bedrock rises steeply from the fen to the west and gently to the east. To the south, the alluvial fan of Pyrrhotite Creek and the road berm mark the southern extent of the fen.

Watershed of Branch 126 Sedge Fen

All of the surface drainage from the northern open pit (North Pit) is carried by Pyrrhotite Creek. However, there is some drainage from the "West Dump" waste pile adjacent to the North Pit, to the northwest, into the Piggot Creek watershed (see Figure 2-5). To the southeast, the South Pit drains into the McKay Creek watershed, initially a small tributary to McKay Lake. Downstream, this is met by Pyrrhotite Creek (see Figures 2-2 and 2-3). McKay Creek almost immediately flows into Murex Creek and that flows into the Tsolum River (see Figure 2-2). Figure 2-5 shows the drainage relationships around the minesite's North Pit, the weirs and their locations in regards to the drainage system.

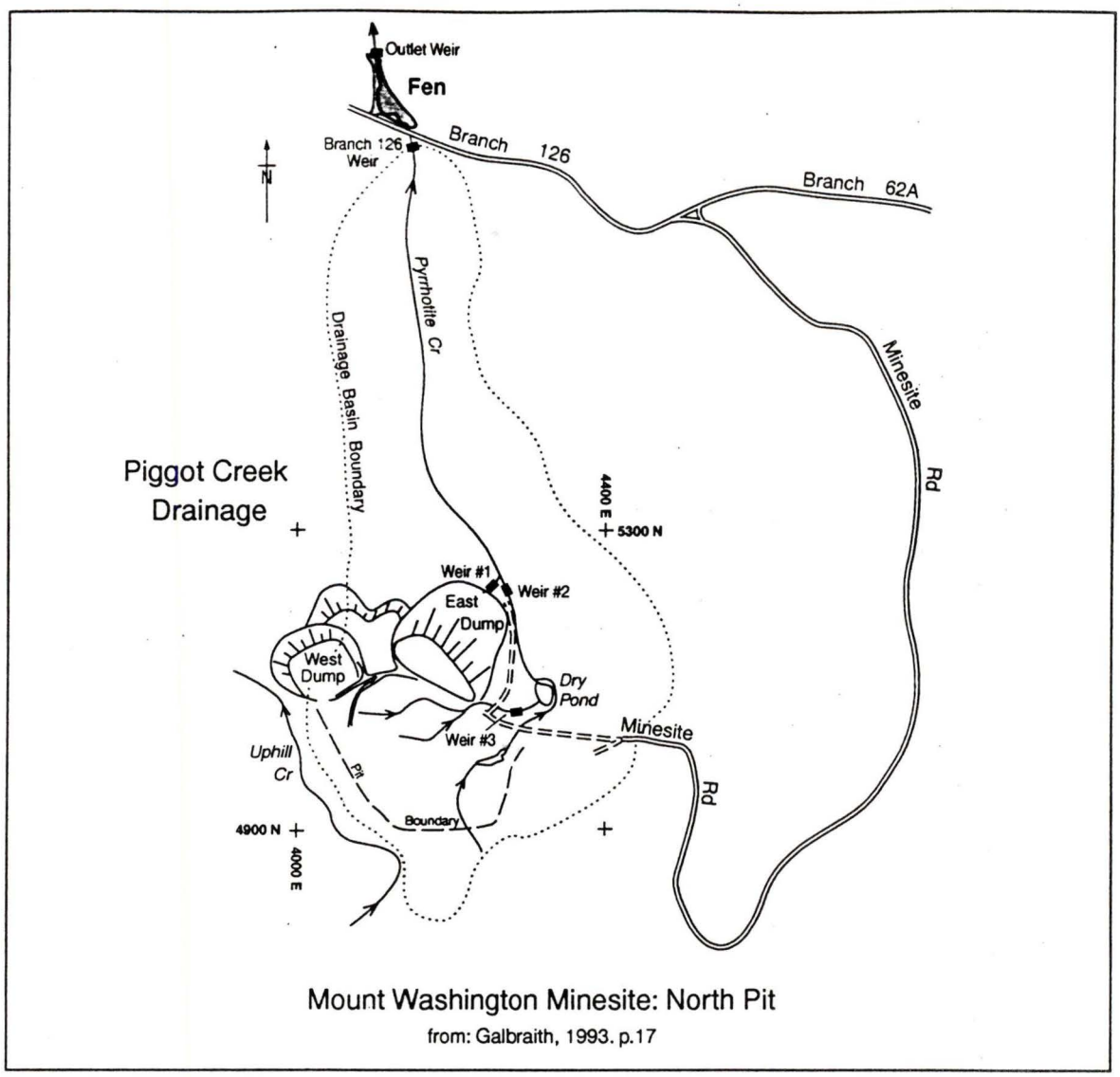

Figure 2-5 Mt. Washington Minesite - North Pit

The watershed of the fen and changes in that drainage area or the established drainage pattern will influence the deposition of sediments and metals in the fen. This must be considered when interpreting changes in the fen through time, such as the variation in metal deposition, the metal species deposited (or removed), the channel stability, and the vegetation of the site.

The surface drainage from the wetland is through the weir at the northern end of Branch 126 Sedge Fen. Almost all (~ 95%, by measurement, see Chapter IV) of the surface drainage into the fen derives from Pyrrhotite Creek, which enters on an alluvial fan at the south end of the fen. The two small inlets which enter on the southwest side and the southeast corner of the wetland (see Figure 2-4) provide a minor amount of surface drainage into the fen.

The local topography and plant ecology of high altitude wetlands tends to remain fairly stable over time, provided major events such as a glacial advance do not interfere (Graumlich, 1994). That is, the local topography tends to become flat and remains flat (although there may be some doming, if the area develops into an ombrotrophic bog), and the plant ecology tends to divert from a "standard" sequence (as the wetland goes from lake or pond → shallow lake or pond → rich fen → poor fen → bog) (Shotyk, 1988; Mitsch and Grosselink. 1993) less in species presence/ absence and dominant species over time than less hygric ecosystems (Graumlich, 1994).

Surficial Geology and Soils in the Fen and Surrounding Area

The bulk of the area surrounding both open pits and adjacent to Pyrrhotite Creek to well below the Branch 126 Sedge Fen is covered by a veneer of till, with the exception of the wetland itself, and bare outcrop. The lower part of the till, where exposed in road cuts, is generally clay-rich, matrix-supported, indurated, almost impervious to water (water does not appear to penetrate below the weathered rind), grey to grey-buff and weathers to a buff gray. The larger clasts range from rounded to angular, but most appeared to be slightly to moderately rounded, and of a very varied lithology (most were intrusive rocks, many others volcanic or metasediments). This till can be seen covering the waste dump in Plate 1 (The more brown-orange streaks on the dump surface are areas of weathered till or ablation till, as can be seen along the roads). The surface layer of this veneer has apparently become weathered and/or there is a layer of ablation till present. These upper layers are porous, orange-brown, full of gravel, and cobble sized clasts, many of which are angular. It is sandier, and more oxidized, and clast-supported. However, the boundary between these layers does not appear to be a depositional boundary, but an oxidation and weathering boundary. With soil creep, solifluction and windthrow, this surface material has moved downslope to become colluvium. Many areas of bedrock are exposed and show strong signs of glacial striae and polishing. The lineations in this area are mainly north-south.

The sedge fen has a volume of about 2000 cubic metres (see previous discussion on topography). From inspection of the cores and soil pits, this volume is almost entirely sedge peat, with some gyttja lenses. Some very faint banding was present in the cores and in the original pits dug in September 1993, which was thought could be due to the Mazama ashfall, but the banding did not correlate between cores and the later soil pits dug, and the banding is believed more likely due to climatic fluctuations, dust, or flood episodes. Also, the fen is beyond the known northern limit of Mazama ashfall (Hebda, pers. com.). No palynological

work has been done yet on the cores, nor has any carbon-14 dating been done, so the age of the fen is not known. However, the Fraser glacial advance overrode most of Vancouver Island, with the exception of Brooks Peninsula, and the retreat of the main ice mass started about 14,000 years ago (Hebda, *et al.*, 1997). Given the fresh-looking striae and the location of the fen, it seems most probable that the fen basin was excavated by glacial action at this time (or cleaned out if it pre-existed this last glacial advance)[1].

The area surrounding the fen would have been clear of ice shortly after the retreat was underway, but the conditions would have been tundra-like for some time, until the main ice mass and most of the alpine glaciers nearby had retreated to the point that the climate approached that of the present (Clague, p. 40, in Fulton, 1989).

The glaciations may have moved mineralized material from the pit area into the till area to the south of the fen, but this seems unlikely, although other sites nearby could contribute mineralized clasts to the fen watershed. Striae to the west and east of the fen show glacial ice movement from the northwest to the southeast at the level of the fen. Some striae are aligned more north-south beside the fen, and the alpine valley glaciation from Mt. Washington going from the cirque in which McKay Lake now sits may have given rise to those, and moved mineralized material into the watershed from the pit area. However, this does not seem probable as the valley glacier would have gone in the general path that McKay Creek follows presently. In discussions with Dr. June Ryder and others[2], it seems likely that the north to south striae and tool marks were the oldest, formed during the height of the Fraser advance as the ice overrode the Vancouver Island Ranges, and the northwest to southeast striae and tool marks were the youngest, formed as the ice was retreating and no longer overriding the Vancouver Island Ranges, but flowing down the Georgia Depression. Some or all of these marks could have been made during an earlier advance or retreat of the glaciers, but there still seems little reason to expect mineralized till from the minesite in the immediate area of the fen.

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[1]This is by no means certain, as a number of small fossil wetlands which predate the last advance have been found and dated from before the Fraser Glaciation. These have been shown on various field trips the author has been on, latterly led by R. Hebda and P. Bobrowsky. (Hebda, pers. com.; Bobrowsky, pers. com.).

[2]Dr. Ryder is with Ryder and Associates, Vancouver, B.C.; the others were Don Howes and Bob Maxwell of the B.C. Ministry of Environment; John Clague of the Geological Survey of Canada, Vancouver Office; and Dan Smith of the University of Victoria Geography Department.

The southern end of the fen, where the road is built, is marked by a small alluvial fan on till. Immediately west and east of the fan, the dense till described above underlies a less consolidated thin veneer of weathered dense till and colluvium (possibly some ablation till). The lower part of the till is the same gray, indurated, matrix-supported clay rich material commented on earlier, and the upper layer is clast-supported, sandy, permeable, oxidized, and orange brown in colour. As in the previous instance, there is no clear depositional boundary. The boundary appears to be a weathering boundary, and the eluviation of clay from the till the reason the material is clast-supported.

The soils in the fen are primarily organic, with a silt component. The silt content is apparently lower in the northern part of the fen (by visual observation), but there were only 4 LOI (Loss on Ignition) tests done to the time of writing. These gave an average of 33% loss on the two samples from the fringe of the fen, and 80% loss on the two samples from the core of the fen. Using the "rubbed fiber" scale (p. 96, Luttmerding, *et al*, 1990), the vast majority of all the soil samples from the fen (and from the background sites) were moderately decomposed, as the rubbing allowed most of the soil materials to wash away. Using the von Post "Scale of Decomposition", the samples from the fen and the background samples were mostly 5, with some possibly just 6 on the Decomposition Class Description (5 is Moderately decomposed; plant structures are clear but becoming indistinct; squeezing yields much cloudy brown water and some peat material escapes between the fingers; residue is very mushy. 6 is moderately strongly decomposed; plant structures are somewhat indistinct but clearer in the squeezed residue than in the undisturbed peat; about a third of the peat material escapes between the fingers; residue strongly mushy.) (Dumanski, 1978). The soil is primarily a Mesisol, and these soils for the Vancouver Island Ranges have been given the name "Ahousat" soils (Jungen, 1985).

As it is in a fen, the extreme upper tier (0.5 cm) is Fennic (p. 56, Canada Soil Survey Committee, 1978), and the layers below that are a thin (~1 cm) Fibrisol/ Fibric Mesisol. These overlie a thick Mesisol which is close to being a Humic Mesisol by the degree of decomposition noted above. Changes in the peat colour, decomposition grade, etc. are very slight down to 0.8 m and beyond, although they exist.

Fresh growing roots from the cotton grass were found down to 0.8 m. Twigs and dead segments of cotton grass rhizomes were noted in the cores and soil pits. The cores were largely a dark umber in colour. Occasionally, small sections of gravels were met and some sapropel-like gyttja. The gravel lenses were interpreted as being either due to floods which carried

stream substrate further down the alluvial fan onto the organic soil areas than normal, or slight variations in the channel location. Only single gravel-sized clasts were noted in the peat away from the fan and away from the channel. In some cases, a layer of deep brown muck was found, which slithered out of the core tube with little urging. This looked, felt and smelled like the gyttja found on the bottom of many small ponds, and was so interpreted to be the evidence of small shallow ponds in the fen. Since this material provides little resistance to the probe rod, it seemed likely that there was an accumulation in the deep spot noted in Figure 2-6 (shown schematically in Figures 2-7a and 2-7b), otherwise it would have been impossible to push the rod down that deep, or withdraw it as readily as was found to be the case. As the fen is usually covered with water, and when not, the surface is only slightly elevated above the water table (well within the distance capillary action will lift water), the soil is peraquic.

A small section to the west side of the fen was included within the border of the fen on Figure 2-4 because it does not support shrubs or trees, and it was difficult to show an exact boundary without digging a lot of holes. The soil in this area, which was shallow to bedrock, was fibric. This was a folisolic fibrisol as described by Jungen (Jungen, 1985, p. 16), with twigs, needles, leaves and roots making up most of the bulk of the material. It is a very minor component of the fen soils.

The organic soils of the background sample sites which are in fens appeared identical to the soils of the subject fen in all respects. The profile and decomposition grades were similar, and there were also gyttja lenses in the background sample sites numbered 8 and 9 in Figure 2-3.

Soundings in the fen conducted with a steel rod indicated an impenetrable layer in most places. Hand pressure easily pushed the rod in until resistance was felt. A 1 kg maul was used to hit the rod, to make sure that the rod had reached bottom, but over most of the fen, this did not result in any movement of the rod. This area where the bottom was "impenetrable" was the entire northern part of the fen. From south of the 30N grid line (see Figure 2-4), the rod could be driven in a few centimetres on some, but not all, of the locations tested for peat depth. Some of the soundings hit buried tree trunks, but these were easily identified by the sound and feel of the rod. Soil pits dug along the 10E line from the 60N to 100N grid lines went directly to bedrock. Figure 2-6 shows the results of this sounding. Figures 2-7a and 2-7b show the presumed cross-sections.

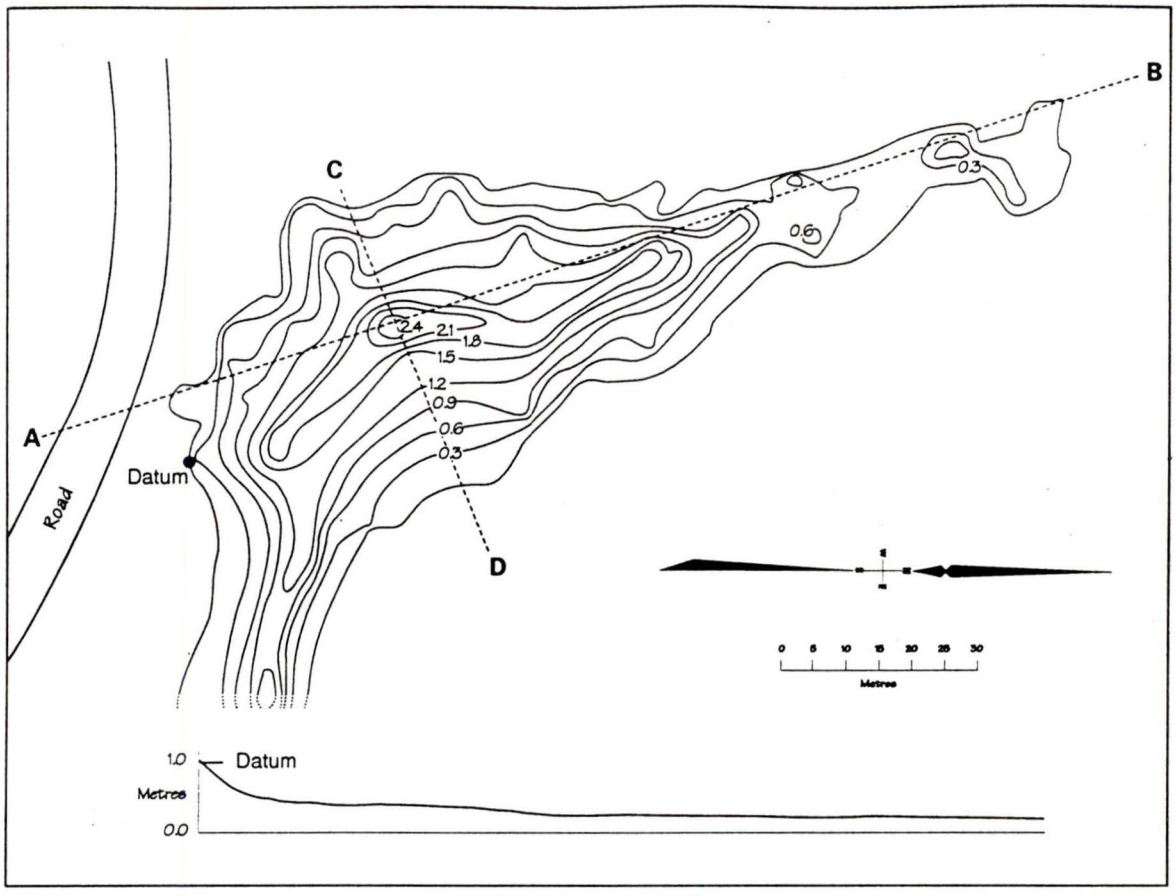


Figure 2-6: Bathymetry of Branch 126 Sedge Fen. Depth of sediments in metres. Line A-B is the cross section shown in Figure 2-7a, Line C-D is the cross section shown in Figure 2-7b.

All the other soils in the adjacent area, which have developed on colluvium on bedrock, and colluvium on till, are Orthic Ferro-Humic Podzols. Those that developed exclusively on a veneer of colluvium over bedrock (where the colluvium is largely derived from weathered bedrock) were named "Smokehouse" soils by Jungen and those which were primarily developed on colluvium derived from weathered till were named "Ritherton" soils (Jungen, 1985). The "Smokehouse" soils in this area are primarily at the elevation of the minesite and above, while the "Ritherton" soils are found from the minesite elevation down to the lower altitudinal limit of the Moist Maritime subzone of the Mountain Hemlock Biogeoclimatic Zone. Below that, the "Rainier" and "Nitinat" soils, also developed from colluvium, which tends to be thicker here (the slope is less steep, but there is a longer rainy, non-frozen period) than higher on the slopes of Mount Washington. These soils are also Orthic Ferro-Humic Podzols (Jungen, 1985). The only other soils of note were those near the Background Sites 1 and 2, where "Moyeha" soils are found, which are Duric Humo-Ferric Podzols (Jungen, 1985).

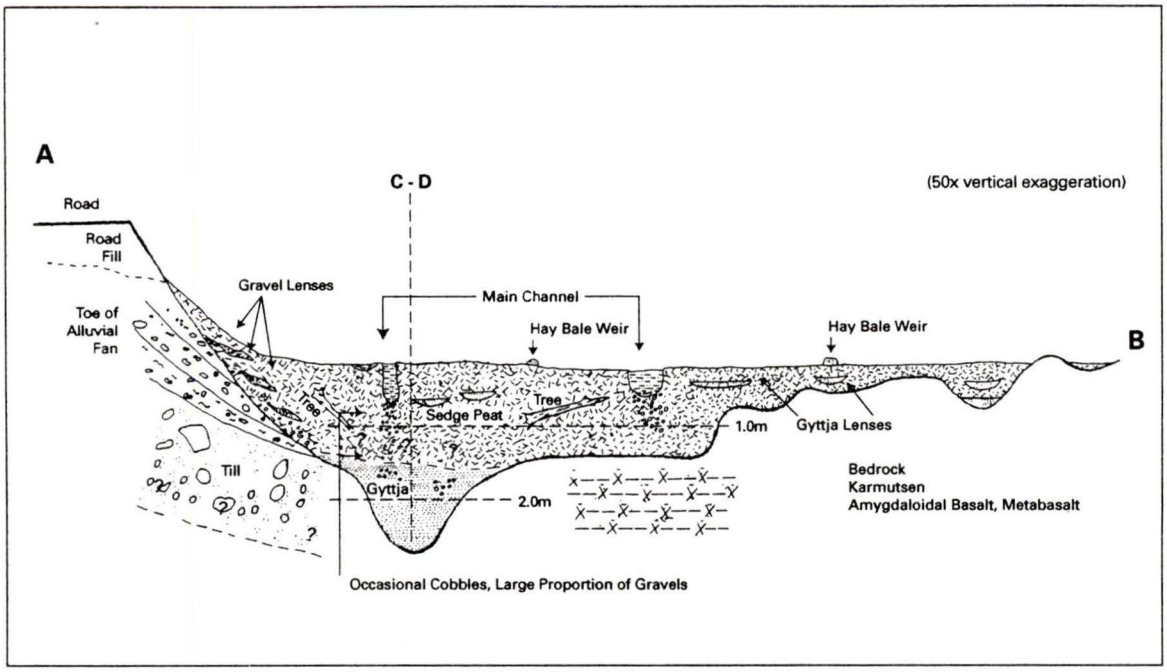


Figure 2-7a. North-South cross section of Branch 126 Sedge Fen

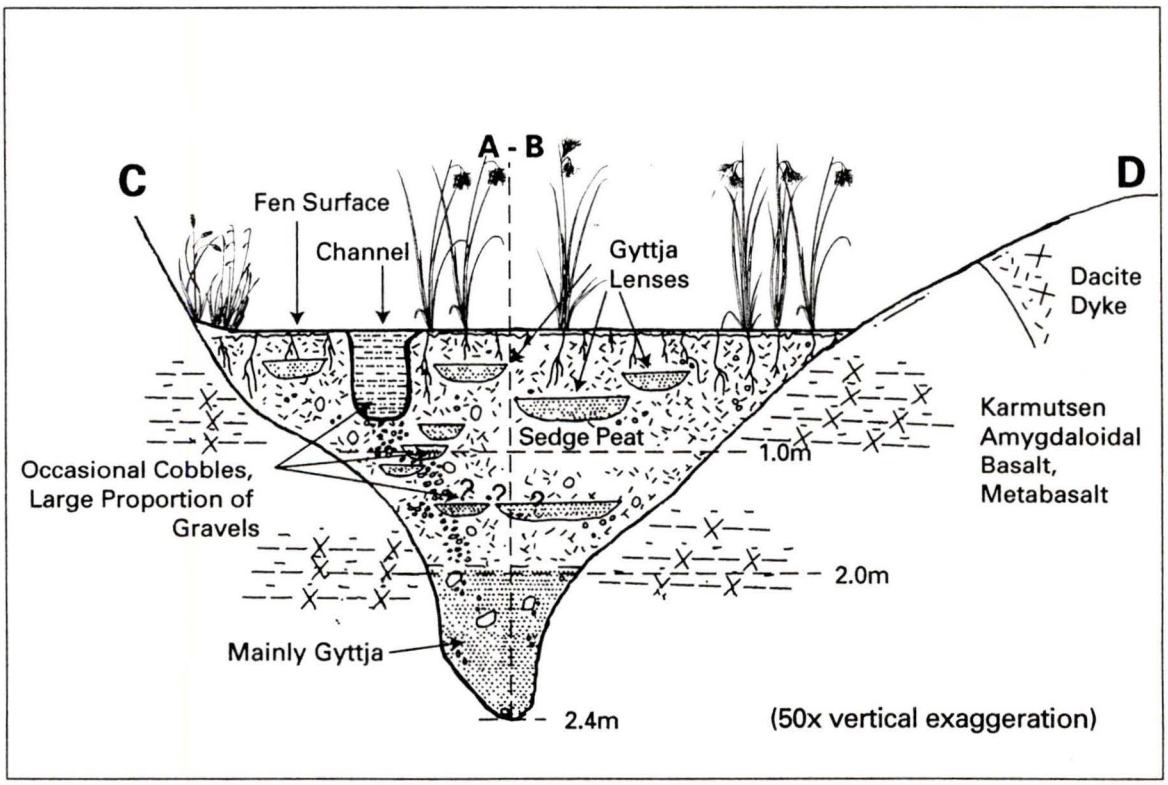


Figure 2-7b. East -West cross section of Branch 126 Sedge Fen

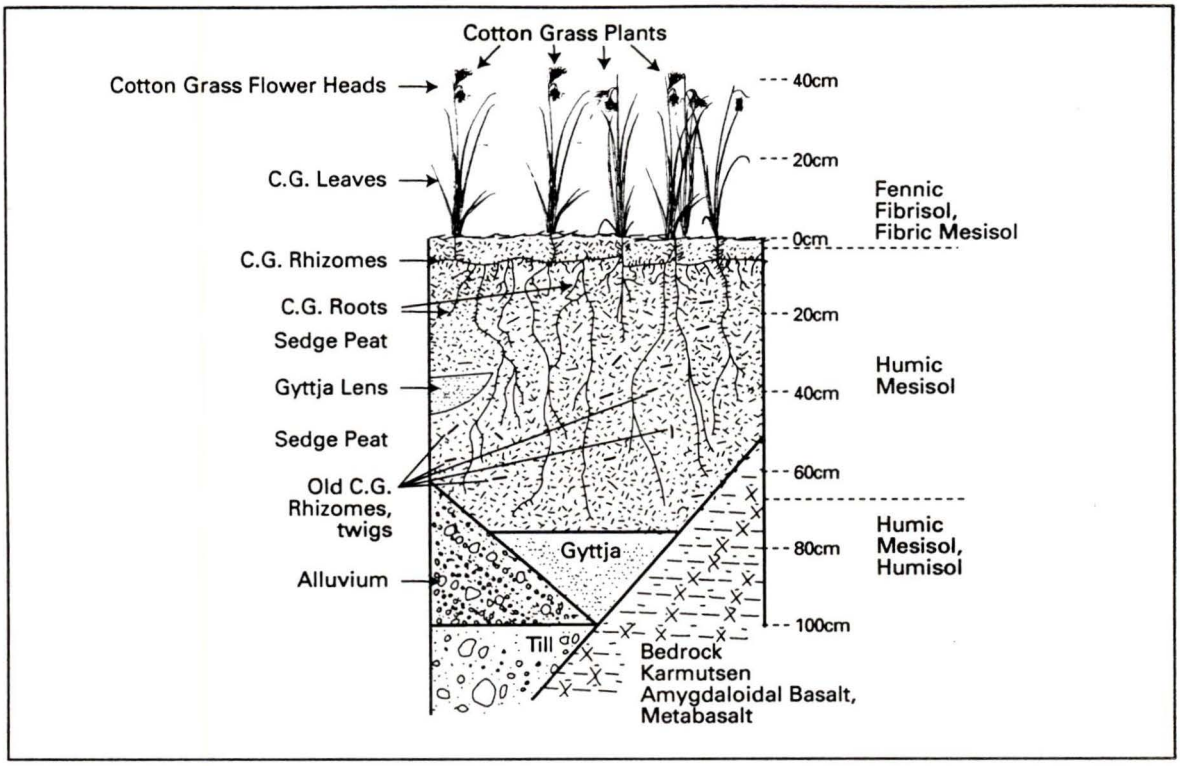
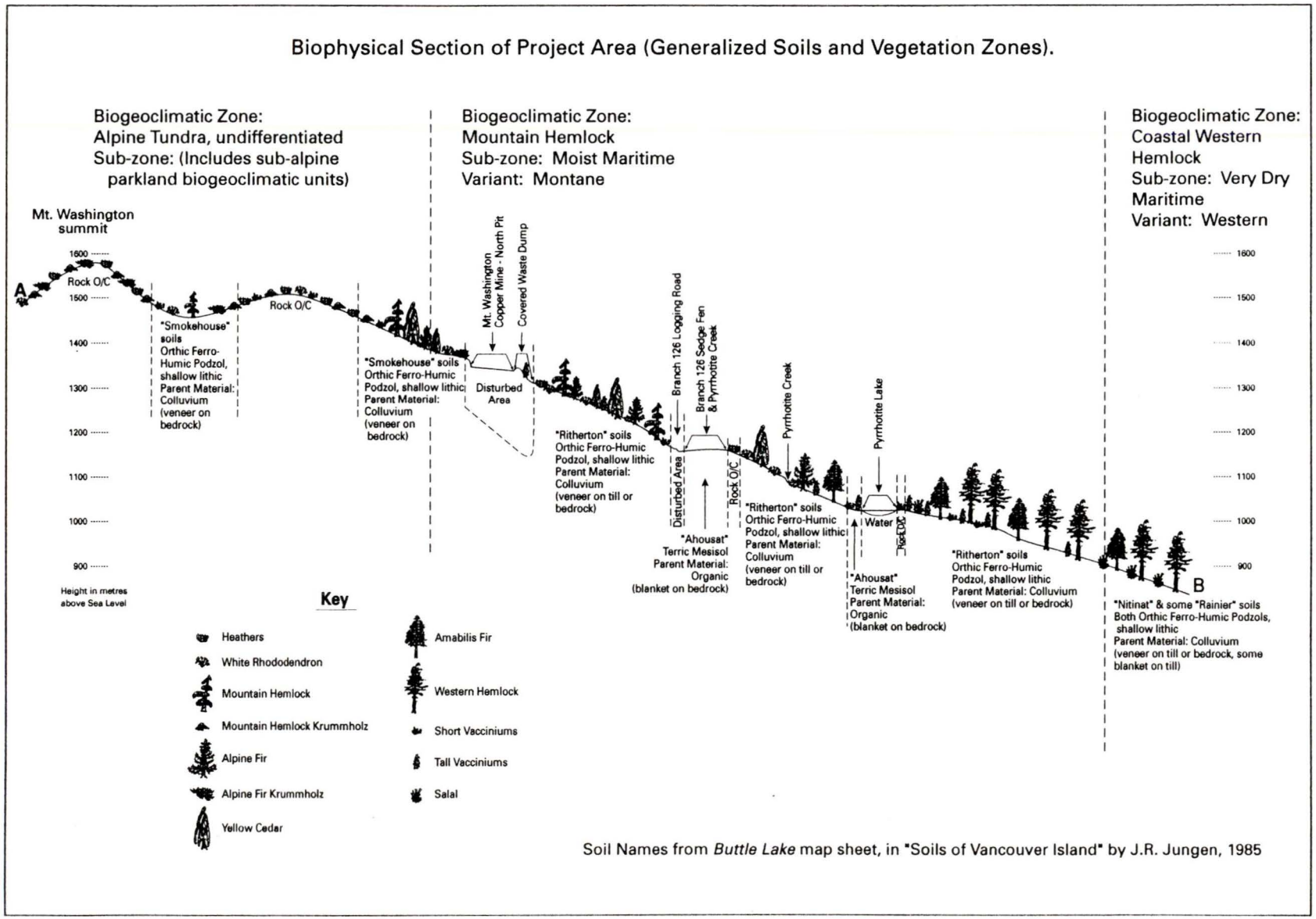


Figure 2-7c. Schematic Diagram-Components of Fen and Fen Basin

Figure 2-8, "Biophysical Section of Project Area (Generalized Soils and Vegetation Zones)" is a generalized soil catena of the project area, see the section line A-B in Figure 2-10 running from the summit of Mt. Washington in a curve through the North Pit, Branch 126 Sedge Fen, and Pyrrhotite Lake.

Bedrock Geology

The Branch 126 sedge fen is underlain by rocks of the Upper Triassic Karmutsen Formation(Figure 2-9a and 2-9b). These rocks are predominantly volcanics and include amygdaloidal flows, feldspar-porphyry flows, pillow lavas, pillow breccia and aquagene tuff. The Karmutsen Formation is overlain unconformably by sedimentary rocks of the Nanaimo Group. These rocks range from Benson member conglomerates to sandstones and siltstones of the Comox Formation of the Upper Cretaceous. Above the Nanaimo Group are Tertiary dacitic tuffs and breccias (possibly lahars, Northcote, 1985). Volcanic and sedimentary rocks have been affected by regional metamorphism and, locally, contact metamorphism associated with the Catface mid-Tertiary intrusions, primarily the McKay Lake quartz diorite stock. Related to the McKay Lake intrusion are a number of quartz diorite porphyry dikes and sills which intrude the surrounding country rock. Considerable brecciated areas resulted



Soil Names from *Buttle Lake* map sheet, in "Soils of Vancouver Island" by J.R. Jungen, 1985

Figure 2-8 Biophysical Section of Project Area (Generalized Soils and Vegetation Zones)

from the "complex multiple phases of brecciation" associated with this set of intrusive events (Muller, 1989; Galbraith, 1991b).

Figure 2-9a shows the overall geology in plan view, while two cross-sections are shown in Figure 2-9b. A cross-section sketch of the North Pit follows as Figure 2-10.

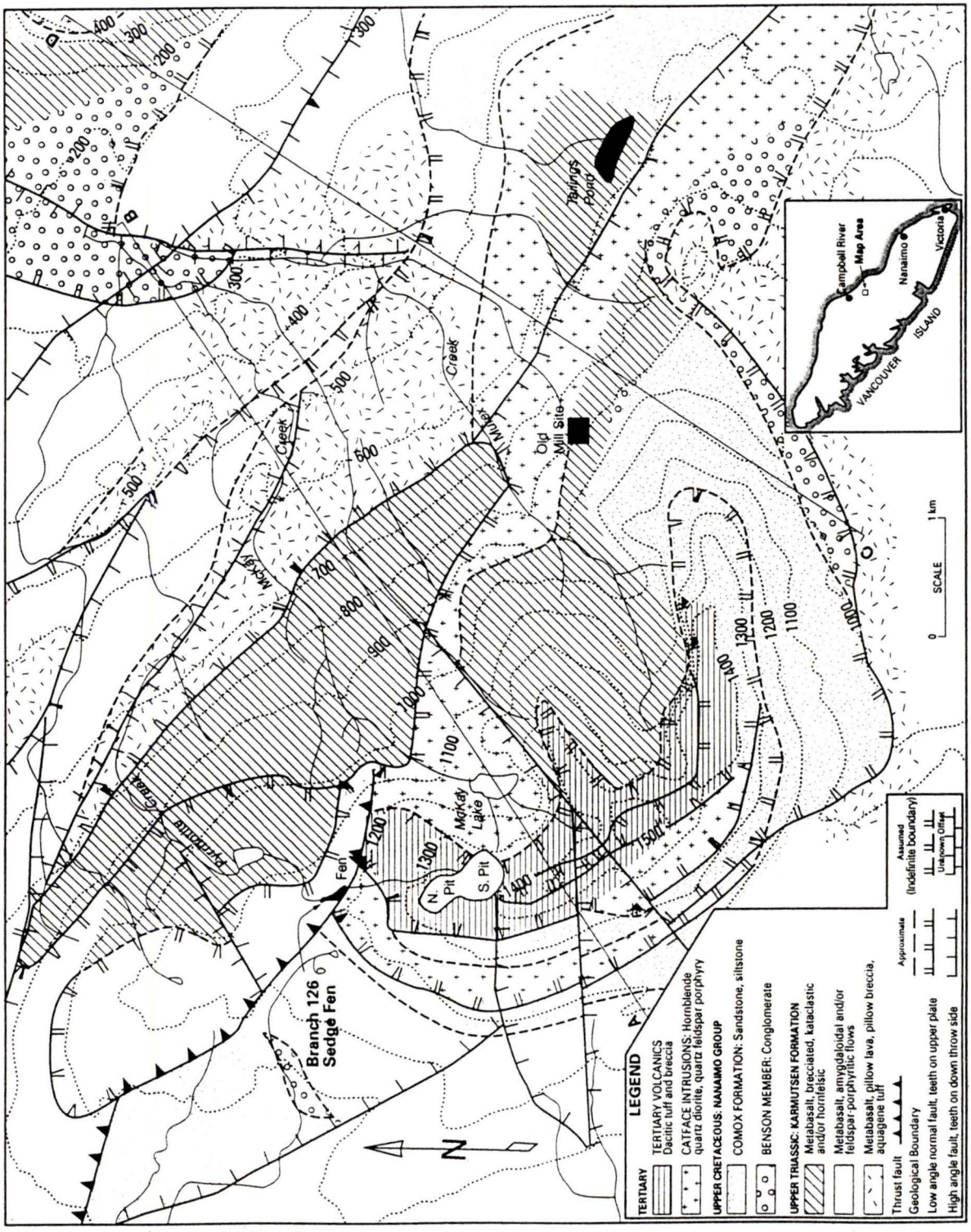
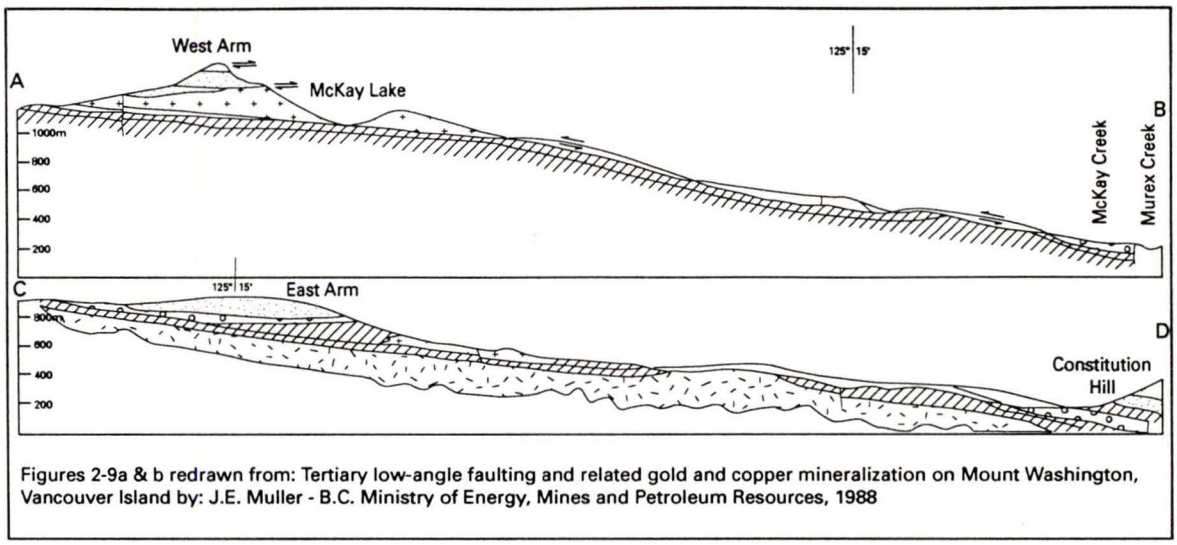


Figure 2-9a Overall Geology



Figures 2-9a & b redrawn from: Tertiary low-angle faulting and related gold and copper mineralization on Mount Washington, Vancouver Island by: J.E. Muller - B.C. Ministry of Energy, Mines and Petroleum Resources, 1988

Figure 2-9b. Cross sections

The structure of the area is dominated by low angled normal and east dipping thrust faults (Figure 2-9b). The east and west arms referred to in the diagram are two of the arêtes leading from the summit area of Mt. Washington referred to earlier. The west arm is the arête west of McKay Lake, the east arm, the arête east of the lake.

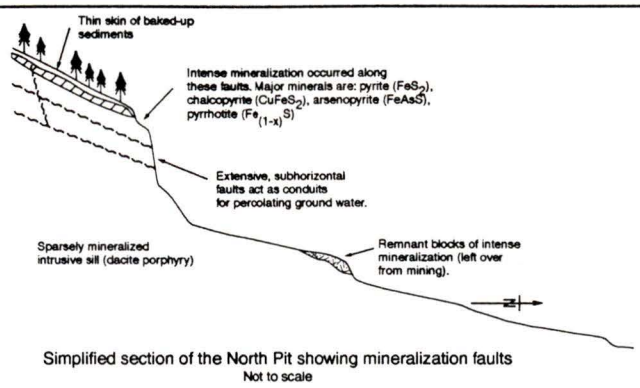
Most of the fen is in a basin carved out of metabasalts, some amygdaloidal, of the Karmutsen Formation. Here, these rocks are intruded by many dikes and sills associated with the Catface intrusions. One dike of the latter forms the resistant lip of the fen outlet. A thrust fault zone surfaces at the road to the south of the fen. The hanging wall consists of quartz felspar porphyry and dacitic tuff (the latter is not mapped on the small scale geological map of Figure 2-9a). Notes on the rocks adjacent to the fen are recorded in Figure 2-12.

The other known highly mineralized areas besides those mined, are: much of the rest of the old "Domineer" claim group to the west and northwest of the North Pit, which drains into Piggot Creek; and the "Lakeview" claim group, which is southwest of Pyrrhotite Lake (Northcote, 1985; Dunn, 1995). Neither are in the watershed of Branch 126 sedge fen.

Minesite Geology and Mineralogy

From the Minfile property report (92F-116), about 382,000 tonnes of ore at just over 1% copper were mined from the North and South pits and 305,000 tonnes of 1.07% copper ore remains in situ. Part of the mineralization [a low grade (≈1%) copper porphyry, with minor amounts of gold, silver, and molybdenum], is related to the middle Tertiary intrusive event. Pyrite, chalcopyrite, and pyrrhotite are finely disseminated through the deposit. Late Tertiary regional faulting and shearing occurred following the first phase of mineralization. Hydrothermal activity at this time resulted in the emplacement of "tabular bodies of vuggy quartz-sulphide veins, stockworks and breccias along sub-horizontal faults. The major sulphides in a rough order of abundance are pyrite, chalcopyrite, arsenopyrite, and pyrrhotite with minor marcasite and molybdenite." (Galbraith, 1991b).

North Pit: In the area of the pit, the sub-horizontal beds of volcanics dip to the north. In the headwall, sub-horizontal, mineralized faults occur in a dacite porphyry sill. These faults dip to the northeast. It appears the sill intruded the unconformity between the Nanaimo Group rocks and the Karmutsen Formation as a zone of weakness, as there is a thin layer on the upper surface of this sill which is a hornfelsed (baked-up) layer derived from the Comox siltstones. This remaining layer is resistant to erosion, due to the contact metamorphism which altered it. Presumably the altered layer was much thicker, but less altered away from the sill and not as resistant to removal by glaciation. The faulting and sub-horizontal jointing is open, and the faults and joints act as conduits for groundwater, along with the less numerous joints and small fault cracks which are near-vertical. Mineralization in the sub-horizontal faults consists of vuggy quartz-sulphide veins, the sulphides being primarily pyrite and chalcopyrite, with some secondary bornite. The veins run from 2 mm to ≈1 metre in width. Figure 2-10 shows a sketch of the North Pit in cross-section, from south to north, illustrating the sub-horizontal veins and faults which carry water through the pit area. These faults and veins are also found beneath the floor of the North Pit, although not as heavily mineralized, according to drilling results (Minfile 92F-116). They are believed to be a large source of acid mine drainage (Galbraith, 1991b).



By S. Banfield in 1991 "Permit for Reclamation" report (unpublished, Reclamation Branch, EMPR)

Figure 2-10 Sketch of North Pit, North-South Cross-Section, Showing Mineralization and Faults.

Geology of the South Pit: Conditions here are similar to the North Pit, except that there is much more carbonate in the vein fillings. In the North Pit, molds of calcite crystals in hydrated iron compounds were noted, but the calcite itself was only present in minute quantities. The calcite clearly visible in the vein fillings in the South Pit is probably the main reason that acid mine drainage is not a problem in the south pit at the moment. Secondary (post-mining) malachite and azurite are common minerals in the South Pit area, which would bear out this supposition. Information on how much calcite is present and estimates of how long it will take to dissolve was not available (Galbraith, 1991b).

Flora of Branch 126 Sedge Fen

At the first visit in October of 1992, the following plants[3] were found growing in the sedge fen (as identified by Dr. A. Ceska (Victoria). They are listed in approximate order of abundance.

Carex pluriflora Hulten	Several-flowered Sedge
Carex spectabilis Dewey	Showy Sedge
Eriophorum angustifolium Honck.	Narrow-leaved Cotton Grass, Many-spiked
Juncus effusus L.	Common Rush
Carex physocarpa Presl *(C. saxatilis L.)*	Russet Sedge
Carex ablata Bailey	Woodrush Sedge
Carex macrochaeta C. A. May	Large-awned Sedge
Calamagrostis canadensis (Michx.) Beauv.	Bluejoint
Carex anthoxanthea Presl	Yellow-flowered Sedge
Carex mertensii Prescott	Merten's Sedge
Carex stylosa C. A. May	Long-styled Sedge, Variegated Sedge

[3]The author used Hitchcock and Cronquist (1973) and Pojar and McKinnon (1994) for identifications;

Deschampsia cespitosa (L.) Beauv.	Tufted Hair Grass
Tofieldia glutinosa (Michx.) Pers.	Sticky False Asphodel, Sticky Tofieldia
Saxifraga ferruginea Grah.	Alaska Saxifrage, Rusty Saxifrage
Platanthera dilatata (Pursh.) Lindl. ex Beck [*Habenaria d.* (Pursh.) Hook.]	White Rein Orchid
Platanthera stricta Lindl. [*Habenaria s.* (Cham.) Correl]	Green Rein Orchid
Also, possibly *Trichophorum cespitosum* (L.) Hartman	Tufted Club-Rush

By the fall of 1994, only: *Eriophorum angustifolium*, the Narrow-leaved Cotton Grass; *Carex pluriflora*, the Several-Flowered Sedge; *Carex stylosa*, the Long-styled Sedge; *Carex ablata*, the Woodrush Sedge; and *Saxifraga ferruginea*, the Rusty Saxifrage; grew in the fen. There is a marginal area to the west side of the fen, which is included within the border of the fen on Figure 2-4 because it does not support shrubs or trees. The principal vegetation was the Several-Flowered Sedge and the grasses *Calamagrostis canadensis* "Bluejoint" and *Deschampsia cespitosa* "Tufted Hair Grass". Some tiny, nondescript mosses and liverworts which were not bearing sporophytes (on which account Dr. Ceska was unwilling to identify them); *Saxifraga ferruginea*, rusty saxifrage, and *Tofieldia glutinosa*, sticky Tofieldia, also grew there in 1994, but were giving way to cotton grass, a process which has continued. The soils in this area, which was shallow to bedrock, were fibric folisols as described by Jungen (Jungen, 1985, p. 16), with slightly decayed twigs, needles, leaves and roots making up most of the bulk of the material.

By the fall of 1995, the sedges were on the periphery of the fen only, as was the rusty saxifrage. Fens can be divided into "poor fens" and "rich fens". Poor fens are low in minerals, especially nutrient minerals, while rich fens have relatively high amounts of mineral nutrients. The plant species found in fens reflect this, and rich fens usually have many more species of plants than poor fens (Pojar and McKinnon, 1994; Shotyk, 1988). The subject fen was originally on the rich fen side of the continuum, and the present paucity of species is most likely due to the presence of the hay bale weirs and the outlet weir, as there was a selection of species, similar to the background sites, growing in the fen (see Figure 2-8, "Flora and Biophysical Data on Background Sites") prior to the installation of the weirs. These weirs have probably "drowned" the fen plants which are not adapted to the more hygric environment caused by the presence of the weirs.

Flora and Biophysical Characteristics of Area Adjacent to Fen

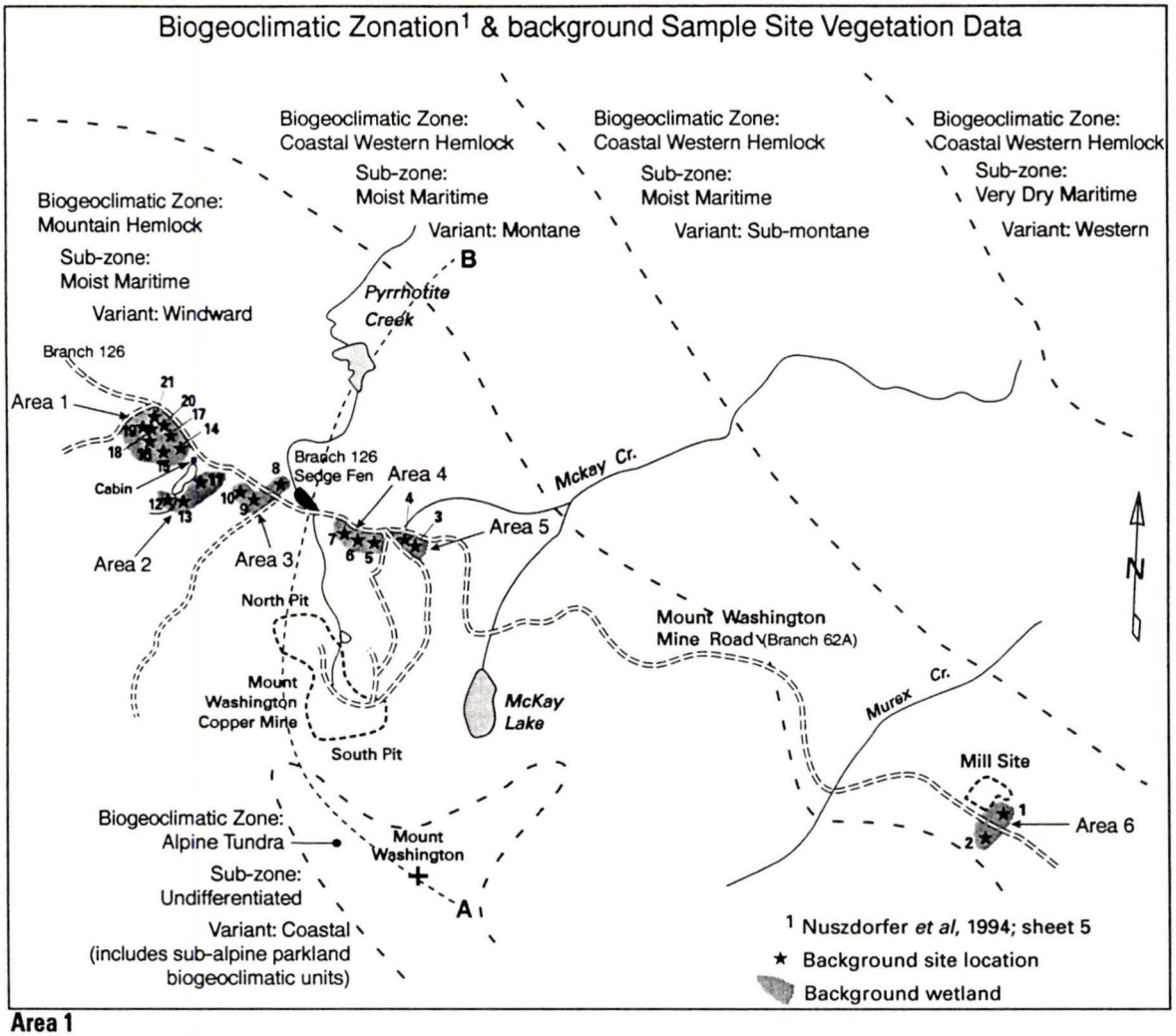
Upon the original work done in 1994, questions were raised about the status of the background sites compared to the sedge fen and the minesite. They can be paraphrased as "How closely did the background sites match the sedge fen?". To answer this question, soils and vegetation data were collected for background sites, identified by number in the areas demarcated as areas 1-6 in Figure 2-11. These data were compared to the information in Jungen's "Buttle Lake" map sheet in the "Soils of Southern Vancouver Island (Jungen, 1985). The vegetation around the fen and around the background sites was also noted, the bedrock geology information obtained and observations made on the surficial materials and soils: in the fen; around the fen; at the background sites; and adjacent to the background sites. This information is presented in Figures 2-8, 2-11 and 2-12.

The area above the minesite is in the Alpine Tundra biogeoclimatic zone, and in the coastal variant of that zone (there are no subzones recognized in this area for that biogeoclimatic zone). From the minesite to below the intersection of the millsite road and Branch 62A, and thus including the fen and all the background sample sites, the area is within the Mountain Hemlock biogeoclimatic zone. In this region, the zone is split into subzones, and all the sample sites (background and Branch 126 sedge fen) were in the Moist Maritime subzone of the Mountain Hemlock biogeoclimatic zone, and almost all were in the "montane" variant of that subzone. The two lowest sites (near the intersection of the millsite road and Branch 62A) were in the "submontane" variant of the subzone.

It appears from the background site diagram and the soils information presented that, apart from Background Area 6, all the background sites are similar to the fen or to sites immediately adjacent to the fen. Figure 2-10 "Biogeoclimatic Zonation and Background Sample Site Vegetation Data" shows the flora and biophysical data for all the background sites and the Biogeoclimatic Zones of the entire Mount Washington area (Nuszdorfer *et al.*, 1994). Figure 2-8, "Biophysical Section of Project Area (Generalized Soils and Vegetation Zones) gives a cross section through the fen, following the line A-B on Figure 2-11. These background sites can be compared to Figure 2-12 "Biophysical Data Adjacent to Branch 126 Sedge Fen".

Comparing biogeoclimatic zonation and background sample site vegetation data given in Figure 2-11, shows that the background sites are fairly similar to the fen, so far as genera (and most species), soils, aspect, and bedrock geology are concerned, especially if the 1992 species for the fen are used as a comparison. Only Background Area 4 drains into the Branch 126 Sedge Fen. Most streams in the background sites are much smaller than Pyrrhotite Creek with the exception of sites 12 and 13 in Background Area 2. It appears that sites 9-13, and 15 to 21 have the most points in common with the fen, and that sites 1 and 2 are not very similar to the fen.

Figure 2-11 Biogeoclimatic Zonation and Background Sample Site Vegetation Data



Area 1

Bedrock: Karmutsen Volcanics, Catface Intrusions, meta-sediments (Nanaimo Group).

Surficial Materials: Basal Till, Rock Outcrop, Colluvium, Organics.

Soils: Rock Outcrop, Ritherton (Orthic Ferro-Humic Podzol, shallow lithic), Ahousat (Terric Mesisol).

Tree Cover: On the exposed bedrock and thin veneer of till, there was a dominant tree cover of: western red cedar (*Thuja plicata*); mountain hemlock (*Tsuga mertensiana*); yellow cedar (*Chamaecyparis nootkatensis*); and western white pine (*Pinus monticola*). In the better-drained fen areas with some mineral soil development (even if primarily peat), there were some trees, primarily mountain hemlock, yellow cedar and Sitka willow (*Salix sitchensis*).

Understory: On the outcrop, colluvium and till-derived soils: juvenile mountain hemlock and western white pine; pink mountain heather (*Phyllodoce empetriformis*); oval-leafed huckleberry (*Vaccinium ovalifolium*); western tea-berry (*Gaultheria ovatifolia*); kinnickinnick (*Arctostaphylos uva-ursi*); false azalea (Menziesia *ferruginea*); dwarf blueberry (*Vaccinium caespitosum*); and bunchberry (*Cornus canadensis*). On the organic materials, the shrub cover here was primarily bog cranberry (*Oxycoccus oxycoccos*, also known as *O. palustris, O. microcarpus, O. quadripetalus, Vaccinium oxycoccos*, and *V. microcarpum*); dwarf blueberry; bog blueberry (*Vaccinium uliginosum*); and crowberry (*Empetrum nigrum*).

Ground Cover: On the outcrop, colluvium and till-derived soils, ground cover consisted of sticky Tofieldia (*Tofieldia glutinosa*), deer fern (*Blechnum spicant*), lady fern (*Athyrium filix-femina*) and pearly everlasting (*Anaphalis margaritacea*). On the organic materials, the ground cover here was primarily narrow-leaved cotton grass (*Eriophorum angustifolium*), dagger-leaved rush (*Juncus ensifolius*), beaked sedge (*Carex rostrata*), sticky Tofieldia, small red peat moss (*Sphagnum capillifolium*, also known as *S. nemoreum*), pearly everlasting, yellow pond lily (*Nuphar polysepalum*), a haircap moss species (prob. *Polytrichum piliferum*), water buckbean (*Menyanthes trifoliata*, Sitka sedge (*Carex sitchensis*), bog cranberry, red peat moss (*Sphagnum rubellum*), and crowberry.

Area 2

Bedrock: Karmutsen Volcanics, Catface Intrusions, meta-sediments and unmodified sediments (Nanaimo Group).

Surficial Materials: Basal Till, Rock Outcrop, Organics.

Soils: Rock Outcrop, Ritherton (Orthic Ferro-Humic Podzol, shallow lithic), Ahousat (Terric Mesisol).

Tree Cover: Dominant on the till veneer on bedrock was mountain hemlock (*Tsuga mertensiana*), western red cedar (*Thuja plicata*), amabilis fir (*Abies amabilis*) and yellow cedar (*Chamaecyparis nootkatensis*). Fen: No trees.

Understory: On the till veneer & bedrock: juvenile conifers (mountain hemlock, amabilis fir, yellow cedar); oval-leafed huckleberry (*Vaccinium ovalifolium*); false azalea (Menziesia *ferruginea*); white mountain heather (*Cassiope mertensiana*), yellow mountain heather (*Phyllodoce glanduliflora*); bog blueberry

Ground cover: On the till veneer and bedrock: Indian hellebore (*Veratrum viride*); small red peat moss (*Sphagnum capillifolium*); pipecleaner moss (*Rhytidiopsis robusta*); big red stem moss (*Pleurozium schreberi*); star-flowered false Solomon's seal (*Smilacina stellata*); sticky Tofieldia (*Tofieldia glutinosa*); and woodland strawberry (*Fragaria vesca*). Fen: narrow-leaved cotton grass (*Eriophorum angustifolium);* small red peat moss; stream violet (*Viola glabella*); Alaska bentgrass (*Agrostis aquivalvis*); water buckbean (*Menyanthes trifoliata*); yellow pond lily (*Nuphar polysepalum*); running pine (*Lycopodium clavatum*); lady fern (*Athyrium filix-femina*); several-flowered sedge (*Carex pluriflora*); Indian hellebore and sticky Tofieldia.

Area 3:

Bedrock: Meta-sediments and unmodified sediments (Nanaimo Group).
Surficial Materials: Basal Till, Rock Outcrop, Organics.
Soils: Rock Outcrop, Ritherton (Orthic Ferro-Humic Podzol, shallow lithic), Ahousat (Terric Mesisol).
Tree Cover: Dominant on the till veneer on bedrock was: mountain hemlock (*Tsuga mertensiana*); some western red cedar (*Thuja plicata*); and Sitka willow (*Salix* sitchensis). Fen: No trees.
Understory: On the till veneer & bedrock; juvenile conifers (yellow cedar, western white pine, mountain hemlock and amabilis fir); Labrador tea (*Ledum groenlandicum*); false azalea (Menziesia *ferruginea*); yellow mountain heather (*Phyllodoce glanduliflora*); bog blueberry (*Vaccinium uliginosum*); western bog laurel (*Kalmia polifolia,* also known as *Kalmia microphylla*); oval-leafed huckleberry (*Vaccinium ovalifolium*); bunchberry (*Cornus canadensis*); and crowberry (*Empetrum nigrum*). Fen: bunchberry; Labrador tea; western bog laurel; bog blueberry; yellow mountain heather; white mountain heather; and pink mountain heather (*Phyllodoce empetriformis*).
Ground cover: On the till veneer and bedrock: Reindeer mosses (*Cladonia* spp.); pearly everlasting (*Anaphalis margaritacea*); common horsetail (*Equisetum arvense*); Sitka burnet (*Sanguisorba canadensis*); Indian hellebore (*Veratrum viride*); sticky Tofieldia (*Tofieldia glutinosa*); and slender rein-orchid (Platanthera *stricta*). Fen: narrow-leaved cotton grass (*Eriophorum angustifolium*); common horsetail; Sitka burnet (*Sanguisorba canadensis*); slender rein-orchid; white rein-orchid (Platanthera *dilatata*); yellow pond lily (*Nuphar polysepalum*); bog buckbean (*Menyanthes trifoliata*); sticky Tofieldia; subalpine daisy (*Erigeron peregrinus*); leatherleaf saxifrage (*Leptarrhena pyrolifolia*); marsh cinquefoil (*Potentilla palustris*); and tufted hairgrass (*Deschampsia cespitosa*).

Area 4

Bedrock: Tertiary Volcanics, Catface Intrusions, some Karmutsen Volcanics.
Surficial Materials: Colluvial veneer over basal till, Organics
Soils: Smokehouse (Orthic Ferro-Humic Podzol, shallow lithic), Ahousat (Terric Mesisol)
Tree Cover: Dominant on the colluvial veneer on till: mountain hemlock (*Tsuga mertensiana);* Western red cedar (*Thuja plicata*); yellow cedar (*Chamaecyparis nootkatensis*); amabilis fir (*Abies amabilis*); and alpine fir (*Abies lasiocarpa).* On the fen: No trees.
Understory: On the colluvial veneer on till: juvenile conifers (mountain hemlock, amabilis fir, yellow cedar); oval-leaved huckleberry (*Vaccinium ovalifolium*); Canada bunchberry (*Cornus canadensis*); creeping raspberry (*Rubus pedatus*); Sitka mountain ash (*Sorbus sitchensis);* pink mountain heather (*Phyllodoce empetriformis*); and Alaska blueberry (*Vaccinium alaskaense*).
On the fen: bunchberry; Labrador tea (*Ledum groenlandicum*); crowberry (*Empetrum nigrum*); yellow mountain heather; white mountain heather; and pink mountain heather (*Phyllodoce empetriformis*).
Ground cover: On the colluvial veneer on till: deer fern (*Blechnum spicant*); oak fern (*Gymnocarpium dryopteris*); lady fern (*Athyrium filix-femina*); heart-leafed twayblade (*Listera cordata*); common horsetail (*Equisetum arvense*); mountain hairgrass (*Vahlodea atropurpurea*); and mosses (inc. *Rhytidiopsis robusta*). Fen: narrow-leaved cotton grass (*Eriophorum angustifolium);* small red peat moss (*Sphagnum capillifolium*); Alaska bentgrass (*Agrostis aquivalvis*); lady fern (*Athyrium filix-femina*); several-flowered sedge (*Carex pluriflora*); other sedges not in flower or fruit; Indian hellebore; tufted hairgrass (*Deschampsia cespitosa*); and sticky Tofieldia.

Area 5

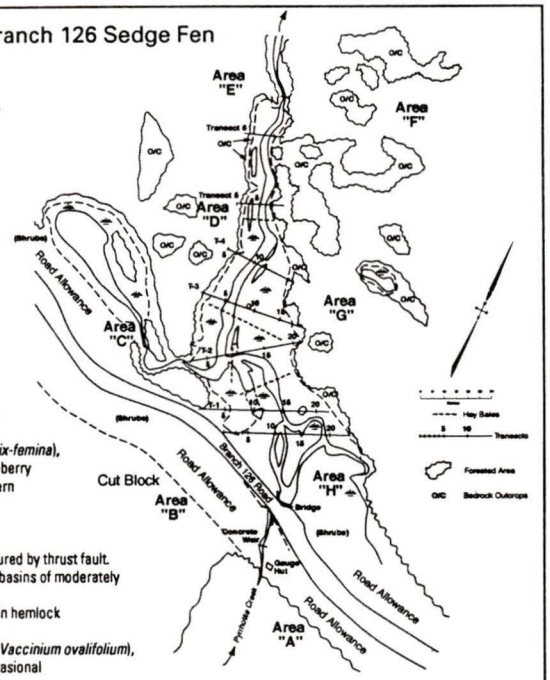
Bedrock: Catface Intrusions, Tertiary Volcanics.
Surficial Materials: Colluvial veneer over basal till, Organics.
Soils: Smokehouse (Orthic Ferro-Humic Podzol, shallow lithic), Ahousat (Terric Mesisol).
Tree Cover: Dominant on the colluvial veneer on till: mountain hemlock (*Tsuga mertensiana);* Western red cedar (*Thuja plicata*); yellow cedar (*Chamaecyparis nootkatensis*); amabilis fir (*Abies amabilis*); and alpine fir (*Abies lasiocarpa).* On the fen: No trees.
Understory: On the colluvial veneer on till: juvenile conifers (mountain hemlock, amabilis fir, yellow cedar); oval-leaved huckleberry (*Vaccinium ovalifolium*); Canada bunchberry (*Cornus canadensis*); creeping raspberry (*Rubus pedatus*); and Alaska blueberry (*Vaccinium alaskaense*).
On the fen: dwarf blueberry (*Vaccinium caespitosum*).
Ground cover: On the colluvial veneer on till: deer fern (*Blechnum spicant*); oak fern (*Gymnocarpium dryopteris*); lady fern (*Athyrium filix-femina*); heart-leafed twayblade (*Listera cordata*); common horsetail (*Equisetum arvense*); mountain hairgrass (*Vahlodea atropurpurea*); and mosses (inc. *Rhytidiopsis robusta*). Fen: narrow-leaved cotton grass (*Eriophorum angustifolium);* small red peat moss (*Sphagnum capillifolium);* Alaska bentgrass (*Agrostis aquivalvis*); lady fern (*Athyrium filix-femina*); several-flowered sedge (*Carex pluriflora*); other sedges not in flower or fruit; Indian hellebore; and tufted hairgrass (*Deschampsia cespitosa*).

Area 6

Bedrock: Karmutsen Volcanics (metabasalts).
Surficial Materials: Mainly till, some colluvium (a veneer over till). Mostly disturbed by road and mill site construction.
Soils: Moyeha (Duric Humo-Ferric Podzol); Nitinat (Orthic Ferro-Humic Podzol, shallow lithic).
Tree Cover: Red alder (*Alnus rubra*) and Sitka Willow (*Salix sitchensis).*
Understory: On the till and colluvial veneer on till: juvenile conifers (mountain hemlock, amabilis fir, yellow cedar); oval-leaved huckleberry (*Vaccinium ovalifolium*); red huckleberry (*Vaccinium parvifolium);* Canada bunchberry (*Cornus canadensis*); creeping raspberry (*Rubus pedatus*); and Alaska blueberry (*Vaccinium alaskaense*).
Ground cover: lady fern (*Athyrium filix-femina*); heart-leafed twayblade (*Listera cordata*); common horsetail (*Equisetum arvense*): narrow-leaved cotton grass (*Eriophorum angustifolium);* Alaska bentgrass (*Agrostis aquivalvis*); sedges not in flower or fruit; running pine (*Lycopodium clavatum*). No real fen development at this site.

Figure 2-12 Biophysical Data Adjacent to Branch 126 Sedge Fen

Biophysical Data adjacent to Branch 126 Sedge Fen



Area "A"
Bedrock: Karmutzen metabasalt intruded by Catface dactic dykes and sills. Catface intrusion to the south.
Surficial Materials: Thin veneer of colluvium over thicker veneer of basal till on bedrock.
Tree Cover: mountain hemlock (*Tsuga mertensiana*); Western red cedar (*Thuja plicata*); yellow cedar (*Chamaecyparis nootkatensis*); amabilis fir (*Abies amabilis*); and alpine fir (*Abies lasiocarpa*).
Understory: oval-leaved huckleberry (*Vaccinium ovalifolium*); Canada bunchberry (*Cornus canadensis*); creeping raspberry (*Rubus pedatus*); Sitka mountain ash (*Sorbus sitchensis*); pink mountain heather (*Phyllodoce empetriformis*); and Alaska blueberry (*Vaccinium alaskaense*).
Ground Cover: deer fern (*Blechnum spicant*); oak fern (*Gymnocarpium dryopteris*); lady fern (*Athyrium filix-femina*); fireweed (*Epilobium angustifolium*); pearly everlasting (*Anaphalis margaritacea*); heart-leafed twayblade (*Listera cordata*); common horsetail (*Equisetum arvense*); mountain hairgrass (*Vahlodea atropurpurea*); and mosses (inc. *Rhytidiopsis robusta*).

Area "B"
Bedrock: Tertiary hornblende quartz diorite bedrock
Surficial Materials: A thin veneer of colluvium on a thick veneer of basal till.
Tree Cover: None - cut block
Understorey: High amounts of oval-leaved huckleberry (*Vaccinium ovalifolium*); moderate amounts of mountain hemlock (*Tsuga mertensiana*) (*Tsuga mertensiana*); and small amounts of: western tea-berry (*Gaultheria ovatifolia*); Merten's sedge (*Carex mertensii*); and Sitka mountain ash (*Sorbus sitchensis*).
Ground Cover: Moderate amounts of: pearly everlasting (*Anaphalis margaritacea*), lady fern (*Athyrium felix-femina*), indian hellebore (*Veratrum viride*), fireweed (*Epilobium angustifolium*); and low numbers of: creeping raspberry (*Rubus pedatus*), Alaska saxifrage (*Saxifraga ferruginea*), Sitka valerian (*Valeriana sitchensis*), bracken fern (*Pteridium aquilinum*) and mosses.

Area "C"
Bedrock: Karmutsen metabasalts, intruded by Catface dacitic mid-Tertiary dykes and sills, probably fractured by thrust fault.
Surficial Materials: A thick veneer of basal till over the volcanic bedrock, with pockets of colluviam and basins of moderately to moderately strongly decomposed peat.
Tree Cover: Yellow cedar (*Chamaecyparis nootkatensis*), but there was a moderate population of mountain hemlock (*Tsuga mertensiana*) and a few alpine firs (*Abies lasiocarpa*).
Understorey: large numbers of white rhododendron (*Rhododendron albiflorum*), oval-leafed huckleberry (*Vaccinium ovalifolium*), black huckleberry (*Vaccinium membranaceum*), pink mountain heather (*Phyllodoce empetriformis*) & occasional crowberry (*Empetrum nigrum*).
Understorey: In drier sites: some bracken ferns (*Pteridium aquilinum*). In hygric sites: narrow-leaved cotton grass (*Eriophorum angustifolium*); moderate numbers of white marsh marigold (*Caltha leptosepala*); and small numbers of Sitka burnet (*Sanguisorba canadensis*), indian hellebore (*Veratrum viride*), fireweed (*Epilobium angustifolium*), arrow-leaved groundsel (*Senecio triangularis*) and leatherleaf saxifrage (*Leptarrhena pyrolifolia*).

Area "D"
Bedrock: Karmutsen metabasalts, intruded by Catface dacitic mid-Tertiary dykes and sills.
Surficial Materials: Either exposed rock or a thin veneer of basal till on bedrock.
Tree Cover: Sparse, with many mountain hemlock (*Tsuga mertensiana*), a moderate number of yellow cedar (*Chamaecyparis nootkatensis*) and a few Western western white pine (*Pinus monticola*).
Understorey: Denser than the areas to the south, with large numbers of oval-leafed huckleberry (*Vaccinium ovalifolium*), juvenile amabilis fir (*Abies amabilis*), white rhododendron (*Rhododendron albiflorum*), black huckleberry (*Vaccinium membranaceum*) and small numbers of crowberry (*Empetrum nigrum*).
Ground Cover: Lichen (including *Peltigera* or *Sticta* spp.) and moss (*Rhytidiopsis robusta* and *Pleurozium schreberi*) species.

Area "E"
Bedrock: Karmutsen metabasalt with Tertiary dacitic Catface dike and sill intrusions
Surficial Materials: Basal till veneer on bedrock.
Tree Cover: Sparse yellow cedar (*Chamaecyparis nootketensis*), with occasional amabilis fir (*Abies amabilis*).
Understorey: oval-leafed huckleberry (*Vaccinium ovalifolium*) & crowberry (*Empetrum nigrum*), with small numbers of white rhododendron (*Rhododendron albiflorum*) & bunchberry (*Cornus canadens*
Ground Cover: Moderate amounts of mosses (*Rhytidiopsis robusta* and *Pleurozium schreberi*).

Area "F"
Bedrock: Karmutsen metabasalt with Catface dacitic Tertiary dike and sill intrusions.
Surficial Materials: Thin till veneer over bedrock.
Tree Cover: Mountain hemlock (*Tsuga mertensiana*) and yellow cedar (*Chamaecyparis nootkatensis*).
Understorey: White rhododendron (*Rhododendron albiflorum*) and white mountain heather (*Cassiope mertensiana*) were present in large numbers; there were moderate numbers of partridge foot (*Luetkea pectinata*) and crowberry; and there were small numbers of pink mountain heather (*Phyllodoce empetriformis*).
Ground Cover: Sparse, some showy sedge (*Carex spectabilis*) was present.

Area "G"
Bedrock: Karmutsen metabasalt with Catface dacitic Tertiary dike and sill intrusions.
Surficial Materials: A thin veneer of till over bedrock, with thicker amounts of colluvium on till in the hollows.
Tree Cover: Dominant mountain hemlock (*Tsuga mertensiana*); the subdominant tree was yellow cedar (*Chamaecyparis nootkatensis*).
Understorey: Pink mountain heather (*Phyllodoce empetriformis*), oval-leafed huckleberry (*Vaccinium ovalifolium*), crowberry (*Empetrum nigrum*) and white rhododendron (*Rhododendron albiflorum*).
Ground Cover: Reindeer moss (*Cladonia* spp.) with some running pine (*Lycopodium clavatum*).

Area "H"
Bedrock: There are Karmutsen metabasalts adjacent to the road, intruded by dacitic Catface mid-Tertiary dykes and sills. A thrust fault, exposed to the east, appears to go through this area.
Surficial Materials: On a till blanket, over bedrock, there are peat soils (moderately to moderately strongly decomposed) next to the channel, alluvial materials adjacent to those, then till or road fill at the surface.
Tree Cover: Moderate numbers of mountain hemlock (*Tsuga mertensiana*) and small numbers of both amabilis fir (*Abies amabilis*) and yellow cedar (*Chamaecyparis nootkatensis*). Or
Understorey: High amounts of oval-leaved huckleberry (*Vaccinium ovalifolium*), and pink mountain heather (*Phyllodoce empetriformis*); small numbers of false azalea (*Menziesia ferruginea*), partridge foot (*Luetkea pectinata*), and crowberry (*Empetrum nigrum*).
Ground Cover: A substantial amount of cotton grass (*Eriophorum angustifolium*) ; but only small numbers of indian hellebore (*Veratrum viride*), showy sedge (*Carex spectabilis*) and Alaska saxifrage (*Saxifraga ferruginea*).

Plates 1 - 13 follow

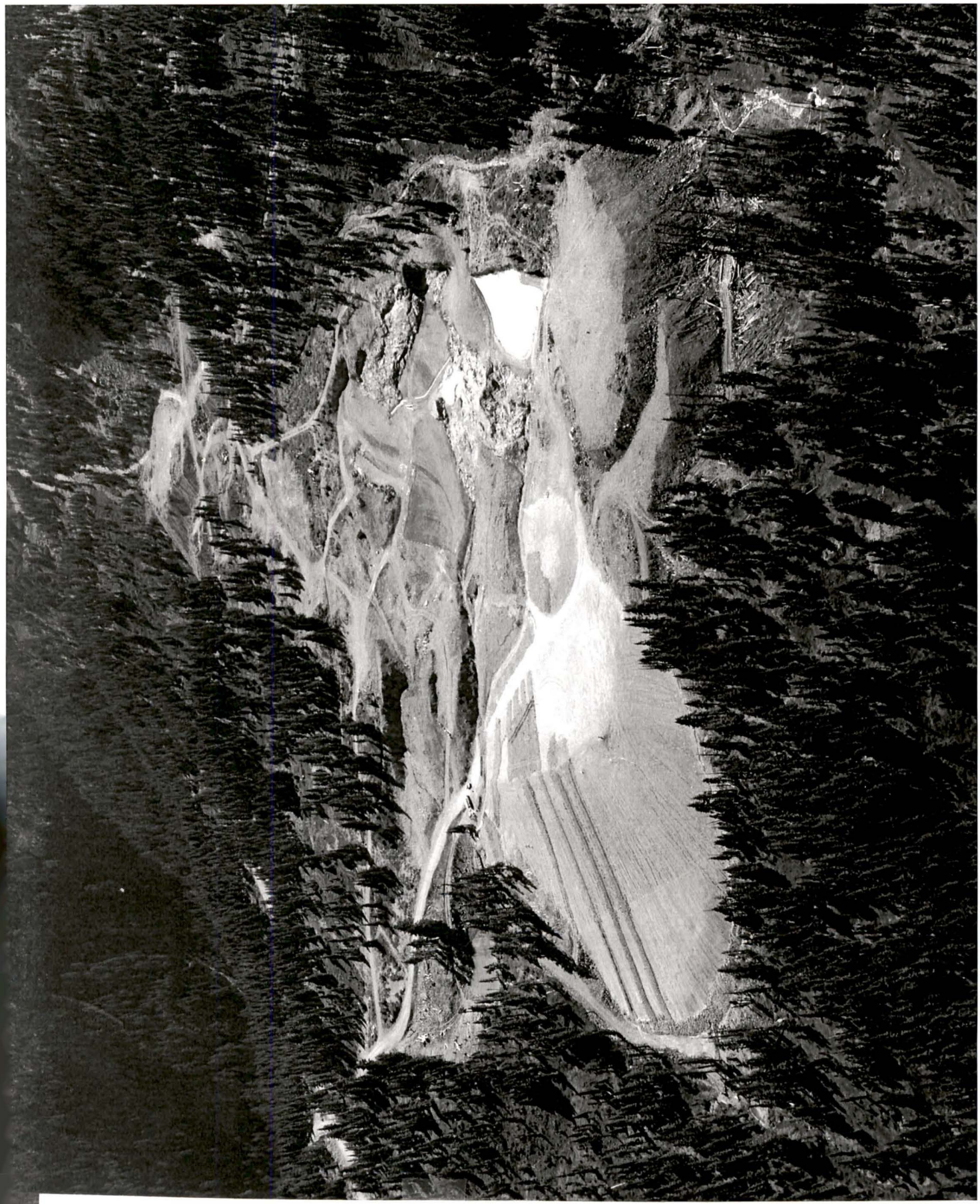


Plate 1. Aerial view of Mt. Washington Copper Mine (North Pit). View to south-southeast.

Plate 2. Branch 126 Sedge Fen in September 1992. Note cotton grass along the channel.

Plate 3. Branch 126 Sedge Fen in October 1992. Note the new hay bale weirs.

Plate 4. Branch 126 Sedge Fen in September 1993. Note the increase in cotton grass seed heads.

Plate 5. Branch 126 Sedge Fen in August 1994. Note the increase in cotton grass seed heads and open water.

Plate 6. Branch 126 Sedge Fen in early June, 1995. Spring Freshet.

Plate 7. Branch 126 Sedge Fen in July 1995. Start of sampling.

Plate 8. Branch 126 Sedge Fen in August 1995.

Plate 9. Branch 126 Sedge Fen in September 1995.

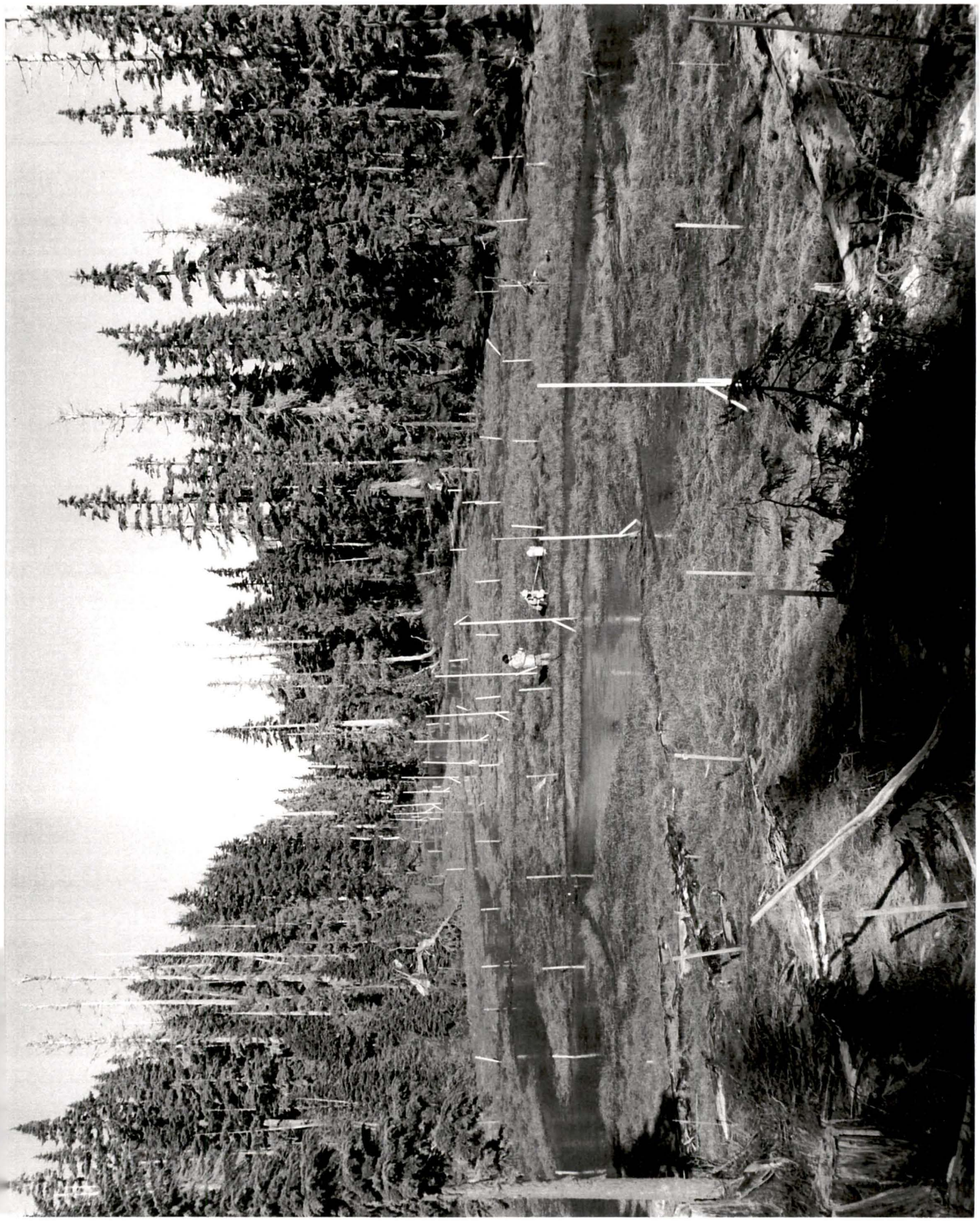


Plate 10.. Branch 126 Sedge Fen in October 1995.

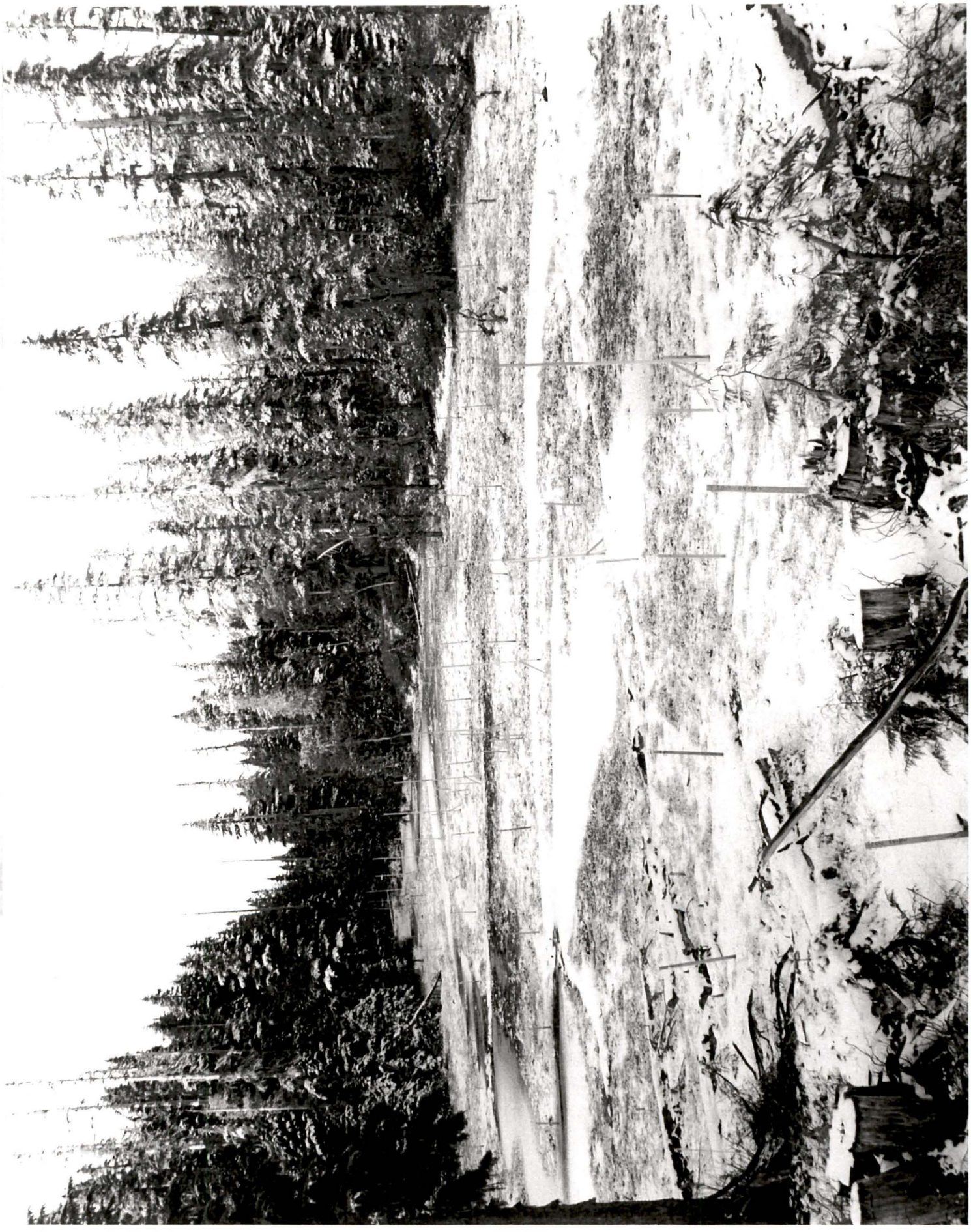


Plate 11. Branch 126 Sedge Fen in Novemeber 1995.

Plate 12. Branch 126 Sedge Fen in September 1996.

Plate 13. Branch 126 Sedge Fen in July 1997.

Chapter III - Sampling, Field Measurements and Sample Analysis

Project Design

Figure 3-1 shows the various inputs and outputs that were considered when determining the most productive avenues for answering the question, "What is/are the most important vector or vectors involved in removing copper (and other metals) from Pyrrhotite Creek water?".

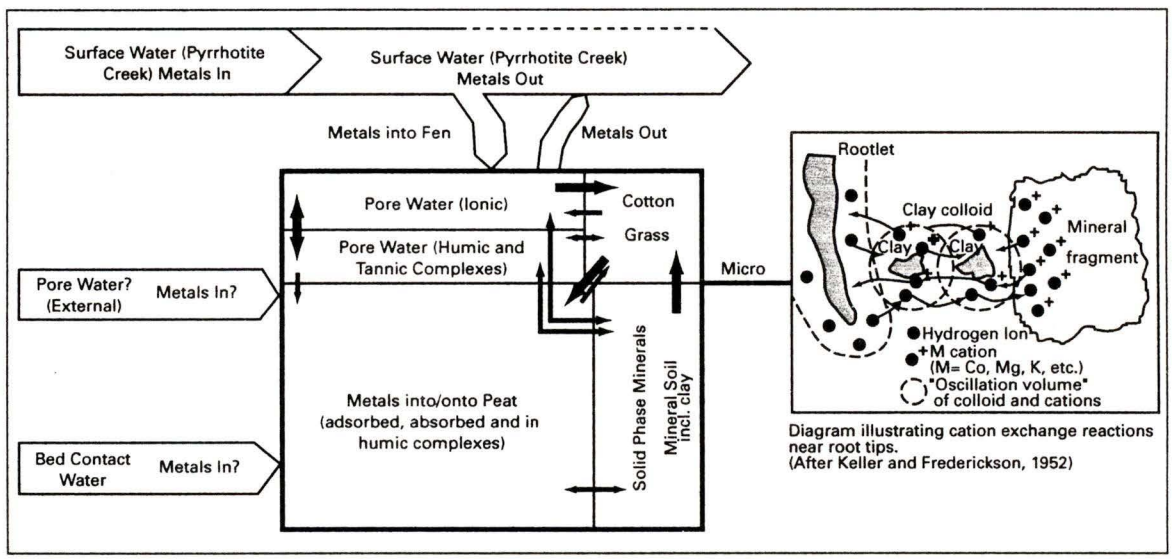


Figure 3-1. Partition Diagram of the sedge fen on Branch 126. The size of the arrows reflects the relative magnitude of the copper fluxes expected.

The principal likely pathways of copper removal given in Chapter I are summarized:

A: The bulk of copper is being taken up in the cotton grass plants.

B: Bacterial reduction of sulphate gives sulphide ions which precipitate copper.

C: The copper ions are being adsorbed and complexed on and by organic materials and compounds.

D: Copper is not being removed. Dilution is occurring, which lowers the copper concentration at the fen outlet and gives the appearance of reduced copper because increased outflow compared to inflow is not being considered.

Note: A, B, C, and D in the following three pages refer to the above A, B, C, and D possible pathways.

The above diagram does suggest that some losses could occur to groundwater, or dilution

from ground water could occur. However, the minor inlets into the Branch 126 Sedge Fen were tiny in comparison to Pyrrhotite Creek (when flowing, they made up less than 10% of the flow in the creek), the fen is in a apparently solid (not fractured) bedrock basin, with a thin veneer of till (very thin in most places), and the bedrock comes to the surface at the outlet. Thus, Pyrrhotite Creek is the major input of metals, and, with the fen being in a competent bedrock basin, it is likely that there is very little groundwater entering the fen. Since the bedrock reaches the surface at the fen outlet, it implies that the loss of fen water into the subsurface flow is minimal, also.

Tests to Apply

A. If the bulk of the copper is being taken up in the cotton grass plants, then harvesting the plants, weighing them, analyzing the copper content and calculating the total removal of copper over the area of the wetland would demonstrate the amount of copper removed. Comparing the mass of copper in (concentration at inlet x flow in x time) to the mass of copper out (concentration at outlet x flow out x time), will give a mass of copper retained in or removed from, the wetland. If the mass in the leaves is greater than 50% of the copper retained, the plants can be considered to be the principal retainer of copper. If the mass in the leaves is less than 50% of the copper retained, the plants can be considered to be the secondary retainer of copper. Since the leaves are deciduous, the metals in the perennial parts of the plants should reach equilibrium, and the flux would be in via the roots and out via the leaves. However, some metal might be disposed of in the leaf bases and senescent roots and rhizomes.

B. If the bulk of copper is being chemically and physically adsorbed by the organic components of the peat, and forming organic complexes, then the bulk of that metal should be bound to organic materials.

C. If bacterial action is the primary removal effector, then the bulk of the copper in the wetland should be as a metal sulphide in the peat. The metals in the plants should be insignificant.

D. If dilution of the effluent is the reason for the reduced copper results, then the amount of water entering the wetland with a fixed copper concentration will be a lesser amount than the quantity leaving at a lower concentration. Furthermore, the amount of dilution will correspond to the amount of "extra", uncontaminated input.

Consideration of Tests

In order to determine what the most effective approach to the problem of discovering the actual size of the vectors of metal removal were, the above statements were examined to consider how they could be tested for, as follows:

A. It is impractical to sample all the wetland, therefore a subset will have to be analyzed. Collecting a representative sample will let us know if the cotton grass is the major factor in the initial removal of copper from the effluent. Seasonal effects will have to be allowed for, and monitored. The growing season at the altitude of the Branch 126 sedge fen is variable, and the aerial photography of the site suggests that the fen can be clear of snow as early as mid-April or as late as mid-July. Identifying the production by unit of surface area, of cotton grass mass and the concentration of copper in that material will allow the calculation of the mass of copper taken up by cotton grass in a season. Losses due to grazing and early leaf fall will have to be determined if they occur (by estimation from the photographs).

B. Taking soil samples and using different extraction procedures for organic copper complexes and adsorbed copper compared to copper sulphides will demonstrate the proportion of chemically and physically adsorbed copper to that in copper sulphides and other minerals. Deniseger and Kwong (1996) suggested metals in peat here are primarily found as sulphides, but their samples may have been biased to the mineral fractions. Checking sulphur content will give figures for the maximum amount of copper that could be held as sulphides, but sulphur will be both inorganic in pyrite, sulphate, copper sulphides, or as other sulphides and as organically bound sulphur compounds. However, it will set constraints.

C. Elemental analysis of a fully representative sample set of the peat soil will give us a way of calculating a reliable figure for the total amount of copper in the fen, but this will be cumulative and does not rule out the cotton grass as being the original primary vector of copper removal. However, it will set limits on the mass of copper held in the fen. If over at least two and preferably more years, an annual set of representative samples are taken and analyzed, it will allow the calculation of the copper flux into and out of the soil.

D. Monitoring the flow into and out of the wetland should be fairly simple. Most of the inflow is via a V-notch weir on Pyrrhotite Creek above the road, and the outflow is over

a bedrock lip at the north end of the fen. The other inflows are minor, and can be bagged for a measure. The V-notch above the wetland (Branch 126 sedge fen) was monitored for a number of years prior to the present study, so historical data are available, and can be compared to other areas to obtain a reasonable approximation of the flows during the present study, provided that the V-notch is monitored during the sampling procedures. Monitoring the flow of the other inlets can be used as a base to calculate the past flows via those other sources. Bagging the flow and/or putting in a V-notch at the outlet would enable an accurate flow measure for the outlet. If the flow of water in is equal to the flow of water out, then the possibility that the lower copper results in the outlet of Branch 126 sedge fen, as compared to the outlet documented by Erickson and Deniseger (1994) is eliminated. Then, by analyzing for the copper concentration in the inlet and likewise for the outlet, the mass of copper in in the inflow can be calculated and compared to that in the outflow (for our survey period).
A positive difference will be the copper being retained in the fen and a negative difference the copper released into Pyrrhotite Creek to flow out of the fen.

From the above, it appears as if the tests for A and D can be done with the equipment likely to be available. Analyses can be done to identify total sulphur content to set the limits in B, but organic sulphur content will not be known.

A mass balance must be made for the wetland to settle question D, to find out if any copper is being retained in the fen, before any of the real pathways of copper removal can be considered. The next pathway possibility to consider is "**A**. Given the high copper concentrations measured in the cotton grass leaves and roots, the bulk of copper is being taken up in the cotton grass plants. The copper could then be converted into other forms, upon the death of the plant, by diagenesis."

Whether or not this (that the bulk of copper is taken up by the cotton grass plants) is the case can be answered by the suggested test. That is, by: collecting a representative sample set of cotton grass through the growing season, noting the unit area production, calculating the total mass produced, and, using a reliable method of elemental analysis to determine copper concentration then calculate the total mass of copper in the cotton grass. These results can then be compared to the mass of copper retained in the fen when the mass balance of copper for the fen has been calculated.

Therefore, let the hypothesis be set as follows:

"The take-up of copper by the Narrow-Leaved Cotton Grass, *Eriophorum angustifolium*, is the primary factor in the removal of copper from the water of Pyrrhotite Creek in the Branch 126 Sedge Fen."

If the hypothesis can be proved, we need go no further from that point. If false, we can proceed to the other pathway possibilities, B (copper bound in various ways to the organic and inorganic components of the peat soil) or C (sulphide production by bacterial reduction of sulphate forms insoluble sulphides), and direct other researchers to those questions.

Survey Design

Two sets of soils, water, and cotton grass were collected and analyzed for copper, iron, aluminum, arsenic, zinc and other elements (sulphur and phosphorous in particular) to quantify ranges and variations in the soils, water and the parts of the cotton grass plants in September of 1993 and November of 1994. The elements[1] besides copper were selected to illuminate soil variations that might affect plant growth and copper removal processes. Based on these results, samples of soils, water, and cotton grass at 107 stations in the wetland and another 24 outside it, with two water-only stations (the inlet and the outlet of the sedge fen) were collected at one month intervals in the summer of 1995 and analyzed to elucidate:

a. the mass balance for the period of the project for copper into the fen compared to copper out;
b. the degree of variation in the background wetlands (for the concentrations of copper, iron, aluminum, arsenic, zinc, sulphur and phosphorous in soils, plants, and waters) and quantify that variation;
c. the degree of variation for copper, iron, aluminum, arsenic, zinc, sulphur and phosphorous in the fen soils, plants, and waters; and quantify that variation;
d. the degree of variation for copper, iron, aluminum, arsenic, zinc, sulphur and phosphorous throughout the growing season for the fen and the background sample sites;
e. the dry matter production of cotton grass per unit area and show variation (minimum/maximum harvests);
f. the amount of copper that could be removed through harvesting as is, and from "d" above, maximum and minimum proportions;
g. the likelihood of toxic amounts of copper and arsenic in the cotton grass[1] being available to herbivores.

The number of sample sites was high enough to allow a statistical test to decide if real differences existed in the elemental concentrations for copper, iron, aluminum, arsenic, zinc,

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[1]Iron, aluminum, arsenic, zinc, sulphur and phosphorous

[2]Funding was provided by Habitat Protection Branch on the proviso that this question be answered.

sulphur and phosphorous between the different sample sites and groups of those sites. Since the preliminary sampling had shown high metal values (for copper in particular, but also iron, aluminum and arsenic) next to the fen margin, there appeared to be a possibility that copper (and other elements) in overland flow (at the surface, or through the near-surface layers of soil), or from groundwater flowing through mineralized till or soil, or both, was flowing into the fen. So, the question "Are the amounts of metals in the mineral soils around the fen high enough to raise concentrations of copper, iron, aluminum, and arsenic in the fen plants, waters, or soils at depth or at the surface?" was asked. To answer that, sample sets immediately adjacent to the fen were required, as well.

Samples were collected along transects crossing the fen, rather than a random number style scatter, for several reasons. These were to establish if:

a. the channel margin was more active in metal removal than the body of the fen, if the reverse was true, or that there was no difference in effectiveness (or ineffectiveness, should that be the outcome);
b. there was any difference in the upstream part of the fen compared to downstream parts;
c. the pattern of cotton grass growth in the fen in units of dry matter per unit area could be determined with a high degree of certainty;
d. there are any substantial amounts of metals in the soils or in the adjacent minor water inflows which should be accounted for.

A set of transects across the fen were drawn which would allow sampling of the margin materials, the body of the fen, and the channel. There were sufficient sample stations established that would allow statistical tests to provide assurance that if any trends were observed, they would be real. Transects were used, rather than random sites, because of the ease of replacement of missing stakes and placement of the lines to cover the different zones of the fen.

Since the time of green-up on the first trip up to the fen had been mid-April, and the snowfall the beginning of October, sampling dates of mid-April, early June, late July, and mid-September were set to give the equivalent of Spring, Summer, late Summer and Fall sampling times (Later, this was altered to early July, mid-August, late September, and late October when dictated by the conditions).

Seven transects (0, 1, 2, 3, 4, 5, and 6) were located in the fen. Because of the shape of the fen, the initial transects had many more stations than the later ones, but it was felt that logistical requirements precluded putting in any more stations in the downstream section of

the fen, and that the transects 4, 5, and 6 could serve as the downstream transects, with the rest as upstream transects. See Figure 3-2 "Transects and Sample Locations"

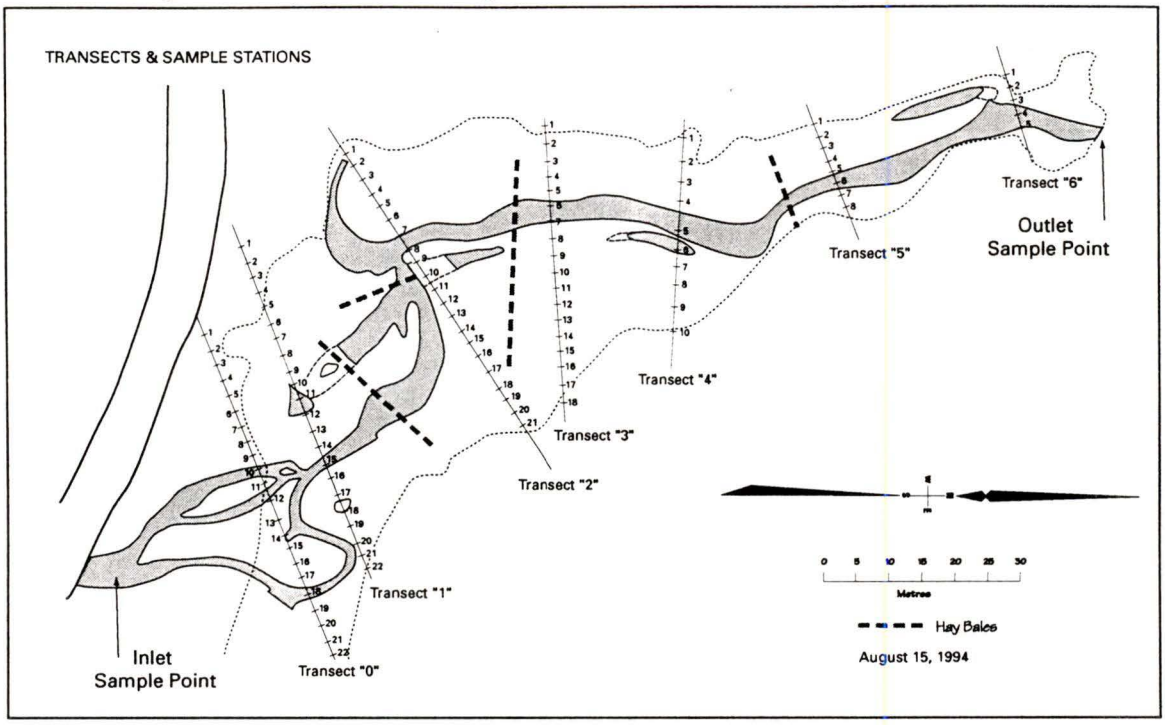

Figure 3-2 Transects and Sample Locations

Field Activities: On-site work, Measurements, Media Sampled, Sampling Procedures and Sample Preparation

On-site Work

A summary of field activities, samples collected, and analyses is shown in Table 3-1: Media Sampled, Time Collected, Method and Laboratory Used.

The laboratories used were: Zenon Environmental Laboratories, Burnaby B.C.; Saskatchewan Research Council Geochemical Lab, Regina, Saskatchewan; Acme Analytical Laboratories Ltd., Vancouver, B.C.; and the Pacific Environmental Science Centre Laboratory, North Vancouver. Colorimetric analyses were done in the B.C. Geological Survey Branch laboratory in Victoria by the author.

The first preparations for a project in this area were made in 1992, when the area was visited twice in the company of John Deniseger and Lloyd Erickson. The weirs were repaired and photographs taken. In September of 1993, the site was surveyed, benchmarks established, and a grid laid out (see Figure 2-4). The paired samples of waters (at the channel

Table 3-1. Media Sampled, Time Collected, Method and Laboratory Used

(n/a - not applicable; not done)

Year and Month	Activity(sampling,measuring, photography)	Medium (Media)	No. of samples taken sampled	Measurements taken (approximate)	Laboratory used	Analytical Method(s) Used	External Quality Control Type(s)
1992 September	Repair Weirs, photography, plant collections	n/a	30 plants collected	Flow	n/a	n/a	n/a
1992 October	Collect Plants, photography	n/a	10 plants collected	Flow	n/a	n/a	n/a
1993 September	Survey site, collect plants	n/a	30 plants collected	Surface area, topography, flow	n/a	n/a	n/a
1993 September	Sampling, photography, pH measurements	Soil cores, Cotton grass leaves, waters.	8 cores, 8 cotton grass leaf samples, 10 waters	pH	Sask. Geochem. Lab	Colorimetric for P and SO4, $HClO_4$ - HNO_3 ICP (Zenon)	None
1994 March	Photography, water samples	waters	3 waters	pH, flow	Zenon	"	Data not used
1994 August	Water Current Speed	n/a	n/a	Current velocities, direction, flow	n/a	n/a	Replicate measurements
1994 November	Sampling, photography,	Soils, C.G.plants, pore water	16 large plugs (for pore water;surface to 15 cm soil; C.G. leaves, rhizomes, leaf bases and roots; and shoots	None, meter froze	Zenon	Colorimetric for P and SO_4 Zenon ICP $HClO_4$ - HNO_3	Replicates and CANMET standard
1995 July	Sampling, photography	Soils, C.G. leaves, water	115 soils, 115 leaves, 60 waters	pH, flow rate	Zenon, PESC, Geological Branch's, ACME	Zenon ICP $HClO_4$ - HNO_3 PESC ICP HCl - HNO_3 2,2-Biquinoline ACME ICP HCl - HNO_3	Replicates, CANMET Colorimetric tests,
1995 August	Sampling, photography	Soils, C.G. leaves, water	115 soils, 115 leaves, 100 waters	pH, flow rate	Zenon, PESC	Zenon ICP $HClO_4$ - HNO_3 PESC ICP HCl - H_2O_2	Replicates, CANMET standards, Colorimetric tests
1995 September	Sampling, photography	Soils, C.G. leaves, water	115soils, 115 leaves, 100 waters	pH, flow rate	Zenon, PESC	Zenon ICP $HClO_4$ - HNO_3 PESC ICP HCl - HNO_3	Replicates, CANMET standards, Colorimetric tests
1995 October	Sampling, photography	Soils, C.G. leaves, water	115 soils, 115 leaves, 100 waters	pH, flow rate	Zenon, PESC, Geological Branch, ACME ACME	Zenon ICP $HClO_4$ - HNO_3 PESC ICP HCl - H_2O_2 2,2-Biquinoline ACME ICP HCl - HNO_3	Replicates, CANMETs standards, Colorimetric tests
1995 October - November	Surveying, sampling, Hammer seismic and steel rod probe	Soils, C.G. leaves, water	Water	3 waters, sedge peat depth contour data, pH flow rate	PESC	PESC ICP HCl - HNO_3	Replicates
1996 August	Sampling, photography	Cotton Grass and Sedge leaves	16 cotton grasses, 4 sedges	flow rate		PESC ICP HCl - HNO_3	Replicates
1996 September	Plant community survey, plant collection, photography	50 plants	n/a	flow rate	n/a	n/a	n/a
1997 July	Measurements, walk from minesite to lake	n/a	n/a	ph along creek, flow rate	n/a	n/a	n/a
4 yr. 11 mo.	10 sets of photos, 4 plant collections, 9 sampling trips	7 sets soils and waters, 8 sets plants for elemental analysis	~460 soil samples and cores ~500 plant samples ~380 water samples	13 sets of flow rates, 6 sets of pH readings, 2 surveys, etc.	5 labs used	3 main methods of analysis, 3 digestions for ICP-AES	

margin and in the body of the fen) discussed previously were taken (see Figures 4-2 to 4-9) and some pH measurements made, then large cores and cotton grass leaves were taken. In March of 1994, some water samples were taken, along with photographs. Then, in the early winter, a set of large samples were taken (plants and cores) by digging through 1.3 to 2 metres of snow, 0.3 metres of ice and then the fen materials. A background site was also

found and sampled. These samples were kept frozen until preparation.
Photographs were taken on every visit - slides and color negatives. Monochrome photographs were taken on several visits.
After the layout of the transects was set in the early spring of the spring of 1995, survey stakes were purchased, equipment borrowed, and volunteers canvassed. The weather refused to co-operate, and the first trip to the site was made in early June, which required an extended trek (1500 metres over snow 1 to 2 metres deep) to reach the site(see Plate 6). The roads to the site were passable five weeks later, and clear shortly after. At that time (the first weekend in July), the transects were surveyed and the stakes located to within 10 cm – using the surveyed grid, chain and compass. Background sites were noted and staked, including the sample stations used for background in the winter sampling. A plywood V-notch weir was installed, and secured by drilling into the bedrock with a mason's drill and inserting cement and a steel rod into the hole. This steel rod was stapled by fencing staples into the plywood. This procedure was repeated on both sides of the plywood sheet. Leaks by the sheet were plugged with plastic sheeting, sheathing tape, and cobbles. Although not expected to survive the winter of 1995-96, this weir was visited in late July, 1997, and showed no erosion or damage. The V-notch itself is made of beveled yellow cedar lath screwed to the plywood backing in a 90° notch.

The following weekend, soil samples, plant samples and water samples were taken along the transects and then again three more times (August, September and October). At the end of October, a hammer seismic and steel rod sounding was made of the fen (See Figure 2-6a), and a channel location survey started, which was finished on November 4, after which the weather precluded further sampling until the following year. In August and September of 1996, plant, soil, and water samples were taken to categorize the magnitude of local variation. Samples were taken from where other samples were taken through the seasons the year previous, but at the same time. In other words, a few of the exact places that had been sampled on a monthly basis the previous summer were sampled at the same time. Striae orientation and plant communities at the background sample stations and around the fen were fully documented at this time. See Figure 2-8 for the plant and surficial materials information.

Measurements

On-site measurements (apart from sample weights, etc. covered below in "Sample Collection and Preparation Procedures) taken were pH, surface water flow into and out of the fen, and current velocity and direction. On the first sampling visit to the fen in September 1993, a Corning Checkmate Multimeter was used with the standard pH electrode. At least three readings were taken at each point measured, and the instrument was calibrated between stations.

In the November 1994 trip, the meter froze, and no measurements were made on site.

In August 1994, a bottle of dye was taken to the site, and small portions of this dye squirted vertically into the water at a number of points where the vegetation growth was not so dense as to make it impossible to see the path the dye took. The movement of the main centre of the dye cloud was measured by tape measure and the direction read by magnetic compass set with the site declination. This procedure was not repeated, as the flow pattern shown in Figure 3-3 "Current Directions and Velocity in Branch 126 Sedge Fen) was dominant during the summer of 1995, as well as in the date noted. The velocities varied but the pattern was similar except for short periods of flood and drought. However, during the winter, Pyrrhotite Creek continued to flow. Since ice covered the channel, and only excavation to the channel revealed a small section of stream, no figure on velocity was obtained. The holes rapidly filled with water, so using a dye cloud was not possible. The roar of the stream was an indication that the current was swift. During the investigation, some visits were cut short by rainstorms. When Pyrrhotite Creek was in spate, the entire fen became submerged, and the flow was smooth from the south to the north, with no fast or slow areas discernible, except directly adjacent to the fen margin, where the current was slower.

During the 1995 growing season, pH measurements were taken of the filtered sample waters, as readings at the stations were very erratic. The literature (Shotyk, 1988; and others) noted

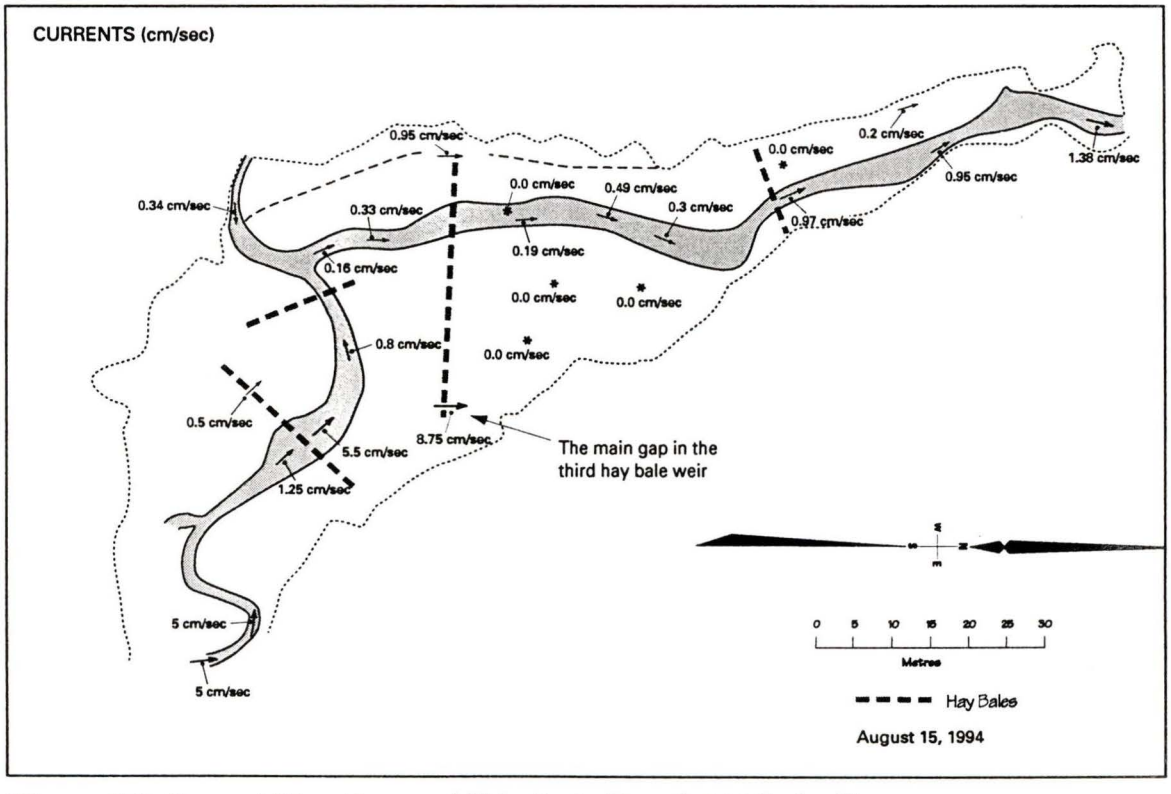

Figure 3-3: Current Directions and Velocity in Branch 126 Sedge Fen

that readings in a wetland with a peat soil could easily vary 1 pH unit, varying with the amount of peat in the water next to the electrode (the more peat, usually the lower the pH reading made[2]). Thus, filtered samples would be more consistent, although likely higher. A potassium chloride solution dropper was used to increase the ionic strength of the filtered water samples intended for pH measurements without incurring significant change in the pH. Even so, great difficulty in obtaining consistent readings was found, and, although three meters had been borrowed for the project and a fourth purchased, it was found very difficult to get agreement between the meters, so all meters that were operational were used at each session.

The weir above the bridge on Pyrrhotite Creek was eroded at the V-notch, so the flow rate was taken by the bag and bucket method. A polyethylene bag was held against the notch by two people, while a third timed the operation. The bag was removed at a signal, and the contents measured. This was repeated for three or four trials, and the flow noted. This same procedure was done on the tiny inlets into the wetland to the west and east of the contaminated inlet, and on the roadside ditch. A V-notch weir was installed as described previously, and flows recorded through the field project.

As described earlier, hammer seismic and steel rod soundings were made at the end of October and the beginning of November in 1995 (See Figure 2-6).

Media Sampled, Sample Collection and Preparation Procedures

Media sampled

- Waters in September 1993 in the sites noted in Figures 4-2 to 4-4 inclusive, cotton grass leaves and cores in the sites shown in Figures 4-5 to 4-9 inclusive.

- Cotton grass samples or sedges from all the points marked as stations on the transect map (Figure 3-2); as well as some from above the "Dry Pond" at the outlet for surface water from the North Pit; and from all background sample points marked as such on Figure 2-3 and 2-11. Sedges were taken only where there was no cotton grass, which occurred on the ends of some of the transects. These were extended into areas which did not have any cotton grass in order to have soil samples adjacent to the fen;

- Water from each plant sampling point possible, in the sedge fen and from the background

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[2]Several explanations for this drop were given in the literature. Shotyk argued in favour of increased CO_2 concentration, while Mitsch and Gosselink argued that ion exchange mechanisms are more influential.

sites; water from the weir above the road on Pyrrhotite Creek, water from the inlet area (below the road bridge over Pyrrhotite Creek), and water from the outlet of the fen at the outlet weir;

- Pore waters were obtained from the mud squeezers acting on sections cut from core samples in the November 94 sampling from the fen and background sites 12 and 13.
Soils from all stations in the fen and from all background sites, taken as core samples where possible and surface "chisel and scrape" where not.

In the core removal and vegetation collection of late September, 1993, approximately 1/4 of a square metre around the grid point was mowed with a sickle. The cotton grass leaves were lightly rinsed with deionized water and patted dry. They were then bagged in a kraft paper bag and weighed. A section of a stainless steel tube was forced into the ground as far as possible and pulled up. The surface top two centimetres were placed into a polyethylene bag and weighed, the section between 9 and 11 cm in depth was placed into another bag, and the deepest section next to 20 cm, 25cm, 30 cm or 35 cm taken. If wood was hit at less than 21 cm deep, another spot was chosen as close to the picked point as possible.

Entire surface soil plugs, with numerous entire plants were collected. These were taken in the November 1994 sampling from the fen and the background sites 12 and 13.

For waters, a set of clean acid-washed polyethylene bottles was provided by MOELP Environmental Protection Branch (later by Zenon Environmental Services, the laboratory used for most of the early work, and by the courtesy of Dr. R. Nordin). These were labeled with the date, station number and whether the water was from the ground (from the core sample hole) or from water present on the surface at the time of sampling. Water was either scooped up in a stainless steel cup, polyethylene cup, or pumped out using the coring tool, collected in cleaned one litre bottles, and taken to be processed.

For soils, where the soil was very thin to bedrock, a small stainless steel trowel was used to collect a surface sample. Where the soils were rocky, a narrow-bladed stainless steel shovel (made specifically for the task) was used to collect a core at least 20 cm long where possible (buried wood, boulders and bedrock prevented sampling to that depth in many places). In the fens (the Branch 126 fen proper and many of the background sites), a coring device (made specifically for the task) was used. The samples were placed in twist-tie polyethylene bags or polyethylene "Ziploc" bags of various sizes as required.

For leaves, three 30 cm squares (inside measure) of yellow cedar lath were made. One of these squares was set on the ground beside the transect stake. Note the following diagram, Figure 3-4, which illustrates the pattern of sampling through the summer. The person cutting the sample looked down at the points where the blades came out of the ground and decided if they were in or out compared to the inside edge of the square.

Any cotton grass which was flattened by the sample squares were manually pulled into or out of the cutting area. A pre-weighed kraft paper lunch bag was used to hold the leaves which were cut off as close to the soil level as possible using a stainless steel knife. The knife, gloved hands, and the samples were given a squirt of deionized water as required to remove dirt, dust and mud. The samples were shaken and "whipped" to remove surface water, and put in the bags. The bag and sample was weighed as soon as any surface water was no longer visible in the samples.

For the entire plants, two adjacent 20-25 cm circular plugs were cut into the surface of the fen with the stainless steel shovel, and levered out into a large "Ziploc" polyethylene bag with the location, date, and materials noted on the bag.

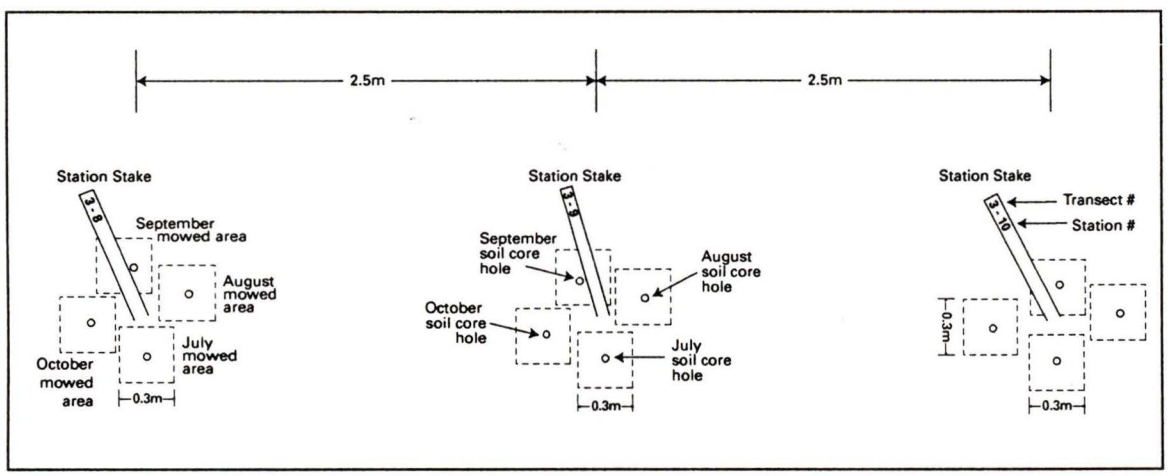

Figure 3-4: Transect Sampling Pattern

Sample Preparation (Field)

Many of the water samples were processed on site (filtered, pH measured, and acidified), but even using very high pressures, the samples could take up to an hour to filter. So, the procedure adopted was to collect the water samples in a large, pre-washed bottle and allow these sample to settle for a period of time, before using the supernatant fluid to filter for

the sample. Even so, some samples still took an hour or more to filter. Later, samples which would take considerable time to filter were stored in a cooler, and filtered in the laboratory.

Four pH meters used during the study were: a Western Digital pH meter with a Beckmann standard electrode for drinking water; a Sentron 2001 with FET electrode; a Corning Checkmate 90 with standard pH electrode; a Hanna Piccolo II with standard electrode; and a Wissenschaftlich Technische für Werkstatten (WTW) Model 310 with a low ionic strength electrode. Each meter produced different results, so an average of up to four meter readings was used. The WTW meter was the only one which gave consistent results, unfortunately it was only acquired at the end of the 1996 project field season. A Taylor Color Comparator Model 10 and British Drug Houses Universal pH indicator solution were also used as a check on the meters.

Sampling Equipment

Core and Soil Samples

Initial cores were taken with a stainless steel spade constructed for the purpose, and the cores were bagged in polyethylene Twist-Tie bags or in Ziploc bags, depending on the size. Some surface soil samples from stony till sites were taken by chiseling with a stainless steel trowel at the collection point.

For the 1995 growing season and afterwards, the cores were taken with a piston coring device built by the author. It allowed the removal of a 33 mm core and incorporated a flap valve on the piston so that it doubled as a pump to remove water from the core hole.

Waters

As described previously, the surface waters were simply scooped up with a clean bowl, mug or the initial sample bottle. Ground waters were pumped out with the core sampler.
For filtration equipment, see below in the Pore Water Collection.

Pore Water Collection

The mud squeezer provided by Dr. Nordin was an acrylic cylinder 10cm in diameter and 10 cm long. It was fitted with a top lid with an air hose and rubber diaphragm which was clamped into the top of the apparatus. With this upside down, the sample to be squeezed was put into the cylinder with a stainless steal spatula and the base screwed on. A com-

pound filter and support was set was set into the base. Air introduced into the top expanded the diaphragm and the water was forced through the filter and out the bottom. This worked well with soft materials but often the rubber ruptured with small sticks, etc.

This original "Mud Squeezer" exploded in the winter of 1994, so a new model, with a piston rather than a rubber membrane was used to squeeze water out of the soil samples. This was somewhat larger, with twice the capacity and able to withstand 150 atmospheres[3]. The cylinder was an anodized and Teflon-coated aluminum cylinder, with a Delrin piston with neoprene rubber o-rings to seal it. A "high molecular weight polyethylene" material was used to build the end caps, with an incorporated filter support and high pressure gas line. This was used for the water sample filtration as well, due to its strength. However, past 20 atmospheres, there was not a substantial increase in flow through the filter with muddy samples. Filtering was done at the same time as the pore water was extracted. A suction apparatus loaned by the MOELP Environmental Protection Branch was used at the start of the project, but turned out to be too slow, while a pressure apparatus nearly as hazardous to the operators as the original mud squeezer described above was used briefly. Then, the far stronger "Mk. II" mud squeezer was used as a water filter holder without the the soil compression piston. For filtering, 10 cm. "Sartorius" 0.45 micron cellulose nitrate and cellulose acetate membrane filters were used, with R.A. paper filters 202 grade and glass fibre filters used for pre-filtration and support for the membrane filters, together with nylon mesh supports.

Nitric acid used to acidify the samples (2 ml to 250 ml samples) was Fisher Analytical Grade and Baker Ultrex II concentrated nitric acid.

Study Methods: Channel Stability

Aerial Photography

Aerial photography offers a glimpse into the past. Unfortunately for our study, the earliest material available dated from 1946. The use of photography to uncover small changes in channel morphology has been much more limited than for studying large-scale changes, but is still considerable (D. Hogan, pers. comm.). The channel shape in plan view could be compared with the present day channel shape, using available photography, and an estimate

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[3] This was constructed by Alan Thorne, an artificer with the Canadian Hydrographic Service, whose services were authorized by Terry Curran, who facilitates provincial-federal interactions there. Funds were provided by B. Kangasniemi of the Water Quality Branch.

made of the degree of channel migration. Further, cores taken along the transects would show channel fillings and sediment lenses where the channel had been previously.

Surface Survey

Since there was a surveyed wetland and channel plan view available at the start of the study (Figure 2-4), and a grid had been set up, it was relatively easy to measure the channel in relation to the remaining grid stakes. This was done, and an outline of the early October 1995 channel view obtained (Figure 4-1). Sectional enlargements of five of the available aerial photographs were obtained (from BC 256-102, BC 2318-22, BC 7400-73, BC 84026-164 and BCC 653-68). Channel and fen outlines were made from these enlargements.

Study Methods: Fen Plant Community Temporal Changes

Photographic Comparisons

Photographs had been taken in late summer of the years 1992, 1993, 1994, 1995 and 1996 from a vantage point on the road due south of the fen.

Collections

Plant collections were made in 1992, 1993, 1994 (accompanied by Dr. A. Ceska), 1995 and 1996 in the fen and surrounding area. These plants were pressed and identified by the author and by the courtesy of Dr. Ceska. For species presence/absence, the entire fen was examined. For abundance, presence/absence was noted at the grid intersections.

Preservation and Laboratory Preparation of Samples

Preservation

All samples were kept in coolers for transport from the site. While awaiting preparation, water samples were refrigerated and the soil samples were frozen. Water samples were acidified with nitric acid immediately after the pH was measured following filtration. Plant samples were dried in the bags they were collected in. The bulk plant with soil samples were kept frozen until preparation. The soil samples were thawed to 0° C just prior to preparation.

Waters not processed in the field were filtered, the pH measured, and the samples acidified after returning to Victoria. The bottles used were marked only with the sample number and the letters DCW - for "D. Coombes' Water" on the bottle and on the lid. The numbers were assigned mostly by chronological order, although gaps for blanks, standards, and replicates were left. The excess sample (since almost all samples were collected in 1 litre polyethylene bottles) of all samples was kept in coolers until the samples were sent off for analysis.

Sample Preparation

General

A room was sealed and provided with filtered air under low pressure, to keep out dust. This room was fitted with sinks, the walls sealed and painted with paint containing only titanium oxide and calcium carbonate white pigments. The floor was sealed and a plastic floor covering installed. A dust precipitator was installed. An outlet for the air was provided at the furthest point from the inlet practical to keep a clean air current through the work area. This room was used for all following laboratory preparations, after inspection by Dr. Nordin and Dr. Lett. The inspection was to ensure that the area was secure for analytical preparation work of the type to be done.

Soils

Soil cores were cut up into measured sections. The volumes of these sections were measured by compression into a graduated cylinder and they were then weighed on pre-weighed watch glasses. On these watch glasses, the samples were dried at 105°C. After drying, the masses of these samples were determined by weighing again and then the samples were ground in a porcelain mortar. The ground soils were then sieved to 177 micron size in a stainless steel mesh sieve (as 177 micron is a standard size - usually noted as 180 micron - that would enable comparison to other data sets), and the samples bagged and numbered. Replicates and standards were added to the sample submission materials. Soils not processed are stored at the Pacific Environmental Science Centre at -40°C.

Vegetation

The leaf samples were dried as bagged samples, dried at 105°C in the laboratory, and weighed again. They were then cut up with stainless steel scissors or a stainless steel chopper on a polyethylene board into 1 cm lengths. These segments were then poured back into the bags they came from and shaken up. A portion of the chopped sample was removed with large tweezers and put into a fresh bag. This bag was only identified by being numbered in Arabic numbers, again somewhat in chronological order, with gaps for replicates and standards left. These gaps were all filled with replicate samples. The weight of the bag and the sample was noted, so that if moisture was picked up by the bag or the sample, this could be identified, and the sample re-dried. Checks by one laboratory (Environment Canada's Pacific Environmental Science Centre) suggested that the moisture picked up by these samples was less than 5%. The other laboratory (Zenon Environmental Labs, in Burnaby) dried the samples as a standard procedure for plant samples.

Large Bulk Samples

The frozen bulk specimens were thawed out in a refrigerator to minimize biological activity. Upon thawing, the cotton grass plants (leaves, roots and rhizomes) were separated from the soil. Surface detritus was bagged separately from the soils. The soil mass was then separated into surface, 2-5 cm, 9-11 cm, and bottom sections (the last two cm. of the plug). These soil sections were put in the mud squeezer and the pore water extracted. This water had been already filtered by passing through the filter pack in the base of the mud squeezer. It was then acidified in a labeled polyethylene bottle.

The plant samples were rinsed off with tap water, and rinsed again with deionized water. Then they were pulled apart manually. Vinyl gloves were worn and these gloves were replaced for each sample. They were washed before handling the sample materials. Plastic trays were used to contain the materials as the plants were dismantled into leaves (these were the full length leaves that were still attached to the rhizome, and showed no signs of decay); shoots (these were the pale green cores enclosed by the mature leaves); rhizomes (this is the underground stem in which the cotton grass stores starch during the summer), leaf bases (these were the fibrous remains of previous season's growth which was still adhering to the rhizome), and roots (these were wiry black roots, quite strong and fibrous). The roots and leaf bases were difficult to separate, so difficult that they were left together as a sample set. Dr. Nordin suggested using Calgon dishwasher detergent to assist in removing soil from the plant parts, and this suggestion worked well. There was a great deal of difficulty in cleaning the sample materials, and up to twenty rinses were required, the last rinses being done with deionized water. Some split samples were done to see if the use of the Calgon changed any of the results, but no discernible effect was noted in our small sample.

Sample Analysis

Laboratories and methods

Both plant and soil samples sent to Zenon Laboratories were analyzed with the same procedure. A "general metals" package was requested. It included phosphorous, aluminum, arsenic, barium, calcium, cadmium, cobalt, chromium, copper, iron, magnesium, manganese, molybdenum, nickel, lead, selenium, strontium, vanadium and zinc. The plants or soils were dried, ground, and a 0.75 g. sample was mixed with 2 ml concentrated HNO_3 (or more if the sample had a high organic content). Digestion proceeded at 100-150°C (hot block) until the brown fumes were eliminated. After cooling 3.75 ml of 70% $HClO_4$ was added, and digestion at 220-250°C was undergone until dense white fumes were produced. The sample was cooled and diluted to deionized water, then filtered. The filtered solution was aspirated into

a Jarrell - Ashe 61E ICP spectrophotometer, and run through an automatic multi-element analysis sequence, the photomultiplier tube results were digitized, which were converted into concentrations by special software. The reference wavelengths were set using special light sources ionizing the particular elements to be tested for. The water samples were aspirated directly, and the "general ions" package was requested, which included aluminum, arsenic, boron, barium, beryllium, bismuth, calcium, cadmium, cobalt, chromium, copper, iron, potassium, magnesium, manganese, molybdenum, sodium, nickel, phosphorous, lead, sulphur, antimony, selenium, silicon, tin, strontium, tellurium, titanium, thallium, vanadium, zinc, and zirconium.

The initial batch of water samples for September, 1993 was handled by Zenon Environmental Labs, Burnaby, B.C. These were water only. Zenon also analyzed all the samples from the November, 1994 sampling (vegetation, soils, and pore water) and the initial batches of the 1995 samples (vegetation).

The September, 1993 soils and vegetation were analyzed by the Saskatchewan Research Council Geochemical Lab for the National Hydrological Institute in Saskatoon, by courtesy of Dr. John Kwong. These samples were small sections cut from thick cores, and cotton grass leaves. The dried soils and leaves were weighed, dried, ground, and ashed in a muffle furnace. The ashes were weighed[4]. Five hundred milligrams of ashes were dissolved in 3 ml. aqua regia (concentrated nitric and hydrochloric acids), the extract made up to 10 ml with deionized water, filtered and the solution run through an inductively coupled plasma atomic emission spectrophotometer[5](ICP-AES). The elements analysed for were copper, zinc, antimony, tellurium, molybdenum, cadmium, arsenic, nickel and cobalt.

Acme Assay Laboratories in Vancouver ran 30 soil samples from transects 3 and 5 of the summer 1995 samples. The Acme laboratory took pre-sieved (177 micron) dried and ground soil samples of 0.500 g, digested them in 3 ml. 3-1-2 nitric acid-hydrochloric acid-water at 95°C for one hour, made up the volume with deionized water to 10 ml, decanted the solution, filtered it, and analyzed the solution using a Jarrell-Ashe Atom 970 ICP-AES. The elements analyzed for were aluminum, arsenic, boron, barium, bismuth, calcium, cadmium, cobalt, chromium, copper, gold, iron, lanthanum, magnesium, manganese, molybdenum,

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[4]LOI figures were provided on the vegetation, but not on the soils, although requested several times.
[5]Requests for information on the model and manufacturer have not been answered. Dr. Kwong's papers (Kwong and Van Stempvoort, 1994; Deniseger and Kwong, 1996) do not give the make or model, either.

sodium, nickel, phosphorous, potassium, lead, antimony, silver, strontium, thorium, titanium, tungsten, uranium, vanadium and zinc.
The remaining work on the waters, vegetation, and soils was done primarily by the Environment Canada Laboratories at the Pacific Environmental Science Centre in North Vancouver.

The Pacific Environmental Science Centre laboratory took the plant samples and weighed them before and after freeze-drying. The freeze-dried samples were ground in a Braun blender before being weighed into Teflon PFA liners and digested in concentrated nitric acid, concentrated hydrochloric acid and 30% hydrogen peroxide in a microwave oven (Q-wave 1000 or Q-wave 3000). The digested samples are cooled and brought up to 10 ml volume with Type 1 deionized water[6]. Soil samples were dried at 60°C then sieved to -100 mesh, rolled to homogenize, and weighed into Teflon digestion liners and digested with concentrated nitric acid and concentrated hydrochloric acid in a microwave oven (Q-wave 1000 or Q-wave 3000). The digested samples are cooled, brought up to 10 ml with Type 1 deionized water, and allowed to settle overnight before being decanted. Preserved water samples are given no other preparation, but samples for total metals are autoclaved with nitric and hydrochloric acids. Samples for this project were filtered and preserved. Analysis of the waters and the solutions from the soils and plants were performed by a ARL/Fisons 3560-AES Inductively Coupled Argon Plasma Atomic Emission Spectrometry (with simultaneous multi-element analysis) equipped with a Gilson 222 Autosampler. The samples were analyzed for aluminum, arsenic, barium, beryllium, calcium, cadmium, cobalt, chromium, copper, iron, magnesium, manganese, molybdenum, sodium, nickel, phosphorous, potassium, lead, antimony, selenium, silicon, silver, strontium, sulphur, tin, titanium, vanadium and zinc.

The 2,2-biquinoline colorimetric test was prepared and run according to the 2, 2-biquinoline testing on water samples for ionic copper after the method of Almond (Stanton, 1966, pp. 57-58) given in Appendix 3. Waters from transects 3 and 5 were run using this 2,2-biquinoline test at the Geological Branch laboratory, by the author under the supervision of Dr. Lett.

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[6]This water has no impurities of concern (metals or non-volatile ions) detectable by the analytical methods used here. Atmospheric gases are not a problem.

Quality Control

Several approaches to quality control were carried out. The preferred method would have been to set up a batch sample procedure, such as is done by Geological Survey of Canada for regional geochemical surveys. Their system sets up numbers which designate 20 sample batches. In each batch of 20 samples sent for analysis is a certified standard, two replicates separated at the preparation lab ("lab splits"), and one pair of samples collected at the same site in the field (a "field split") (Friske and Hornbrook, 1991). It is advisable to add blanks, also (blanks being water, sediment or vegetation samples prepared to have very low concentrations of trace elements). The certified standard provides an indication of the extraction efficiency and how the analysis compares with other analyses done in other laboratories using the same methods. These standards give a measure of laboratory accuracy. The additionof blanks serves to monitor contamination during handling and analysis, the samples separated in the preparation lab give an indication of the laboratory precision and the variability to be expected in the sample materials. The field split gives an indication of the combined sample site variability, sampling variability, and analytical variability (precision). By examining the other variations, and comparing to the variations in the field split variability, site sample variability can be estimated if it is sufficiently greater than the other sources of variation to be detected.

The GSC batch procedure was reluctantly modified because of the small numbers of samples analyzed. The amounts of metals in the samples were generally high and in the ranges which can be expected to provide accurate results using the standard procedures of the different laboratories used, it was not expected that the over-all results would be in jeopardy, particularly since all the laboratories used ran their own quality control procedures. These results are included below. Wherever possible, batches of samples sent for analysis included a standard, field replicates, and an analytical replicate.

The LKSD standards were obtained from Canmet, in Ottawa. These were selections of lake sediments which emphasized certain elements and have been analyzed by a number of different laboratories with different methods, in order to compare analytical results on sediments. Two standards were used, the LKSD1 and the LKSD4 sediment standards. The Canada Inland Waters Directorate in Saskatoon provides some samples for comparing results for water analysis. TMDA-54 is a laboratory standard sample used to compare laboratory results for natural waters, while ION-96 is a laboratory standard sample used to compare laboratory results for ions in drinking water. This laboratory standard sample is used for comparing the results after testing water for potability. NBS-1571 is a laboratory standard available from the National Standards Bureau, in Washington, D.C., used to compare laboratory results on elemental analyses of vegetation. It is a standardized collection of deciduous orchard leaves. NBS-1572 is a laboratory standard available from the National Standards Bureau, in Washington,

D.C., used to compare laboratory results on elemental analyses of vegetation. It is a standardized collection of citrus orchard leaves.

Zenon 1993-94

For the September 1993 sampling, no standards were run with the samples submitted.
For the November 1994 sampling, laboratory standard LKSD4 from Canmet was run with the soil samples submitted, and laboratory standards TMDA-54 and ION-96 from Canada Inland Waters Directorate was submitted with the pore water samples submitted.

Soils

For the elements of concern (Concentrations in ppm): Canmet certified standard LKSD4 (for HNO_3, HCl extraction) (Bowman,1994). Zenon analysis below (1 sample).Phosphorous was listed at 0.2 % as P_2O_5 in the figures for total elements (Bowman, 1994).

Table 3-2. Comparison of Zenon Analysis for Canmet Standard LKSD-4 Vegetation:

Lab/standard	As ppm	Cu ppm	Fe ppm	P ppm	Zn ppm
LKSD4	12	30	27,000	870	195
Zenon	18	28	22,200	1250	173
% recovery	150%	93%	82%	144%	89%

Unless specified, all concentrations are in ppm/dry weight.
Two samples were split in the lab and sent in as "blind duplicates". However, the materials in the second sets ("b" and "d" below) were more decomposed. The variable examined was sample concentration range.

Table 3-3a. "Field 2 (Leaf Bases and Roots)", split in the in-house laboratory.

Field 2 samp.		As ppm	Cu ppm	Fe ppm	P ppm	Zn ppm
Result "a"	228	4850	27,700	1010	59	
Result "b"	390	3440	36,500	1280	41	
% Mean diff.	52%	34%	27%	24%	36%	

Table 3-3b. "Adjacent to Field 2 (Leaf Bases and Roots)", split in the in-house laboratory.

Adj. 2, samp	As ppm	Cu ppm	Fe ppm	P ppm	Zn ppm
Conc. "c"	138	2310	33,000	647	46
Conc. "d"	137	2050	26,500	553	25
% Mean diff.	0.7%	12%	22%	16%	59%

Waters

Table 3-4 compares TMDA-54 Canada Inland Waters Directorate Standard (The range refers to the 95% confidence limit), Zenon analysis below. These were sent in blind.

Table 3-4. TMDA-54 - Zenon Analysis Compared to Standard

Std./Lab.	Al ppm	As ppm	Cu ppm	Fe ppm	P ppm	S ppm.	Zn ppm
TMDA-54	0.487±.072	0.0214±.0064	0.437±.0592	0.2825±0.0292	-	-	0.5415±0.0616
Zenon	0.48	0.212	0.444	0.285	<0.04	2.23	0.557
% Recovery	≈100% [in limits]	≈99% [in limits]	≈102% [in limits]	≈101% [in limits]	- n/a	- n/a	≈103% [in limits]

All the results are within the 95% confidence limits. This laboratory operates under the standard ± limits when the sample concentration is >5x the minimum detection limit (mdl). The standard is the mean of the concentrations found by laboratories operating under the very strictest procedures for a particular analytical protocol. A lab. operating within these guidelines should return analytical results within the limits 19 times out of 20. One sample was analyzed.

Table 3-5 compares the ION-96 Canada Inland Waters Directorate Standard) to the Zenon analysis (below). This was sent in blind.

Table 3-5. ION-96 - Zenon Analysis Compared to Standard

Std./Lab.	Al ppm	As ppm	Ca ppm	Cu ppm	Fe ppm	P ppm	S ppm.	Zn ppm
ION-96	-	-	94.7±8.35	-	-	<0.04	33.4±3.9	-
Zenon	<0.02	<0.0005	90.6	0.002	0.007	<0.04	33.7	0.005
% Recovery	n/a	n/a	≈105%, [in limits]	n/a	n/a	n/a	≈99% [in limits]	n/a

(one sample) % recovery of comparable elements Sulphur ≈99%, Calcium ≈105%. Both are well within the 95% confidence limits. See text for note on meaning.

Table 3-6. Minimum Detectable Limits (mdl) for Zenon and PESC ICP-AES Analyses of water, soil and plants. Concentrations in ppm

Element	Zenon Water	Zenon Soil	Zenon Plants	PESC Water	PESC Soil	PESC Plants
Al	0.02	10	10	0.005	8.0	4.0
As	0.0005	10	10	0.05	0.5	4.0
Cu	0.001	1.0	1.0	0.005	0.8	0.4
Fe	0.003	1.0	1.0	0.005	0.8	0.4
P	0.04	5.0	5.0	0.01	300	8.0
S	0.03	–	–	0.05	8.0	4.0
Zn	0.002	1.0	1.0	0.002	0.3	0.2

Saskatchewan Research Council Geochemical Laboratory

The Saskatchewan Research Council Geochemical Lab ran replicates 1 and 2 below in Table 3-7. All samples were as ash. These were internal standards.

Table 3-7. Saskatchewan Research Council Geochemical Laboratory Replicates

SRGCL	Cu ppm	Zn ppm	Sb ppm	Te ppm	Mo ppm	Cd ppm	As ppm	Ni ppm.	Co ppm
a. LSW3	43	196	6	3	16	6	5	40	32
b. LSW3	47	200	6	4	15	6	7	41	34
% Mean diff.	8.9%	2%	0%	29%	6.5%	0%	33%	2.5%	6.1%

These standards are of lower concentrations for many elements than a large proportion of the fen samples submitted. They show "fair" precision but data on accuracy is lacking, since the known concentrations have not been provided.

Zenon 1995

The 1995 Zenon analytical results for plants included a blank in which all metals were below the mdl concentrations except for iron (28 ppm), calcium (7 ppm), and chromium (1 ppm). Concentrations found in the blank samples suggest that there is not a likelihood of laboratory contamination affecting the results to any meaningful degree, since the amounts of iron in the plants were usually orders of magnitude greater, and neither calcium nor chromium were a concern.

The results of the standard analyses reported below are those which Zenon reported, not blind test results.

Table 3-8a. Zenon Analysis of NBS standard 1571 "orchard leaves".

NBS 1571 Orchard Leaves, Zenon results below. 95% uncertainty limits of ±35%					
Std./Lab.	Al ppm	As ppm	Cu ppm	Fe ppm	Zn ppm
NBS 1571	-	10–3.5	12–4.2	300–105	25–8.75
Zenon	-	10.27	8.838	213	19.54
%Recovery	n/a	103%	74%	71%	78%

Table 3-8b. Zenon Analysis of NBS standard 1572 "citrus leaves".

NSB 1572 Citrus Leaves, Zenon results below. 95% uncertainty limits of ±35%					
Std./Lab.	Al ppm	As ppm	Cu ppm	Fe ppm	Zn ppm
NBS 1572	92–32	3.1–1.1	16.5–5.78	90–31.5	29–10.2
Zenon	125	5.679	11.5	84.1	22.1
%Recovery	136%	183%	70%	93%	76%
		<2xmdl			

Table 3-8c: Zenon Plant Analysis Duplicates (duplicates run by Zenon for internal checking).

Sample	Al ppm	As ppm	Cu ppm	Fe ppm	P ppm	Zn ppm
Zenon a	261.6	7.585	35.93	642.7	1273	32.6
Zenon b	348.6	5.615	41.8	696.4	1421	37.92
% Mean diff.	29%	30% <5xmdl	15%	8%	11%	15%

For comparison between Zenon Environmental Laboratories results and those of the Pacific Environmental Science Centre Laboratory, see the scatter diagrams (Figure 3- 6) at the end of the "PESC" scatter diagrams.

Comparisons of Replicate Analyses by PESC

Figures 3-5 a-c. Scatter Diagrams for Duplicate Samples Analyses by PESC

Figure 3-5a: Scatter Diagrams for Copper in Blind Duplicate Water Samples (PESC pairs)

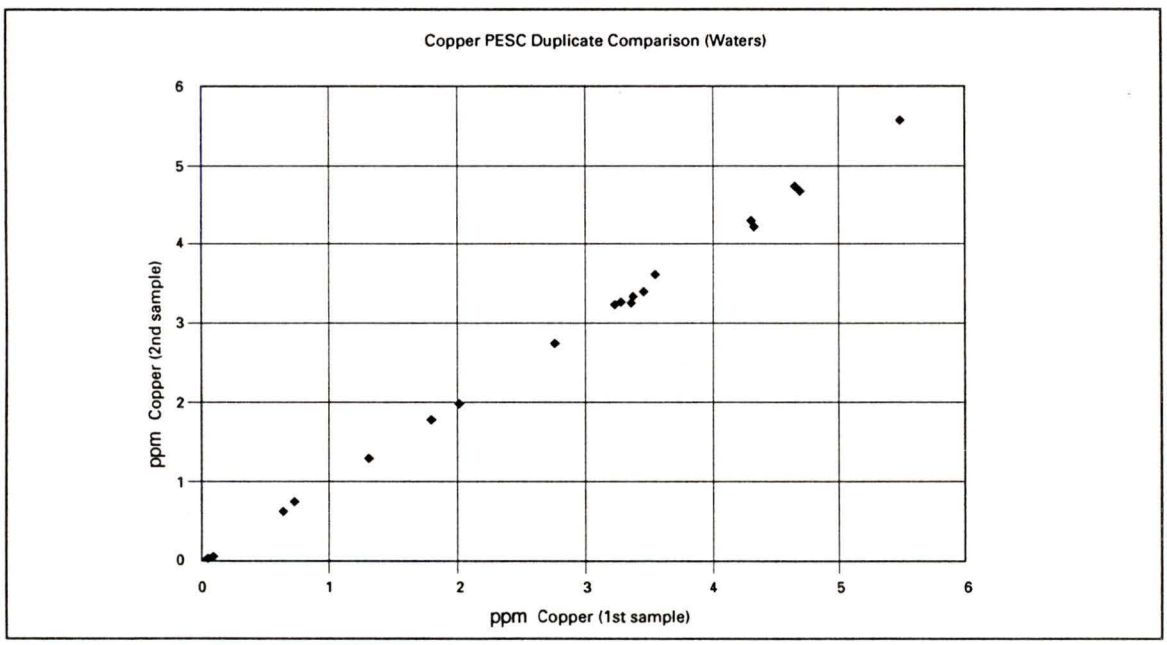
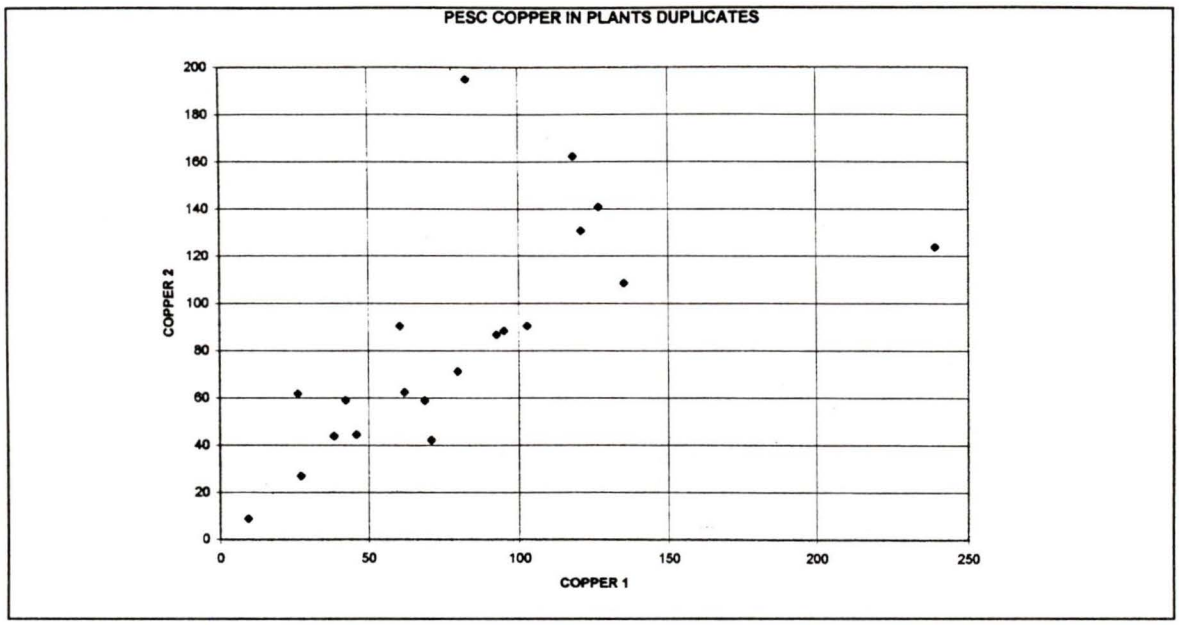


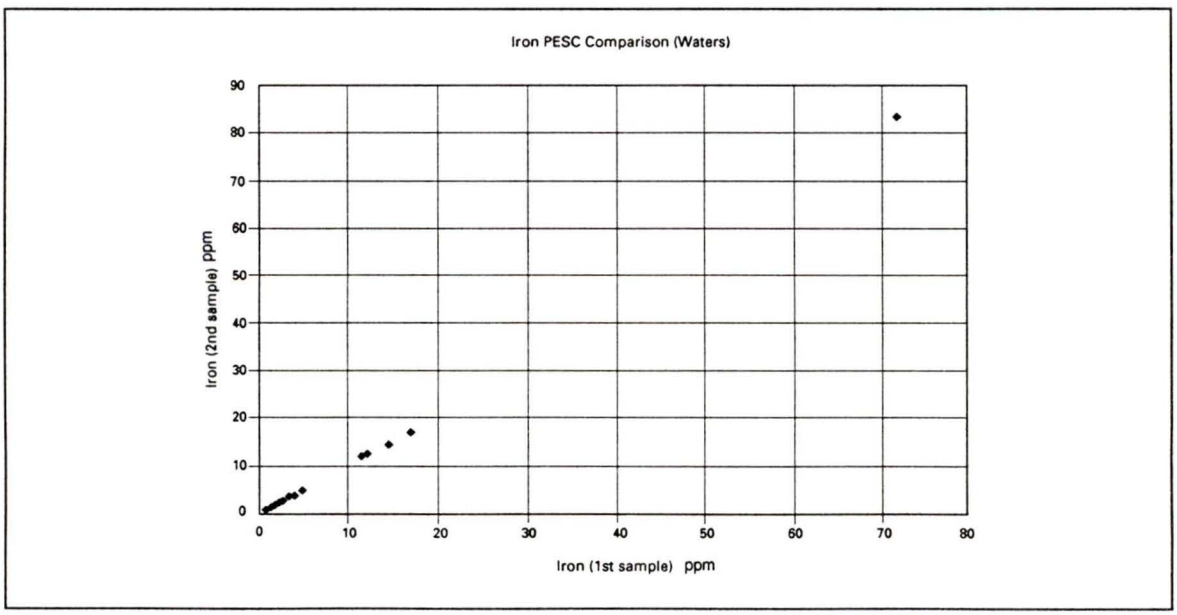
Figure 3-5a shows the correlation coefficient for Cu1 against Cu2 in the scatter diagram. Figure 3-5a was 0.9997. The blind sample pairs are almost identical. This demonstrates that copper content in the water samples was uniform and the analyses consistent.

Figure 3-5b. Scatter Diagram for Copper in Blind Duplicate Plant Samples (PESC pairs)



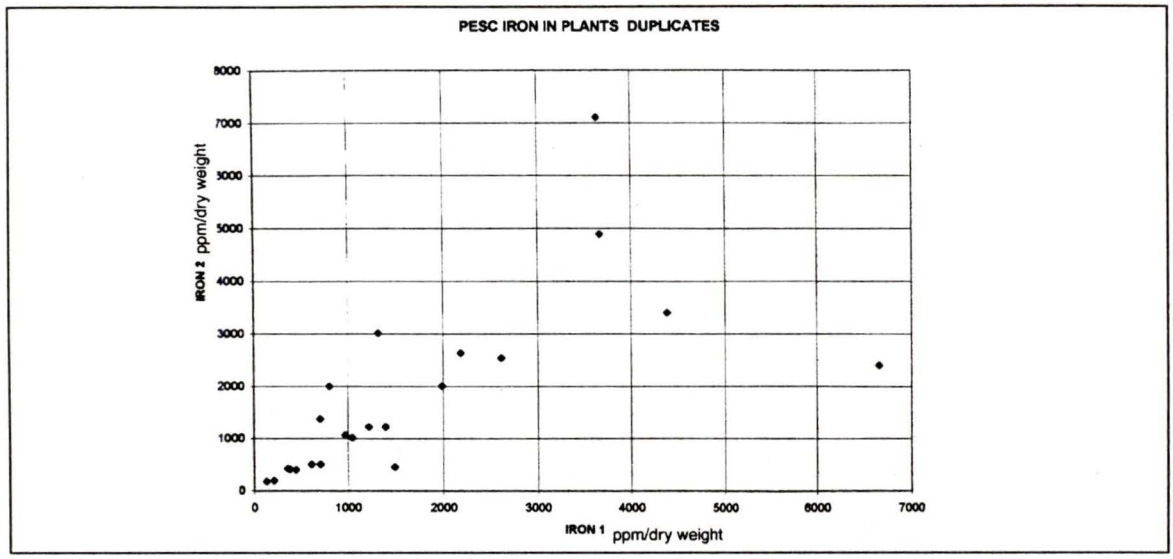
The correlation co-efficient for Cul against Cu2 in the scatter diagram is 0.641. Copper concentrations in most pairs are similar, but there are some outlier values. The material analyzed was cotton grass leaves chopped into ≈1 cm lengths, and there may have been some physical partitioning into heavier and lighter or finer versus coarser plant materials in the shaking and tumbling before taking a sample or incomplete sample digestion may have occurred. Consequently, some of the blind duplicates have different copper values.

Figure 3-5c. Scatter Diagram for Iron in Blind Duplicate Watrer Samples (PESC Pairs)



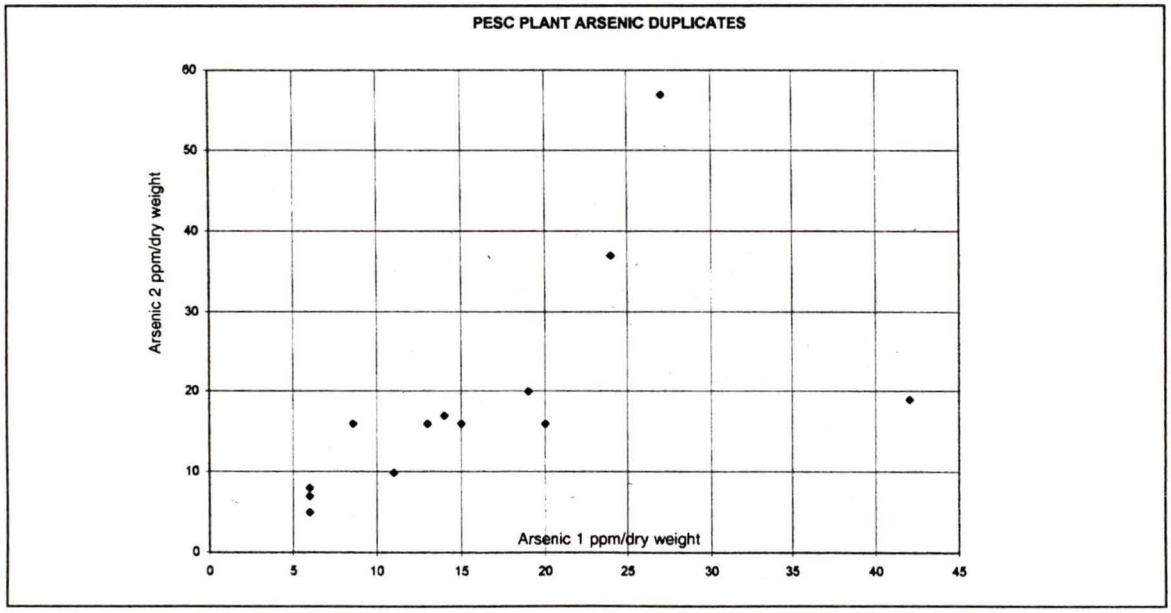
The correlation co-efficient for Fe1 against Fe2 in the scatter diagram Figure 3-5c is 0.909. The blind sample pairs are almost identical for analysed iron content, even up to over 80 ppm. This demonstates that iron content in the water sample was uniform and the analyses consistent. Also, precipitation did not occur, so the preservation was successful.

Figure 3-5d. Scatter Diagram for Iron in Blind Duplicate Plant Samples (PESC pairs).



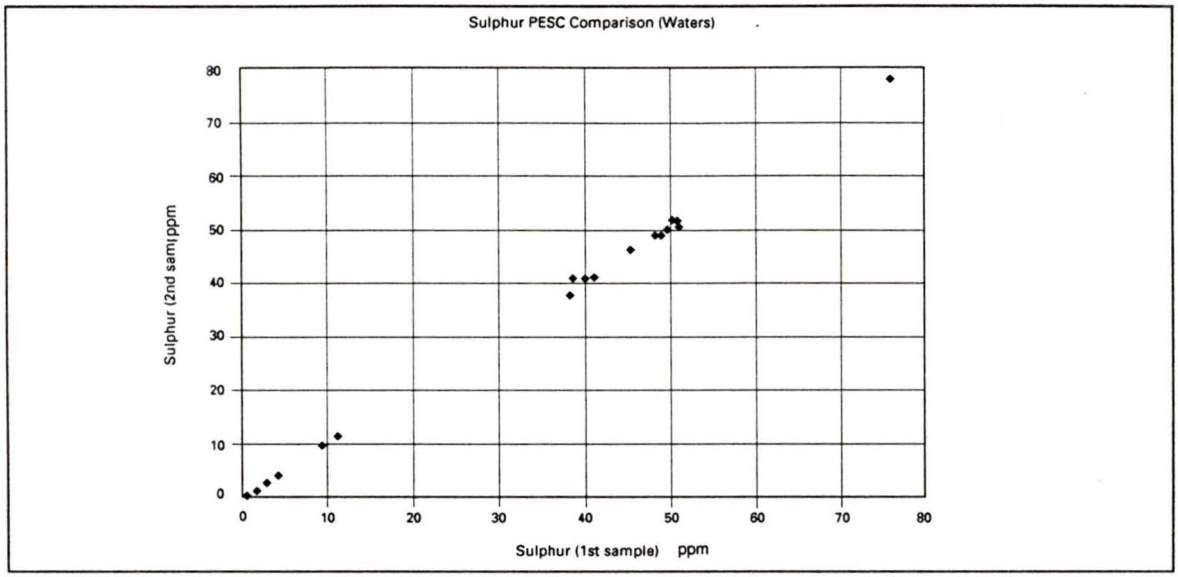
The correlation co-efficient for Fe1 against Fe2 in the scatter diagram Figure 3-5d is 0.673. Iron concentration in most pairs are similar, but there are some outlier values. As noted for copper in Figure 3-5b, physical partioning leading to sample inhomogeneity in the chopped cotton grass leaves may have occurred. Also, incomplete sample digestion may have lead to different analytical results.

Figure 3-5e. Scatter Diagram for Arsenic in Blind Duplicate Plant Samples(PESC pairs).



The correlation co-efficient for As1against As2 in the scatter diagram Figure 3-5e is 0.572. Arsenic concentration in most pairs are similar, but there are some outlier values. As noted for copper in Figure 3-5b, physical partioning leading to sample inhomogeneity in the chopped cotton grass leaves may have occurred. Also, incomplete sample digestion may have lead to different analytical results. If so, this is surprising, since microwaved samples are supposed to be completely dissolved (Lamothe, *et al*, 1986).

Figure 3-5f. Scatter Diagram for Sulphur in Blind Duplicate Water Samples (PESC pairs).



The correlation co-efficient for S1 against S2 in the scatter diagram Figure 3-5f for sulphur in water is 0.9995. The blind sample pairs are almost identical. This demonstrates that the sulphur content in the water samples was uniform and the analyses consistent.

Table 3-9. Field Duplicates of Plant Materials (PESC).[6] (mdl = minimum detectable level)
Sample Site = "ss", numbers in brackets refer to sample station number. Concentrations below mdl not used (not considered "0").

ss 3-11(4)	Cu ppm	As ppm	Al ppm	Fe ppm	S ppm	Zn ppm
Mean	54.7	7.7 (3)	296.3	1130.8	3082	45.1
Min/Max	46.0/68.7	6/10	188/394	1027/1238	2978/3270	37.9/50.9
S. Dev.	11.4±	2.1±	92.8±	112.2±	135.5±	6.1±
N=4, 95% Con. limits	42%	55%(N=3)	63%	20%	9%	27%
	The field sample from station 11 of transect 3 was split into four bags on site.					
ss 6-5(4)	Cu ppm	As ppm	Al ppm	Fe ppm	S ppm	Zn ppm
Mean	81.3	8 (2)	335	1011	4206	42.1
Min/Max	60.5/102.6	n/a	155/488	703/1491	3608/4827	38.3/51.7
S. Dev.	18.9±		163±	504±	500±	6.4±
N=4, 95% Con. limits	46%	n/a	97%	143%	28%	30%
	The field sample from station 5 of transect 6 was split into four bags on site.					
Minesite(8)	Cu ppm	As ppm	Al ppm	Fe ppm	S ppm	Zn ppm
Mean	66.7	13 (n=2)	77.8	592.9	6937	37.6
Min/Max	26.1/178	7/19	25/235	171/1630	4325/12420	23.0/73.5
S. Dev.	51.4±	n/a	70.6±	568±	2832±	16.1±
N=8, 95% Con. limits	154%	n/a	181%	192%	82%	86%
	A large area at the "Dry Pond" inlet was harvested, filling eight bags consecutively.					

[6]Soils and water field duplicates are not yet analyzed.

Analysis of the field duplicate sample analyses reveals that there is a very high degree of variability in the concentrations found due to combined sample site variability, sampling variability, and analytical variability. By examining the results for copper from the plant sample duplicates (see the PESC scatter diagram Figure 3-5b), it appears that the variability in the samples is the same order of magnitude as the analytical variability of the plant materials. In the above, using the minesite copper figures in cotton grass leaves as an example, one could expect the concentrations to go from 0 to 169.5 ppm copper [66.7 –(2 x SD51.4) = -36.1/+169.5] based solely on sampling and analytical variability.

Pacific Environmental Science Centre (PESC)- Environment Canada 1995-1996 Samples

The Environment Canada laboratory ran standards, blanks and their own duplicate samples. Blind duplicates were submitted with the sample batches. The PESC internal check results are shown in Tables 3-10 a-e.

Tables 3-10 a-e. Quality Control (blanks, replicates, and standards) Provided by PESC.

Table 3-10a

						Reference Material Q1004		
		H_2O	Duplicates					
Element	mdl	Blanks	Rep1	Rep2	*%RD	Found	Certified value	**% Recovery
units	mg/l	mg/l	mg/l	mg/l	%	mg/l	mg/l	%
Cu	0.005	<0.005	<0.005	<0.005	NA	2.06	2.00	103
Fe	0.005	<0.005	0.053	0.05	5.8	2.08	2.00	104
S	0.05	<0.05	17	17.2	1.2	<0.05	<0.05	NA
Zn	0.002	<0.002	<0.002	<0.002	NA	2.10	2.00	105
Cu	0.005	<0.005	2.81	2.81	0	2.02	2.00	101
Fe	0.005	<0.005	14.1	14	0.7	2.00	2.00	100
S	0.05	<0.05	28.2	28.2	0	<0.05	2.00	NA
Zn	0.002	<0.002	0.124	0.123	0.8	2.01	2.00	101
Cu	0.005	<0.005	2.24	2.25	0.4	1.98	2.00	99
Fe	0.005	<0.005	30.4	30.5	0.3	1.96	2.00	98
S	0.05	<0.05	29.5	29.6	0.3	<0.05	<0.05	NA
Zn	0.002	0.002	0.124	0.124	0	1.97	2.00	99
Cu	0.005	<0.005	4.79	4.85	1.2	1.98	2.00	99
Fe	0.005	<0.005	0.141	0.138	2.1	1.94	2.00	97
S	0.05	<0.05	42.2	42.6	0.9	<0.05	<0.05	NA
Zn	0.002	<0.002	0.192	0.193	0.5	1.95	2.00	98

Table 3-10b

							Reference Material Q1643	
			Duplicates					
Element	mdl	Blanks	Rep1	Rep2	*%RD	Found	Certified value	**% Recovery
units	mg/l	mg/l	mg/l	mg/l	%	mg/l	mg/l	%
Cu	0.005		3.63	3.63	0	0.021	0.0205	102
Fe	0.005		12.1	12	0.8	0.091	0.0912	100
S	0.05		46.6	46.5	0.2	0.06	NC	NA
Zn	0.002		0.156	0.157	0.6	0.07	0.07248	97
Cu	0.005		0.141	0.142	0.7	0.021	0.0205	102
Fe	0.005		1.21	1.2	0.8	0.091	0.0912	100
S	0.05		0.91	0.9	1.1	0.06	NC	NA
Zn	0.002		0.01	0.01	0.0	0.071	0.07248	98
Cu	0.005	<0.005	8.79	8.77	0.2	2.02	2.00	101
Fe	0.005	<0.005	20.5	20.4	0.5	1.98	2.00	99
S	0.05	<0.05	9.55	9.5	0.5	<0.05	<0.05	NA
Zn	0.002	<0.002	0.088	0.088	0.0	2.01	2.00	101

Table 3-10c

								Reference Material Q1014
	mdl		Duplicates					
Element	biota	Blanks	Rep1	Rep2	*%RD	Found	Certified value	**% Recovery
units	ug/g	mg/l	ug/g	ug/g	%	ug/g	ug/g	%
As	4	<0.05	9.6	10	4.1	15	16.6	90
Cu	0.4	0.007	63.9	61.5	3.8	27.6	25.8	107
Fe	0.4	0.014	1251	1224	2.2	1104	1103	100
S	4	<0.05	2519	2447	2.9	11410	NC	NA
Zn	0.2	0.003	39.4	37.3	5.5	88.34	85.8	103
As	4	<0.05	<4	<4	N/A	14	16.6	84
Cu	0.4	0.008	4.6	4.6	0	28.5	25.8	110
Fe	0.4	0.016	172.3	152	12.5	1097	1103	99
S	4	<0.05	2479	2488	0.4	11680	NC	NA
Zn	0.2	0.003	45.8	46.1	0.7	90.98	85.8	106
As	4	<0.05	26	26	0	15	16.6	90
Cu	0.4	0.013	136.8	143.2	4.6	27.6	25.8	107
Fe	0.4	0.074	4576	4243	7.6	1183	1103	107
S	4	<0.05	2466	2510	1.8	11850	NC	NA
Zn	0.2	0.043	36.2	37.4	3.3	84.85	85.8	99

Table 3-10d

						Reference Material Q1015		
Element	mdl biota	Blanks	Duplicates Rep1	Rep2	*%RD	Found	Certified value	**% Recovery
units	ug/g	mg/l	ug/g	ug/g	%	ug/g	ug/g	%
As	4	<0.05	<4	<4	NA	25	21.6	116
Cu	0.4	<0.005	18.9	20.5	8.1	101.5	106	96
Fe	0.4	0.01	107.8	109.3	1.4	99.79	105	95
S	4	<0.05	1358	1442	6	10530	NC	NA
Zn	0.2	0.002	27.9	29.5	5.6	180.9	180	101

Table 3-10e

						Reference Material Q2704		
Element	mdl soil	Blanks	Duplicates Rep1	Rep2	*%RD	Found	Certified value	**% Recovery
units	ug/g	mg/l	ug/g	ug/g	%	ug/g	ug/g	%
As	0.5	<0.05	282	282	0	25	23.4	107
Cu	0.8	<0.005	158	161	1.9	107	98.6	109
Fe	0.8	<0.005	43640	42790	2	27500	41100	67
S	8	<0.05	3068	3156	2.8	3814	3970	96
Zn	0.3	<0.002	92	85.2	7.7	414.7	438	95
As	0.5	<0.05	681	683	0.3	23	23.4	98
Cu	0.8	0.015	3206	3273	2.1	100	98.6	101
Fe	0.8	0.01	41520	42390	2.1	36870	41100	90
S	8	<0.05	4844	4928	1.7	3843	3970	97
Zn	0.3	0.003	62.3	64.2	3.0	435.1	438	99

Table 10 Notes: *%RD (percent relative difference): limit = < 20% for results greater than 2 x mdl

****% recovery: limit =80% - 120%**

NA = not applicable

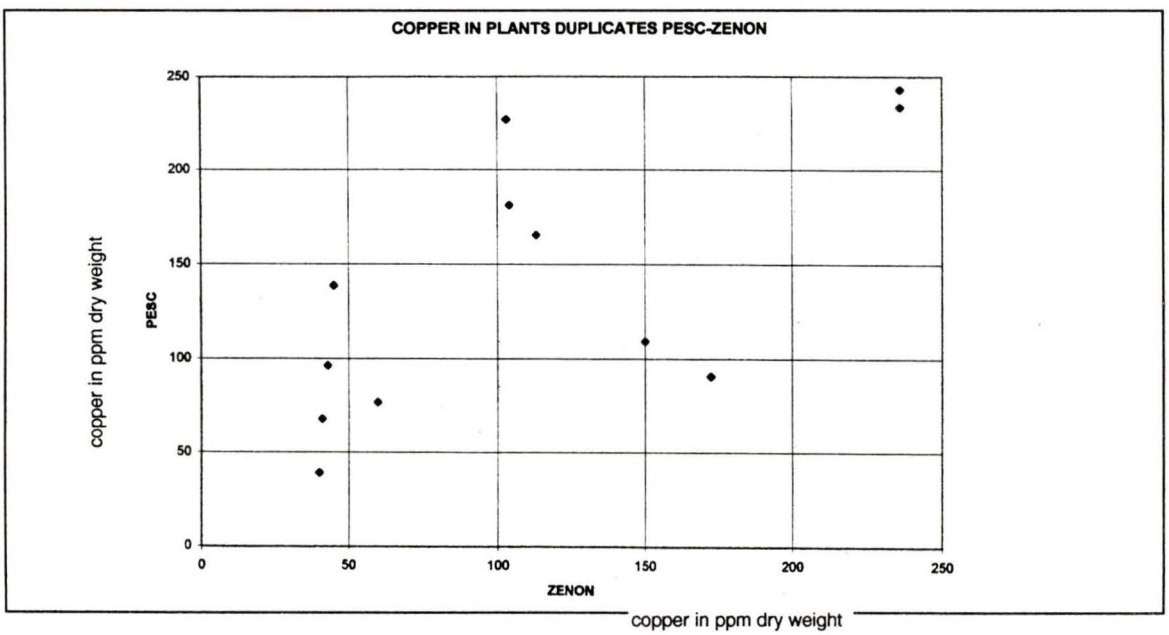
NC = not certified

mdl = Minimum detection level

Zenon Environmental Laboratories analyzed the plant samples for Transects 3 and 5. These duplicated some of the samples run by for PESC for those transects. A scatter diagram of the copper results is shown in Figure 3-6.

Figure 3-6 indicates that there is a high degree of variability in copper concentrations produced by the two digestion procedures (microwave with peroxide in the use of PESC, nitric-perchtoric in the case of Zenon). However, this may not be the case. There appears to be more variability in this diagram than in the comparisons between the PESC/PESC analytical results (Figure 3-5b), but the correlation coefficient is 0.678, slightly higher than the 0.641 for PESC/PESC results. From both this Figure 3-6 and the Figure 3-5b, show that the variability due to sampling variability analyses is high, requiring large numbers of results to make statements that can be proved with statistical methods to a high degree of certainty. Any variation cased by differences in recovery with the two digestion procedures in copper concentration seems to be less than that caused by sample inhomogeneity.

Figure 3-6: Scatter Diagram of PESC/Zenon Analytical duplicates for Copper in Cotton Grass Leaves.



ACME Analytical Laboratories, Ltd. 1995 Soils.

Acme Labs ran standards, and a duplicate, plus a standard, LKSD-1, was included in the materials submitted.

Table 3-11. ACME Analytical Laboratories Results of Certified Standard, Duplicate and Blind Duplicate Analyses.

LKSD-1 Aqua regia extraction upper row, 2 Acme results below, figures in ppm.

Std./Lab.	As ppm	Cu ppm	Fe ppm	P ppm	Zn ppm
LKSD-1	30	44	18,000	580	331
Acme a	36	47	22,300	680	353
Acme b	35	45	22,900	680	363
%Recovery	117-120%	102-107%	124-127%	117%	107-110%

Acme's duplicate results (DCS 22)

Acme Dup.	As ppm	Cu ppm	Fe ppm	P ppm	Zn ppm
Acme a	519	3405	52,200	940	72
Acme b	515	3469	51,800	940	73
% Mean diff.	0.8%	1.9%	0.8%	0%	1.4%

Submitted Duplicates:

Sample #	As ppm	Cu ppm	Fe ppm	P ppm	Zn ppm
DCS 8	961	3608	61,400	640	112
DCS 11	947	3555	60,300	640	108
% Mean diff.	1.5%	1.5%	1.8%	0%	3.6%

Submitted Duplicates:

Sample #	As ppm	Cu ppm	Fe ppm	P ppm	Zn ppm
DCS 27	793	2376	49,600	840	53
DCS 35	802	2404	49,600	840	50
% Mean diff.	1.1%	1.2%	0%	0%	5.8%

The Acme results appear to demonstrate good reproducibility. Their duplicate samples are in the same range (of % mean difference) that the blind duplicates were concentrations of arsenic, copper, iron, phosphorous and zinc.

Some soil samples were split, and the splits run through the Environment Canada Laboratory at the Pacific Environmental Science Centre ("PESC") and Acme. By chance, the figures are all fairly close together (the distribution of concentrations is fairly narrow), so that a scatter diagram would not show the relationships with these samples clearly.

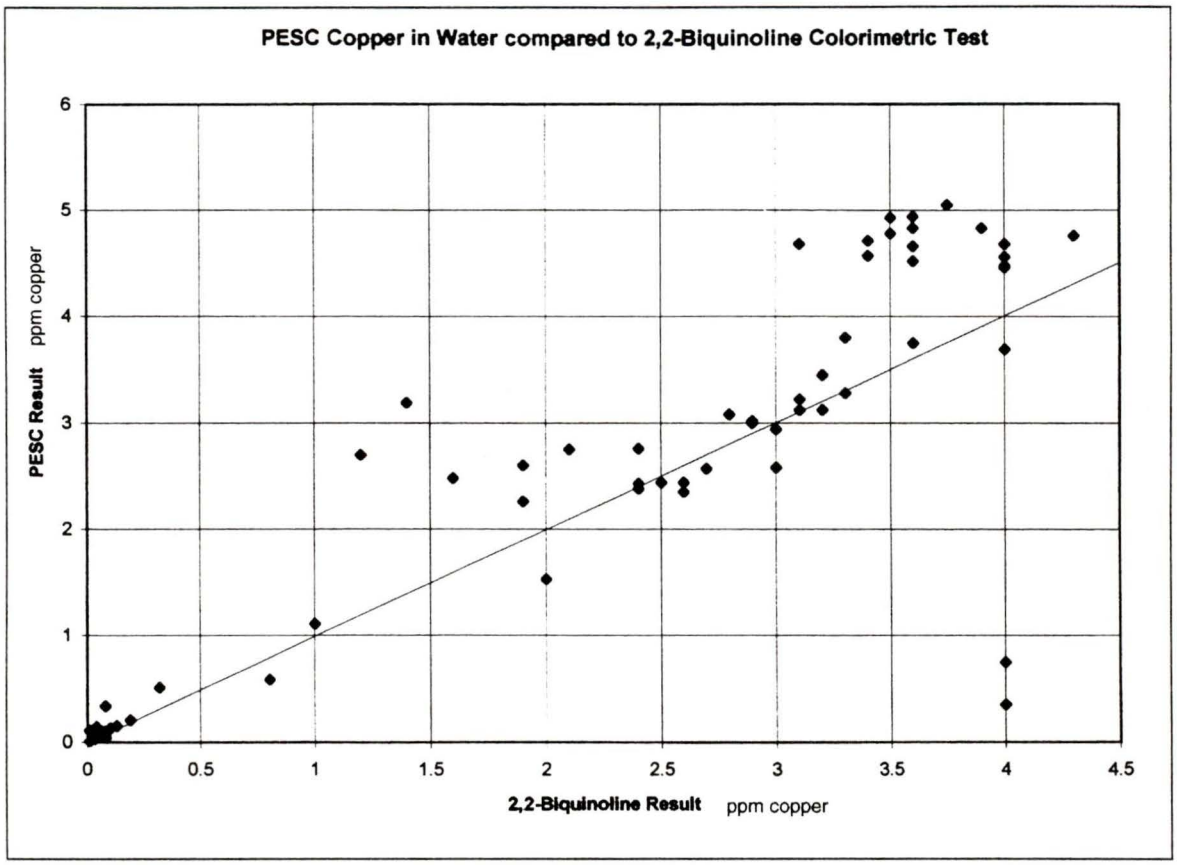
Table 3-12. Comparison between ACME and PESC Analyses (blind duplicates).

Lab	As ppm	Cu ppm	Fe ppm	P ppm	Zn ppm
Acme	947	3555	60,300	640	108
PESC	1010	3571	65,190	820	92
% Mean diff.	6.4%	4.5%	7.8%	25%	16%
Lab	As ppm	Cu ppm	Fe ppm	P ppm	Zn ppm
Acme	654	2648	41,400	940	50
PESC	676	2623	42,080	1100	40.8
% Mean diff.	3.3%	0.9%	1.6%	16%	20%
Lab	As ppm	Cu ppm	Fe ppm	P ppm	Zn ppm
Acme	886	3739	69,200	720	101
PESC	966	3951	76,260	990	107
% Mean diff.	8.6%	5.5%	9.7%	32%	5.8%
Lab	As ppm	Cu ppm	Fe ppm	P ppm	Zn ppm
Acme	554	3954	43,600	980	57
PESC	574	3923	44,550	1200	50.5
% Mean diff.	3.5%	0.8%	2.1%	20%	12%
Lab	As ppm	Cu ppm	Fe ppm	P ppm	Zn ppm
Acme	802	2404	49,600	840	50
PESC	846	2391	52,520	1100	46.5
% Mean diff.	5.3%	0.5%	5.7%	27%	7.3%

These are organic soils, so, considering that the digestion methods are different, with Acme using an aqua regia digestion and PESC using an aqua regia plus concentrated hydrogen peroxide digestion, the results are strikingly similar, with only phosphorous showing a different recovery level. This could indicate that arsenic, copper, iron and perhaps zinc, are primarily adsorbed onto organic matter, not as an intrinsic chemical component of the organic matter; whereas much of the phosphorous is a component of the organic matter, and released with the more complete digestion of the organic matter with the strongly oxidizing digestion procedure used by PESC.

A set of water samples for the transects 3 and 5 that corresponded the locations that the soils Acme (previous paragraph) ran were tested with 2,2-biquinoline indicator solution. The samples were diluted to 10% before being run, and if no colour or only faint colour was noted, the full strength samples were run. These concentrations found were tabulated with the first set of results from Environment Canada, to see: what the degree of agreement was; and: if there appeared to be considerable amounts of copper held in organic complexes or not (proportion of ionic copper to non-ionic, complexed copper). The results of this tabulation are shown graphically in Figure 3-7.

Figure 3-7. Scatter Diagram for Copper Water Sample Duplicates Analyzed by 2, 2-Biquinoline and ICP-AES (PESC).



The correlation coefficient for copper determined by the two methods is 0.879. The line shown is the 1.0 coefficient line. The agreement of the 2,2-biquinoline results and the PESC ICP-AES results appear to be within the expected error of a colorimetric test[7], indicating that most of the copper in the fen and background water was extractable by the 2,2-biquinoline. However, there is a difference, which becomes marked at higher concentrations. A visual inspection of the above graph will show that the PESC results between 4 and 5 ppm copper average out to about 4.6-4.8, while the colormetric results average out to about 3.6, indicating about 1.1 ppm copper is strongly bound to dissolved organic compounds, almost a quarter of the dissolved copper present. The pH values for the higher copper concentrations were generally lower than those for the lower copper concentrations, but there was considerable overlap (see Appendix II, Table A2-1).

[7] Given as ±10% in "Hach" kit manuals

Chapter IV - Description of Results

Biophysical Changes in the Fen

Introduction

Determining the stability of the fen environment, and especially the fen drainage channel, was considered to be important for interpreting the geochemical results. Changes in channel morphology and in the composition of the vegetation communities could affect the amount of metals retained or released into the environment. If the environment is unstable, and the channel that crosses the fen has been laterally displaced (the soft materials of the fen would seem to be very subject to erosion from Pyrrhotite Creek), very large changes in the composition and the non-mine related sediments in the fen can be expected. Furthermore, the volume of the fen should be determined so that an estimate for the size of the metals reservoir in these sediments can be made. Erosion of peat soils in the fen could carry large amount of suspended copper-rich sediment. This sediment could easily reach the Tsolum River. With the high (80-270 l/sec) winter flows of a low (3.5-4.5) pH (Deniseger and Pommen, 1995), some of this suspended copper could become desorbed, and become biologically available dissolved copper. The proportion would depend on the stability of the complex or compound, the water pH, and the exposure time. Desorption and release could occur rapidly in response to a drop in pH.

The local topography and plant ecology of high altitude wetlands tends to remain fairly stable over time, provided major events such as a glacial advance do not interfere. That is, the local topography tends to become flat and the plant ecology tends to diverge from a "standard" sequence (as the wetland goes from deep lake or pond → shallow lake or pond → rich fen → poor fen → bog) typical of low elevations (Shotyk, 1988; Mitsch and Grosselink, 1993). The natural evolution of these basins may be dramatically slowed or arrested at one of the stages, and maintain an intermediate stage, changing less in species presence/absence and dominant species over time, in response to climatic changes, than hill slope ecosystems. This may be due to climatic effect (a pond may freeze to the bottom every winter, and this may force the annual sediment deposition to, and over the pond sites, maintaining the slope and volume indefinately) or differences in growth rate (growth and deposition of plant materials may be completely balanced by decay) (Graumlich, 1994; Owens and Slaymaker, 1993). However, there appeared to be some changes in the Branch 126 sedge fen channel morphology and vegetation community composition from October 1992 to September of 1994 which challenged that concept.

Results of studying physical and biological variables

Physical and other variables that could influence geochemistry are:

1). The stability of the channel through the Pyrrhotite Creek sedge fen,

2). Road construction,

3). Hay bale weir installation,

4). Changes in plant communities,

5). Sedimentation.

1). Channel Stability

Remarkably, comparison of the channel outlines showed only slight changes through time. The main differences in channel boundary location were considered to be due to water level changes [see Plate 6, taken at freshet, which is comparable to the May 1957 outline water level (Figure 4-1b). Water level variations can be seen in Plates 2 to 13. Also, note changes in the channel which enters just east of the main junction. This channel may be identified in the outlines as Channel B. Channel A is the main channel.

Channel B almost disappeared in the period 1987-1993, but is re-forming. The re-formation of channel B was the observation which led to the belief that rapid changes were occurring. This re-formation is an indication that the forces which eroded it in the first place are operating again.

There was no evidence that channel A downstream of the main inlet moved significantly over the 50 years covered by the photographs in this investigation. The soft peat soils have not been eroded to form new channels after the installation of the hay bale weirs (put in by Environmental Protection in 1991, and extended in 1992), although heavy rain events and high spring runoff periods would result in new channels forming and change in the existing channel, if erosion occurs after snow melt. The following Figures 4-1a to 4-1g show the small degree of channel displacement during the time period covered, while Figure 4-1h superimposes the channel outlines from the 1946 aerial photograph on the surveyed outline from 1995. Most apparent variation is on the 10 to 20 cm range, which is insignificant. Photographic distortion may account for some of it.

Figure 4-1a Sedge Fen outline in May, 1946

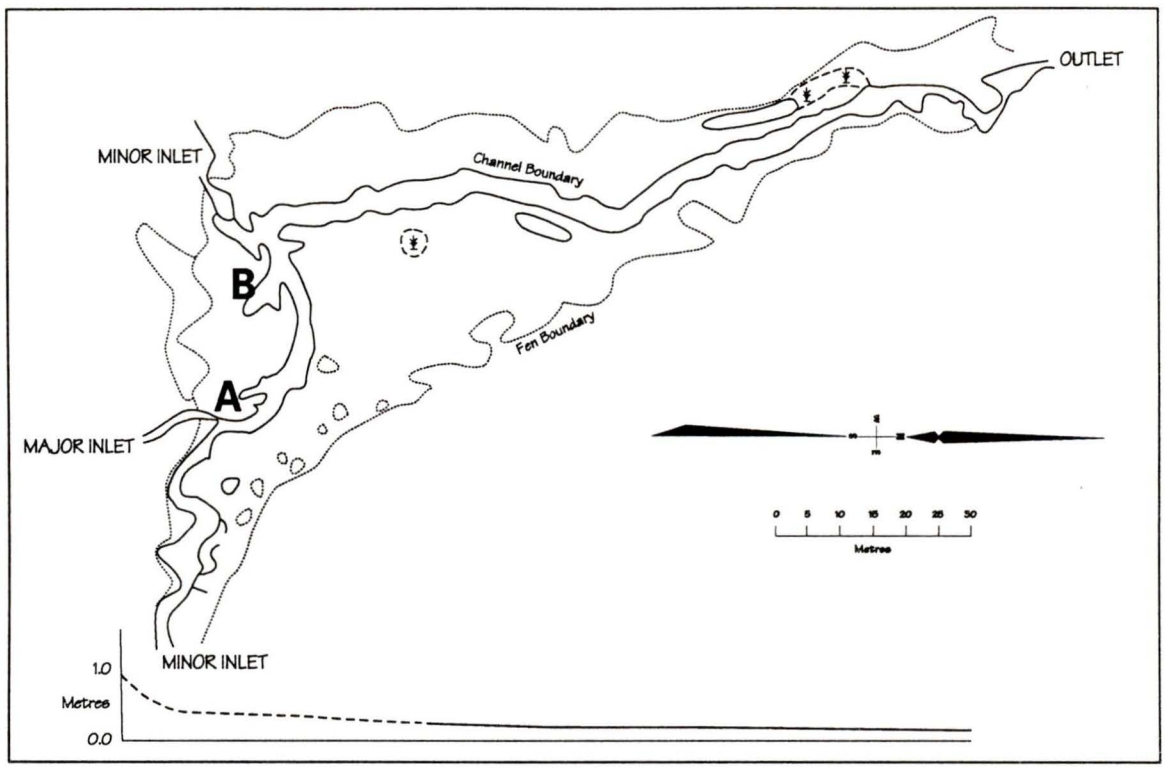


Figure 4-1b Sedge Fen outline in May, 1957

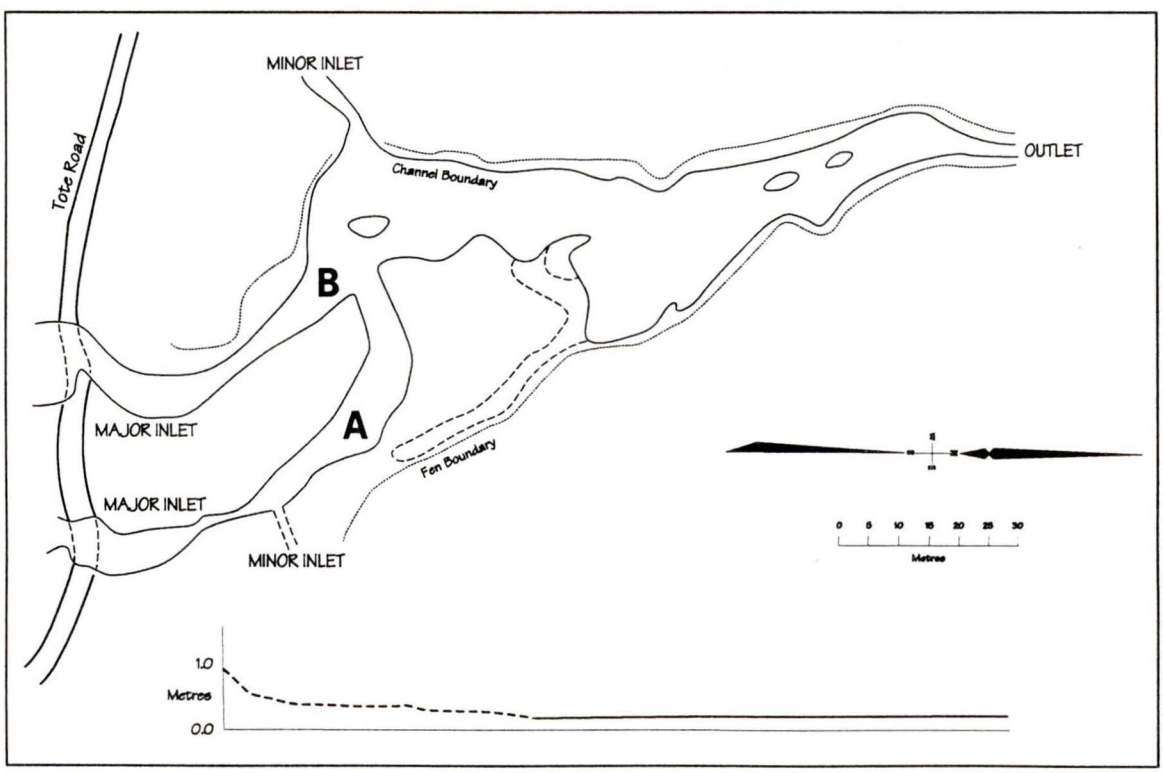


Figure 4-1c Sedge Fen outline in July, 1972

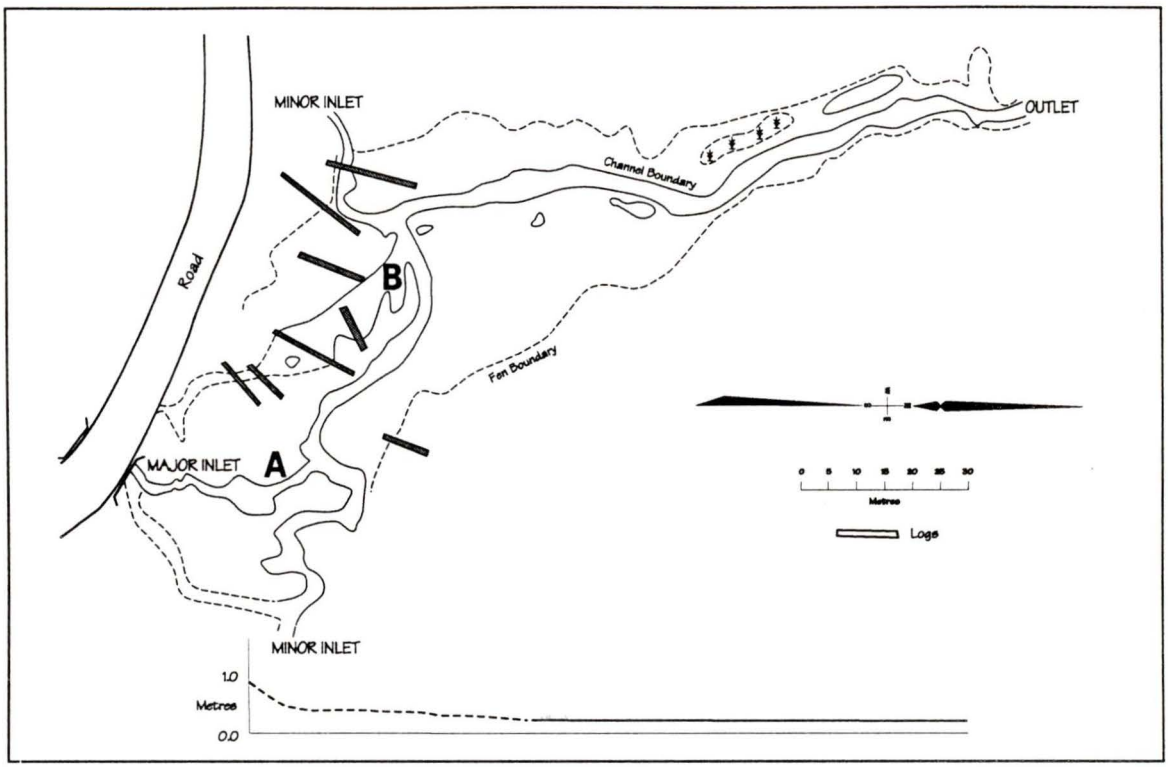


Figure 4-1d Sedge Fen outline in July, 1984

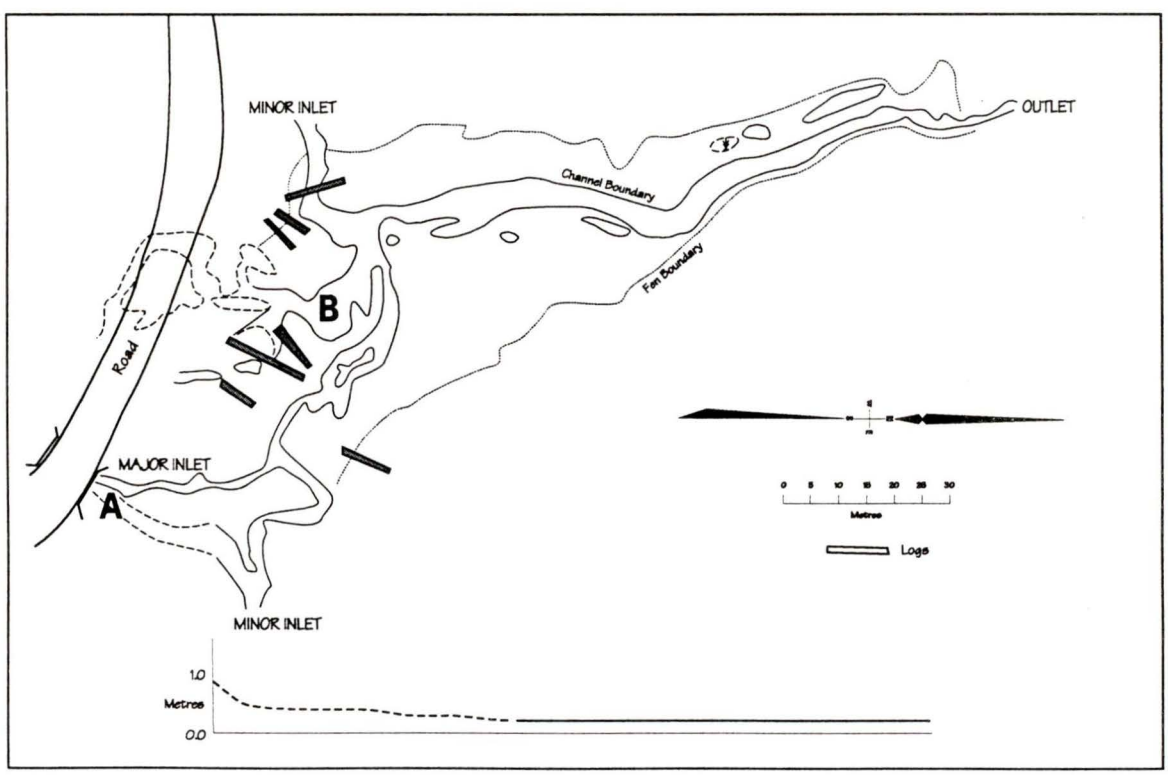


Figure 4-1e Sedge Fen outline in July, 1987

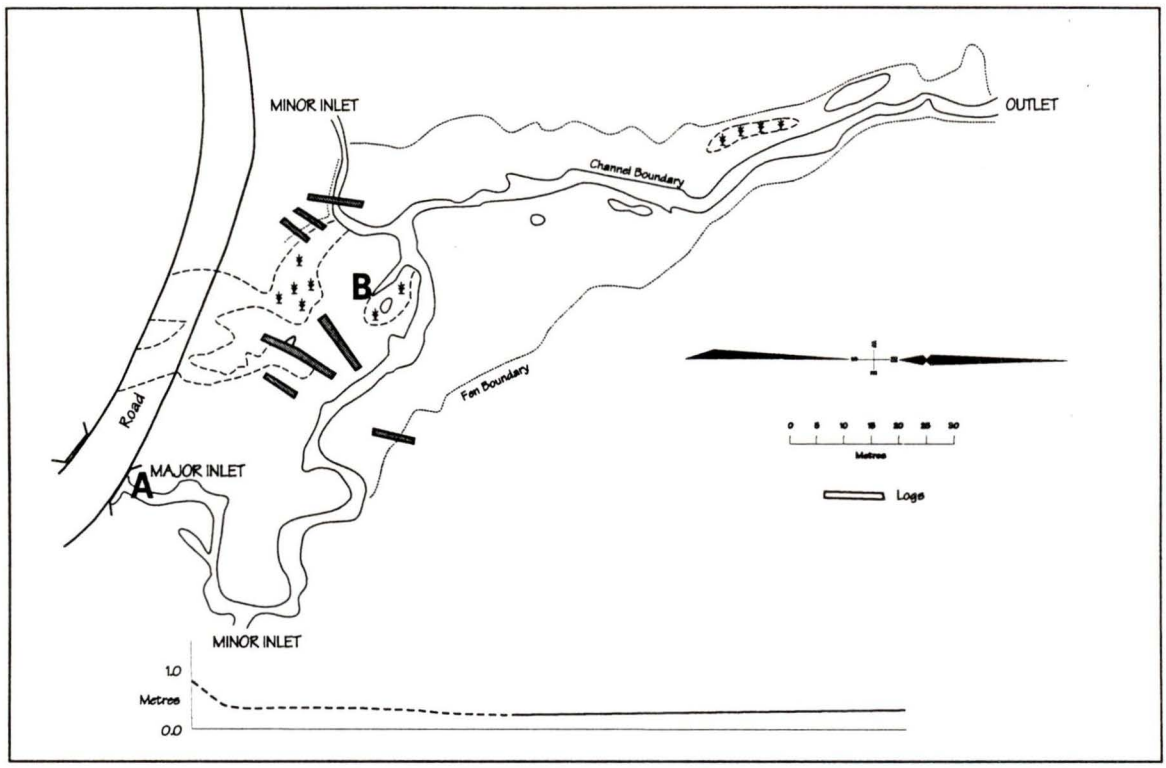


Figure 4-1f Sedge Fen outline in September, 1993

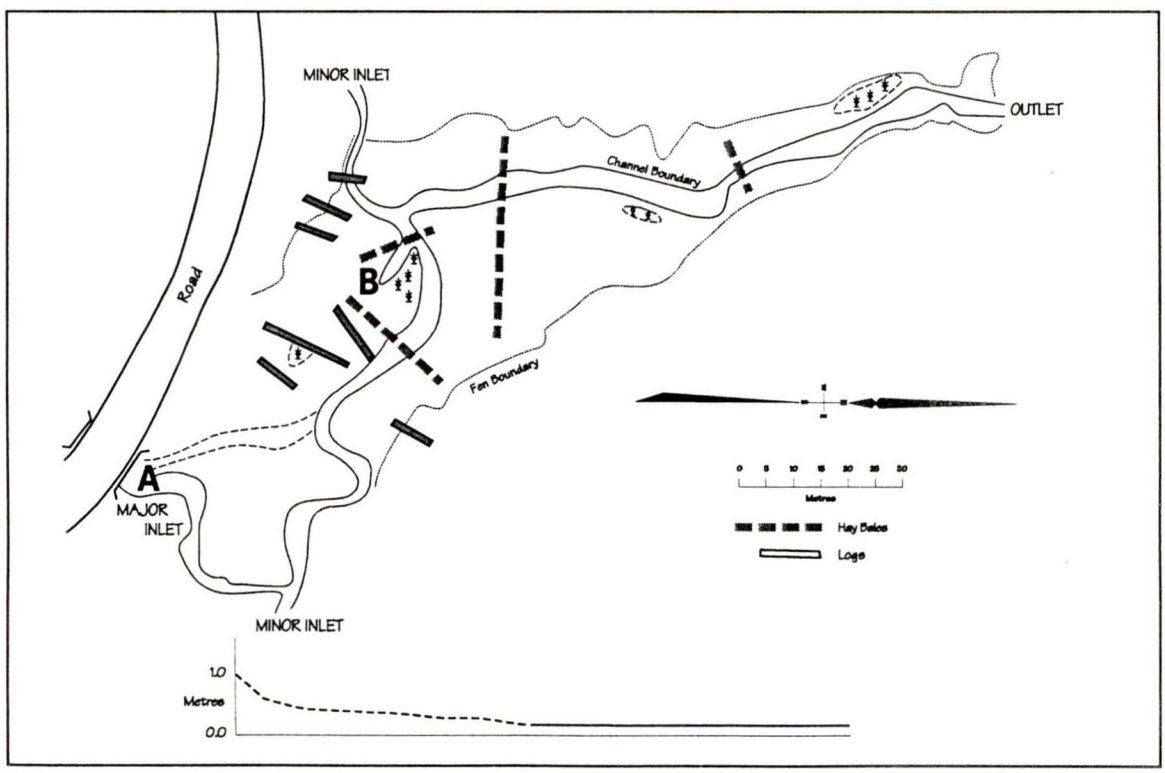


Figure 4-1g Sedge Fen outline in October, 1995

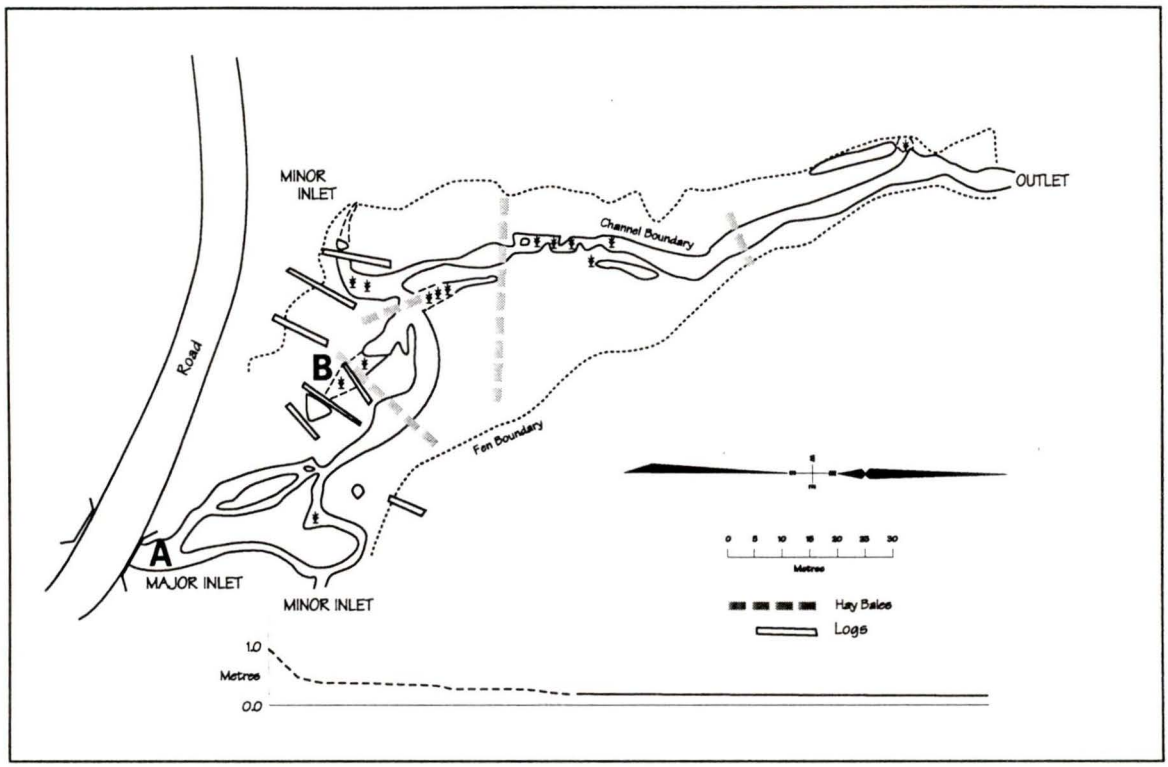
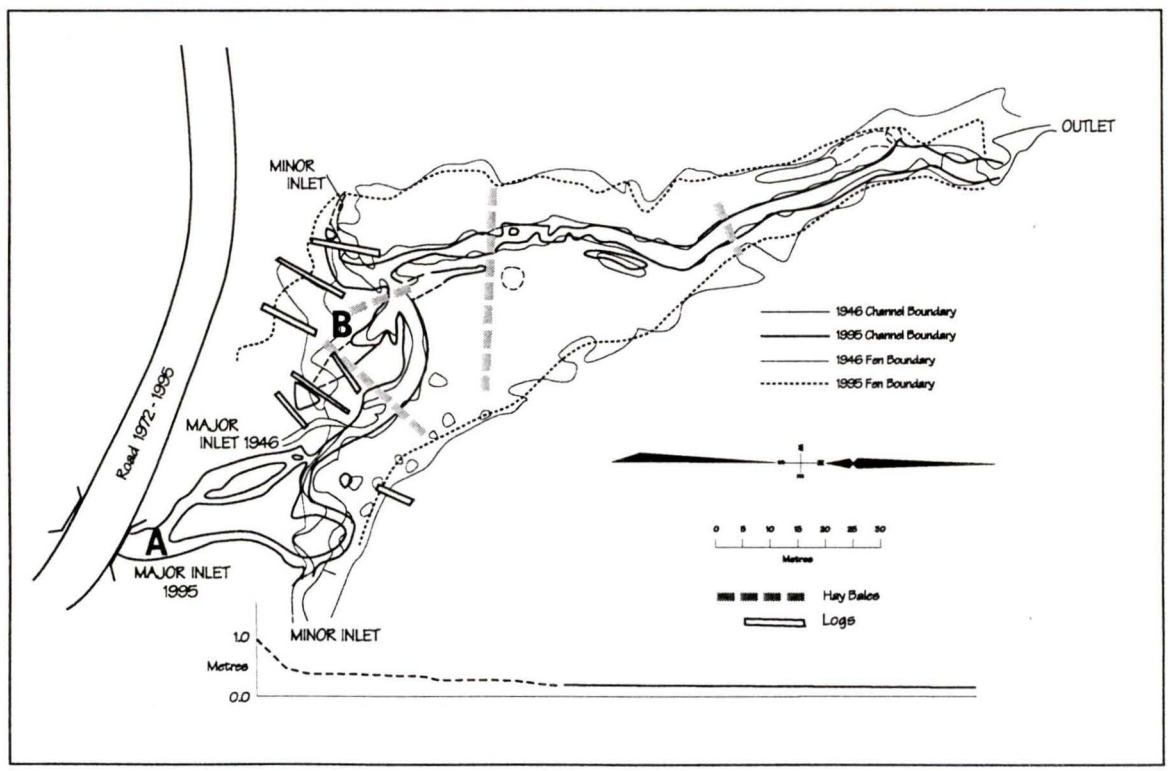


Figure 4-1h Sedge Fen outline in October, 1995, compared to outline in May, 1946



During the 1995 channel outline survey, a number of small boulders were found near the outlet. These did not appear permanent (no moss, which is growing on some large boulders upstream), but did not move during the study period based on the photographs taken through the project. Also, gravel pockets were detected in some of the pools along the channel. This indicates that the current velocity is high enough to move gravel-sized clasts frequently, and larger clasts occasionally.

At some sites immediately adjacent to the main channel, gravel was felt while driving the sounding rod in. Nothing was noted away from the channel while soundings were taken. Occasional single pebbles would be noted in the soil cores or soil pits, but this was very rare. This appears to support the concept that the channel has occupied its present position relative to the edges of the fen for a very long time.

2). Road Construction

The road construction started in 1955. The road was widened in the years preceding the opening of the mine in December of 1964. Logging in the 1970's removed trees on the alluvial fan at the south end of the fen. The bridge was inadequate to handle the flow of Pyrrhotite Creek at freshet, and erosion of the road surface occurred up until 1990, when the Reclamation Branch of EMPR rebuilt the bridge (examination of the aerial photography; Galbraith, 1991a).

3). Influence of the hay bale weir construction

The hay bale weirs were constructed in 1991 and 1992 to increase the retention time of the metal-rich water by the fen [Hydraulic Retention Time or "HRT" (Golder, 1997a)], which dramatically increases the proportion of metals removed (Sobolewski, 1997b; Hammer, 1989; Means and Hinchee, 1995). Since the hay acts as a reducing material, they were also expected to participate in metal removal. These hay bale weirs have made the surface of the fen more likely to have standing water on it (which appears to have had a strong effect on the plant communities), and they have probably increased the sedimentation rate also. Examining the plates, the log in the middle ground of the photographs which cuts across channel B, appears lower relative to the ground surface in Plates 12 and 13 than in Plates 2 and 3. Sediments have collected in the hay bales, and their interior is a reducing environment as shown by a jet-black colour and strong hydrogen sulphide odour. An orange-grey (on drying) crust has formed on many bales at the surface of the bale at the upstream side. Their height relative to the fen surface has decreased. Inspection shows that the bales have

deformed, becoming oval. They have collapsed and have sunk into the surface, and there is a difference in fen level upstream and downstream of the weirs. That is, the soil surface, water level, and height of the cotton grass is higher on the upstream side of the weirs, compared to the downstream side. This appears due to sedimentation on the upstream side of the weirs.

4). "Stability of Plant Communities" investigation results

Visual comparison of the slides and prints showed a great increase in cotton grass flowering and seed head production in 1994, compared to the earlier years (green-up in 1995, 1996 and 1997 was 8 weeks later than in 1993 and 7 weeks later than 1994 - pers. ob.). Since cotton grass reproduces largely through rhizomes, young nodes will not flower for two or three years. The 15 samples taken from the fen and planted in 1995 in a tank to check low-altitude survival had one flower in 1996 and two in 1997. If a cotton grass community is spreading, it may take years before a colonized area will flower and produce the distinctive seed heads for which the plant is named. So, there appeared to be a substantial increase in adult plants in the 1992 to 1994 periods, but it was not clear from this if the increase was due to an increased number of adult plants or a better season for the plants than previously photographed, or the presence of the hay bale weirs. The period of observation was too short.

As reported in Chapter II, 16 plant species (possibly 17) were found in the fen at the time of the first visit. Collections were made in September 1993 and 1994, the latter while accompanied by Dr. Adolf Ceska. Only:
Eriophorum angustifolium, the Narrow-leaved Cotton Grass;
Carex pluriflora, the Several-Flowered Sedge;
Carex stylosa, the Long-styled Sedge;
Carex ablata, the Woodrush Sedge; and
Saxifraga ferruginea, the Rusty Saxifrage;
grew in the fen at that time. The grid established in 1993 was walked and plants examined along those lines.

By the fall of 1995, the sedges were on the periphery of the fen only, as was the rusty saxifrage. The background sites showed no changes in species presence/absence or abundance. As reported in Chapter II, the meadow area on the western fringe was being occupied by cotton grass by this time.

From the first collection in 1992, which gave a preponderance of sedges in the fen and 20 species (total) of plants (16 vascular plants); to 1994 when only cotton grass grew over the bulk

of the fen and there were 3 species of sedges and one saxifrage on the outskirts of the fen; to 1995 when the saxifrage no longer grew in the fen, there has been a reduction of species. Plate 2 shows the wetland late September 1992 (the white tufts are cotton grass seed heads) while Plate 9 shows the wetland October 1995, with 100% cotton grass from just past the stumps to the end of the picket line. Nearby sedge fens appear to have a high proportion of cotton grass, but support many other plants as well. See Figures 2-8, 2-11, 2-12 on the Branch 126 sedge fen biota and that of the background sites. In 1992 a rough 10 metre square grid was used, but from 1993 on, the surveyed grid was used with a linear census along the grid lines and notation of plant locations on the grid. Simple numerical measurements of population sites (numbers of plants of a particular species) were made.

By the end of the summer in 1997, there were few changes noted from the end of summer 1995. The channels A and B were in their pre-road construction configuration, from the southern portion of the fen next to the alluvial fan to the outlet, sedimentation appeared to be high, and the vegetation over the body of the fen was entirely the narrow-leaved cotton grass *Eriophorum angustifolium*, with the occasional sedge and saxifrage, as noted previously, right along the fen margin.

5). Sedimentation rates

At first, it was assumed that the sedimentation rate throughout the fen was very low, and that the "disappearing act" of the stakes used to mark the grid was due to the stakes sinking. These stakes were 52 cm in length, and initially pushed in approximately 20 cm, so that the ends could be seen above the cotton grass leaves, but they became harder and harder to find, some having only 8 cm above the soil surface in September 1996. To test this "sinking stake" hypothesis, 12 stakes with long cross-pieces were placed in the wetland and pushed in to the point where the cross-piece's lower edge was against the cotton grass rhizomes and roots (see Table 4-1). Taking a similiar stake and pushing it in adjacent to the previous allowed a height difference to be measured. This allowed a rough estimate for the initial sedimentation rate of ≈2.0 cm per annum, which would suggest that the ponds, supposedly collecting sites for sediments, should have been buried under a metre of soft sediments since the 1946 photographs. Even allowing for compression and dewatering, this sedimentation rate seemed high, given the net sedimentation rates of Durno (1961) or Owens and Slaymaker (1993). There was no substantial increase in density (the density of all samples, including surface samples, remained constant). The core samples had a average density of 1.0-1.1 (the wet samples were pressed into a graduated container, then the volume and mass of the samples was measureed and density determined), and for a set of paired samples from near the surface and from a depth of 6 cm, the moisture content (loss on drying at 105°C) was 81.32% for the surface and 81.26% for the 6 cm samples.

Table 4-1. Sedimentation throughout the Branch 126 Sedge Fen.

Station	Sedimentation Rate (cm/Year)	Station	Sedimentation Rate (cm/Year)	Station	Sedimentation Rate (cm/Year).
10N+01E	+3.1	34N+01W	+1.0	51N+00	+1.5
16N+01W	+4.5	40N+0.5V	+1.0	55N+00	+4.0
22N+01E	+0.7	40N+1.5E	-3.0	60N+01.5E	+3.5
30N+02.5E	+3.8	45N+01E	+4.0	65N+02E 70N+01.5E	-1.0 +3.5
Average, S.End	+3.0	Average, middle	+0.75	Average +2.3 N. End	Overall +2.0 Average

The ponds A, B, C (see Figure 2-4) are not being buried, so this could indicate that the sediments compress and dewater very abruptly (common to organic-rich sediments). This could also indicate that, although the hay bale weirs and the water flow weir have increased the sedimentation rate far beyond the rate when the fen was not modified, there are geomorphological processes which are maintaining these ponds, such as the formation of ice lenses. This work does not take into account erosion of the sediment, but observation during flooding episodes suggests that although some of the very fine surface sediment is washed away, especially in the channel, there is net deposition elsewhere. This is to be expected as Pyrrhotite Creek loses velocity when spreading out over the fen. A repeat of the original grid survey in the future would probably be the only way to determine the recent overall sedimentation rate, and for the past, to use carbon 14 dating. Figures for England (reported in Durno, 1961) suggest a sedimentation rate or growth rate in the order of 12 to 147 cm per 1000 years. Owens and Slaymaker (1993) reported sedimentation rates of 0.04 mm-0.07mm/annum (–0.03—0.05) over the past 2350 years in tarns in the Coast Range, and noted that the banks appeared stable over time, with winter erosion being nearly equal to summer deposition. The indications from their work suggest that some small alpine to subalpine ponds, once established, can last millennia, and do not go through the lake to wetland sequence noted in the introduction on the human time scale, although they might on the geological time scale.

Much of the surface sediment noted was flocculent ruddy particles, which tended to block the filters used when preparing the water samples. This dried to an orange-gray, and stained hands, clothing and tools a distinctly rusty hue.

Geochemistry

Initial Results

Fall 1993

1). Water

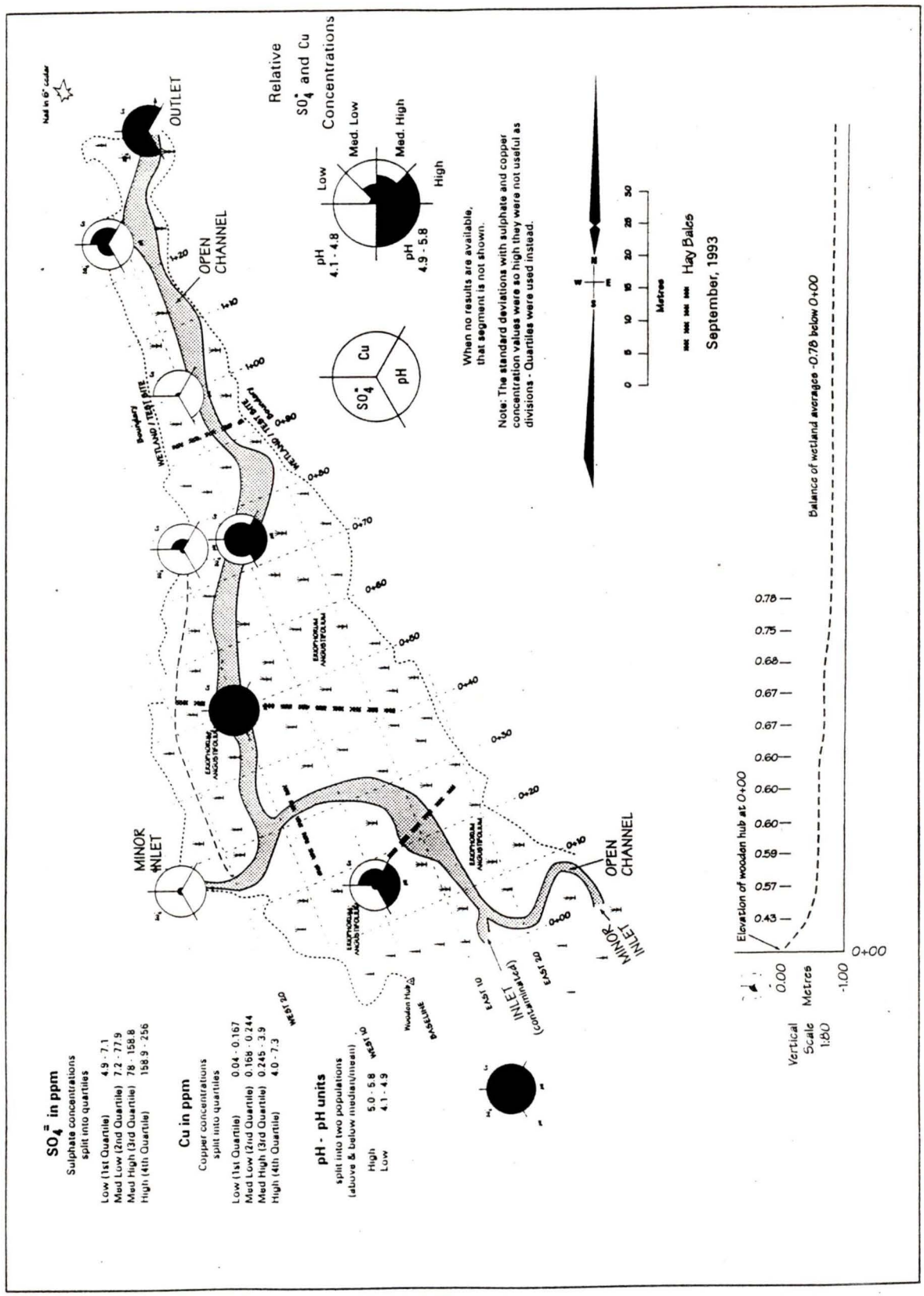
One set of four water samples were taken late in September 1993 from the main channel through the fen and one set of five water samples from the vegetated area. Two samples were taken from the minor inlets to the southeast and southwest of the main body of the fen. Five large cores were taken along the baseline. One core was cut out at the margin of the fen, and two more cores were taken to the east of the baseline, one opposite the point where the principal inlet entered the channel running through the fen. The other core was taken 10 metres to the east of the main inlet, in a area which appeared to be more under the influence of the minor inlet at the southeast corner of the fen.

The initial results from the fall of 1993 sampling showed a high copper concentration of 7.3 ppm in the inlet water, while along the channel, going downstream, there were results of 4.6 ppm, 3.6 ppm, and 4.0 ppm. In the vegetated area, the results (again going downstream) were 0.82 ppm, 0.19 ppm, 0.16 ppm and 0.29 ppm. Channel water averaged 4.1 ppm of copper in the channel, but vegetated area water samples averaged .4 ppm, a full order of magnitude difference. See Figure 4-2 for the locations of the water sample locations and Figure 4-3 for the plant and soil sample locations.

Dissolved sulphate (SO_4=) samples showed even more dramatic results. Inlet water contained 265 ppm of sulphate, and samples along the channel, going downstream, contained 174, 127, 135 and 168 ppm of sulphate. Average sulphate in channel samples was 151 ppm. Sulphate in the off-channel vegetated areas was 3.4, 5.9, and 10.9 ppm ("downstream"). Average sulphate was 6.7 ppm. See Figure 4-2 for the locations of these points.

The minor inlets had low levels of copper and sulphate compared to Pyrrhotite Creek, but copper levels at 0.01 and 0.04 ppm exceeded MOELP guidelines of 0.004 ppm for aquatic life. The pH figures for these inlets of 5.5 and 5.6 were equivalent to many rivulets in the area. Many tiny tributaries of Pyrrhotite Creek were recorded in the 5.5-5.7 range up to 7.02 in late July 97. Flow rates for the minor inlets into the fen were noted over 1 litre per second only once. On most visits there was no discernible flow at all, but on a few times flow rates were recorded at close to 0.1 litre a second. See Figure 4-2 for the locations of the initial pH points.

Figure 4-2. Map of Comparative pH Compared with Dissolved Sulphate Ion and Dissolved Copper Concentrations in September 1993 in Branch 126 Sedge Fen.



The preceding map shows the locations of pH values and water samples taken during September 1993. A set of paired samples was taken from the vegetated areas of the fen and the channel areas, plus samples were taken in the two minor and the major inlet (Pyrrhotite Creek). Unfortunately, some results are not available, due to a laboratory error. The main inlet and the channel through the fen had high sulphate concentrations, from 127 up to 265 ppm, and high copper concentrations, from 3.6 up to 7.3 ppm. The vegetated areas had sulphate concentrations from 3.4 to 10.9 ppm, and copper concentrations from 0.16 to 0.82 ppm. Because the range was great, the standard deviation was very high, and not suitable to base the separation for graphical purposes. Quartiles were used instead (after Kürzl, 1988).

2). Vegetation

Cotton grass leaves showed high copper values next to the main channel and low values at the edge of the fen. High copper results of 143.0 and 120.1 ppm by dry weight of copper were obtained from samples at the south end of the fen, but another high result of 131.8 ppm was noted at the north end, with moderate to low copper contents of 85 and 37.9 ppm by dry weight noted between these points. The samples on the southwestern margin and on the meadow next to the southeastern minor inlet were both low at 23.1 and 21.7 ppm by dry weight copper content respectively. These sample sites were slightly higher than the body of the fen, and were not receiving surface water from Pyrrhotite Creek at the time of sampling. All the other samples were in areas receiving surface water from Pyrrhotite Creek. See Figure 4-3 for the location of these points.

3). Soil

Soil samples from 1, 10 and 20- 30 cm were taken and analyzed for a number of metals (see Chapter III), including copper, zinc, and arsenic. The surface copper content ranged from 1381 ppm dry weight next to the point that the contaminated water reached the fen; to 2960 ppm dry weight copper content at the 100 m point north from the beginning of the fen. The "low" 1381 ppm Cu result seemed to be anomalous, but visual inspection of the sample materials show more obvious silicate clasts (gravel, sand, silt) than seen elsewhere. Of the four samples along the base line, three showed high to very high (4300 ppm Cu by dry weight) copper contents at depth in the cores. In fact, the copper content at 20 to 30 cm depths was almost twice the surface amounts. All the other stations had a maximum copper content in the surface samples, although the 10 cm levels were sometimes more or less than the deeper ones. See Figure 4-3 for these points and the relative amounts of metal[1]. The maps with full numerical data are in Appendix 4.

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[1]On observing these results, Dr. Nordin noted that the soils of the area adjacent to the fen would have to be checked for copper content, to rule out copper-rich groundwater.

Figure 4-3. Map Comparing Copper and Zinc Concentrations in Vegetation to the Soil Copper and Zinc Concentrations at the Surface, at 10 cm, and from 20-30 cm depths, for September 1993 in Branch 126 Sedge Fen.

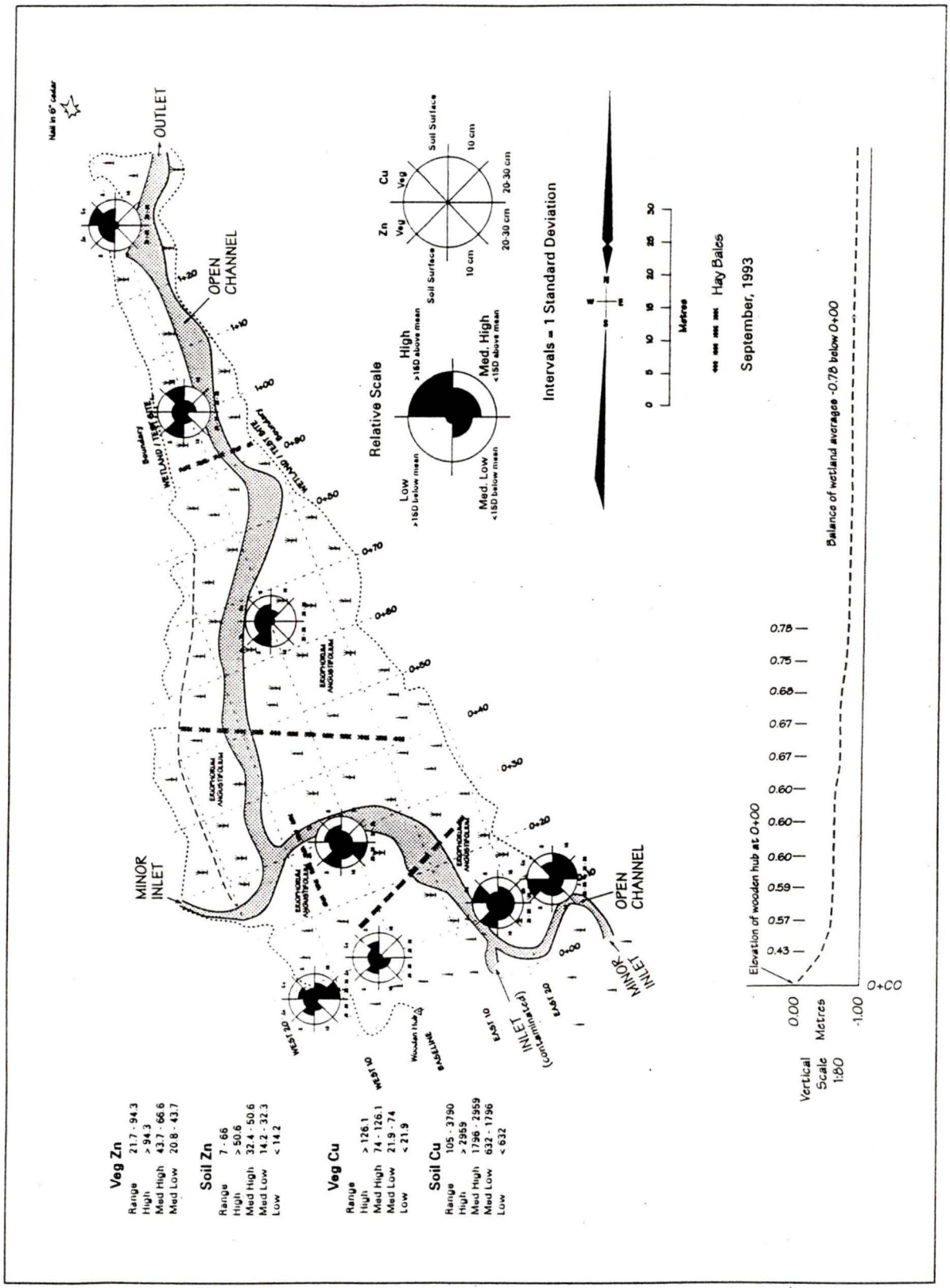

Figure 4-3shows copper and zinc concentrations in the fen vegetation compared the concentrations in the fen soil. Note the high concentrations of copper at depth near the southeast and on the southwest margin of the fen.

Zinc concentrations are included as a comparison. See Figure 4-3 for the "Zinc in Soil" and for the "Zinc in Vegetation" concentrations. Zinc is known to accumulate in wetlands infrequently (Sobolewski, 1997a), and Branch 126 Sedge Fen is no exception. Zinc concentrations for the fen fall within the background concentrations. Zinc is considered quite labile in plants and soils (Kabata-Pendias and Pendias, 1992), and even in this site, where the waters are approximately a tenth as high in zinc as in copper, the highest concentration of zinc in the soil was 66 ppm. This is about ten times the lowest concentration of 7 ppm zinc in soil, as compared to copper, where the lowest value of 168 in the soil was about 4% (a ratio of ≈1:25) the highest value of 4300 ppm in this set of results. Zinc in the cotton grass leaves ranged from 21.7 ppm by dry weight to 94.3 ppm, about a fourfold increase.[1]

The distribution of arsenic in the soil did not resemble that of copper. Arsenic levels were high over the entire surface of the fen, with 838 ppm at the southwest margin, 803 to the southeast, 600 – in the centre (600, 653, 631, and 596 ppm), and 698 at the northern end. There was a definite decrease in the lower (not the surface) samples from the 10 metre line going north (downstream), as the results from the 10 cm depth samples adjacent to the channel from the inlet point go 604 ppm, 595 ppm, 574 ppm, 363 ppm, and 93 ppm. See Appendix 4, Figure A4-6 for the mapped arsenic concentrations found.

Winter 1994-95 Results

The samples obtained after freeze-up in the November 1994 sampling were separated into components and the analytical results for selected elements mapped for: soils, cotton grass leaves, cotton grass shoots, cotton grass roots and leaf bases, cotton grass rhizomes, cotton grass shoots, and for the water squeezed out of the soil samples. The maps with numerical data are in Appendix 4, see Figure 4-4 for a graphical representation of: copper in cotton grass leaf bases and roots; copper in cotton grass leaves; copper in the water squeezed out of the samples; and copper, arsenic and zinc in the soil. These samples were taken from as close to possible to the sites used in the previous sampling in September 1993.

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[1]Background variations and conentrations found in contaminated areas is covered in Kabata-Pendias and Pendias (1992). Hutchinson (1975) gives some wetland plant examples also.

1). Pore Water

The pore water levels for copper are shown graphically in Figure 4-4. Numerical data for copper, arsenic and zinc are mapped in Appendix 4. Apart from the site at the fen edge at 10N+15W, those stations with high copper values are found near the inlet area, as are all those stations with high sulphur values. This could indicate that there is some movement of Pyrrhotite Creek water through the fen soil, as sulphate is metabolized fairly quickly in an anaerobic environment. This would be slowed down by the low temperatures of the fen at the time of collection.

2). Vegetation

The individual sample site results are shown in Figures A4-10 to A4-13.

2.1) Leaf Bases and Roots

Since it was almost impossible to separate the leaf bases (with no abscission layer, the leaves stay attached to the rhizomes, after senescence) from the cotton grass roots cleanly, they were amalgamated into a sample material. November 1994 was the only time this was sampled. Copper is notably concentrated in these parts of the cotton grass plant, as the average for the fen was 2215 ppm copper in the leaf bases and roots. Arsenic concentrations were also high in these plants, but the sites closer to the fen margin which had copper concentrated in them, did not show the same arsenic concentrations. Arsenic concentrations of 140 ppm up to 580 ppm were seen in the core area of the fen, in these plant parts (leaf bases and roots), which was still generally lower than the soils there. The zinc and phosphorous concentrations in the fen were similar to the background concentrations, and, for zinc, in fact, 11 of the concentrations in the fen were lower than the background concentrations, only 6 were higher. In one split sample, the results were 25 ppm and 46 ppm zinc in the leaf bases and shoots, indicating the variation in one site of the fen. Sampling and analytical variation in all samples of these materials for zinc and phosphorous was almost identical to the variation in any grouping of samples (background or fen).

Although the concentrations of copper in the leaf bases and roots were high, the mass per unit area of leaf bases and roots collected was less than the mass per unit area of leaves. Since this collection was extremely labour-intensive, removing copper by harvesting this material appeared impractical.

2.2) Rhizomes

Cotton grass rhizomes had high copper concentrations, an average of 683 ppm for the fen for November 1994, which is still much lower than the soil, which averaged to 2139 ppm in the surface for the November 1994 results. Cotton grass rhizomes showed some high phosphorous con-

centrations compared to the background samples. The average of the two background rhizome samples was 433 ppm phosphorous, and 1475 ppm phosphorous in the soil. The average for the fen was 1779 ppm phosphorous in the rhizomes, but 956 ppm in the soil, so the plants concentrate phosphorous compared to the soil in the fen, but the reverse was true in the background sites. Unpublished figures provided by Dr. C. Dunn (pers. com.) show that aspen shoots in the spring can run up to 25,000 ppm (2.5%) P. This degree of concentration is unusual, but many other plants, particularly those grown for food or fodder (Quinton and Ryder, 1983) concentrate phosphorous. Arsenic values were somewhat high (over 200 ppm) in some rhizomes in the southern part of the fen, closely matching those sites with the highest (over 500 ppm) leaf base and root arsenic concentrations. However, the fen average for arsenic in the surface layer of the soil was 536 ppm arsenic, so it appears that there may be some mechanism which sequesters arsenic in the less vital areas of the plants, or that shut out arsenic from some parts.

The mass of the cotton grass rhizomes was low, about 20 to 50 g. per square metre. Harvesting rhizomes also appeared impractical as a method to remove copper.

2.3) Leaves

Copper in cotton grass leaves showed a striking difference between the September 93 sampling and the November 94 sampling. The average for the fen cotton grass leaves in September 1993 was 74 ppm copper, with the highest value 143 ppm, while the average for the fen cotton grass leaves in November 1994 was 1174 ppm copper, and the highest value was 3300 ppm copper.

Harvesting cotton grass leaves provided substantial mass (100 to 120 g per square metre) and could be done without killing the plants.

2.4) Shoots

Cotton grass shoots were analyzed in the November 1994 sampling, but showed no concentrations high enough to be useful for remediation purposes. Phosphorous was high, as expected. See Figure A4-14 in Appendix 4, which gives the analytical results for phosphorous, arsenic, copper and zinc for the fen, with one background sample. The mass of cotton grass shoots per unit area was about 12 to 20 g per square metre. Removal would kill the plants and was far too labour-intensive to be practical.

3). Soils

In the surface soils, of the six sampling points reached in November 1994; the four southern points had higher surface concentrations for copper in the soil than the September 1993 concentrations, while the two northern points were substantially lower is copper. However, the adjacent points sampled (adjacent to the 1993 sample points) were not as low. See Table

4-2. 100N+00 had copper at 2960 ppm in September 1993 and 966 in November 1994, while 102N+00 had copper at 2360 ppm in November 1994. At 130N+00, the September 1993 concentration was 1920 ppm copper, but 533 ppm copper in November 1994, yet 130N+02W had the surface copper concentration of 1560 ppm. Table 4-2 compares the concentrations for copper, arsenic and zinc in soils, and this suggests that there are few differences between the fen in 1993 compared to 1994 in copper and zinc, but there is in arsenic. Using the two-tailed Student's T-test, there were no significant differences between the 1993 and 1994 copper and zinc concentrations. Only arsenic concentrations showed significant differences. This concentration difference could be a seasonal change. The object of the 1995 sampling program was to cover the growing season. Also, one transect ("0") in the 1995 sampling program was sited to cover possible sources of contamination from the road bed (note the high copper and arsenic soil results close to the road).

Figure 4-4. Map Comparing Relative Copper, Arsenic and ZincConcentrations in the Surface Soil, Compared to the Relative Copper Concentrations in Cotton Grass Leaves, Cotton Grass Leaf Bases and Roots, and in the Pore Waters, Branch 126 Sedge Fen. ppm dry weight or mg/l. Based on divisions of 1 standard deviation.

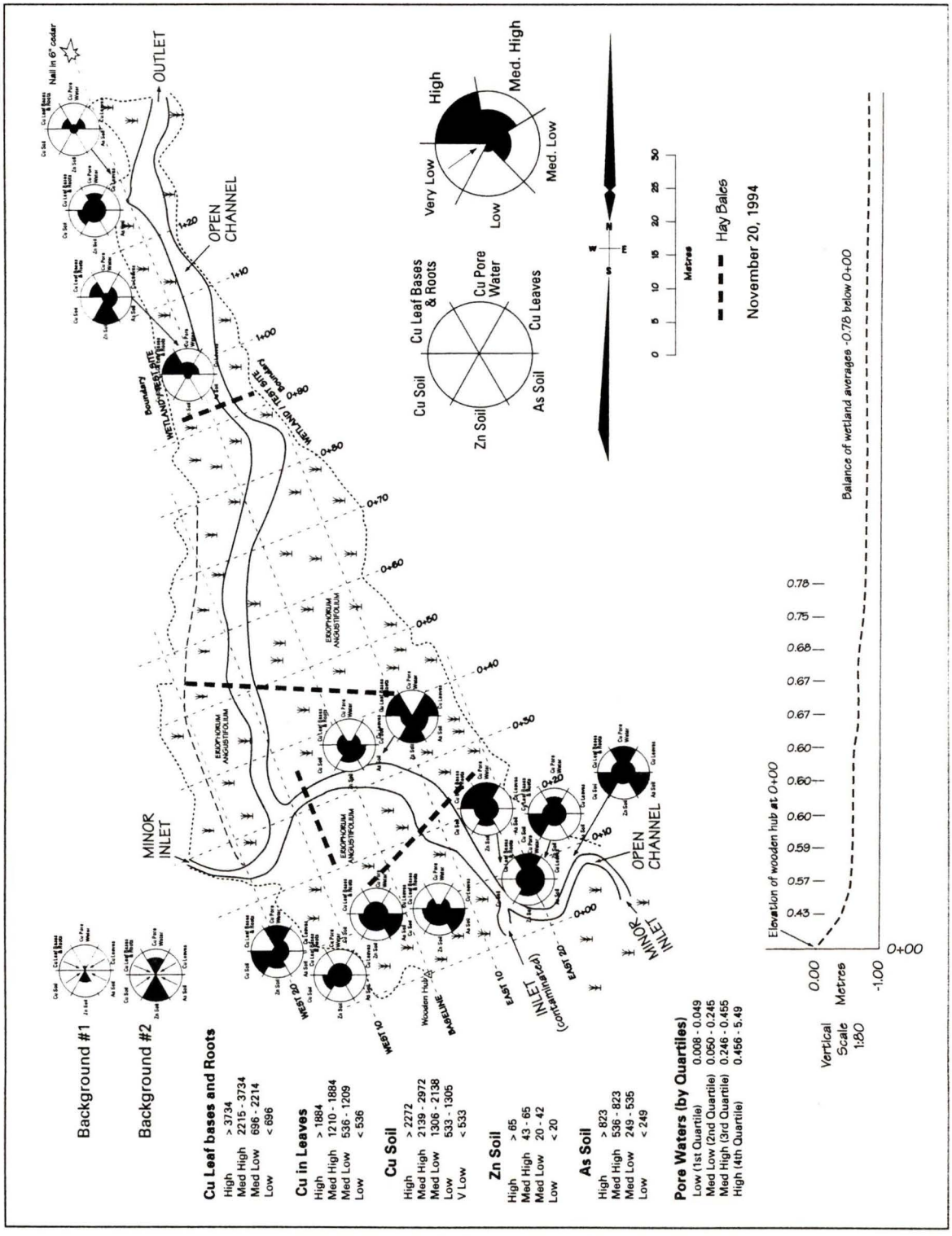


Figure 4-4 shows the location of sample points and the relative concentrations of elements in the soils, pore water and vegetation there. The divisions are based on one standard deviation, with samples below the second standard deviation increment shown as an arrow.

Table 4-2. Copper, arsenic, and zinc concentrations in the Fen surface soils, September 1993 compared to November 1994. Stations from South (inlet) to North (outlet).

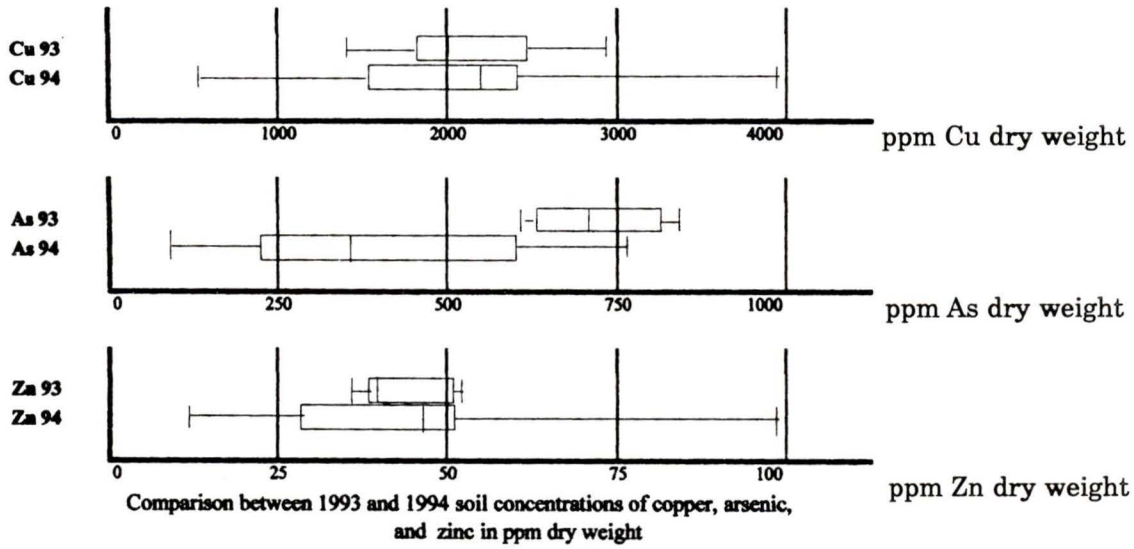
Surface Soil Elemental Analysis Values in ppm dry weight.
(93) is September, 1993 and (94) refers to November 1994.

Station	Copper (93)	Copper (94)	Arsenic (93)	Arsenic (94)	Zinc (93)	Zinc (94)
10N+00		2450		220	36	49
10N+02W	2030	2210	817	87		46
% Mean Diff.		10%		87%		6%
10N+15W	1649	3080	838	255	36	34
08N+12W		2320		223		26
% Mean Diff.		28%		13%		27%
10N+15E	1381	1570	600	610	52	51
10N+17E		1440		766		54
% Mean Diff.		9%		23%		6%
10N+25E	2000	3980	803	457	40	29
08N+25E		3370		831		41
% Mean Diff.		17%		58%		34%
30N+01W	2870		653		52	
33N+04W		2000		597		99
35N+02W		2100		752		51
% Mean Diff.		5%		23%		64%
100N+00	2960	966	596	195	49	19
102N+00		2360		474		66
% Mean Diff.		84%		83%		111%
130N+00	1920	533	698	93	40	12
130N+02W		1560		353		31
% Mean Diff.		98%		117%		88%
Standard Dev.	591	953	104	256	7	22
Average	2115.7	2138.5	715.0	442.4	43.6	44.4

Table 4-2 compares the Surface Soil Elemental Analysis Values in ppm dry weight for copper, arsenic and zinc for September 1993 to those of November 1994.

There is a possibility that there was a real drop in copper concentrations downstream in the fen, and an increase upstream, in the fen soil surface materials from September 1993 to November 1994, but a Student's two-tailed t-test applied to the results for copper concentrations showed no significant difference (to the 95% ± confidence level) between the two sets of values. In these results the site variability (% mean difference) appears relatively low for many of the stations. It is apparent that the only significant difference in the results for the soil surface is the November 1994 arsenic results, as being substantially lower than previously found. This can be seen in the following box plots.

Figure 4-5. Copper, Arsenic, and Zinc Concentrations in the Fen Surface Soils, September 1993 compared to November 1994, using box plots based on quartiles.



This figure shows the variation between the two periods by the range and quartiles (Kürzl, 1988). Again, it is apparent that one significant difference between the two sample sets is in the arsenic concentrations, which are lower in the 1994 sample set than the 1993. The vertical lines in the boxes are the median concentrations. The other is the much greater variability in the 1994 data set as compared to 1993.

Summer 1995 Season Results - Harvesting of Cotton Grass

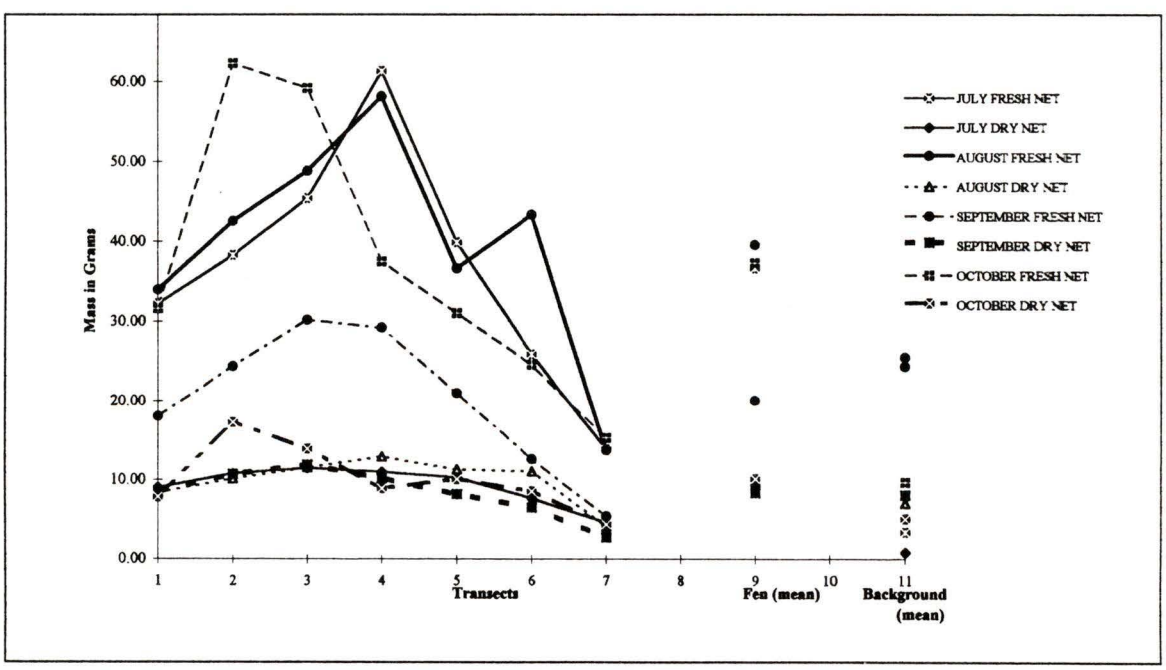
Since the growing season started in June, all plant production in unharvested areas would be from June to the time of harvest. I harvested cotton grass in the fen and the background sites at four intervals: July, August, September and October. The first issue considered was the actual production of cotton grass per unit area over the season, month by month. Two related ideas were examined. 1. Is there enough cotton grass to make a harvest practical, if the metal content, especially copper, was sufficient? The removal of copper by harvesting cotton grass is feasible if there is sufficient growth of grass, sufficient copper content and if the system chemistry is favourable for the grass to absorb copper. 2. Is there enough dry matter production to allow the precipitation and/or adsorption of all the metals present in the Pyrrhotite Creek water as occurs in other wetlands. The processes and circumstances are noted in: Lett (1978); Hammer (1989); Means and Hinchee (1995); Sobolewski (1996, 1997a, 1997c); and Golder (1997a).

Table 4-3. Branch 126 Sedge Fen Harvesting Results.

Sample site	July 1995		August 1995		September 1995		October 1995	
	Fresh	Dry	Fresh	Dry	Fresh	Dry	Fresh	Dry
Transect 0	32.21	9.01	33.98	8.39	18.04	8.48	31.62	7.84
Transect 1	38.29	10.77	42.55	10.11	24.36	10.69	62.33	17.28
Transect 2	45.43	11.43	48.86	11.52	30.17	11.83	59.24	13.86
Transect 3	61.41	10.98	58.24	12.89	29.24	10.16	37.49	8.89
Transect 4	39.94	10.28	36.66	11.29	21.01	8.18	31.03	10.06
Transect 5	25.88	7.62	43.43	11.05	12.60	6.50	24.56	8.54
Transect 6	13.82	4.60	13.73	4.15	5.40	2.78	15.30	4.40
Mean of Fen	36.71	9.24	39.64	9.91	20.12	8.37	37.37	10.13
Mean of Background	23.38	7.04	25.53	8.07	9.68	5.07	9.0	10.60

Table 4-3 shows the harvest yields by 0.09 square metre plot by transect and month. The units are grams.

Figure 4-6. Chart of Branch 126 Sedge Fen Harvesting Results (1995). Cotton grass harvest yields for 0.09 square metre plots.



The averages of the fen results were very close to 10 grams per sample site (0.09 square metres) across each transect. Although groups of stations in the transects gave results clos-

er to 20 grams per 0.09 square metres (or approximately 220 g per square metre), this was only in small areas. There was little variation in the amount of dry matter harvested per unit area in the fen over the season (see Table 4-3), which ranged from 8.4 g average per sample site to 10.1 g average per sample site. Dry weights of the cotton grass ranged from close to half to about one-sixth the fresh weight. The harvest level in October 1995 was 112.5 g per square metre.

At the background sites, although the fresh weight varied strikingly, the dry weights for all the wetter sites were close to 10 g (Figure 4-16) per .09 square metre, or about 100- 110 g a square metre, similar to the fen. This figure stayed approximately the same throughout the growing season for the wet sites, but the drier sites and the shaded sites brought the harvest level down overall.

Twelve 1 square metre sites were treated with a slow-release lawn fertilizer (12-4-4), at about 800 grams a site in the fall of 1995, to establish if the growth of the cotton grass could be accelerated with fertilizer. These sites were checked in August and September, 1996. No increase in growth or dry matter production was observed compared to the control sites.

1995 Analytical Results

1). Waters

All 313 of the water samples prepared (including duplicates) were analyzed. Some samples were lost due to container breakage.

Note on the background samples. A storm forced curtailment of July water samples. Other background waters are missing because they could not be pumped. The core holes were dry, or showed no inflow. The background ID numbers are those used for the background stations noted in the map in Figure 2-11. The station is on the downstream side of the access road. All the results are high compared with more common background levels, but the concentrations found are typical in this general area (Deniseger, pers. com.), and have implications in the remediation of the Mt. Washington site. Background station 1 is anomalously high, even for this area, and this may be due to low-grade ore having been used in the road bed. Since the background levels are so high, the streams are very close to the limits noted in Table 1-1 under natural conditions, requiring that the remediation of Mt. Washington be especially efficient (Deniseger *et al.*, 1995; Sobolewski, 1997b).

Table 4-4. Dissolved Copper in the "Background" Water Samples for 1995 (copper in ppm, mg/l)

Surface waters. Number in brackets = number of samples.				
	July 1995 (9)	August 1995 (7)	September 1995 (4)	October 1995 (5)
Mean	0.054	0.050	0.046	0.160
Median	0.052	0.051	0.040	0.144
St. Dev.	±0.029	±0.026	±0.039	±0.125
Min/max	0.024/0.115	0.16/0.99	0.01/0.094	0.042/0.35
Ground waters. Number in brackets = number of samples.				
	July 1995 (4)	August 1995 (1)	September 1995 (0)	October 1995 (4)
Mean	0.352	0.046		0.315
Median	0.38	n/a		0.329
St. Dev.	±0.216	n/a		±0.248
Min/max	0.063/0.586	(0.046)		0.019/0.584

The table above indicates that there are a wide range of copper in the background waters, and that ground water in this area can be very high in copper, even for a volcanic bedrock area, which can often have high background copper levels in the soils (Lett, pers. com.).

Drought in the middle of summer (August and September) also dried up the fens and affected the ground water. The fens were wet but the water seemed to be entirely wicked up by capillary attraction, and pumping did not produce water.

Table 4-5. Copper in Fen Water by Transect and Month, 1995, concentrations in ppm (mg/l).

Transect 0				
	July 1995 (9)	August 1995 (8)	September 1995 (7)	October 1995 (13)
Mean	3.98	1.42	2.10	2.36
Median	2.97	0.92	0.79	1.28
St. Dev.	±3.65	±1.45	±2.08	±2.38
Min/max	0.063/10.3	0.039/3.12	0.164/5.08	0.019/5.89

Transect 1

	July 1995 (11)	August 1995 (8)	September 1995 (7)	October 1995 (15)
Mean	1.83	0.52	0.99	0.97
Median	1.37	0.17	0.43	0.16
St. Dev.	±2.24	±.88	±1.11	±1.81
Min/max	0.088/7.62	0.086/2.67	0.030/2.93	0.044/5.64

Transect 2

	July 1995 (11)	August 1995 (8)	September 1995 (10)	October 1995 (15)
Mean	2.03	1.95	2.49	2.80
Median	2.3	2.54	3.31	2.46
St. Dev.	±1.79	±1.17	±1.69	±2.17
Min/max	0.05/6.03	0.038/2.71	0.009/4.2	0.047/5.27

Transect 3

	July 1995 (6)	August 1995 (8)	September 1995 (10)	October 1995 (14)
Mean	2.52	1.97	2.24	3.91
Median	2.73	2.44	2.1	4.64
St. Dev.	±0.96	±1.09	±1.16	±1.57
Min/max	0.752/3.69	0.102/2.94	0.419/3.58	0.079/5.05

Transect 4

	July 1995 (0)	August 1995 (9)	September 1995 (6)	October 1995 (9)
Mean	-	1.25	3.00	3.06
Median	-	1.16	3.02	4.29
St. Dev.	-	±1.03	±0.39	±1.85
Min/max	-	0.105/2.34	2.49/3.43	0.160/4.72

Transect 5

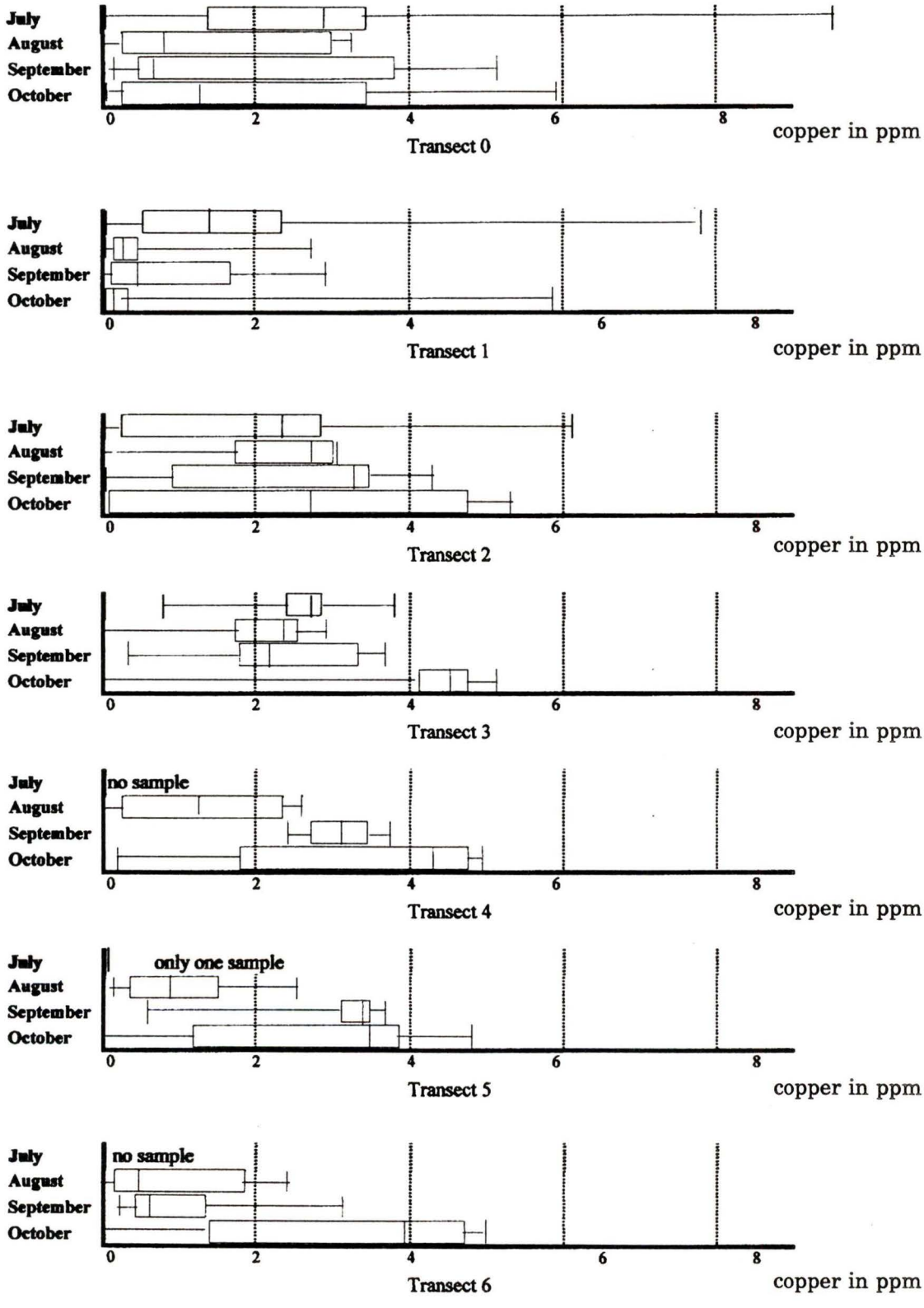
	July 1995 (1)	August 1995 (6)	September 1995 (5)	October 1995 (7)
Mean	0.115	1.01	2.72	2.53
Median	0.115	0.93	3.19	3.28
St. Dev.	-	±0.91	±1.18	±1.81
Min/max	0.115	0.099/2.44	0.62/3.47	0.055/4.48

Transect 6				
	July 1995 (0)	August 1995 (8)	September 1995 (10)	October 1995 (15)
Mean	-	0.92	1.14	3.00
Median	-	0.35	0.57	3.88
St. Dev.	-	±1.10	±1.32	±2.19
Min/max	-	0.056/2.34	0.313/3.12	1.30/4.94

First, the tables above show that the fen water chemistry is very different from water at background sites, although there is considerable overlap in the concentrations found in the analyses. The above table shows July concentrations generally higher than August, and September is also higher than August, while October concentrations were the highest overall. There are not enough results from July to say if they would have been the same, higher, or lower than September. All the standard deviations are comparatively very high, meaning that variation is very high also.

The above table is graphically represented by the following set of box plots, which show the distribution of the fen copper concentrations by quartiles (after Kürzl, 1988).

Figure 4-7. Box Plots by Quartiles of Copper Concentrations in Fen Water.



The transect numbers in the table and plots refer to the sample site locations noted in Figure 3-2, so flow is from transect 0 north to transect 6. Full tables showing the raw figures the above summaries were prepared from have been placed in Appendix 1.

As can be seen in the table and the box plots, transects 0 and 1 had the most variable results. Substrate materials are varied across transect 0, and transect 1 runs from just off the fen and across the main channel plus a secondary channel and near the eastern minor inlet. Transect 2 also runs from just off the fen itself and across the fen. Transects 3 to 6 are entirely fen sites. July results are missing for transects 4, 5 and 6 because a rainstorm occurred, and the rate of meteoric water input would have made the results meaningless, as the fen water was being diluted substantially.

There were two sets of pH measurements taken. One set was taken while the water was being removed, and the other was taken after filtering. This was done because rainfall occurred on the first water sampling, and it was felt better to get the samples and then measure them, and because Shotyk (1988) noted that the presence of peat next to the electrode of a pH meter could reduce measured pH by as much as 1 unit. Since the pH is of great importance in copper solubility (the lower the pH, the more soluble the copper), the range and distribution of copper values to pH was investigated.

Table 4-6. Comparison of pH and Copper Concentrations in all Waters Covered in the Mt. Washington Project.

	1st Quartile (Cu 0.009-0.144)	2nd Quartile (Cu 0.149-1.8)	3rd Quartile (Cu 1.85-3.27)	4th Quartile (Cu 3.28-10.3)
pH #1 Mean	5.34 (42)	4.08 (35)	4.30 (43)	4.13 (14)
" Med.	5.33 "	5.2 "	4.14 "	3.80 "
" St. D.	±0.56	±0.49	±0.42	±0.68
Min/max	4.2/6.95	3.93/5.83	3.94/5.86	3.59/5.92
pH #2 Mean	5.91 (69)	4.84 (71)	4.10 (63)	3.89 (66)
" Med.	6.05 "	4.62 "	4.04 "	3.85 "
" St. D.	±.90	±0.89	±0.38	±0.17
Min/max	3.26/7.34	3.56/6.91	3.60/6.27	3.66/4.41

pH #1 values are taken at the sampling location, pH #2 values were taken after filtration. Copper concentrations in ppm. Number of samples measured in brackets. Each quartile had 78 copper concentration values.

Tables 4-5 and 4-6 include all copper concentrations and all pH measurements taken in waters for the 1995 season. Each quartile of copper concentrations had 78 values in it, so there were 18% to 55% of the water sample quartiles that had pH measurements made on them in the field and 81% to 91% of the filtered samples had pH measurements made on them.

The filtered samples were thought likely to have a higher pH, considering the comments of Shotyk (1988) than the unfiltered. They did not. The on-site, unfiltered samples did not show a strong tendency for all the high copper concentrations to have a distinctly lower pH, although the median figures show a strong trend. For the filtered samples, both the mean and the median pH values show a strong correlation for lower pH with increased copper concentrations, but many samples with high copper concentrations had a high pH as well, as shown by the high standard deviation.

Fen Copper Retention

Table 4-7. Copper Retention in Branch 126 Sedge Fen (as estimated by comparing inlet and outlet copper concentrations.)

	Weir	**Inlet**	**Flow In**	**Loading**	**Outlet**	**Flow Out**	**Loading**	**CuRet.**
Units	ppm	ppm	l/sec	kg/Cu/mo.*	ppm	l/sec	kg/Cu/mo.	kg/Cu
Jul-95		3.0	12.8	100	2.38	14	70	13.0
Aug-95		2.49	1.2	7.8	2.31	0.8	4.8	3.0
Sep-95	5.54	4.83	0.4	5.0	3.02	0.4	3.1	1.9
Oct-95		5.98	7.0	110	1.11	5.8	70	92.0**
Nov-95		4.93	7.0	90.0	4.78	8.0	99.0	-9.7
95 "Summer Season"							Total **100.0**	
Sep-96	4.57	3.45	7.0	63.0	3.22	6.0	50.1	13.0

* kilograms of copper per month.

** this high retentive rate is suspect.

Flow measurements accurate to 0.1 l/sec.
Ground water and meteoric water inflow appears approximately equal to evapotranspiration.

Table 4-7 shows the copper concentrations in the waters flowing into and out of the Branch 126 Sedge Fen. The weir is the permanent v-notch weir built on Pyrrhotite Creek above the Branch 126 logging road, and is upstream of the fen. The concentrations are from 1 sample analysis and the flow measurements were averaged from five measurements.

**Curiously, the copper concentration in the water entering the fen in October was 5.98 ppm, and the water leaving the fen was 1.11 ppm, which leads to a high degree of retention rate calculation. However, just upstream of the outlet on Transect 6, the measured concentration

was about 5 ppm. Balancing that, the concentration in the main inlet on transect 0 was about 10 ppm copper, and just downstream 8 ppm. Therefore, the retention rate must be treated with caution until continuous sampling and flow measurements are available.

Temperatures ranged from 0.5°C to 15°C during the investigation, and the higher temperatures appeared to favour copper retention. Unfortunately, the time required to complete a sampling set meant that the water temperature ranged 4 - 10°C during sample collection interval, due to the time required. This was one reason that the inlet and outlet water samples were taken separately from the transect samples and within ten minutes of one another if possible (to minimize variations caused by water temperature changes).

Water copper concentrations shown in Figure 4-2, indicates that the levels in the vegetated areas were generally lower than the copper concentrations in and adjacent to the channel, with the exception of the high current area on Transect 3 (near stations 15-18) shown in Figure 3-3. Table 4-5 shows that the copper concentrations were highest in October in the downstream transects 3, 4, 5, and 6, but the July results in the upstream stations were higher than the October results for 0, 1, and 2. Unfortunately, water samples were not taken in July for the transects 4, 5 and 6 due to a violent storm which interrupted the sampling. The August and September results were very similar, and lower levels of copper were seen than in July and October.

Table 4-8. Flow Regime of Pyrrhotite Creek

	July				August				September			
	Max	Min	Mean	Mo	Max	Min	Mean	Mo	Max	Min	Mean	Mo
1986	0.010	0.001	0.004	9.5	0.001	0.000	0.000	0.3	0.39	0.000	0.001	2.8
1987	0.055	0.002	0.013	33.5	0.004	0.000	0.002	5.5	0.001	0.000	0.000	0.6
1988	0.026	0.001	0.008	22.3	0.010	0.001	0.002	5.4	0.004	0.000	0.001	2.4
1989	0.039	0.003	0.010	27.1	0.011	0.001	0.004	10.4	0.002	0.000	0.001	3.0
1990	0.021	0.001	0.003	9.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

	October				November			
	Max	Min	Mean	Mo	Max	Min	Mean	Mo
1986	0.123	0.000	0.007	18.0	0.122	0.002	0.011	29.2
1987	0.001	0.000	0.000	0.4	0.009	0.003	0.005	13.1
1988	0.067	0.001	0.005	14.0	N/A	N/A	N/A	N/A
1989	0.221	0.000	0.018	48.3	0.069	0.003	0.010	27.9
1990	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Flow at Branch 126 weir from Deniseger and Pommen.
Max, Min, Mean - Flows in cubic metres per second.
Mo - monthly flow in cubic decametres (= 1000 cubic metres).

Comparing the flow data in Table 4-7 to Table 4-8, it is apparent that the flows recorded during the summer of 1995 fall close to those mean flows recorded in the 1986-1990 periods by Deniseger and Erickson (reported in Deniseger and Pommen, 1995)

2). Vegetation:

212 of the 422 vegetation (cotton grass leaf) samples (including replicates) prepared were analyzed.

Table 4-9. Copper Concentrations in Vegetation (cotton grass leaves) in ppm/dry weight (PESC analyses).

Figures in brackets = no. samples.

Transect 0

	July 1995 (0)	August 1995 (20)	September 1995 (18)	October 1995 (0)
Mean	-	54.4	86.3	-
Median	-	45.6	43.0	-
St. Dev.	-	±21.2	±75.4	-
Min/max	-	11.8/145	9.42/282.2	-

Transect 1

	July 1995 (0)	August 1995 (18)	September 1995 (7)	October 1995 (0)
Mean	-	89.7	54.8	-
Median	-	69.7	37.1	-
St. Dev.	-	±45.0	±36.5	-
Min/max	-	23.6/280.6	13.7/140.0	-

Transect 2

	July 1995 (0)	August 1995 (17)	September 1995 (16)	October 1995 (0)
Mean	-	125.0	116.6	-
Median	-	117.2	133.5	-
St. Dev.	-	±50.6	±47.1	-
Min/max	-	3.7/250.8	2.5/224.0	-

Transect 3

	July 1995 (0)	August 1995 (5)	September 1995 (2)	October 1995 (0)
Mean	-	120.8	141.4	-
Median	-	109.5	141.4	-
St. Dev.	-	±31.6	±102	-
Min/max	-	77.3/181.6	39.4/243.4	-

Transect 4

	July 1995 (0)	August 1995 (9)	September 1995 (9)	October 1995 (0)
Mean	-	94.0	95.3	-
Median	-	90.1	117.3	-
St. Dev.	-	⁻31.8	⁻43.6	-
Min/max	-	30.4/164.0	19.2/153.9	-

Transect 5

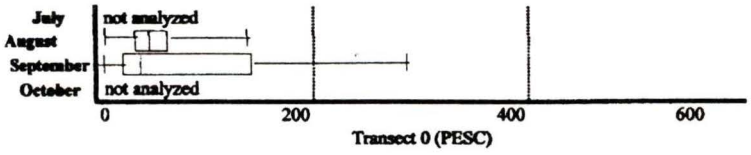
	July 1995 (0)	August 1995 (3)	September 1995 (1)	October 1995 (0)
Mean	-	108.5	227.1	-
Median	-	91.1	-	-
St. Dev.	-	⁻38.2	-	-
Min/max	-	68.5/165.8	-	-

Transect 6

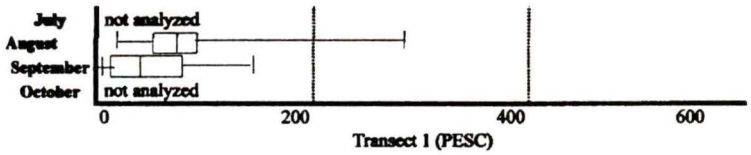
	July 1995 (0)	August 1995 (3)	September 1995 (4)	October 1995 (0)
Mean	-	74.85	62.4	-
Median	-	67.0	39.2	-
St. Dev.	-	⁻7.85	⁻10.3	-
Min/max	-	63.9/82.7	24.9/108.8	-

The transect numbers in this table refer to the transect sample site locations noted in Figure 3-2. Flow is from transect 0 to transect 6, but see Figure 3-2 for full details. Full tables for the above have been placed in Appendix 1.

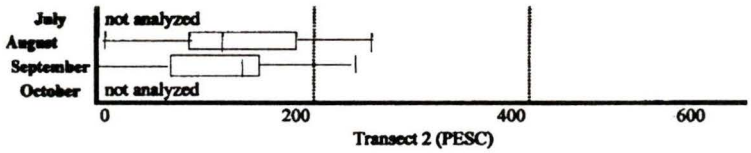
Figure 4-8. Box Plots by Quartiles for the Copper Concentrations in Cotton Grass Leaves (PESC analyses and Zenon analyses).



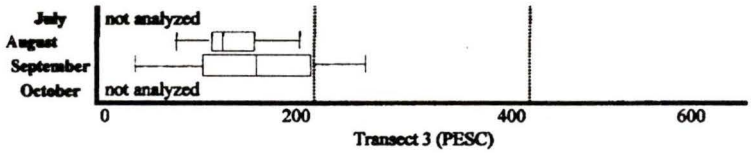
ppm Cu dry weight



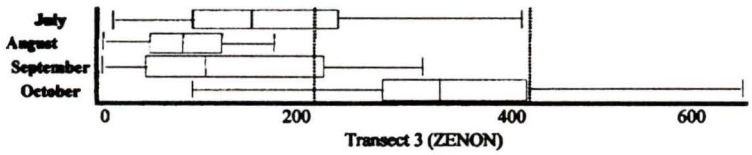
ppm Cu dry weight



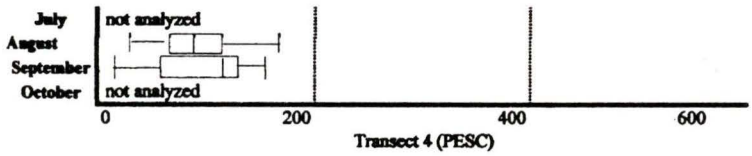
ppm Cu dry weight



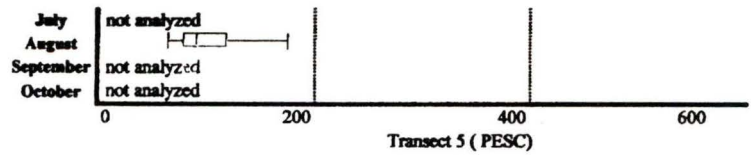
ppm Cu dry weight



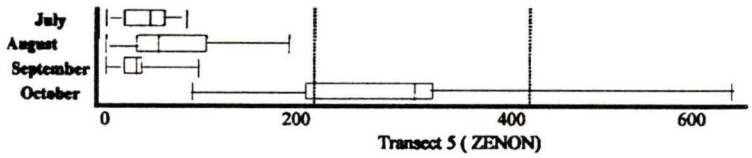
ppm Cu dry weight



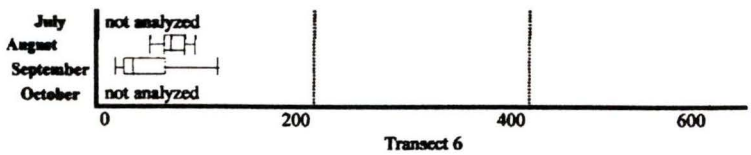
ppm Cu dry weight



ppm Cu dry weight



ppm Cu dry weight



ppm Cu dry weight

Table 4-8 and the box plots in Figure 4-8 (Kürzl, 1988) show the results of the analyses of the plants received to date. The Zenon results for transects 3 and 5 contain analyses for all samples taken, but the PESC results are incomplete for most transects shown.

The high concentrations found for stations at the east end of Transect 3 (see Figures 4-11 and 4-12, and the graphs in Appendix 1), appear to be related to a gap in the hay bale weir there, which results in a strong current in that area. These high concentration values increase the upper range of the results as seen by the maximum/minimum values in the table and as seen as the upper hinges and whiskers on the upper limb of the box plots. See Figure 3-3 for the current velocities and directions noted at one point in time.

When comparing cotton grass collected from the minesite, fen and the background sites, a curious phenomenon was noted, as can be seen in the following table 4-10. The most immediate impression is the lack of elevated metals in the minesite samples as compared to the background. Copper is only twice the background levels, and the range of values is similar. Average iron levels in the minesite samples are almost identical, and the range smaller than the background levels. The same is true for the zinc levels in the minesite and background samples. Of the elements shown, only sulphur levels are notably higher in the minesite cotton grass leaves as compared to the background and fen cotton grass leaves.

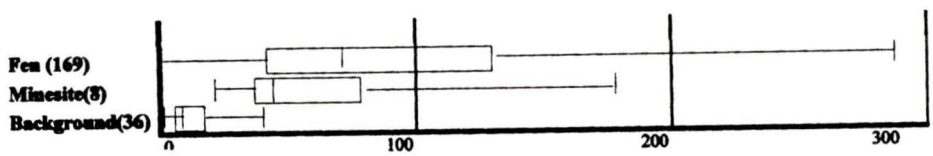
Table 4-10. Comparison of Copper, Iron, Sulphur and Zinc Concentrations in Plant Tissue Between the Background Sample Sites, the Branch 126 Sedge Fen, and the North Pit of Mt. Washington Mine.

Location/ sample no.		Copper	Iron	Sulphur	Zinc
Minesite (8)	Mean	66.7	593	6937	38
	Max.	178	1630	12420	74
	Min.	26.1	171	4325	23
Fen (169)	Mean	115	1828	2900	37
	Max.	280.8	10910	8589	88
	Min.	3	13	1334	9
Bkgrd. (36)	Mean	18	436	1831	41
	Max.	94	2283	4082	110
	Min.	3	13	889	21

Concentrations are in ppm of dry matter of cotton grass leaves, and are only those samples from the summer of 1995 and 1996.

Comparing the above means and ranges, it is clear that the three populations are distinctly different, although there is considerable overlap in concentrations of elements in the plant materials. The minesite plants are highest in sulphur, the fen plants are highest in copper and iron, and the background plant populations are lower then the others in copper and sulphur.

Figure 4-9. Box Plots by Quartiles of Copper Concentrations in Plant Samples from the fen, minesite and background compared. Copper concentrations in ppm/dry weight.



Plant copper concentrations: Comparison among populations ppm Cu dry weight

The box plots of the copper concentrations in cotton grass demonstrate again that the three populations are different (Kürzl, 1988). The minesite plants have a narrower range than the fen plants, and the mean and median concentrations are lower than the fen, but higher than the background sample set.

3). Soils

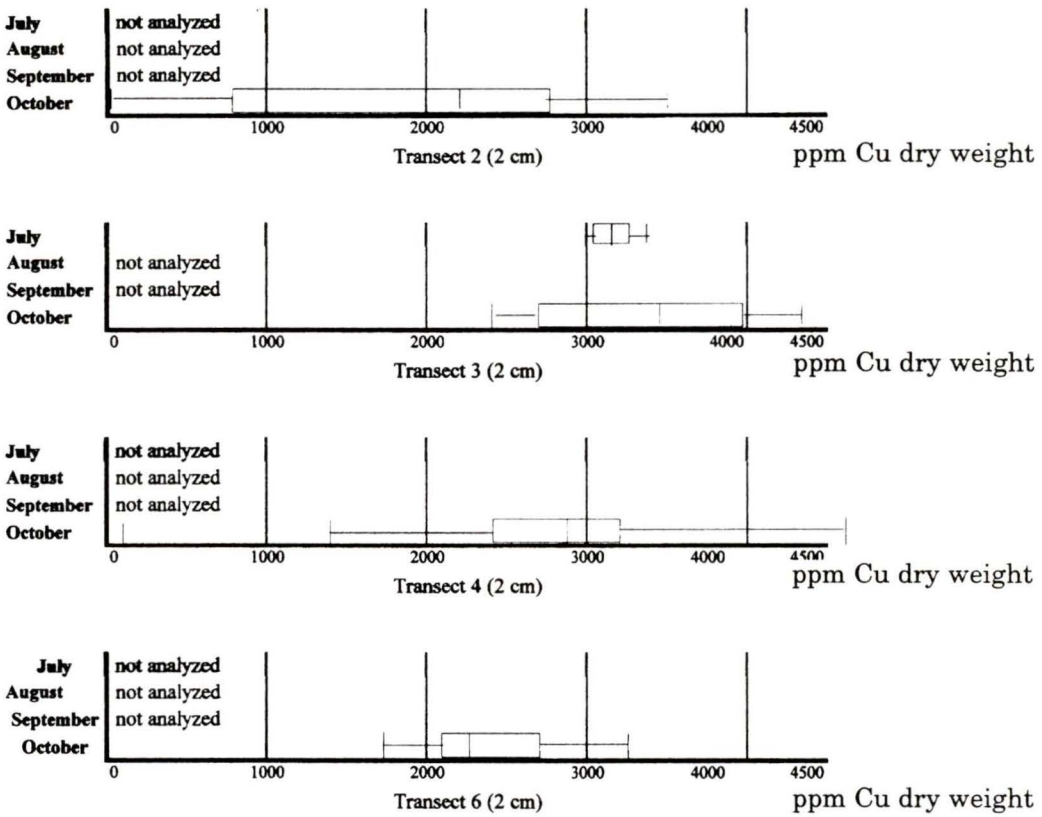
Table 4-11 shows the copper concentrations in the soil of those samples analyzed to date.

Note : Transect 0 has the most variation in materials compared to the other transects, as it runs across an alluvial fan and there is also some alluvium from the road. Analyses of the soil samples is incomplete. Complete analyses are only available from 95 of the 720 soil samples prepared from the 1995 samples.

Table 4-11. Fen Soil Copper Concentrations for the 2 cm depth ("cotton grass root depth"). Material for missing months and transects not yet analyzed.

Transect 2				
	July 1995 (0)	August 1995 (0)	September 1995 (0)	October 1995 (13)
Mean	-	-	-	2337
Median	-	-	-	2847
Min/max	-	-	-	1341/4730
Transect 3				
	July 1995 (2)	August 1995 (0)	September 1995 (0)	October 1995 (7)
Mean	3149	-	-	3354
Median	3149	-	-	3469
Min/max	2949/3350	-	-	2376/4286
Transect 4				
	July 1995 (0)	August 1995 (0)	September 1995 (0)	October 1995 (9)
Mean	-	-	-	2776
Median	-	-	-	2847
Min/max	-	-	-	1341/4730
Transect 6				
	July 1995 (0)	August 1995 (0)	September 1995 (0)	October 1995 (3)
Mean	-	-	-	2494
Median	-	-	-	2230
Min/max	-	-	-	1862/3217

Figure 4-10. Box Plots by Quartiles of Fen Soil cCopper Concentrations. (2 cm. depth, principal cotton grass rooting depth). In ppm dry weight, of those samples analyzed to date.



The preceding box plots for copper concentrations in the fen soils were done for the 2 cm soil analyses ((Kürzl, 1988). The 2 cm depth was used, as around that depth down to 5 cm was where the majority of the cotton grass roots were observed to be located. Some roots went much deeper, but they were seen to be a minor number in comparison to the shallow roots. The range, median and quartile points for transect 2 October results fall below those of transects 3 and 4 October results. The July results as shown for transect 3 are based on only two samples, so cannot be given much weight.

Vegetation, Soil and Water

Figures 4-11 and 4-12 chart the concentration of copper in the cotton grass leaves, soil and water along Transect 3 in July and October, respectively, in 1995. The concentrations in the plants were multiplied by 10 to show them on the same scale as the soils, and the water concentrations were multiplied by 500, to show them on the same scale, also. The hay bale weirs and channel locations are noted on the y axis of the charts. Stations 1 and 18 were bedrock.

Figure 4-11. Comparison of Copper Concentrations in Plants, Water and Soil along Transect 3, July 1995.

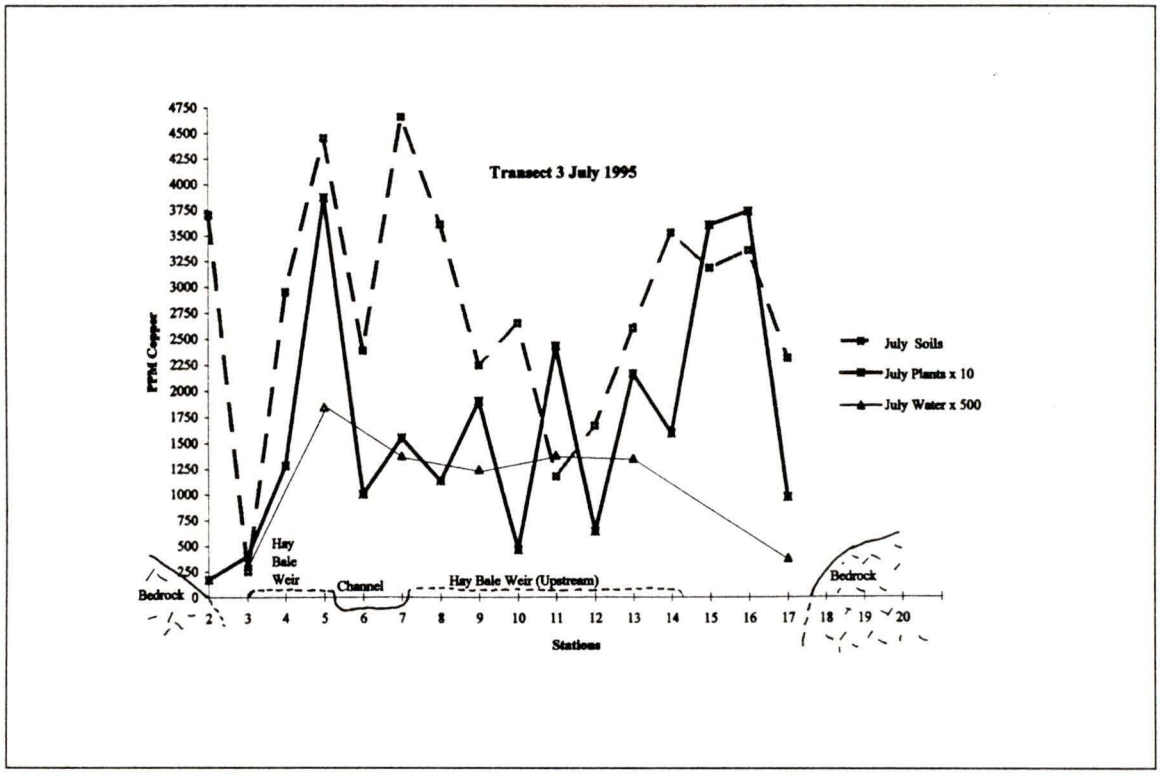
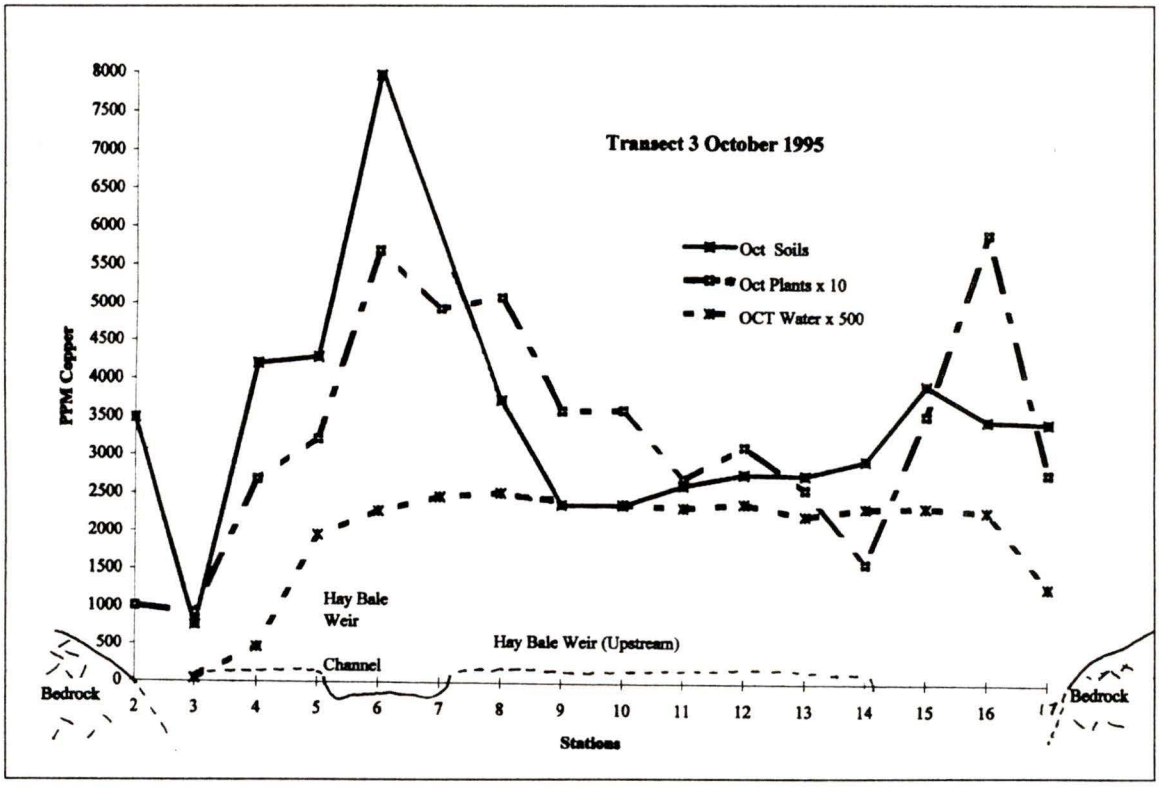


Figure 4-12. Comparison of Copper Concentrations in Plants, Water and Soil along Transect 3, October 1995



These two diagrams show that the higher values of copper in the soils and vegetation are associated with the stream channel and the ends of the hay bale weir, where the current is strongest in the water (see Figure 3-3). Although the copper concentration at the ends of the weir was lower in comparison to the rest of the transect, this seems to have made only a slight difference in the copper concentrations in the soil and plants.

Box plots comparing PESCand Zenon results, and graphs of the copper concentrations in different media (Figure 4-11 and 4-12), reveal the following.

Transect 3: For copper, July concentrations were higher than the August and September results, but the October values are much higher, although still well below the average 1174 ppm from the previous November over the fen.

Transect 5 results were comparatively lower for July, August and September, but the October results were comparable to the Transect 3 station figures. Those are all from Zenon's analyses. By using the box plots, it appears the Zenon and PESC results can be more readily compared when examined using this method (Kürzl, 1988). The comparison would be more meaningful if all the plant samples taken had been analyzed by PESC.

Chapter V: Discussions

Discussion of Channel Stability

Channel stability in the Pyrrhotite Creek wetland is high. The 1946 and 1972 channel morphology is close to that of 1995, suggesting that the perceived changes in the channel network seen in the 1992-95 period were due to its returning to a close semblance of its original morphology. This is possibly after the effects of the road building disturbances have diminished and clastic sediment input reduced.

Pits dug into the main channel (through 1 to 2.2 metres of snow cover) in both March and November 1994, penetrated a resistant, thick (20 to 30 cm) layer of ice which was solidly frozen onto the peat soil next to the channel (see Plate 7, taken November 3, 1995, which shows the initial formation of this layer). When this layer was penetrated to the channel in November 1994, water spurted up through the hole, demonstrating considerable water pressure.

It appears that the freezing of the surface layers of the fen (water, plants and soil) to either side of the channel results in a confined channel in which erosion and deposition occurs during freshet under a frozen cover. This frozen mass and the snow on top of it also helps to stabilize the peat soil through pressure. Otherwise, the presence of the secured sections of the porous hay bale weirs would have caused channel avulsions into the soft sediments. Further evidence of the velocity and erosive capability of the flow is demonstrated by the boulders deposited in the channel near the fen outlet, although these may be relicts of the deglaciation. The fen constricts at this point, but not the channel, so if flood events (overtopping the banks) were involved, one would expect that the boulders would have been washed downstream. There is a small drop at the outlet which would allow the water to flow out across the downstream area after eroding a hole in the cover. Thus, there would be a velocity decrease and sedimentation of large clasts could occur in the later stages of freshet. There would be still considerable confinement, so smaller clasts would not be deposited until freshet was almost over. However, more of them would be deposited upstream, where the channel is wider and the flow spreads out initially.

The reforming of the secondary channel from the main inlet may be due to the decrease in sediment transport from the road or to ground water melting some of the capping, allowing passage of high pressure water during later stages of freshet.

Inspecting the aerial photographs and the outlines, it can be seen in the 1957 outline (Figure 4-1b), the 1972 outline (Figure 4-1c), and the 1984 outline (Figure 4-1d) that Pyrrhotite Creek often overflowed the culvert and ran over the road. This would have resulted in considerable coarse sedimentation as the road metal and fill was eroded. This eroded material had probably filled the secondary channel alluded to earlier, Channel B, the secondary channel which appeared to be growing when the site was first visited and surveyed. The eroded section is almost exactly uphill of that secondary channel. With the construction of the bridge over Pyrrhotite Creek in 1990 (Galbraith, 1991a), these floods over the road have ceased to occur. Fen channel stability has increased since the bridge was constructed.

Discussion of the Harvesting Results

It is apparent from table 4-3 that the rate of new growth is similar to the rate of senescence after the initial spurt of growth in June, as the new production is almost matched by the death of mature leaves, otherwise the amount harvested per unit area would increase or decrease over the season. The dip in dry matter per unit area harvested in September may be due to drought or other weather-related effect. Dry weights of the cotton grass ranged from close to half to about one-sixth the fresh weight. The harvest level in October of 112.5 g per square metre would be the equivalent of 1125 kilograms per hectare of dry matter. In comparison a productive farmed pasture site near Smithers can produce about 7000 kg per hectare in a summer and a "fair quality" farmed pasture site near Williams Lake can produce about 3400 kg per hectare of dry matter. Both production figures are from agricultural grasses (Broersma and Tingle, 1987). This demonstrates that the fen is not very productive and is a poor producer of dry matter compared to farmed pasture land. However, it falls into a moderate range of production for browse and grazing in non-farmed wild lands, which would normally be a mix of species and plant types (grasses, sedges, herbaceous plants, shrubs, and trees) (Quinton and Ryder, 1983; Robbins, 1983).

As noted, the twelve 1 square metre sites treated with high-nitrogen "slow acting" lawn fertilizer showed no increase in growth or dry matter production compared to the control sites. Goodman and Perkins (1968a,b,c) found that potassium was the only element which increased growth when applied in a fertilizer on *Eriophorum* in the U.K. The use of lime to

increase growth, the only other technique they found to increase growth, was not tested. Potassium available[2] to the cotton grass was at a concentration of approximately 3% in the soil of the sedge fen, more than adequate for optimal growth. *Eriophorum* appears somewhat unusual, as most graminoids (true grasses and unrelated grass-like plants such as the sedges) show growth increases with increased nitrogen (C. Haddow, pers. com.).

Gebauer *et al.* (1995) noted that *Eriophorum angustifolium* could have its growth rate improved by fertilization, and that it would outperform *E. vaginatum* ssp. *spissum* in anoxic growing conditions. In fact, *E. angustifolium* would take over from the latter species in a perennially flooded wetland, even without extra nutrient input. Extra nutrients may be detrimental to the *E. vaginatum* ssp. *spissum*, as it is known as a poor fen species (Glaser, 1987; Shotyk, 1988). So, the takeover of the fen by the cotton grass may be due to an adverse impact of nutrients from the open pit on the other fen plants and to the waterlogging of the site with the hay bale weirs improving the growth situation for the cotton grass.

Discussion of the Biogeochemistry

Introduction

The uptake of metals by plants is controlled by their environment: sediment geochemistry, the water chemistry and plant physiology; and the genotypic differences between plant species, varieties and stocks, as mentioned earlier. The chemical speciation "profoundly alters elemental, including metal, bioavailability and toxicity to aquatic organisms. It is less widely appreciated that many "bioavailabilities" exist for a given chemical species, because of physiological differences with respect to uptake sites and mechanisms between species, within individuals, and between genotypes within species." (Outridge and Noller, 1991). Metals are taken up by plants via adsorption, followed by passive and/or active transport across membranes. Only dissolved species are directly taken up (Keller and Fredrickson, 1952; Outridge and Noller, 1991).

Copper is being removed from the water flowing through Branch 126 Sedge Fen (see Table 4-7). There was less copper dissolved in the waters flowing out of the fen, than in the water flowing into the fen for the months of July, August, September, and October, but more flowing out in November than flowed in. Over the period of the project in 1995, it appears that about 100 kg of copper was retained by the wetland.

---

[2]Potassium results are in the raw data from PESC.

It was noted earlier that the cotton grass could be removing copper by direct adsorption, or becoming involved in other biogeochemical processes. Plants raise the pH of a solution through photosynthesis and production of OH^- (HCO_3^- (aqueous) + 6 H2O $\rightarrow$ $C_6H_{12}O_6$ + 6 O_2 + 6 OH^- (Wildeman *et al.,* 1995), they provide a habitat for a variety of microorganisms, and they provide nutrients for many more, some, the sulphate reducing bacteria, of particular importance. These, by sulphate reduction, raise the pH by the oxidation of glucose from the hydrolysis of cellulose ($6H^+ + 3\ SO_4^= + C_6H_{12}O_6 \rightarrow 3\ H_2S + 6\ H_2CO_3$) (Wildeman *et al.,* 1995). The sulphate reducing bacteria are anaerobic, and the "waste" hydrogen sulphide produced can dissociate to give sulphide ions, which can then react with the metal ions in solution to precipitate them as insoluble sulphides. The decaying remains of the plants provide numerous sites for the adsorption of metal ions, especially copper (Lett, 1978; Sobolewski, 1996).

There are also a number of other, chemical and physical processes at work to remove metals. The formation of iron oxyhydroxides acts to lower pH ($Fe^{3+} + H_2O \rightarrow Fe(OH)_3 + 3\ H^+$). Under low pH conditions, the copper in solution is less likely to precipitate, however, some copper will be lost to adsorption onto the iron oxyhydroxides (Lett *et al.*, 1997; Sobolewski, 1996). Aluminum also acts as a buffer, along with the iron, to keep pH low [$Al^{3+} + H_2O \Leftrightarrow Al(OH)^{2+} + H^+$, $Al(OH)^{2+} + H_2O \Leftrightarrow Al(OH)_2^+ + H^+$, $Al(OH)_2^+ + H_2O \Leftrightarrow Al(OH)_3 + H^+$] (Wildeman *et al.,* 1995).

Because of the effect on pH noted above, early iron and aluminum removal in any remediation situation will allow the pH to rise rapidly with the removal of H+ in sulphate reduction, which has the benefit of bringing more sulphide ions into solution from the reactions by sulphate reducing bacteria. So, although iron is not normally toxic and aluminum is much less toxic than copper (see Table 1-1), removal of these metals is a priority in acid rock/acid mine drainage remediation.

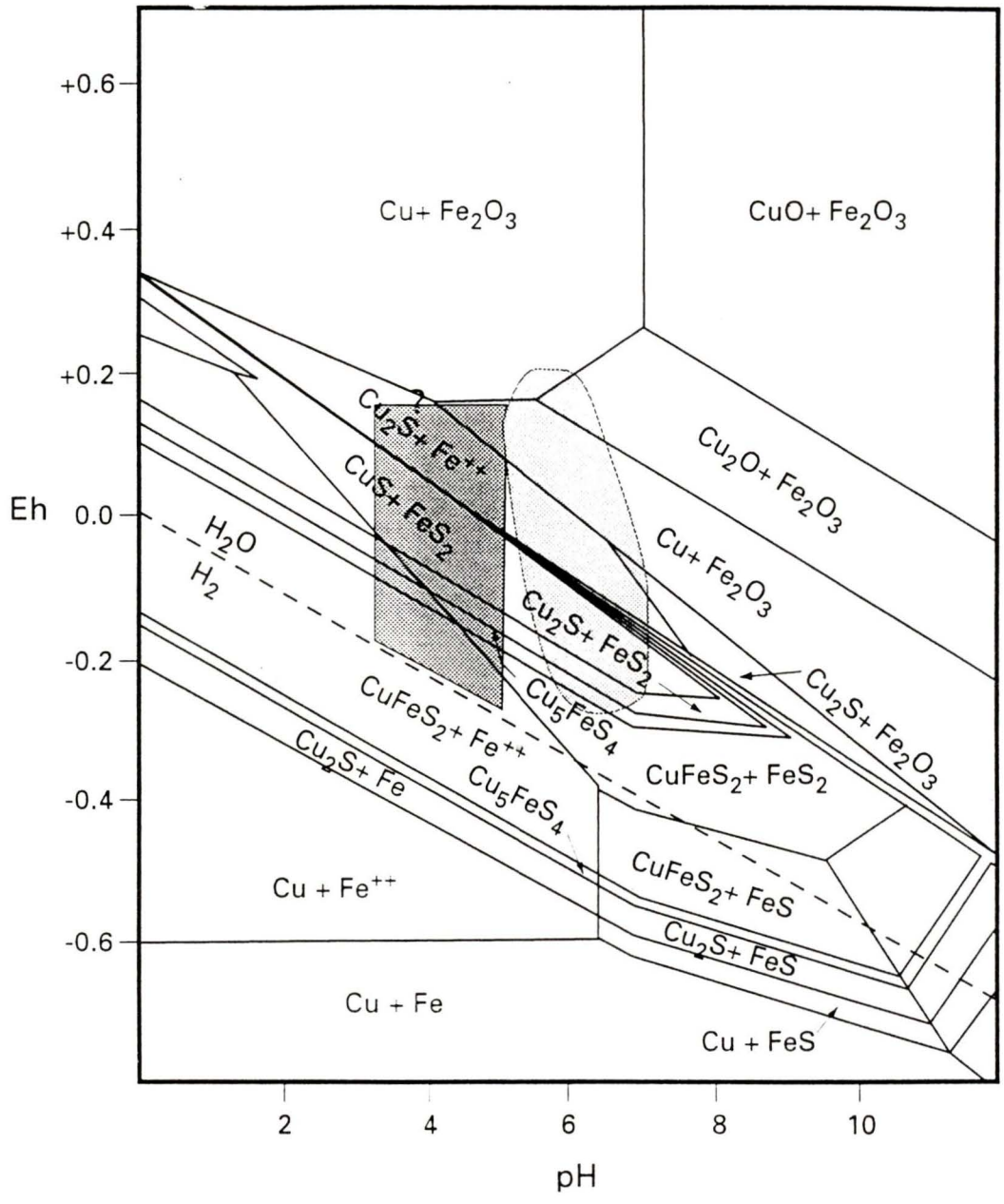


Figure 5-1. Simplified Eh-pH Diagram for Mineral Relationships in the Cu-Fe-S-O-H System at 25°C and 1 Atmosphere Pressure.

Total dissolved sulphur concentration is 10^{-4}M and the dark shaded area represents the approximate Eh-pH of the Branch 126 Sedge Fen. The light shaded area represents the approximate Eh-pH range of central bog waters in the southern Cascade Mountains (Lett, 1978). The diagram is based on that given by Garrels and Christ (1965) and modified by Lett (1978). The Eh range of the waters is believed to be within the range ±200 millivolts, as constrained by the hydrogen - water line in the diagram. Superimposed on the Eh-pH diagram is a dark shaded field with the values found in the Branch 126 Sedge Fen. (Eh was determined empirically). It will be noted that the Eh-pH range found by Lett (the lightly shaded area) barely overlaps the range found in the Branch 126 sedge fen.

It appears from Figure 5-1 that a number of copper and iron minerals would be stable in the fen soils. Covellite, bornite, chalcocite, chalcopyrite, and pyrite would be stable during the summer. There is a chance that magnetite could also be stable.

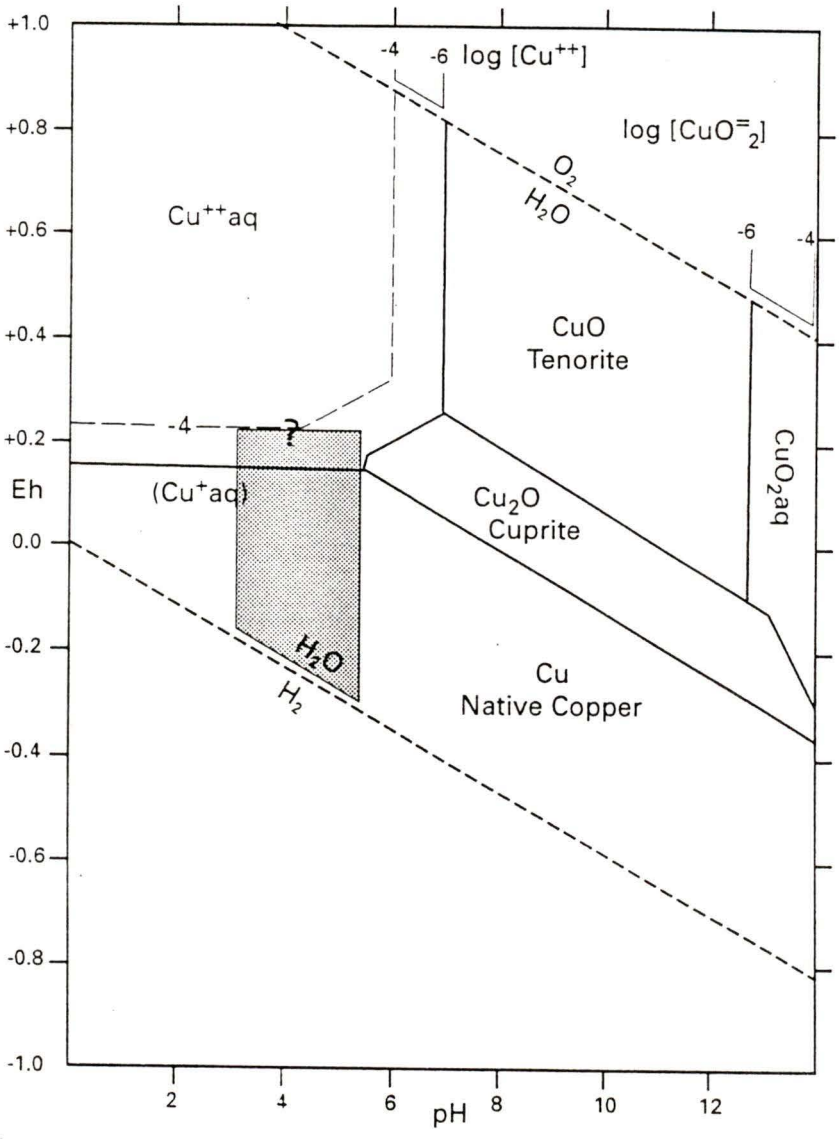


Figure 5-2. Stability Relationships Among Copper Compounds in the System $Cu\text{-}H_2O\text{-}O_2$ at 25° C and one Atmosphere Pressure.

Figure 5-2 is based on that given by Garrels and Christ (1965). The dark shaded area is that area which covers the conditions in the upper level of the Branch 126 Sedge Fen. The Eh range of the waters is believed to be within the range ±200 millivolts, as constrained by the hydrogen - water line in the diagram. Superimposed on the Eh-pH diagram is a field with the values found.

Figure 5-2 suggests that, under the summer conditions experienced, the species present in the fen could have been Cu++, Cu +, and native copper. The pH in the fen did not go high enough for cuprite to be stable, however, remediation efforts which raise the pH in Pyrrhotite Creek sufficiently, could allow the formation of cuprite.

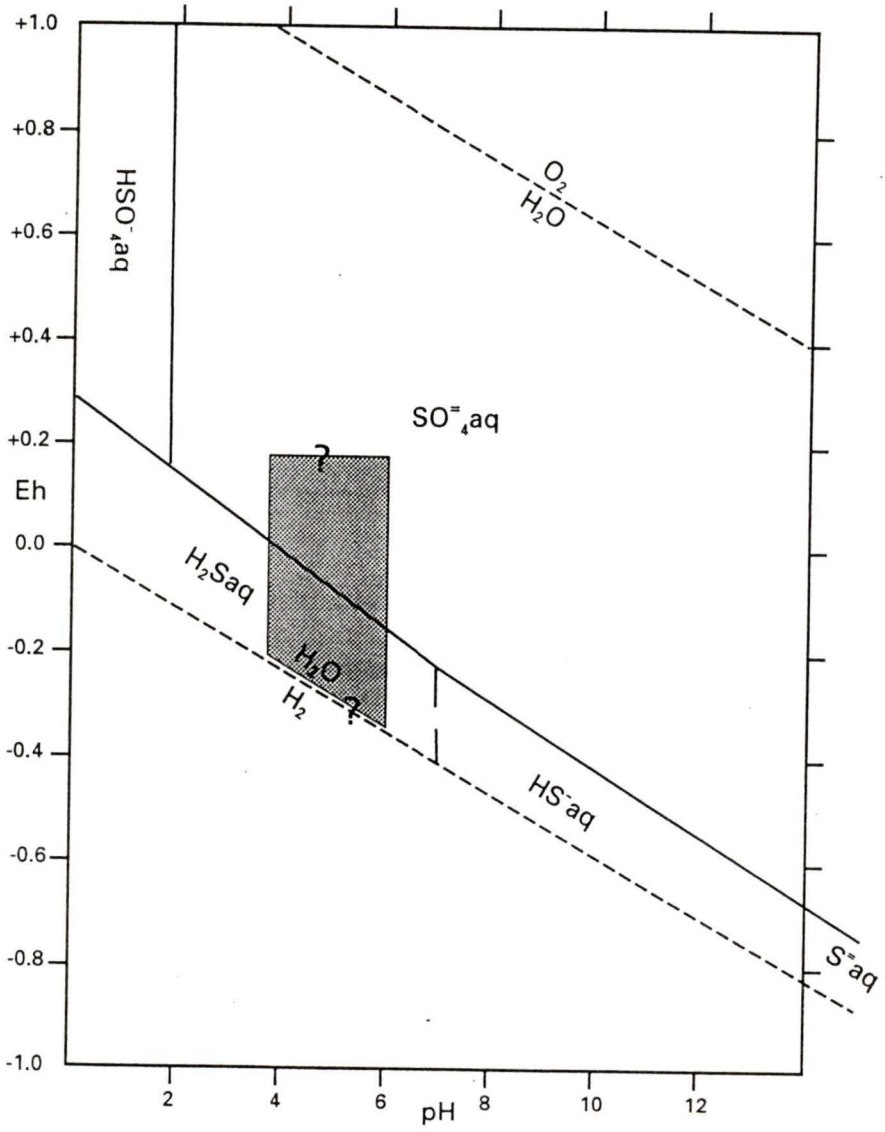


Figure 5-3. Equilibrium Distribution of Sulphur Species in Water at 25° C and 1 Atmosphere Total Pressure

Figure 5-3 is based on that given by Garrels and Christ (1965). The dark shaded area is that area which covers the conditions in the upper level of the Branch 126 Sedge Fen. The Eh range of the waters is believed to be within the range ±200 millivolts, as constrained by the hydrogen - water line in the diagram. Superimposed on the Eh-pH diagram is a field with the values found.

Figure 5-3 indicates that hydrogen sulphide can be stable in aqueous solution under the conditions found in the Branch 126 Sedge Fen, provided no oxygen is present. It has limited solubility, up to approximately 0.01 molar (Garrels and Christ, 1965) at STP, so it could reach a higher concentration with the cooler temperatures prevailing at the sedge fen (8 to 20°C during the summer months, down to 0 at the end of October and in early November).
Dissociation into HS^- ions, which would allow for greater concentrations and faster reactions with copper and other metals, does not take place to any degree until the pH is above 7.

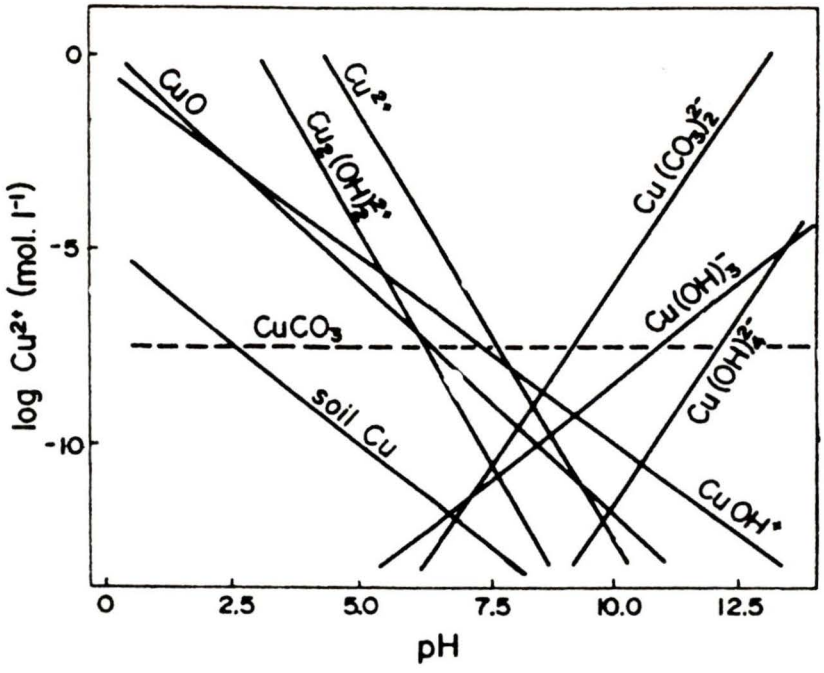


Figure 5-4. Schematic Diagram of Solubility of Copper Ionic Species and Copper Compounds in Soil (from Kataba-Pendias and Pendias, 1992).

Figure 5-4 shows that copper species in soil are at their least soluble at a pH range between 7 and 8. Hence, the importance of reducing acidity in removing copper from AMD/ARD.

1). Vegetation

Cotton Grass in Branch 126 Sedge Fen

At Mount Washington, both long-term and short-term adaptive accommodations may have been made by the cotton grass and sedges in the area, as the rocks were high in pyrite, which would have been oxidizing even under natural conditions, as shown by the gossan areas on some rock faces above the minesite and off the mine access road, releasing iron, aluminum and copper. When the mining activities resulted in increased concentrations of

aluminum and copper. When the mining activities resulted in increased concentrations of metals and lower pH, there were already many plants around which could survive amounts of heavy metals toxic to their less capable neighbours. It is likely resistant forms were isolated somewhat from one another, so different strategies could have evolved to handle the toxic loads. According to Brooks (1995b, and pers. com.), selection for very resistant varieties can result in short time periods. He mentioned a century for biennial and perennial plants, but when annual plants are involved, even shorter time periods could result in the selection of fairly resistant varieties.

Copper in Cotton Grass

Figure 4-11 and Figure 4-12 indicate that the copper in the cotton grass is more closely related to the amount in the soils than in the water. High values in the water are directly comparable to the proximity of the Pyrrhotite Creek channel in many locations, and only during those periods when the water levels in the fen were raised, are high values of copper in the water seen uniformly across a portion of the relevant transect. In most cases, they do not extend to the borders of the fen, except in the case of the eastern end of Transect 3, where there is a break in the hay bale weir which encourages water flow through that area of that transect (stations 15-18).

The total mass of copper held in the fen cotton grass plants is impossible to estimate accurately with the present data. The laboratory separations done would indicate slightly more than half the dry mass of the plants was in their leaves (more leaf material was seperated than the rest of the plant, by weight), but considerable material from the rhizomes, leaf bases, and roots was lost in rinsing. Limits can be set, as it seems unlikely that more than 3 times the mass of the leaves would be in the underground portion of the plants. Gebauer *et al.* (1995) found that *Eriophorum angustifolium* under different fertilization schemes and soil oxygen regimes had 25-50% of its boimass as leaves and flower stalks, 20-30% as roots, and 30-40% as rhizomes. Reasonable estimates for the amount of copper in leaves are easily calculated (ppm have been converted to %, grams to kilograms in the following):

July: 0.00924 kg x 1 m^2/0.09m^2 x 4300 m^2 (area of fen) X 0.0109 % = 0.05 kg Cu

August: 0.00991 kg x 1 m^2/0.09m^2 x 4300 m^2 (area of fen) x 0.0087 % = 0.04 kg Cu

September: 0.00837 kg x 1 m^2/0.09m^2 x 4300 m^2 (area of fen) x 0.0086 % = 0.03 kg Cu

October: 0.01013 kg x 1 m^2/0.09m^2 x 4300 m^2 (area of fen) x 0.0311 % = 0.15 kg Cu

November: 0.010 kg x 1 m^2/0.9m^2 x 4300 m^2 (area of fen) X 0.1174 % = 0.56 kg Cu

The areas have not been weighted, and the concentrations of copper in the cotton grass leaves for July and October are based solely on Transect 3 and 5 results. Using the November 1994 average copper level of 2522 ppm (discarding the outliers, 2429 ppm), for the cotton grass roots and leaf bases (together, by far the greatest part of the underground mass of the cotton grass plants), if the underground mass is the same as the surface, we could have 1.2 kg. of copper in the underground part, up to possibly 3.5 kg. if the underground mass is as much as three times the leaf mass. Then, reasonable estimates for the total copper in the cotton grass plants of Branch 126 sedge run from ≈ 1.5 kg to an outside level of ≈4.0 kg. However, figures in the literature (Gebauer *et al.*, 1995) indicate that the underground mass of rhizomes and roots is roughly equivalent to the surface mass of leaves, shoots, and fertile stems (depending on nutrient availability, water level, etc.). Removal of all the plant would require a couple of years for replanting and re-growth, and it would be very difficult to avoid erosion of the soil, so total plant removal is not practical for remediation. Mowing the leaves is practical, using hay mowing and baling equipment.

Harvesting in November is not practical. The fen is usually under snow cover from the early part of November. So, harvesting for copper would have to be done in October for maximum effect. All the copper from the North Pit flowing down Pyrrhotite Creek in a year could be as much as 3500 kg (Deniseger and Pommen, 1995), and to remove this would require an area of cotton grass (1ha/0.43 ha x 0.15kg Cu = 0.35 kg/Cu ha, 3500 kg Cu/ 0.35 kg Cu/ha = 10,000 ha) of 10,000 ha. Special husbandry techniques, growing the cotton grass at lower elevations, and mowing later in the year would undoubtedly improve that figure, but not by the three orders of magnitude required to make it useful in this case.

The concentrations of copper in the cotton grass leaves at the minesite (see Table 4-9 and Figure 4-9) were lower than expected. There may be a simple explanation for this. The plants at the minesite are growing in a sludge of iron compounds (goethite, limonite, and other iron oxyhydroxides) which have formed a crust on the roots. This crust may act as a filter of sorts. It is possible that copper is adsorbed onto the iron compounds, which are allowing only water, some nutrients and dissolved sulphate through in any quantity. There may be chemical interactions occurring at the moment of precipitation which is removing metal ions other than iron from solution, as noted by St.-Cyr and Campbell (1996). Robinson (1981) and Benjamin and Leckie (1981) give examples and describe circumstances when this can be expected to occur, including those at the minesite and the fen. Lett *et al.* (1997) note that some mineral springs in northern B.C. have a limonitic incrustation which is enriched in various metals (zinc in particular). Presumably, then, the waters of these springs are purer downstream from the incrus-

tations than at their source. However, the co-precipitates are formed an annual basis, and the downstream waters are still high in zinc, cobalt, nickel, arsenic, molybdenum, uranium and other elements (Lett, pers. com.).

On a last note, the "fen" cotton grass samples with low values are on the ends of the transects, and not in the fen itself (see Figure 3-3).

2).Waters

The September 1993 copper concentrations in water over the vegetated areas of the fen averaged 0.4 ppm copper, while the average copper concentrations in water in the channel was 4.1 ppm. The analytical results along the transects (see Appendix 1, Figures A1-1a to A1-1g), for 1995 are not quite as striking, but the lower copper concentrations in the water over the vegetated areas compared to the channel areas, with the exception of the high current area on Transect 3 (near stations 15-18) shown in Figure 3-3. pH is also higher in the vegetated areas (see Figure 4-4), indicating that the cotton grass has an effect on the pH. It seems unlikely that the copper in the soils and plants comes from any other source (such as mineralized ground water) except surface flow from Pyrrhotite Creek. The minor inlets had copper concentrations an order of magnitude lower than the main inlet, Pyrrhotite Creek. High copper levels in the soils and plants are associated with moving water and spots near moving water which could indicate that only a proportion of the copper is being removed at any one time. Let us say that the area with the faster current removes only 5% the copper in the water, whereas a placid area removes 85%, but 20 times as much copper-laden water goes by in the faster current area than in the placid area, so the fast current areas become copper-rich in comparison to the placid areas. Evidence indicates that the time copper-rich water spends in contact with the substrate is very important as a factor in copper removal effectiveness (Sobolewski, 1996).

The copper concentrations in the inlet water as noted in Table 4-7 do not appear to be reflected in the copper concentrations in the plants. However, with a mean soil surface copper concentration of ≈2800 ppm in July and a mean soil surface copper concentration of ≈3500 ppm in the fall, these could be related to the changes in the copper concentration in the water flowing into the fen (the copper concentration goes from 3.0 ppm in July, 2.5 ppm in August, 4.8 ppm in September, 6 ppm in October and 5 ppm in November). Without data on the copper concentration in the soils for the intervening months, however, the change could reflect the volume of flow, plus the increase in biological activity, more than the concentration.
The copper concentration in the ground water in the background sites in July, as noted in Table 4-4, was six and a half times the copper concentration in the surface waters of these same

background sites. In August, the copper concentrations of both surface and ground water in these background site were similar and in October, the ground water had twice the copper of the surface water in the background sites. The sample populations are not directly comparable, as it was difficult to get water from the background sites in August and September. The background soils are not analyzed to date in any numbers, but there are some plant analyses, which do not suggest any high copper in the background site plants. This groundwater copper may be largely bound to dissolved organic compounds, such as fulvic and humic acids, but testing with 2,2-biquinoline or other assay methods for weakly bound and ionic copper versus strongly bound, non-bioavailable copper would be required to clear up this question.

The diagram of copper in water concentrations by the 2,2-biquinoline test compared to the copper in water concentrations as determined by PESC shows a difference. The PESC analyses are done with ICP-AES, which uses atomized solution heated to form a plasma, so that all the dissolved copper in the water, even if not converted into ionic form by the digestion procedure, will be detected. The 2,2-biquinoline will not extract strongly bound copper, and it is useful as a tool to find out how much copper is likely available to aquatic organisms, as the strongly bound copper is not likely to enter into biological processes (Lett, 1978; Negpal, 1995). In the samples with the highest concentration of copper in Figure 3-7, about a quarter of the copper was not accounted for in the 2,2-biquinoline testing. Generally, most of the PESC samples showed a higher concentration than the colorimetric results, except for two samples, which it is believed could have been misread by the PESC laboratory staff (background site Z being mistaken for background site 2). Apart from those two, the variations between the methods is likely due to copper being bound to organic molecules such as fulvic and humic acids, and to the errors inherent in a colorimetric test.

The pH values recorded over the summer, as noted in Table 4-7, demonstrated several unexpected features. The filtered samples were expected to have a higher pH, considering the comments of Shotyk (1988), which suggested that the peat particles touching the electrode would lower the pH markedly. In fact, the mean pH values for the second to fourth quartiles of copper concentration (on-site, unfiltered samples) did not show a consistent decrease.

Examination of the data show that there are a number of high pH sites (almost neutral) throughout the data, which skew the mean results. There may have been biological processes which were raising the pH values in the site situation, which were slowed by the filtration at 0.45 microns and the refrigeration employed.

The pore water results from November 1994, show copper concentrations ranging from 0.008 to 5.49 ppm. Four of the five highest concentrations (5.49, 0.662, 0.496, 0.441 ppm Cu) are very close to the channel, while only one (0.56 ppm Cu) is well away from the channel. Since the water in the channel is under pressure, it could be forced into the peat, and between the surface of the fen and the ice. However, the "distant from the channel" high copper concentration is still less than the highest background pore water (one station had 0.584 and 0.586 ppm concentrations of copper, see Table 4-4), so there could be some minor copper-rich seepages in the background sites. More likely, there are some areas of the fen where summer-deposited copper is subject to re-solution in the winter, giving a high copper concentration in the pore water. So long as there is not a strong flow, there may not be any marked effect on the fen's copper mass balance.

3). Soils

Branch 126 Sedge Fen

The Branch 126 sedge fen is probably aerobic for most of the year in the surface and near surface layers. There was little sign of the dark iron banding (an indicator of reducing conditions) until late in the season, and no hydrogen sulphide odour in the core holes until the fall sampling. Hydrogen sulphide odour was noticed in the hay bales when they were dug into, both at the fen and at the minesite, but only sparingly in the fen soils when the cores where removed in the fall. The presence of oxygen and low sulphide ion levels in the surface soils would suggest the process copper adsorption onto organic materials and iron oxyhydroxides over the formation of sulphides. Iron compounds were noted on the hay bales on the fen and very markedly at the minesite. Looking at Plate 1, to the left of the centre of the photograph, there is a small pale turquoise pool, which is called the "Dry Pond". On the right hand side, the dark green cotton grass is growing in an arc beside the hay bales, and a orange deposit[3] is clearly visible on the hay bales, and running into the pond.

Sulfur levels in the soil are high, and more than enough to immobilize all the copper in the soils as copper sulphides. There are almost no soil samples in which the sulphur would not be enough to form covellite (copper is 1.98 x the sulphur content by mass in covellite, CuS). Chalcocite, Cu_2S, gives an even greater "copper immobilization index" of 3.96. Copper is 3.96 x the mass of sulphur in that mineral. But, there is iron present, and at very high levels, so pyrite and chalcopyrite would be expected, as per the diagram in Figure 4-20. There is more than enough iron to react with the sulphur present in the soils (pyrite has 1.15 x the mass of sulphur compared to the mass of iron) of the fen.

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[3]Cliff Rennie of Better Resources tested this material several times. Copper concentrations between 2800 to 3200 ppm copper were found (C. Rennie, pers. com.).

A final point, is simply that in other wetlands, there are large amounts of sulphur present in the organic materials, not related to the presence or absence of sulphate, which are seldom involved in hydrogen sulphide generation, which is almost exclusively due to bacterial sulphate reduction (Shotyk, 1988). For this fen, the amounts of sulphur in the cotton grass leaves (which make up the organic component of the fen peat soil) average out to 2900 ppm in the fen and 1831 ppm in the background samples of cotton grass. Assuming that the cellulosic and lignin components of the sedge decompose and concentrate the organic sulphur components of the sedge and cotton grass leaves, there is a large supply of organic sulphur in the fen soil which is not bound to metals, iron or copper. So, it is unlikely that there is a large proportion of copper sulphides in the soil of Branch 126 Sedge Fen. However, extraction sequences such as those used by Lett (1978), Gormley *et al.* (1992), and Sobolewski (1996), on a representative suite of soil samples would be required for a conclusive answer to the proportion of copper in sulphides, adsorbed on iron compounds or adsorbed in organic compounds.

Copper in Fen Soils

The mass of copper held in fen soils can be calculated from the following data:
Fen average x 2000 cubic metres [mass = Average density of 1.05 x 25.8 % (mass retained after drying, 2100 x 25.8 %] = 541.8 tonnes dry matter running 1800-2000 ppm copper. Using the average for the 1993 sampling of 1835 ppm copper gives an estimate of 994 kg, or close to one tonne of copper in the soils of the fen.
Over the 30 years since the mine started operating and assuming- almost certainly incorrectly- that there was no appreciable copper in the wetland prior to the mine opening, 994kg/30 yr. gives a retention of 33 kg copper per annum.

Table 4-7 gives a figure of 168.5 kilograms of copper retained in the fen during the summer season of 1995. The calculation was based on the measured flows at the inlet and the outlet of the fen, and are for only one or two times for the month, not a daily accumulation. There would be flood episodes which would have pushed up the total flow through the wetland, but, since the hydraulic retention time would have been brief, little copper removal or deposition would appear likely. The retention rate of 13% for July is similar to the results Erickson and Deniseger (1994) reported for earlier years (pre-1993) as being approximately 15-18%. Their 1993 results are given below, followed by this study's findings.

Table 5-1. Proportion of Copper Retained in Branch 126 Sedge Fen, Summer 1993 Compared to Summer 1995

June	July	August	September	October	November	
MOELP 1993[4]	13%	n/a	21%	31%	13%	20%
95	n/a	13%	38%	38%	85%	-11%

Table 5-1 gives the percentage difference in the mass of copper going into the fen compared to the mass going out (copper retained is %, lost is -%). Figure 5-5 shows this graphically.

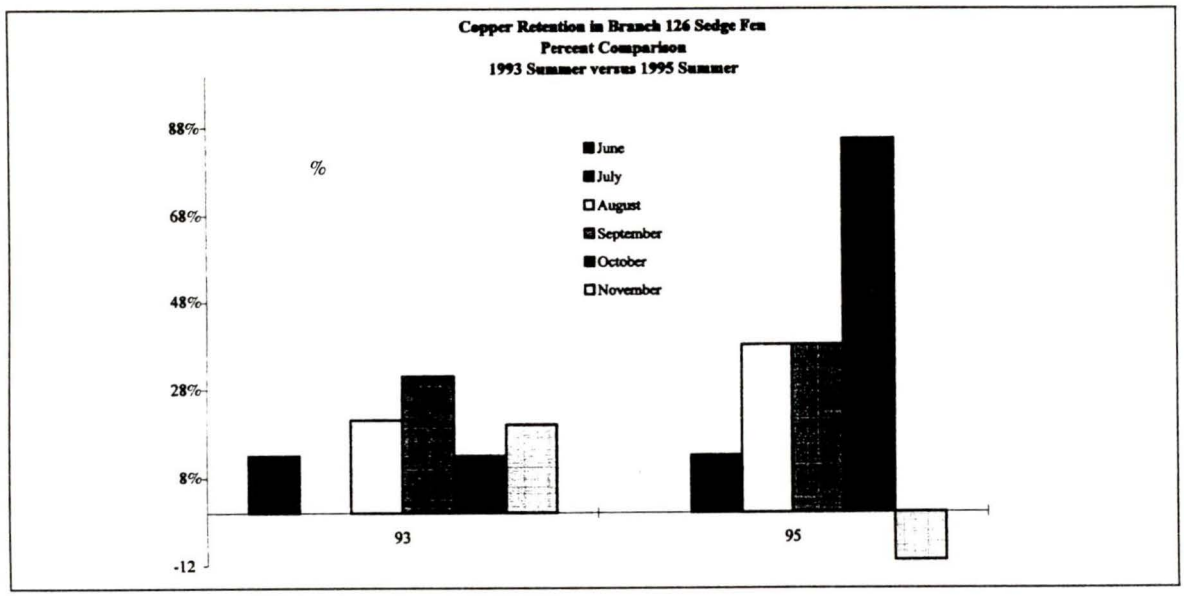

Figure 5-5. Proportion of Copper retained in Branch 126 Sedge Fen Summer 1993-Compared to Summer 1995

Figure 5-5 shows that the proportion of copper being retained in the fen was higher for the summer months of 1995 as compared to the summer months of 1993.Both November results are for the beginning of November. The MOELP June levels are for June 28.

Provided the principles of the estimation are valid, two principal hypotheses can be formulated to explain the discrepancy between the calculated estimate of 33 kg copper retention per annum from the soil concentrations and that of 100.5 kg from the estimate calculated from the flow rate/copper loading calculation (see Table 4-7).

A. Copper is removed from the fen during the winter.

B. The rate of copper retention has increased dramatically.

The second hypothesis seems to be favoured by the evidence. Sedimentation is high, and the amounts of copper in the surface soil has increased over time. The 1993 average is used because the available 1994 and 1995 figures are weighted in favour of higher surface sample

[4]Concentrations from Deniseger (1995) report for the Ministry of Environment, Lands and Parks (MOELP)

levels. For instance, the surface average of the 1993 samples was 2130 ppm copper, which compares almost exactly with the 1994 surface sample average of 2140 ppm (see Figure 4-5). The surface samples for both July and October 1995 transects 2,3,4, and 6 averaged 2913 ppm copper (see Table 4-10 and Figure 4-10), while the 6 cm horizon for transects 2, 4, and 6 averaged 2798 ppm copper (from Table A2-3). These stations are in the centre and northern, downstream area of the fen, so not exactly comparable to the 1993 and 1994 results which have a larger population of sample sites (1993, 5 to 3 ; 1994, 10 to 4) in the southern, or upstream area of the fen. Having said that, it should be noted that the 5, 1993 southern surface samples show an average of 1986 ppm copper, the northern 3 surface samples an average of 2371 ppm copper. The 1994, 10 southern surface samples show an average of 2452 ppm copper, while the 4 northern ones an average of 1355 ppm copper. The sample sizes are too small to be certain if there is any upstream/ downstream bias, but there is a close to certainty indication that the fen had a higher copper content in its soil in 1995 compared to 1993 (compare Figure 4-10 to Figure 4-5 for a graphical comparison using quartiles)[1].

Examining Figures 4-11 and 4-12, there appears to be a rough correlation between copper levels in the soil to the copper levels in the cotton grass leaves. This would indicate that the copper in the soil is somewhat bio-available, but there are only a few samples which can be directly compared. As the results in the cotton grass leaves is moderately high in July, low in August and September, but high in October, and very high in November, there is an indication that copper might become more bio-available in the spring and the fall. Data from other sites (Gormley, *et al.*, 1992) would indicate that the higher results in the fall are more likely due to the metabolism of the plants, and not to the soil or water levels.

Metals other than Copper

Considering that the arsenic levels in the water were generally below the detection limit (<0.04 ppm), arsenic is being removed and stabilized effectively. More effective analyses would be required to quantify the proportion of arsenic immobilized, but it appears to be very high.

Comparing individual sample soil iron concentrations to the concentrations of arsenic, copper, aluminum and zinc in the same samples (see the scatter diagrams in Appendix 1, part 4, Figures A1-4a to A1-4d), there is a strong correlation between iron concentrations and arsenic concentrations (high iron samples are relatively high in arsenic and vice versa), and a lower correlation between zinc and iron concentrations. This supports the concept that adsorption onto iron oxyhydroxides is extremely important in the removal of arsenic and zinc from water containing those elements (Benjamin and Leckie, 1981; Robinson, 1981).

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[1]Since there were only 8 samples for 1993 and they did not fit a normal distribution, the two-tailed Student's T-test could not be applied properly.

The correlation between iron concentrations and copper concentrations in these samples is weaker, suggesting that other processes as well as adsorption onto iron oxyhydroxides are also involved.

Discussion: Conclusions of Geochemistry

It seems reasonable to propose that the initial copper removal is through adsorption onto the iron oxyhydroxides seen on the surface of the fen. However, under the low pH conditions, this will be a minor proportion. This is followed by copper adsorption by the organic materials and the formation of organic copper complexes in the upper layers of the fen. This process, I believe, is the principal agent in removing copper from the water in the fen. As the pH of the water rises, percolating through the fen soils adjacent to the plants, more copper will be adsorbed by organic materials and the formation of organic complexes, plus, a large portion will be adsorbed onto the iron oxyhydroxides. Later, a portion of copper that leaches out of these materials (organics and iron compounds) may undergo diagenesis into sulphides. The sulphide ions for this process come from the dissociation of hydrogen sulphide produced by the sulphate reducing bacteria, which exist primarily at depth. As the summer season progresses, and the amounts of oxygen in the fen are reduced, the sulphide formation comes closer to the surface, as was observed in the hay bales that make up the weirs in the fen in September and October, 1995.

Summary Model

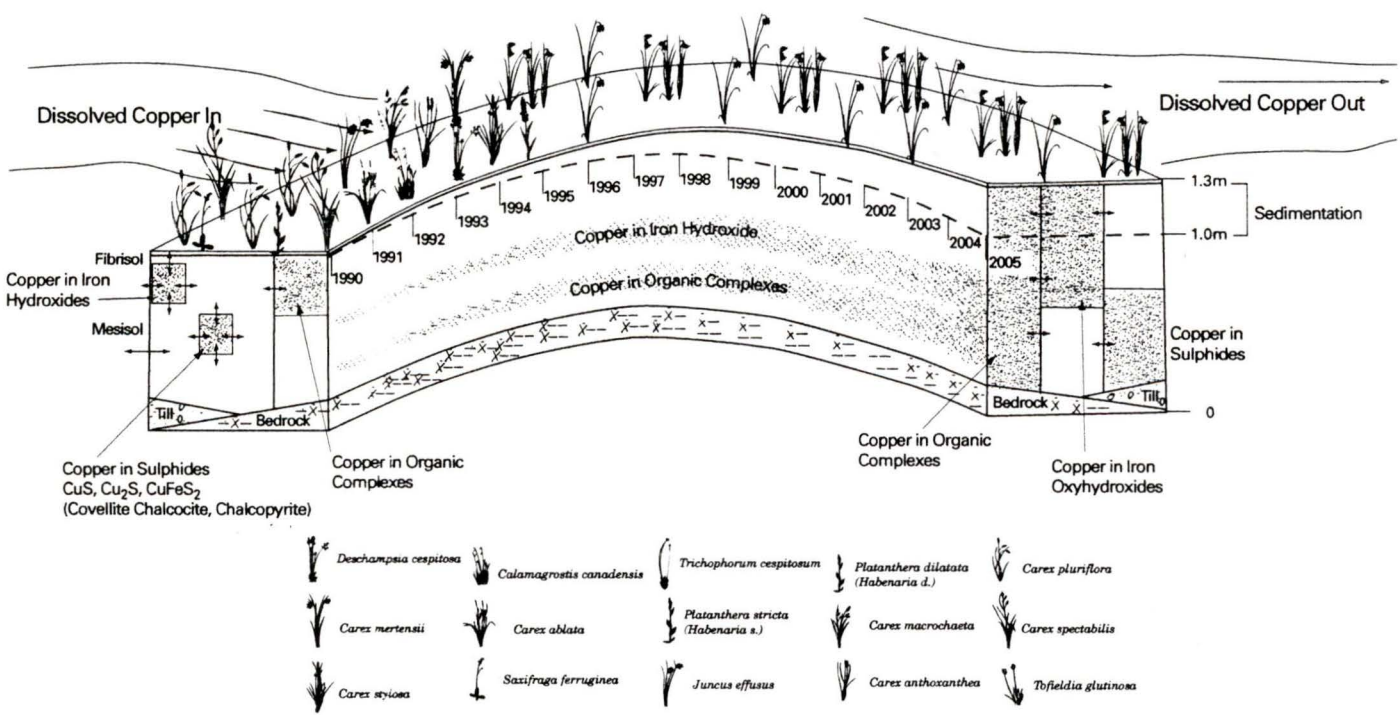


Figure 4-18: Branch 126 Sedge Fen Through Time.

The preceeding cartoon shows the perceived changes in the sedge fen through the past few years into the immediate future. The plants are shown as noted, but, the future may hold sedges such as the Beaked Sedge, *Carex rostrata,* and the Water Sedge, *Carex aquatilis,* in the population there. Both have been planted or have grown adventitiously in wetlands receiving acid mine drainage (Gormley, *et al.*, 1992.)

A matrix may be built that shows some relative factors which must be explained, to cover all the observations of the 1995 sampling season. Some data from the earlier samples is included.

Copper Flux through Fen

July- High. August - Low. September - Low. October - High. November - High

Copper in Soils (surface).

Sept. 1993. 2120 ppm,

Nov. 1994-2140 ppm

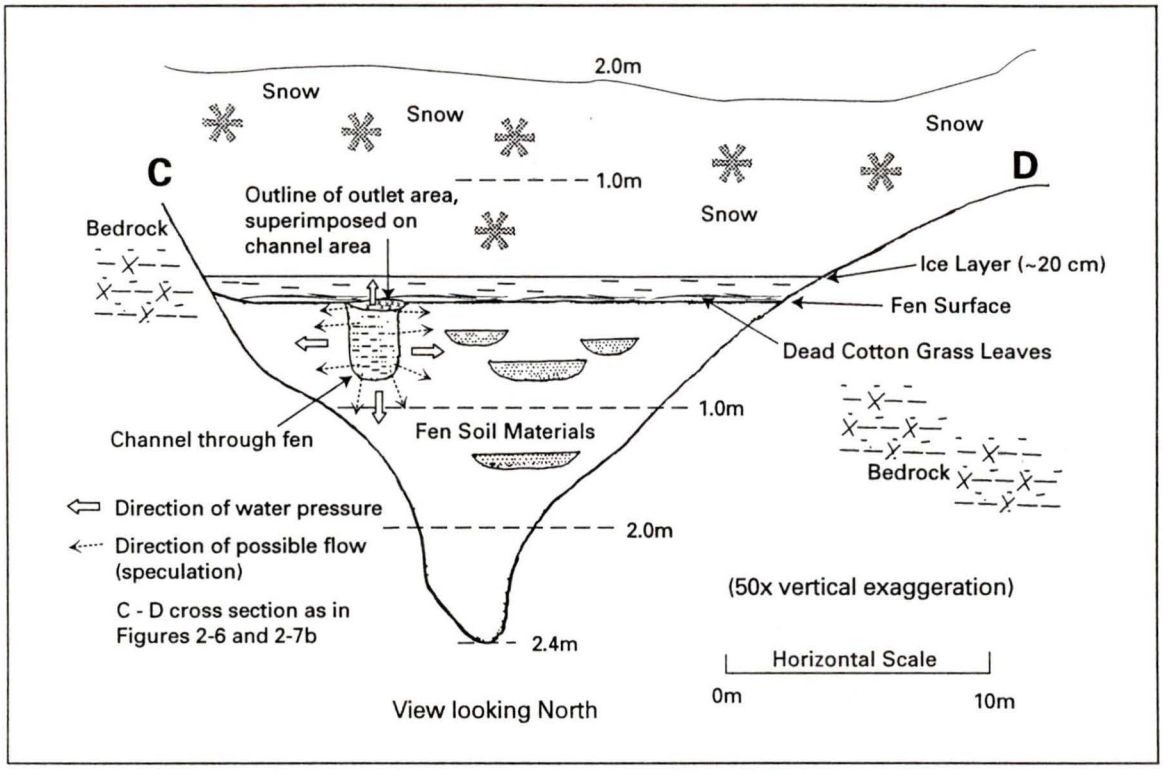
July 1995-2800 ppm Aug. 1995-N/A Sept. 1995-N/A Oct. 1995-3500

Copper in Plants

July - Moderately high Aug. - Low Sept. - Low October - High Nov. V.High

The high copper flux in July, October and November is due to increased flow down Pyrrhotite Creek from climatic factors (high rainfall). Likewise, low copper flux during August and September is due to low flows, again due to the climatic factors there. The production of AMD is slowed during the cold weather, but the over-winter accumulation is not flushed away until the period of snowmelt (freshet) occurs, so both flow and concentration may rise (Chaudry, 1991). Since the copper concentrations in the soil appear to be climbing, even from November of 1994 to July of 1995, it seems likely that large amounts of copper are not being dissolved out of the wetland during the winter and early spring high flows. Since the wetland is, for all intents and purposes, a pipe at this time, and it is under pressure, it is difficult to see how there could be any substantial flow out of the fen soil. See Figure 4-19, below. From the evidence in the fen (see Figure 4-11 and 4-12), it appears as if the cotton grass plants pick up copper from moving water better than from placid water, and it is during July, October, and November (before freeze-up) that there is more water on the surface of the fen, and higher movement, than in August and September. Otte *et al.* (1995), note that in placid conditions, the take-up of metals by plants creates a diffusion gradient which allows the plant to continue taking up metals, but at a slower pace than at the initial conditions. So, even a small current that brings fresh copper-rich water to the roots can improve the plants' capability to absorb copper.

Figure 4-19: Cross-Section through the Branch 126 Sedge Fen during winter.



The black section on the channel outline in this sketch shows the approximate size of the outlet of the fen in relation to the rest of the channel. This view is from the south to the north. The large arrows show the direction of water flow during winter in the fen, due to the sealing of the fen surface by ice, and the sealing of the inlet down from the bridge by ice also, making the channel into an irregular tube for the period between freeze-up and freshet. It shows that flow out of the fen peat soils is unlikely during winter, although, during spring, when the ice cover has gone, such flow could occur.

Practical Applications

Acid Mine Drainage

My observations suggest that treating acid mine drainage with a modified natural wetland is a very proposition. The Branch 126 Sedge Fen could probably remove much more copper than it does at present, if the high iron and aluminum content of the water of Pyrrhotite Creek could be reduced. They inhibit the ability of the growing plants to raise the pH by acting as a buffering agent to keep pH low, and iron plaque reduces the plant uptake of nutrients (Otte *et al.*, 1995). In other words, raising pH and reducing the iron allows the plants to grow faster. If lime could be added to the stream, it would increase the efficiency

of the wetland [increasing growth rates of the wetland microbes and the cotton grass biomass (Goodman and Perkins, 1968b), and, by raising the pH, lowering copper compound solubility, and raising the solubility of the hydrogen sulphide from bacterial reduction of sulphate). Since direct addition of limestone to the channel would result in a iron and aluminum hydroxide armour on the limestone, placing the material along the banks of Pyrrhotite Creek, all over and around the minesite would be more effective. Lime is more soluble in cold water, so the rate of dissolution would be higher during fall rain on snow events and at freshet, when the AMD release is highest. Additional sulphate, especially in the form of gypsum or anhydrite would also assist the removal of copper by providing nutrients (calcium for the plants and sulphate for the sulphate reducing bacteria). Since the effectiveness of the fen in removing copper is highest when it is warm during summer, the storage of the runoff from the mine at the minesite, to be released during the summer to flow through the fen would both reduce the impact of the fall runoff and the spring freshet, but, if allowed to warm during the summer, improve the effectiveness of the wetland. Improving retention of the water of Pyrrhotite Creek and modifying the downstream wetlands to allow the water to flow slowly through modified natural wetlands would also reduce the impact of fall runoff and spring freshet.

The data suggest that the amount of copper actually taken up by the cotton grass is improved by water movement over the roots. Since Gebauer *et al.* have shown that this species of cotton grass grows better in anoxic water than oxygenated, non-turbulent flow through the root areas should be encouraged. Using an anoxic limestone drain system and having the effluent rise through the bottom of beds planted with *Eriophorum angustifolium* would accomplish this.

Great care should be taken to avoid raising the pH too much (over a pH of 7.0), and turning the fen water alkaline, as the arsenic would become labile under those conditions. Also, many of the organic complexes become soluble at higher pH levels, which could cause further difficulties.

Chapter VI- Conclusions and Suggestions for Further Research

Conclusions

The amount of copper retained in the sedge fen over a growing season is far greater than the copper retained in the cotton grass of the sedge fen. The principal copper reservoir is in the sedge fen soil. The adsorption of copper on organic materials, iron compounds, and the precipitation of dissolved ionic copper by its reaction with sulphide ions is far more significant than the flux of copper through the cotton grass into the fen.

The importance of the Narrow-leaved Cotton Grass in the removal of copper from the water of Pyrrhotite Creek is in providing organic matter for the adsorption and complexing of copper, modifying the pH, providing a matrix for the iron oxyhydroxides to precipitate in and on, and providing nutrients for sulphate reducing bacteria.

Water movement in the fen is important in the removal of copper. To maximize the copper removal, the flow over the fen should be evened out. The stagnant areas should have circulation improved, and in the areas with a swifter current, that current should be impeded.

The use of the cotton grass for the "green remediation" of Brooks (1995a), and Chaney and Angle (1993), is impractical under most conceivable conditions. The area required is too extensive for the amount of copper that has to be removed from the water of Pyrrhotite Creek to bring it within the standards of the B.C. Ministry of Environment, Lands and Parks.

Branch 126 Sedge Fen by itself is unlikely to make a major impact on the the water quality of Pyrrhotite Creek, unless as one part of a remediation plan which uses site reclamation, constructed storage facilities, modified natural wetlands, and constructed wetlands.

Suggestions for Further Research

Extraction of the copper in a representative sample of Branch 126 Sedge Fen soils as per the sequence described in Sobolewski (1996) which would allow the quantification of copper speciation. This could indicate avenues for remediation of the Mt. Washington Copper Mine, and other, similar situations by amending the inflow with extra sulphate, organic matter, limestone, or chemical fertilizer; or simply altering the flow regime, dilution and storage times of the effluent.

The flow, copper loading and retention, copper content of the soils and the sedimentation rate in Branch 126 sedge fen should be monitored. There is now enough past material to indicate the magnitude of any changes and their direction accurately, provided that all the samples collected in 1995 are analyzed and the analyses made available in a accessible format.

The hay bale weirs in the fen have raised the water level and this has improved the growing conditions for the cotton grass. There may be other wetland plants which could do even better than the cotton grass if planted and nurtured. The surrounding area could be combed for possible candidates, as there are high copper levels in other mineralized areas close to the project area, where other hyperaccumulators may be found.

All the remaining plant and soil samples collected which have not been analyzed should be analyzed as soon as possible. This would allow comparisons with later measurements on the fen to monitor the changes against a fairly complete baseline sample set. It is especially important to have a representative soil sample set analyzed for total copper and the partioning of the copper (proportion adsorbed in iron compounds as sulphides, etc.).

Rebuilding the weirs should be considered, especially if controlled discharge storage at the minesite is constructed to reduce peak flows during the fall and spring high runoff periods.

Recommendations

The narrow-leaved cotton grass is well-suited to reclaiming metal-contaminated sites. It thrives under conditions which few other plants would even survive, and it is nutritious for herbivorous wildlife. Toxic levels of copper in the leaves do not occur when the plants are available to wildlife.

As a practical matter, the physical integrity of the sedge fen at Branch 126 should be monitored. If sedimentation is proceeding as fast as has been measured, the build-up of copper-rich peat soil could produce a fen with a raised surface in relation to the basin that it is in. This would make it more likely to be washed out in an extreme flood episode, releasing large amounts of suspended copper-rich sediment. This sediment is not very dense, and most of the density measurements done for this study gave a density of 1 gram per cubic centimetre. Although the copper appears to be in a non-bioavailable form (otherwise the cotton grass leaf copper concentration would reflect the soil copper rather than the water concentration levels), under the usually low pH conditions at freshet (3.5-4.5), copper could be leached out and reach the Tsolum River as dissolved copper, along with the suspended organic sediments themselves. Deniseger and Kwong (1996) suggest that: at the temperatures found during freshet; the amount of dissolved organic compounds; the pH of the water after dilution; and the nature of the sediments themselves mean that under most situations copper resolution is not likely to be a problem. There is a risk that copper in these sediments could become soluble, however. A high summer rainfall event could impact the mountain area without a corresponding rainfall in the surrounding watershed (which would dilute the runoff and raise the pH). The higher temperatures and lower pH than normal would mobilize copper quickly, and very toxic conditions could occur (depending on the severity of the rainfall, the temperature, and the flow stage of the rest of the watershed).

Limestone and gypsum would improve the rate of removal of copper by the Branch 126 Sedge Fen fen if added upstream of any acid mine drainage. The work of Goodman and Perkins (1968a) indicates this will improve the rate of growth of the cotton grass.

Reclamation of the minesite would reduce siliciclastic sediment input, and extend the lifespan of the Branch 126 Sedge Fen and Pyrrhotite Lake. It should also increase the amount of dissolved organic carbon in the water, and thus decrease the copper bioavailability. Such a reclamation appears to be without risk, and should probably have been done earlier. It is not a panacea, but can be carried out incrementally, and should be started. It is probably unrealistic to cover the entire site with soil, but using prepared soil in critical areas, old hay bales and geotextiles to anchor the soil and hay, all exposed mineral soil and rock surfaces would be covered with material which would support plant growth and lead to the development of a vegetated soil cover. The experiments of Galbraith, visible on site, have demonstrated this.

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Ceska, Adolf. Botanist. Conservation Data Centre, Ministry of Environment, Lands and Parks, Victoria, B.C.

Deniseger, John. Biologist. Resource Stewardship Branch, Nanaimo, B.C.

Dunn, Colin. Geochemist. Geochemical Research Section. Geological Survey of Canada, Ottawa, Ont.

Galbraith, Murray. Retired Reclamation Engineer, formerly with the Ministry of Employment and Investment, Reclamation Branch, Victoria, B.C.

Haddow, Cindy. Range Specialist, Resource Stewardship Branch, Ministry of Environment, Lands and Parks, Victoria, B.C.

Hebda, Richard. Curator, Royal B.C. Museum, Victoria, B.C. Geologist and botanist, School of Earth and Ocean Sciences, University of Victoria, Victoria, B.C.

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Lett, Ray. Geochemist. Geological Survey Branch. Ministry of Employment and Investment, Victoria, B.C.

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Appendix 1: Charts for the available results for the Fen and Background Elemental Analyses.

1. Copper in plants, Transect 0-6 and Background

2. Copper in waters, Transects 0-6 and Background

3. Copper in Soils, Transects 2, 3

4. Comparison of Iron concentrations in soil to concentrations of Arsenic, Coppper, Zinc and Aluminum in soils (Mount Washington project).

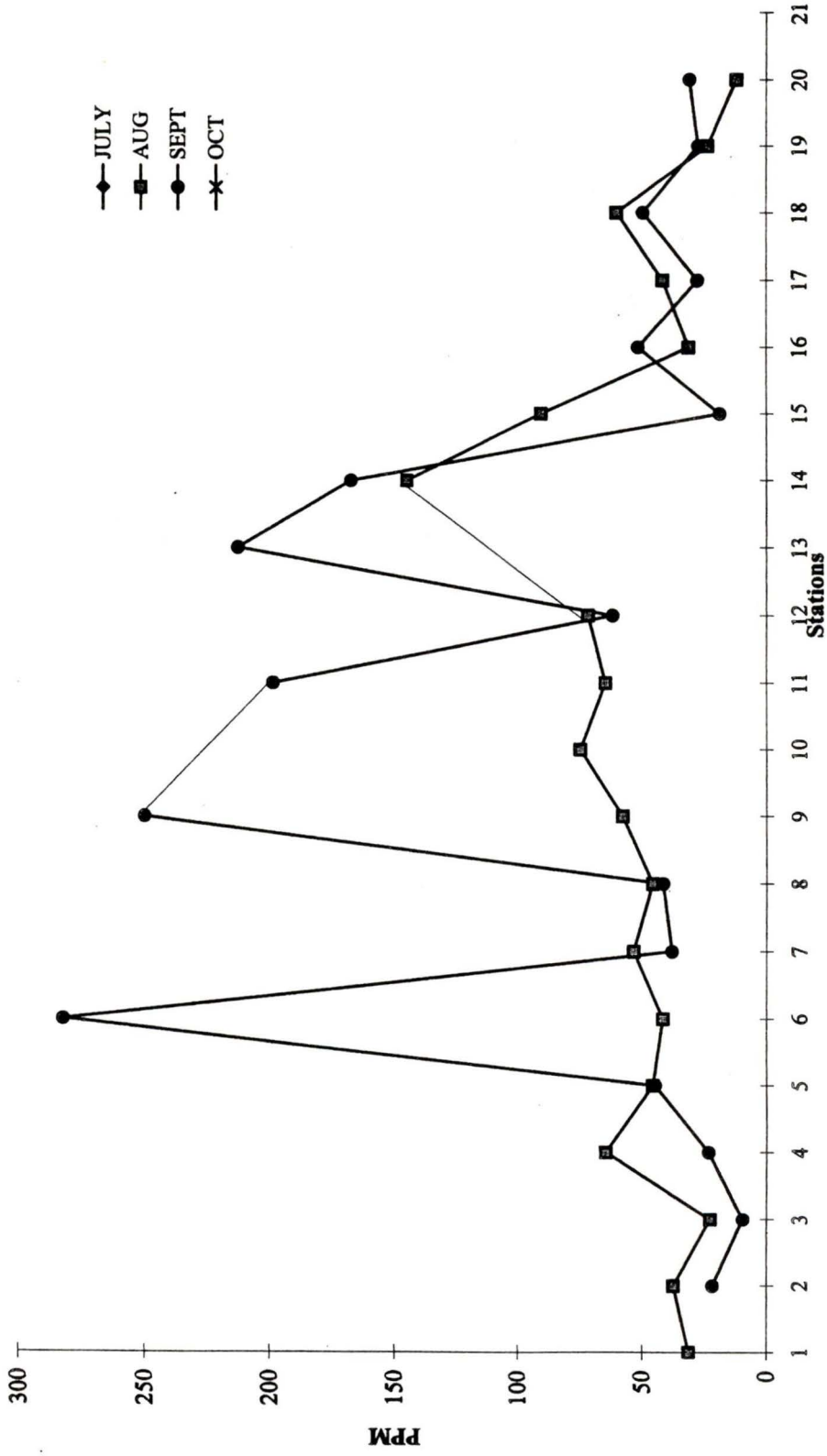


Figure A1- 1a: Copper in Plants (cotton grass leaves) Transect 0, PESC Analyses

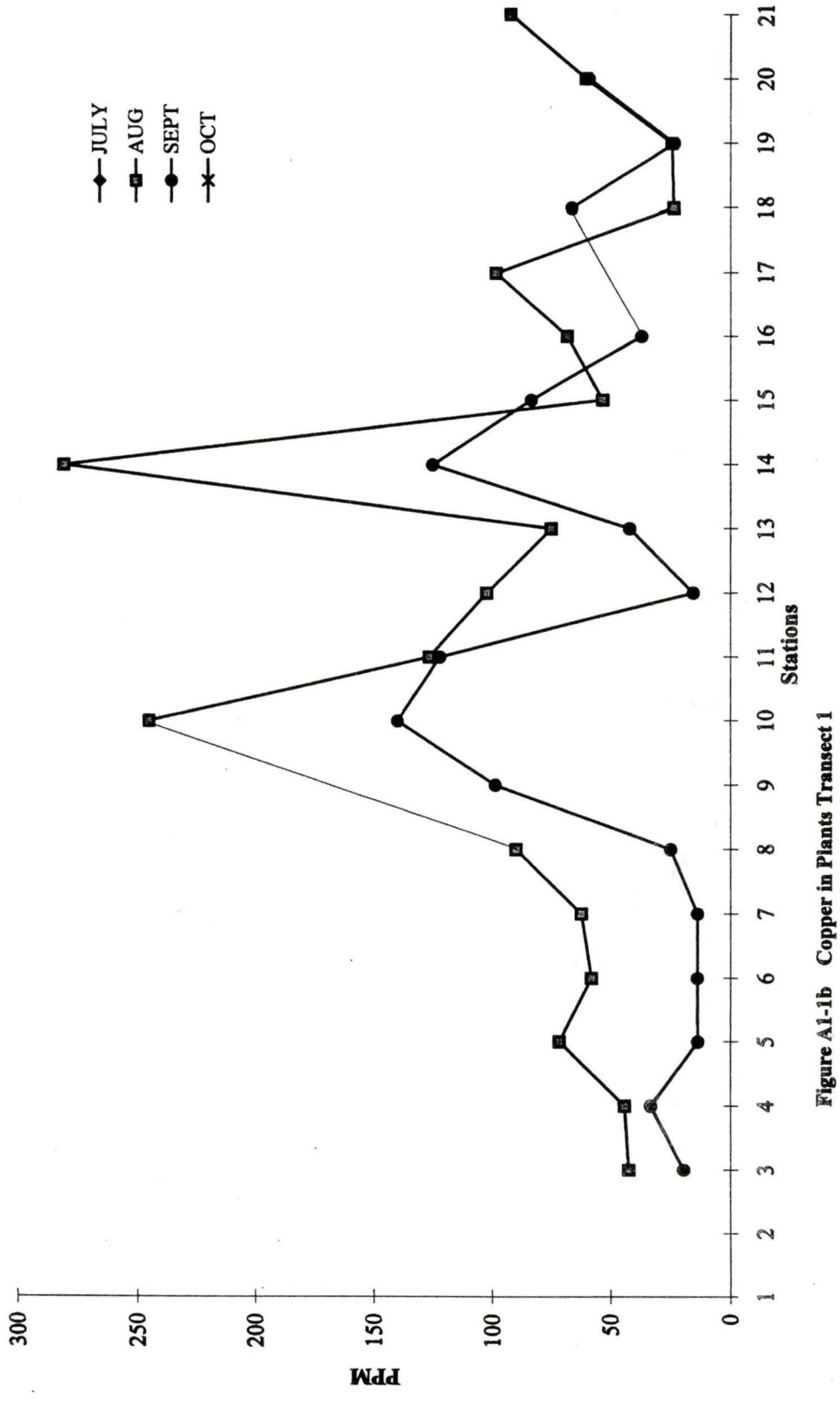


Figure A1- 1b: Copper in Plants (cotton grass leaves) Transect 1
PESC Analyses

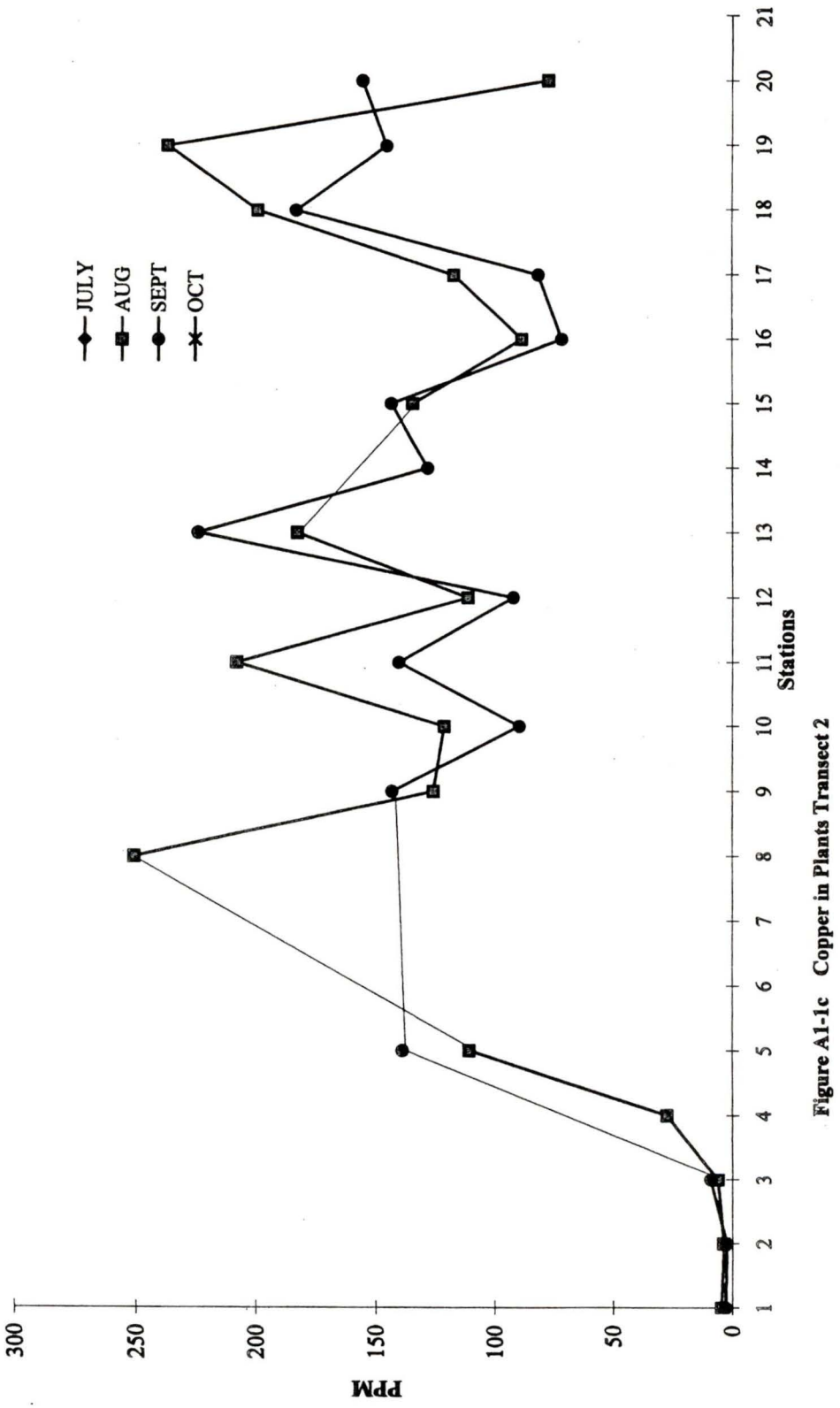


Figure A1- 1c: Copper in Plants (cotton grass leaves) Transect 2
PESC Analyses

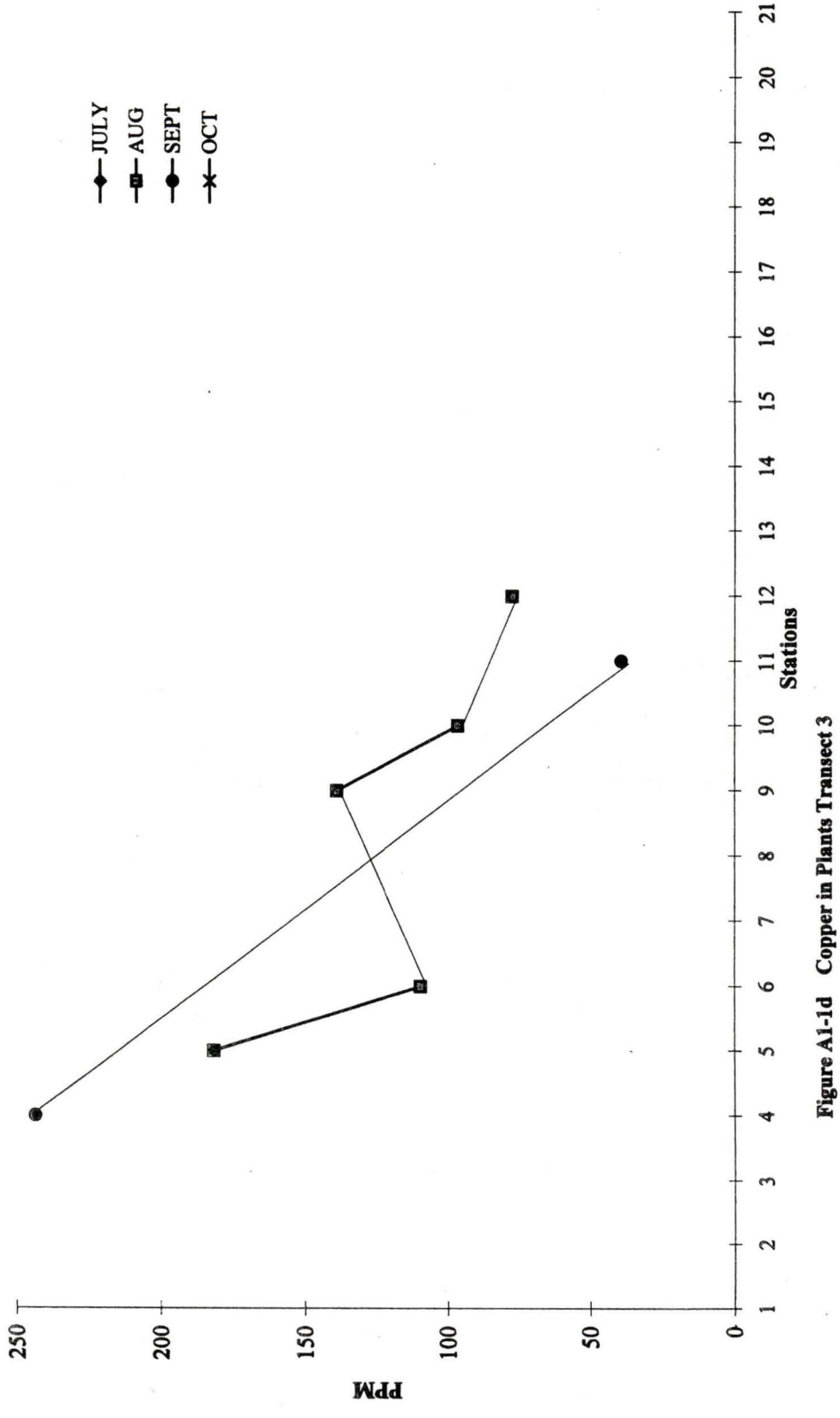


Figure A1- 1d: Copper in Plants (cotton grass leaves) Transect 3
PESC Analyses

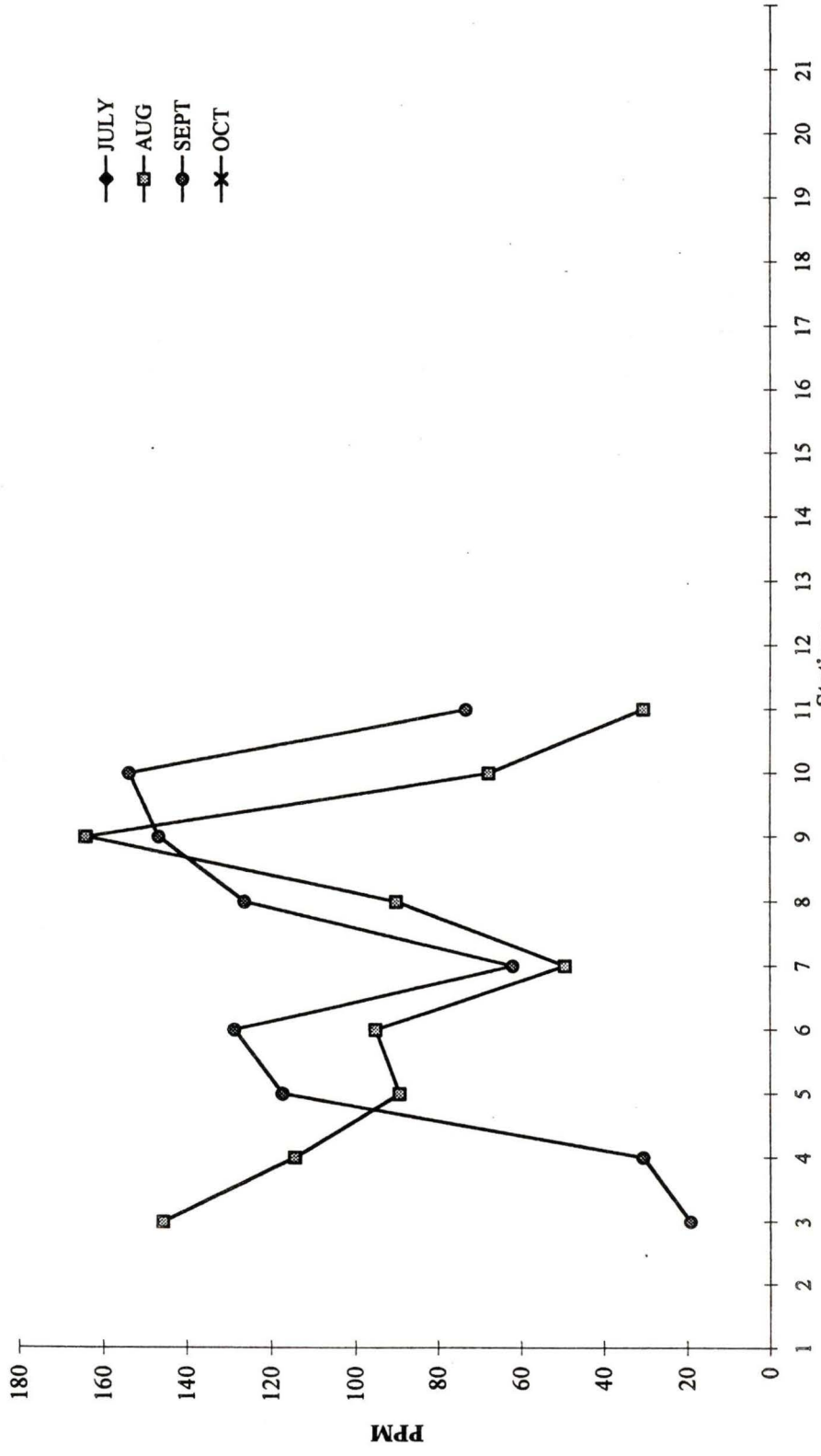


Figure A1- 1e: Copper in Plants (cotton grass leaves) Transect 4
PESC Analyses

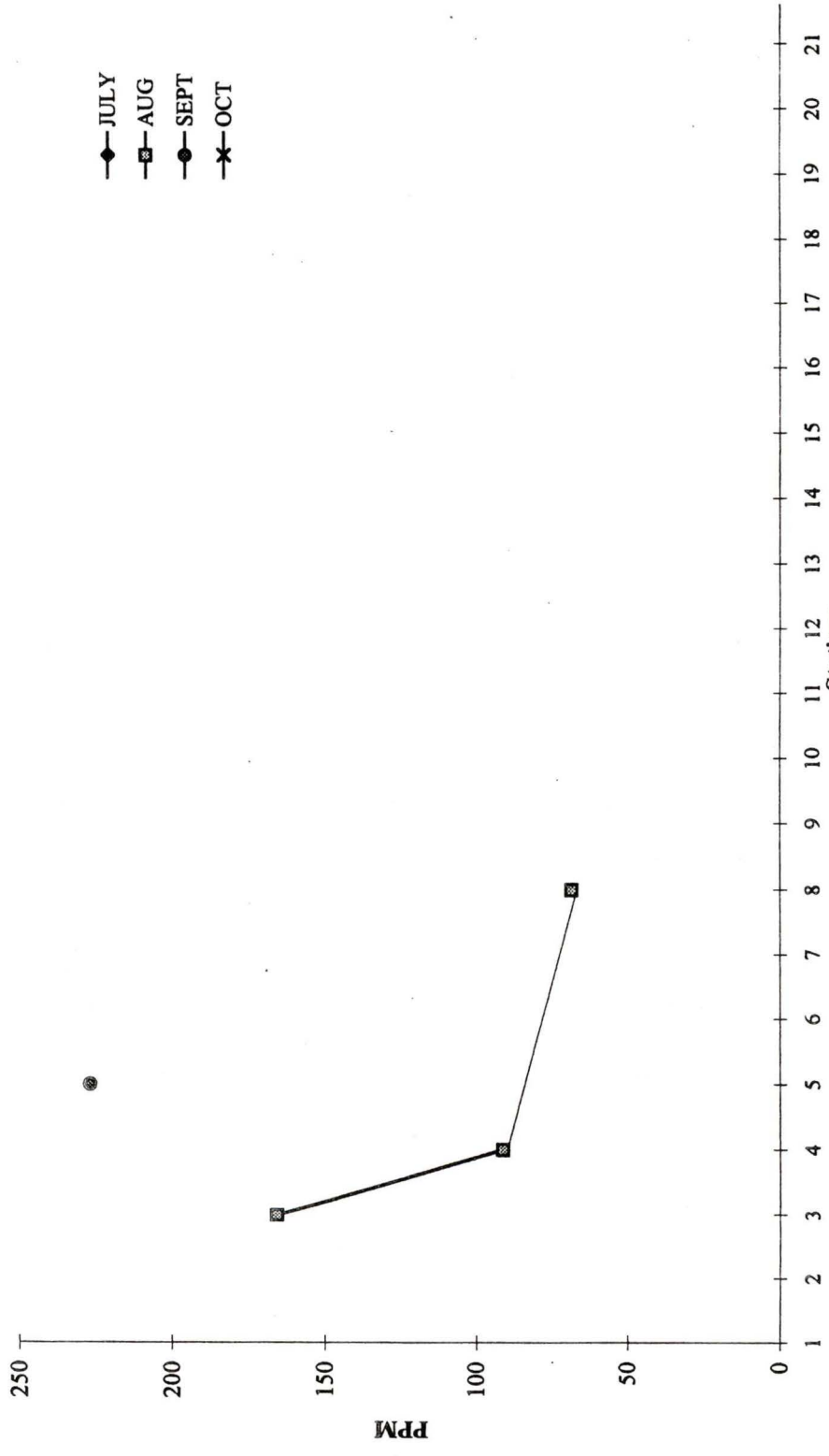


Figure A1- 1f: Copper in Plants (cotton grass leaves) Transect 5
PESC Analyses

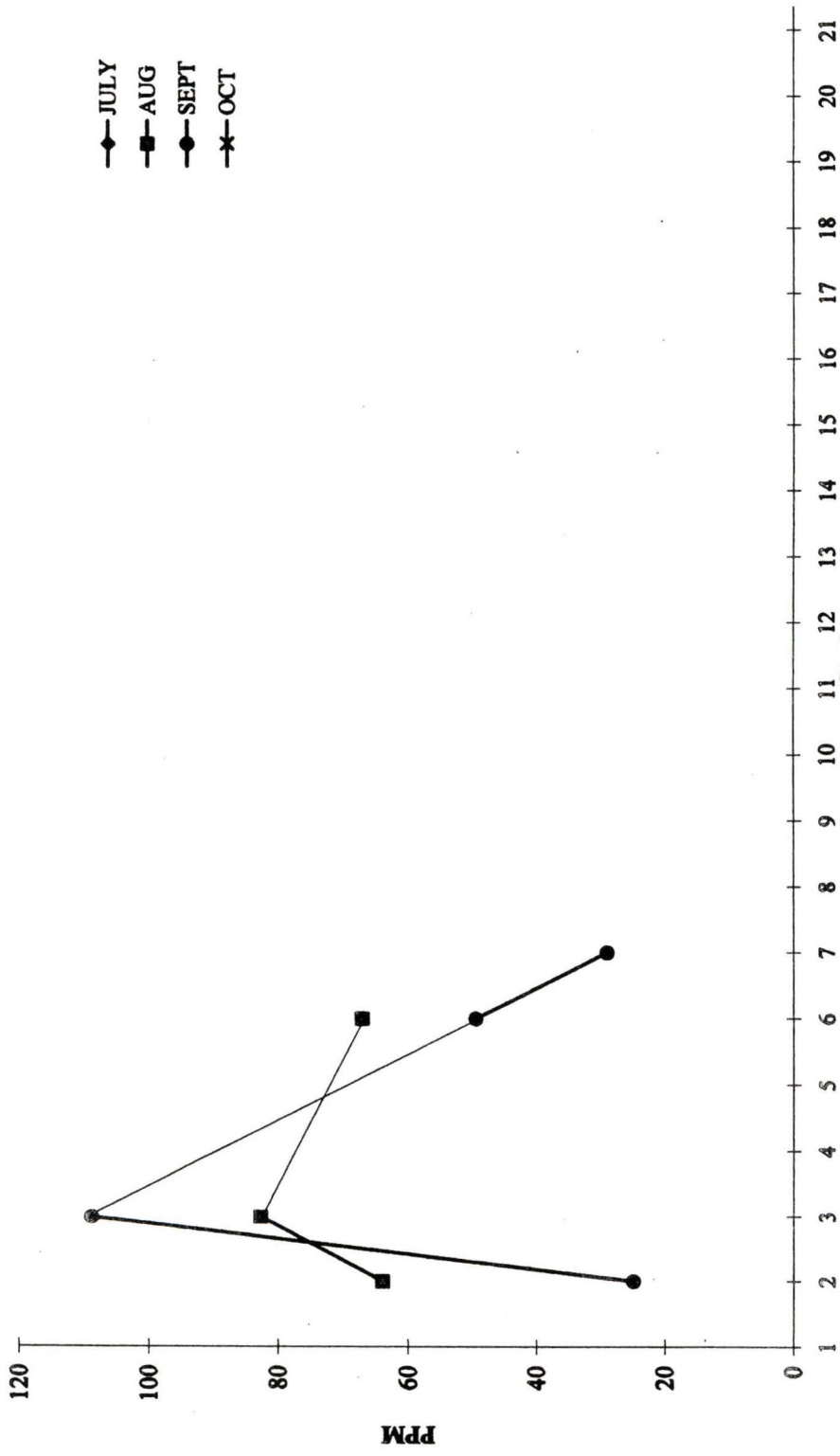


Figure A1- 1g: Copper in Plants (cotton grass leaves) Transect 6
PESC Analyses

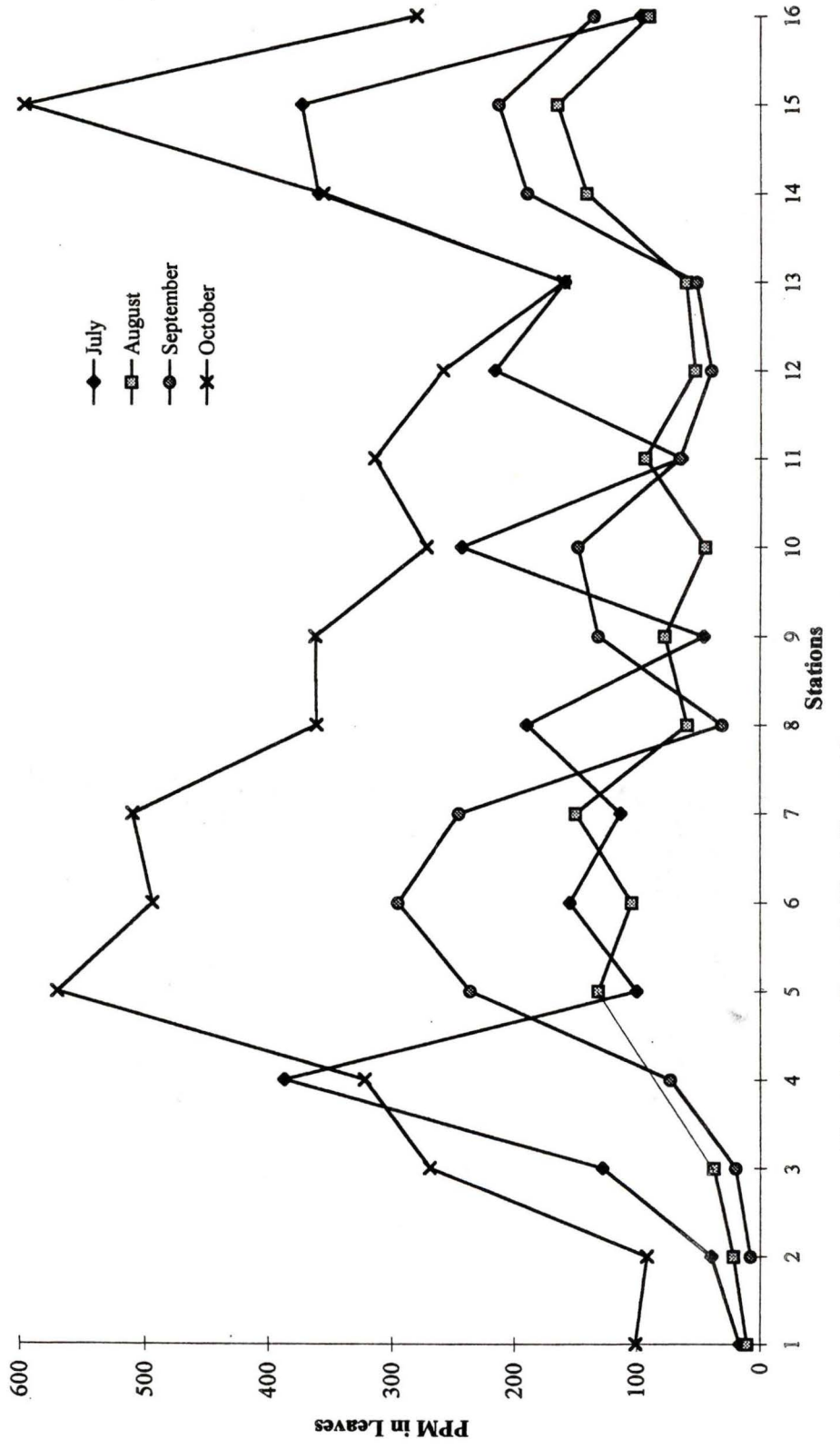


Figure A1-1h Copper in Plants Transect 3

Figure A1- 1h: Copper in Plants (cotton grass leaves) Transect 3 Zenon Analyses

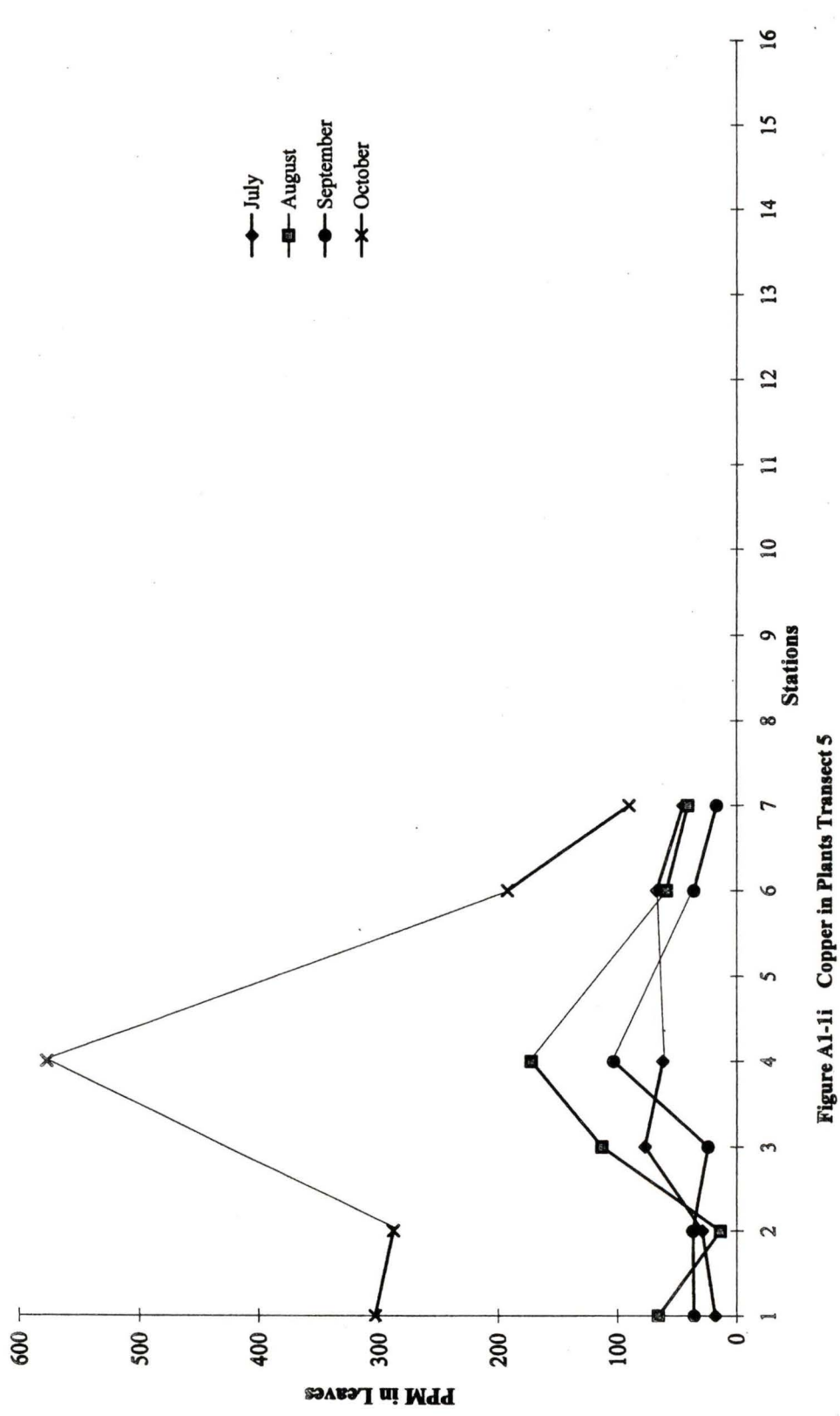


Figure A1- 1i: Copper in Plants (cotton grass leaves) Transect 5
Zenon Analyses

PESC Analyses

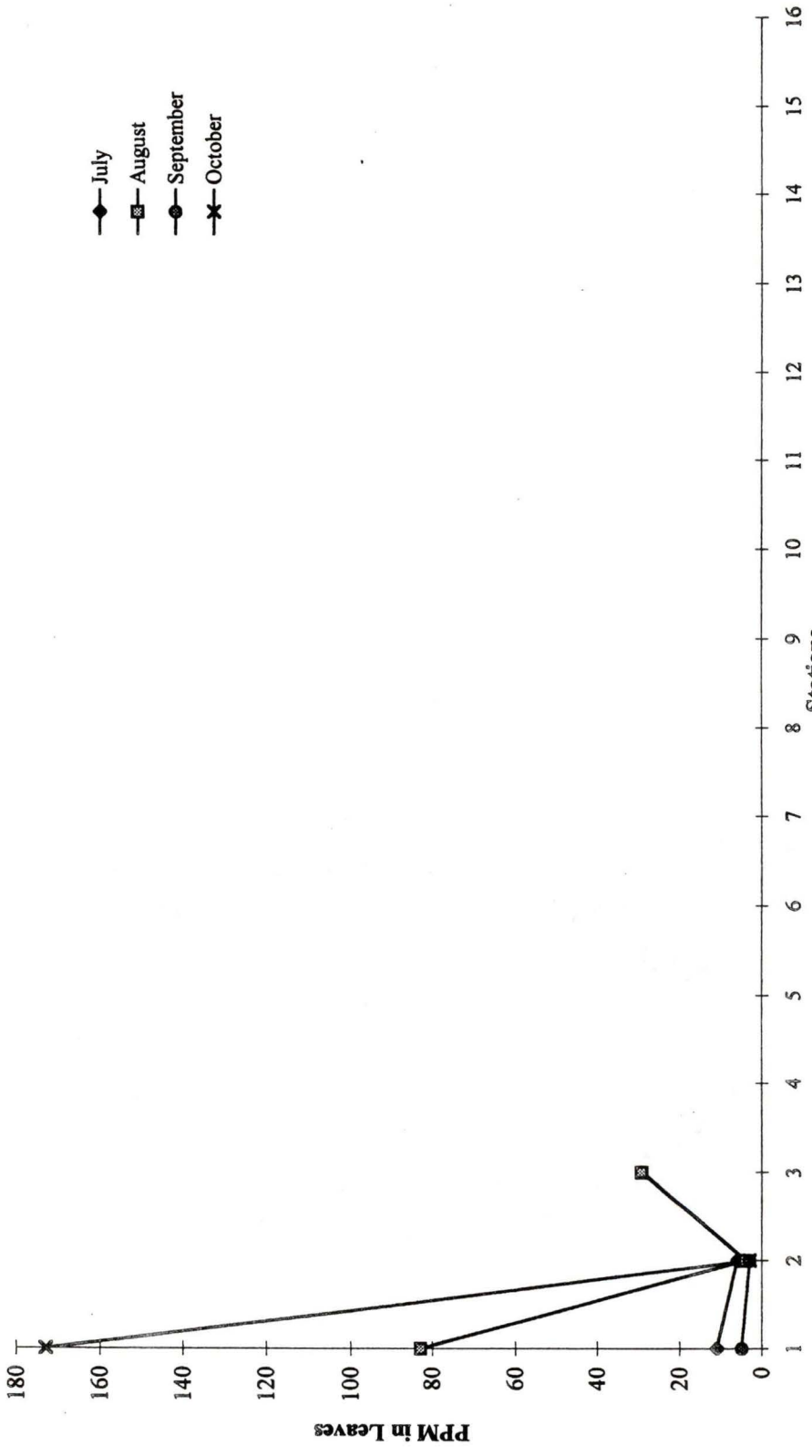


Figure A1-1j Copper in Plants Background

Figure A1- 1j: Copper in Plants (cotton grass leaves) Background PESC Analyses

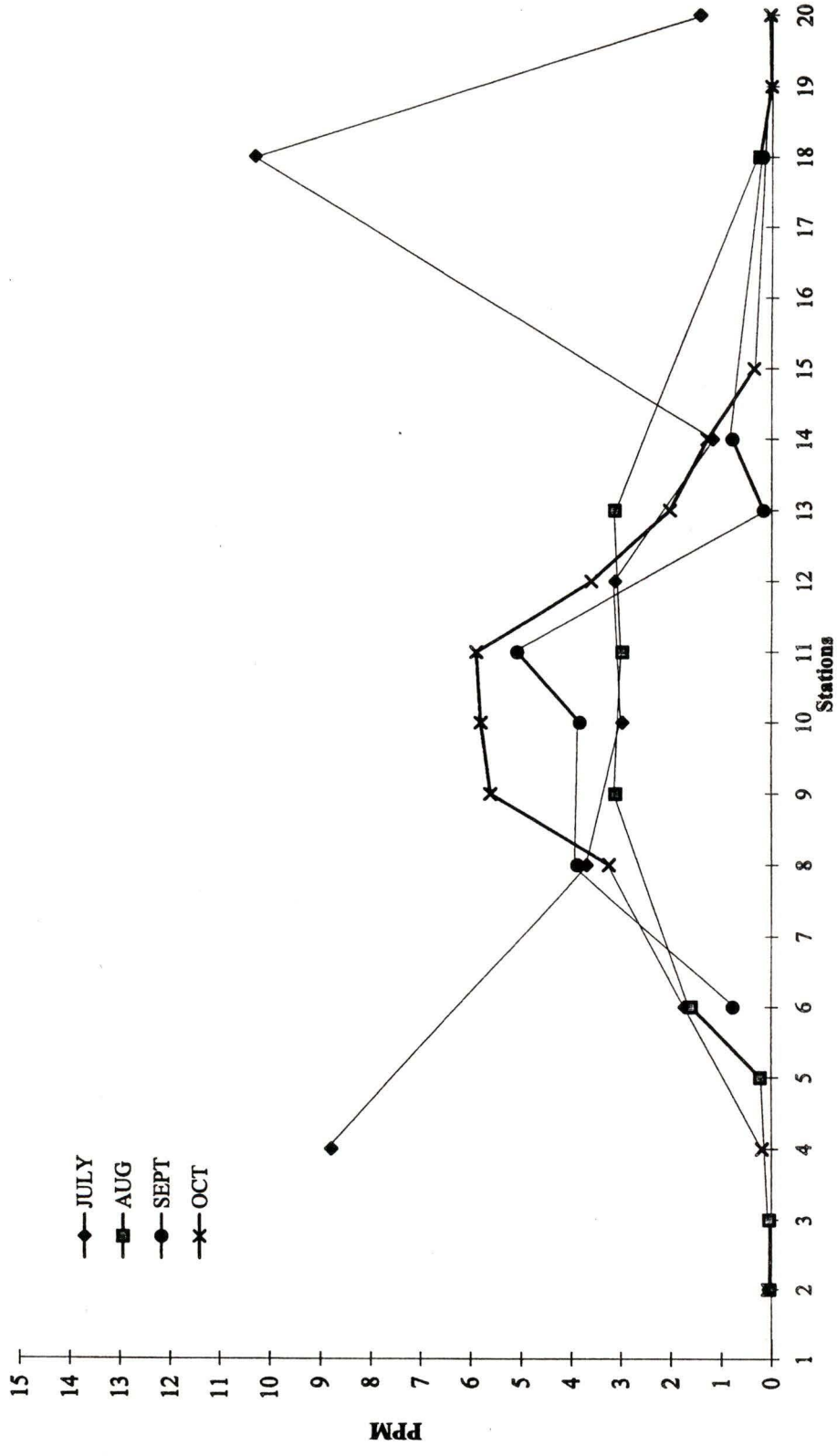


Figure A1- 2a: Copper in Fen Waters 1995 Transect 0
PESC Analyses

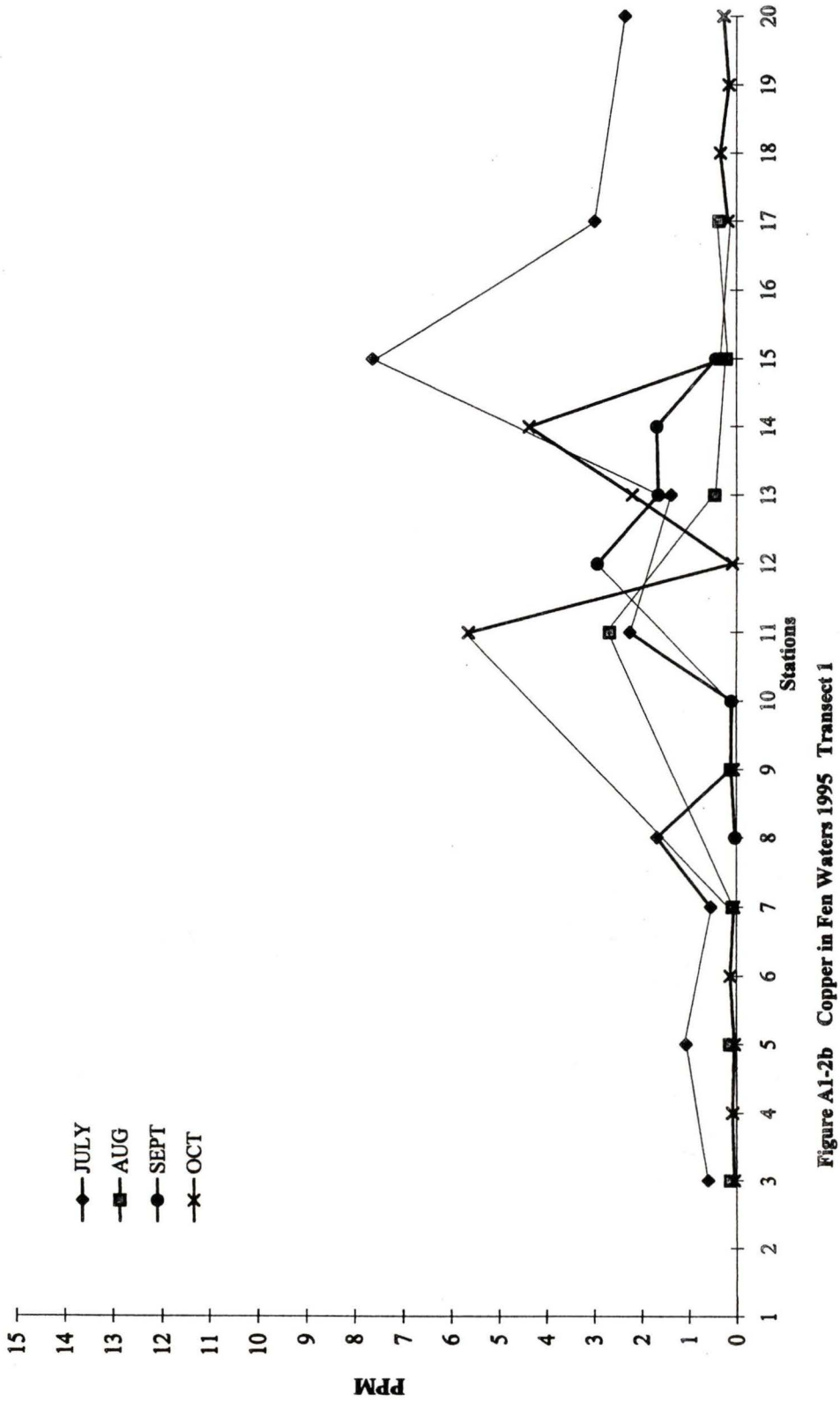


Figure A1- 2b: Copper in Fen Waters 1995 Transect 1
PESC Analyses

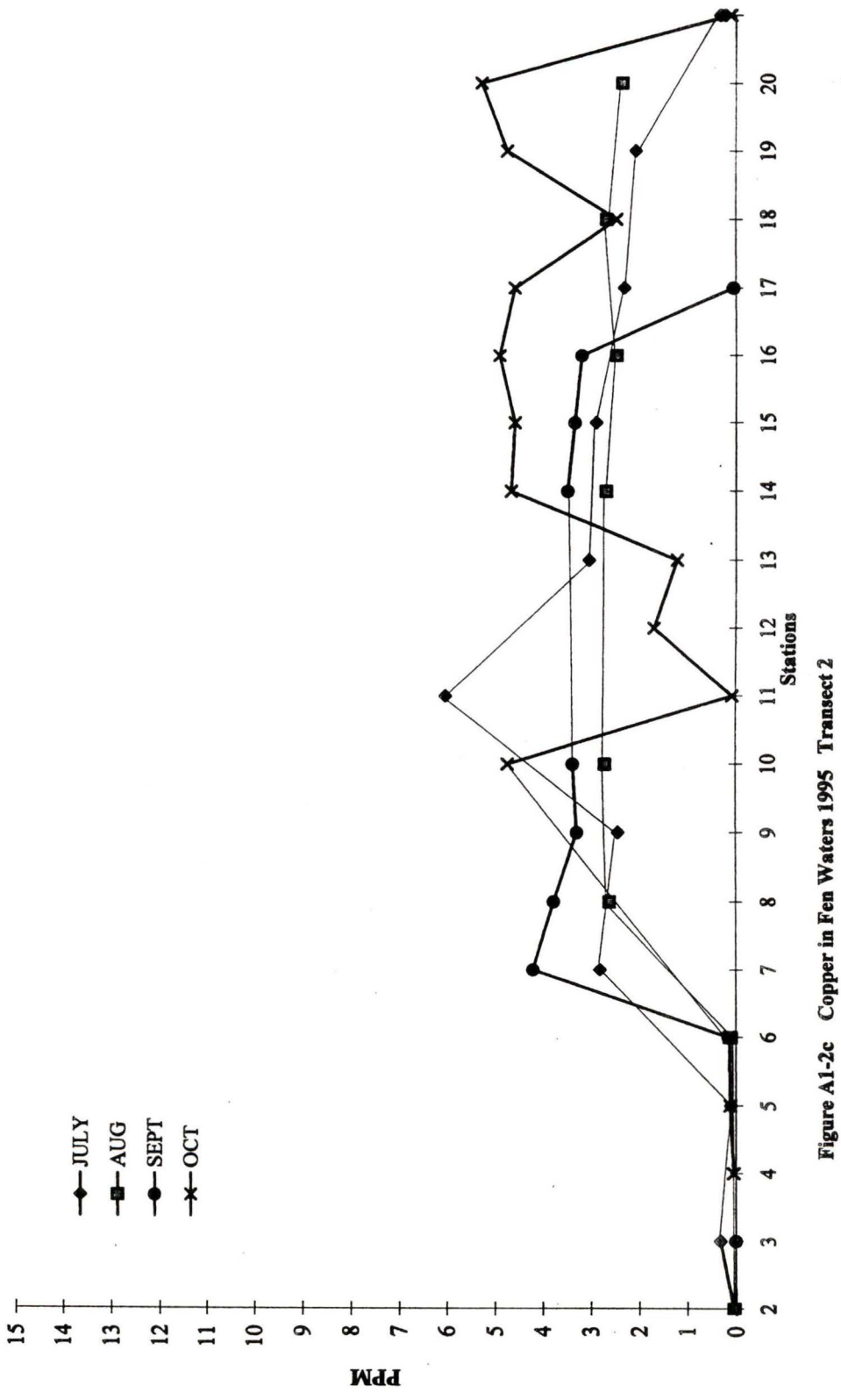


Figure A1- 2c: Copper in Fen Waters 1995 Transect 2
PESC Analyses

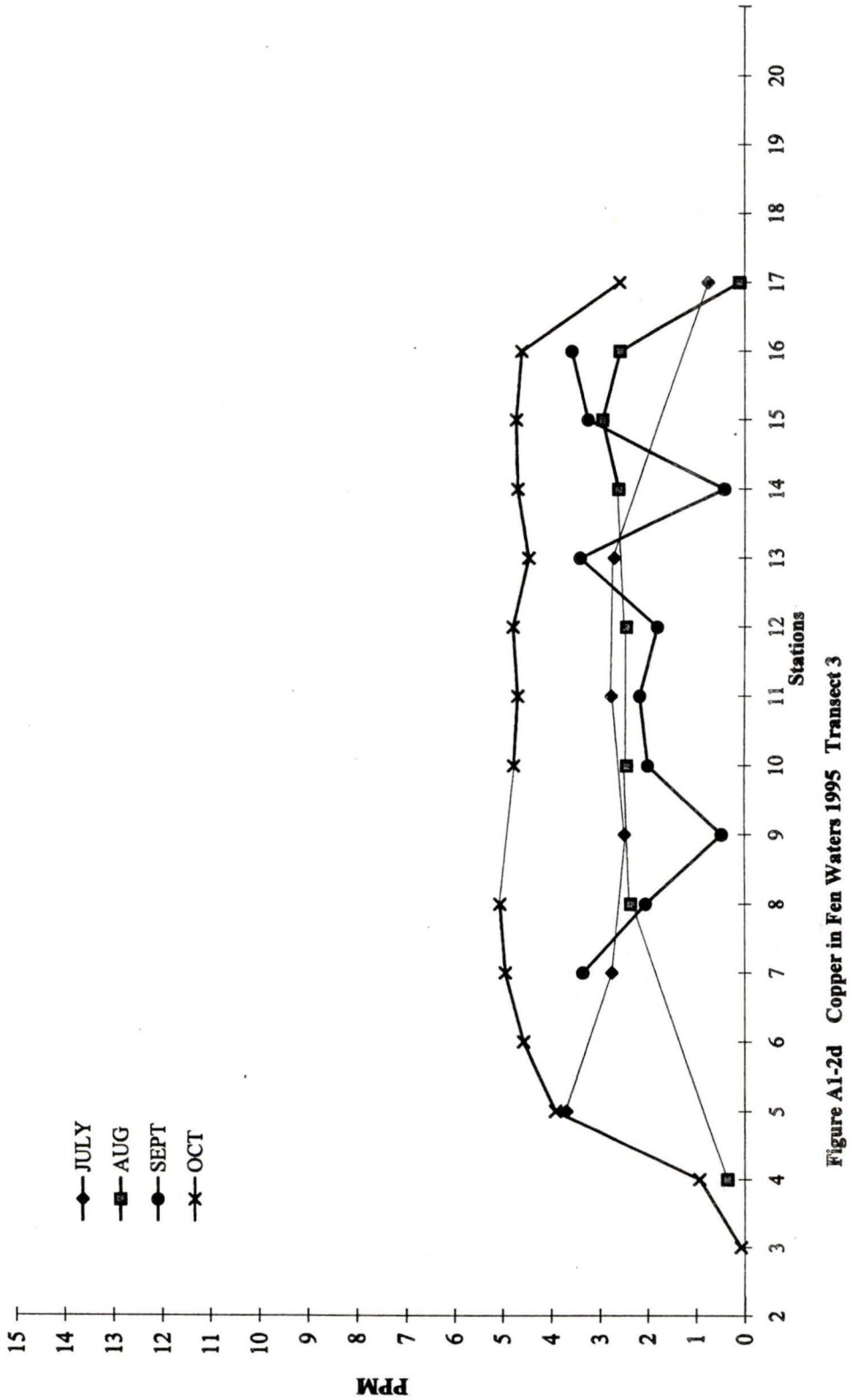


Figure A1- 2d: Copper in Fen Waters 1995 Transect 3
PESC Analyses

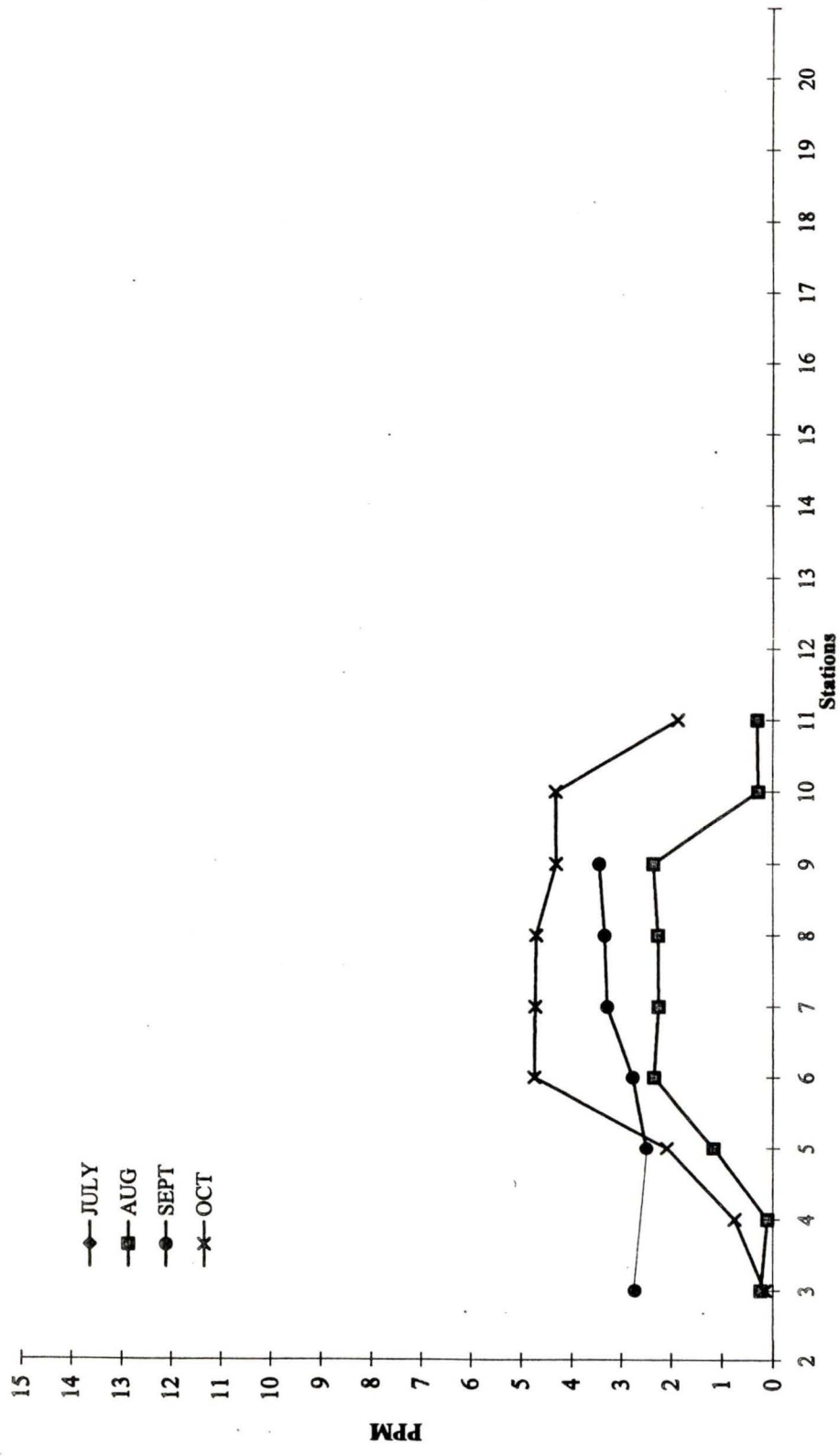


Figure A1-2e Copper in Fen Waters 1995 Transect 4

Figure A1- 2e: Copper in Fen Waters 1995 Transect 4
PESC Analyses

Figure A1- 2f: Copper in Fen Waters 1995 Transect 5
PESC Analyses

Figure A1-2f Copper in Fen Waters 1995 Transect 5

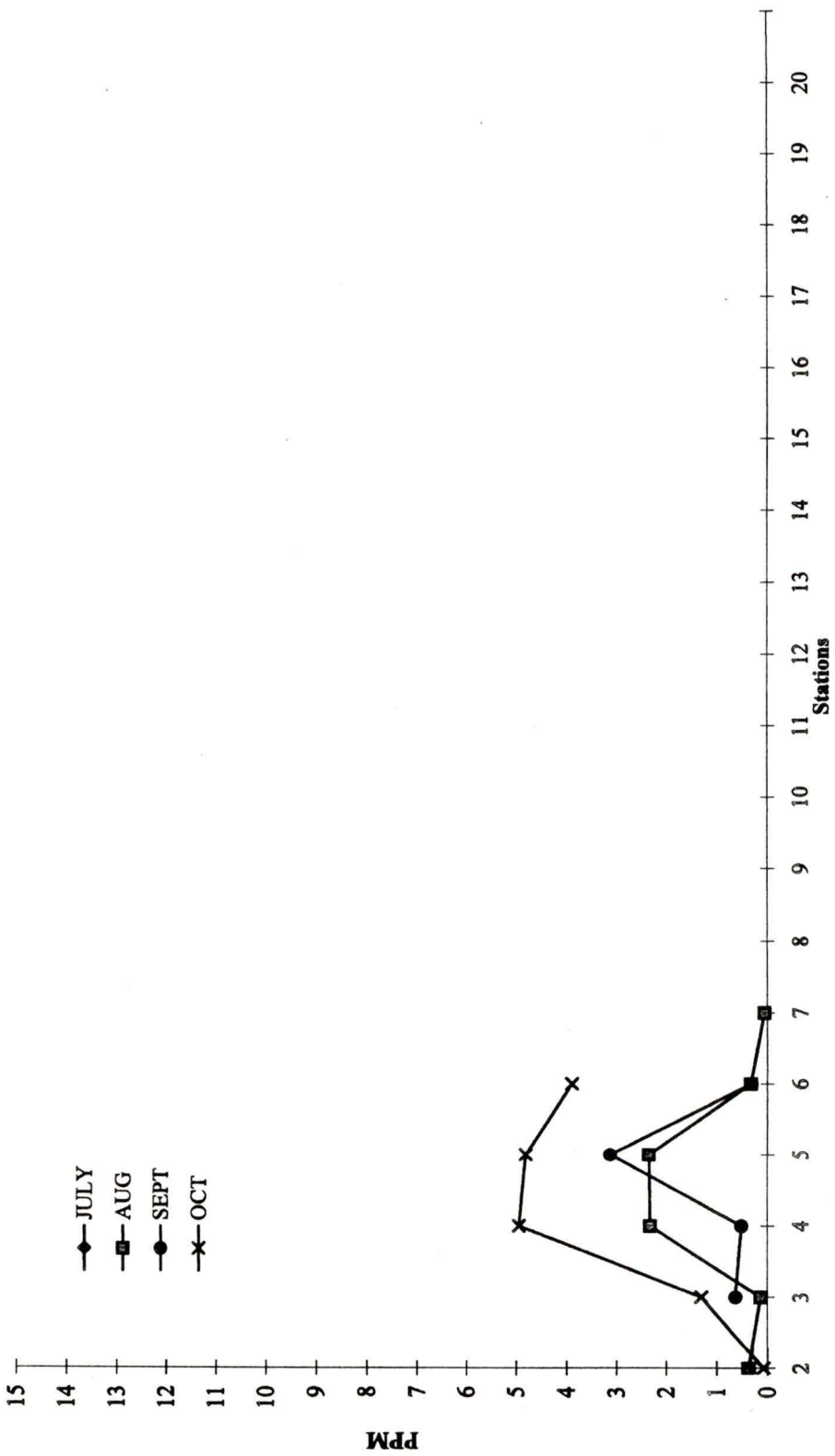


Figure A1- 2g: Copper in Fen Waters 1995 Transect 6
PESC Analyses

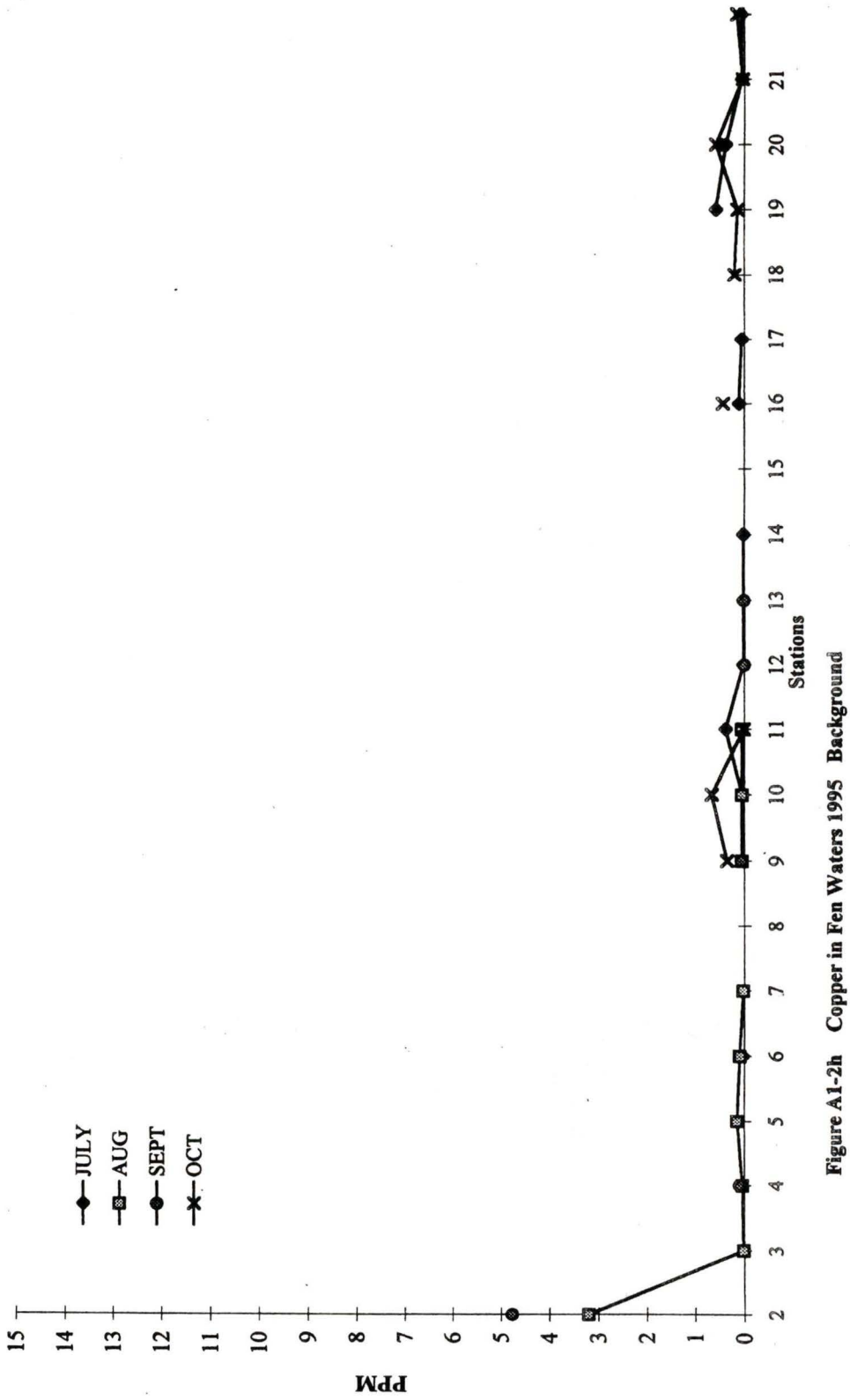


Figure A1- 2h: Copper in Fen Waters 1995 Background Fens
PESC Analyses

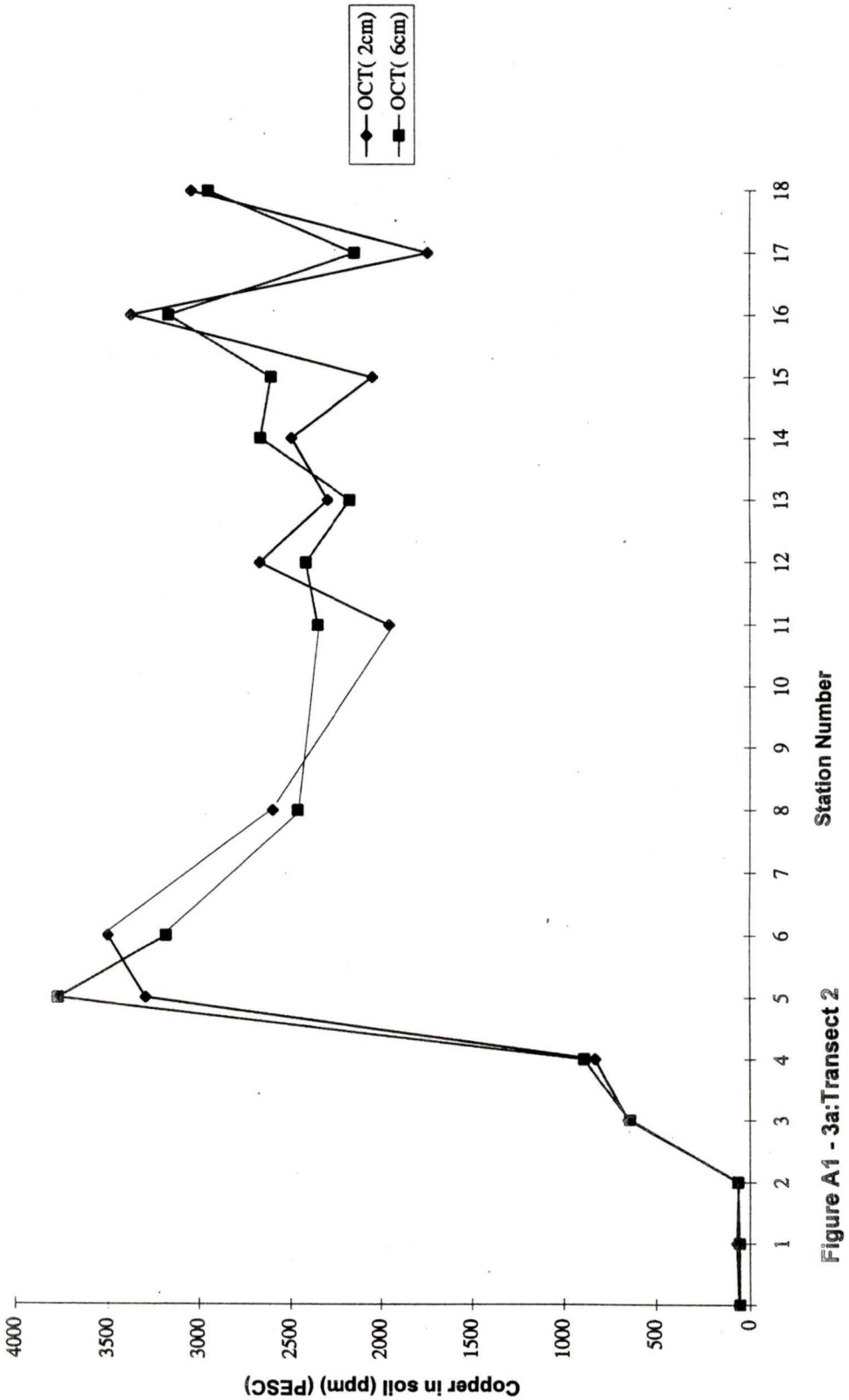


Figure A1- 3a: Copper in Fen Soils October 1995 Transect 2
PESC Analyses 2 cm vs 6 cm depths

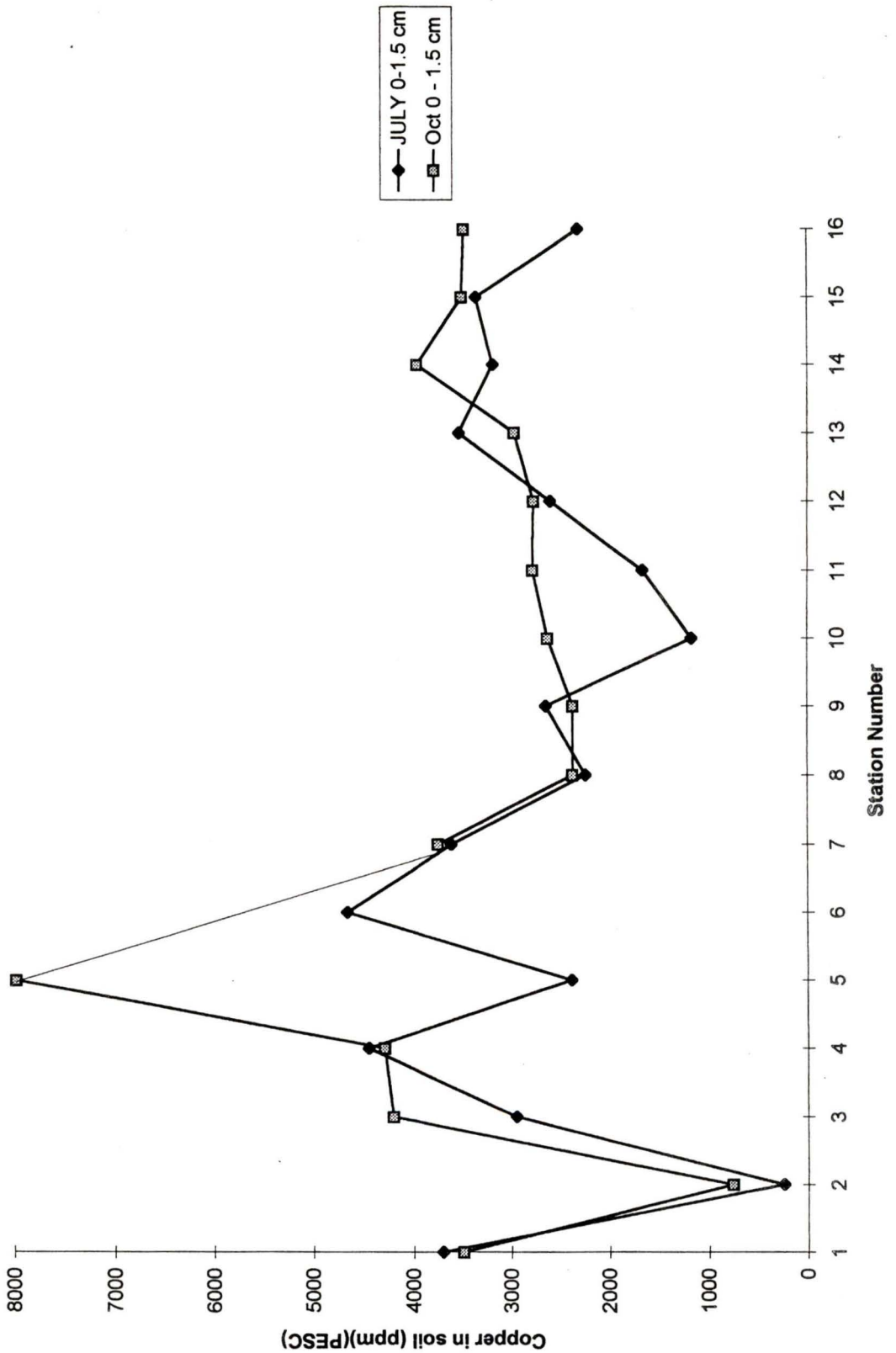


Figure A1- 3b: Copper in Fen Soils July vs. October 1995 Transect 2 PESC Analyses 0-1.5 cm depth

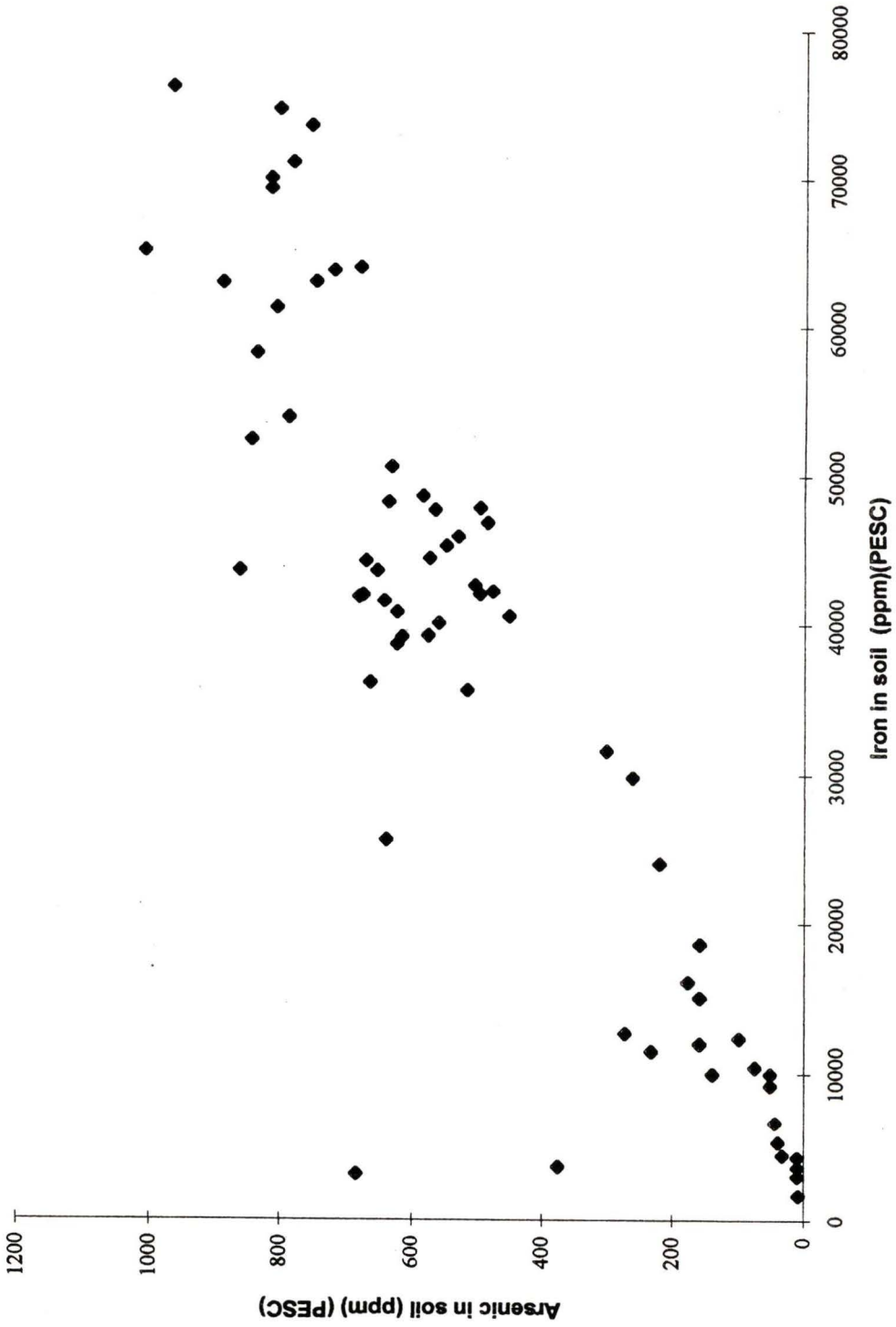


Figure A1- 4a: Scatter Diagram of Iron Concentrations in Soil Compared to Arsenic Concentrations in Soil PESC Analyses, all 1995 data considered.

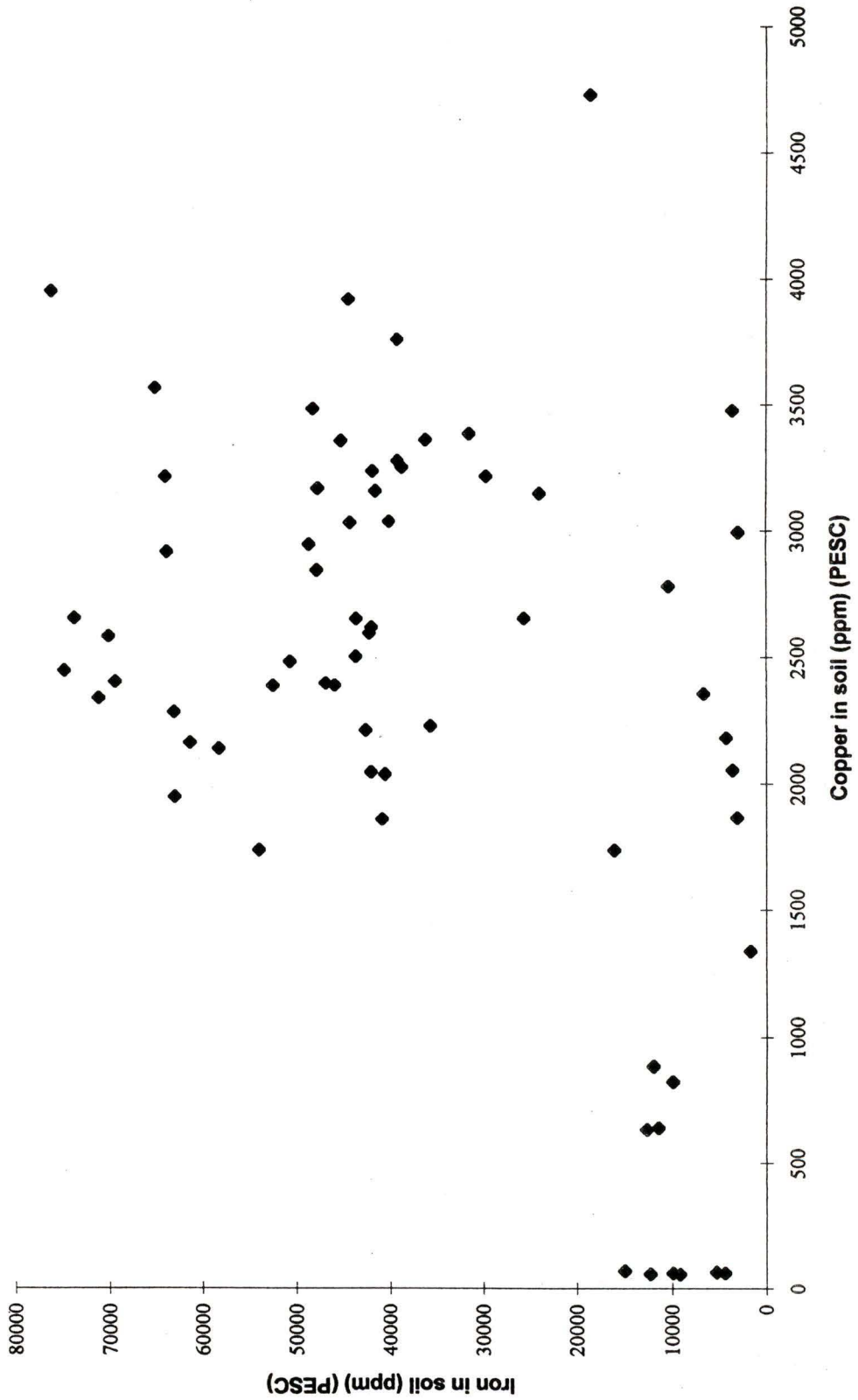


Figure A1- 4b: Scatter Diagram of Iron Concentrations in Soil Compared to Copper Concentrations in Soil PESC Analyses, all 1995 data considered.

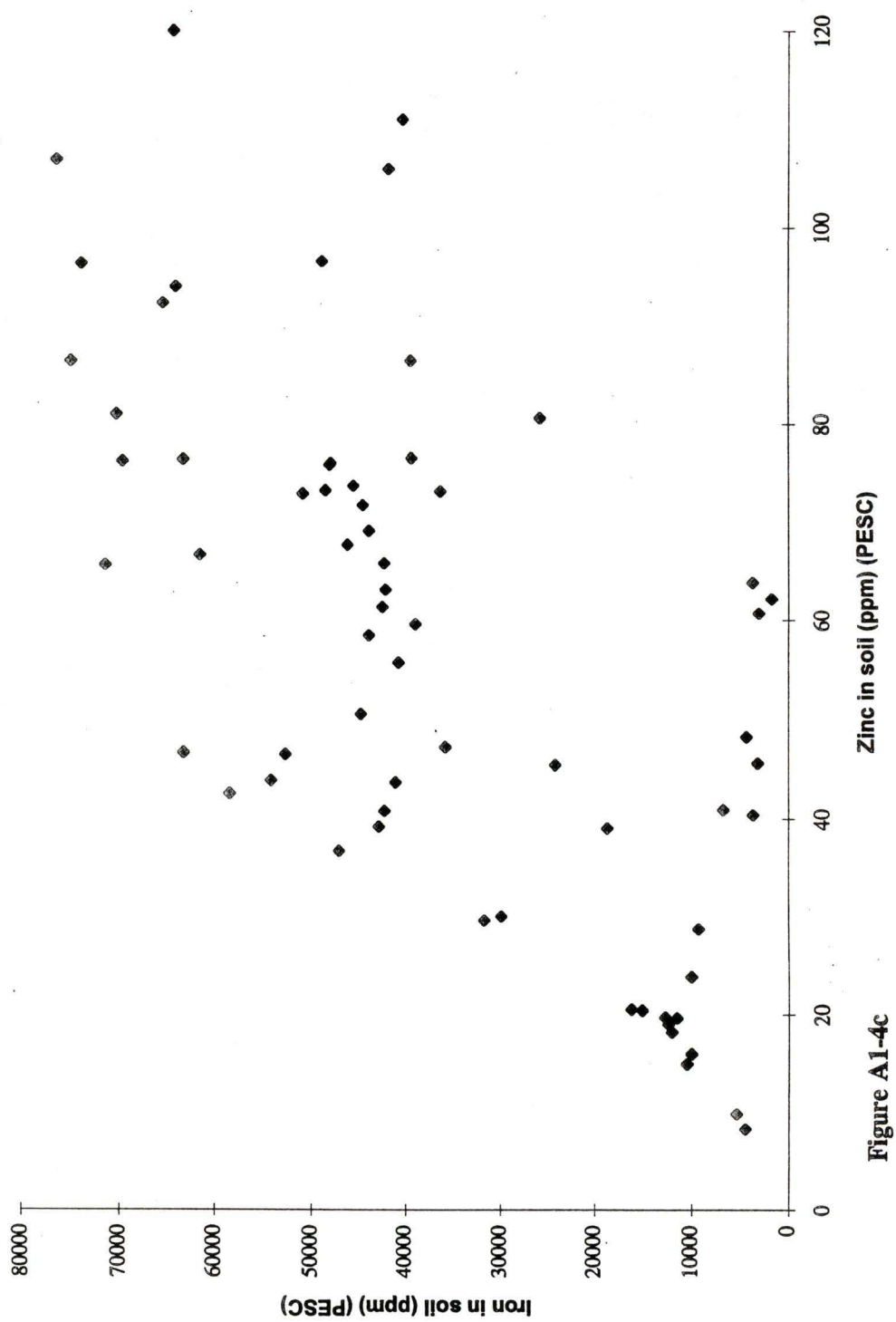


Figure A1-4c

Figure A1- 4c: Scatter Diagram of Iron Concentrations in Soil Compared to Zinc Concentrations in Soil PESC Analyses, all 1995 data considered.

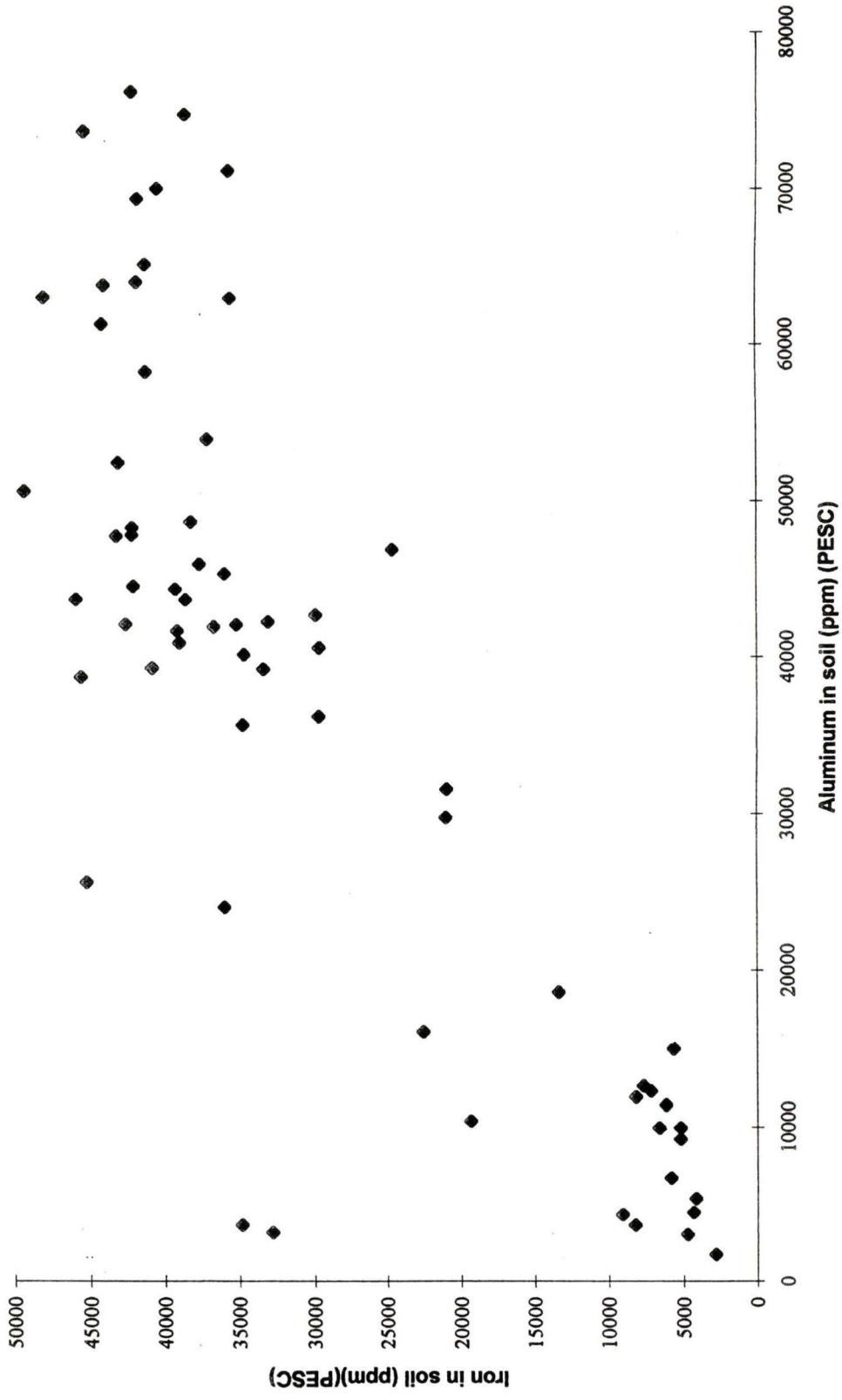


Figure A1- 4d: Scatter Diagram of Iron Concentrations in Soil Compared to Aluminum Concentrations in Soil PESC Analyses, all 1995 data considered.

Appendix 2: Tables of Analytical Results

Part 1: Table of Water Results for 1995.

Part 2: Table of Vegetation Results for 1995-96

Part 3: Table of Soil Results for 1995.

SAMPLE#	DATE	STATION#	TRANSECT #	BGRD ID	Al	As	Cu	Fe	P	S	Zn	pH	pH 2	Sur/Grnd
#123	950813	2	0		0.25		0.063	0.237		0.84	0.005		6.62	S
#87	950813	4	0		6.62	0.57	8.78	20.5	0.2	9.53	0.088		4.26	G
#84	950813	6	0		2.67		1.72	12.6		18.1	0.056		4.25	S
#96	950813	8	0		4.55	0.09	3.69	27.2	0.1	31.6	0.042	4.96	3.7	G
#115	950813	10	0		3.44		2.97	1.13		33.9	0.116	3.94	4.1	S
#103	950813	12	0		5.38	0.05	3.12	6.34		27.9	0.108		3.98	G
#175	950813	14	0		3.47	0.08	1.18	9.84		18.7	0.051	5.2	4.07	S/G
#145	950813	18	0		13	0.9	10.3	159		12.9	0.13	5.92	4.36	G
#107	950813	20	0		1.7	0.09	1.44	6.85		1.51	0.016	5.2	4.39	G
#94	950820	2	0		0.14		0.039	0.118		0.8	0.003	5.46	6.79	S
#82	950820	3	0		0.16		0.043	0.198		1.02	0.005	5.32	6.41	G
#77	950820	5	0		0.32		0.226	1.68		3.1	0.012	5.35	5.49	S
#151	950820	6	0		1.44		1.63	4.74		19.3	0.053	4.96	4.3	S
#182	950820	6	0		1.57		1.54	4.62		21.4	0.068		4.12	S
#142	950820	9	0		3.47		3.11	1.2		32.5	0.117	4.21	3.94	S
#149	950820	11	0		3.56		2.97	1.01		33.8	0.121	4	4.04	S
#33	950820	13	0		5.79		3.12	1.4		48.7	0.161	5.5		S
#130	950820	18	0		0.32		0.253	2.53		3.66	0.013	5.52	6.18	S
#279	950923	6	0		0.66		0.773	6.25		23.1	0.054	4.8	3.86	
#307	950923	8	0		5.05		3.88	1.24		54.6	0.161	3.59	3.7	S
#282	950923	10	0		5.53		3.83	3.05		59	0.174	3.73	3.71	S
#308	950923	11	0		7.37		5.08	1.21		72.2	0.224	3.79	3.88	S
#310	950923	13	0		0.28		0.164	7.34		10.5	0.064	5.58	4.55	S
#270	950923	14	0		0.45		0.789	10.4		22.3	0.054	4.97	3.76	S
#309	950923	18	0		0.22		0.185	3.04		4.28	0.043	5.57	6.36	S
#191	951028	4	0		0.26		0.189	0.556		3.78	0.019		5.05	S
#215	951028	8	0		5.58		3.24	4.63		50.5	0.153		4.01	
#159	951028	9	0		6.34		5.61	2.18		46.3	0.219		3.82	S
#165	951028	10	0		6.44		5.8	2.86		47.6	0.204		3.75	S
#163	951028	11	0		6.44		5.89	3.02		47.8	0.203		3.71	S
#193	951028	12	0		3.3		3.6	0.442		29.6	0.135		4.27	S
#198	951028	13	0		2.74		2.02	0.631		28.7	0.114		3.95	S
#206	951028	14	0		1.17		1.28	0.023		20.9	0.074		3.85	S
#192	951028	15	0		0.69		0.354	8.07		1.61	0.02		5.15	G
#213	951028	18	0		0.16		0.243	1.33		4.81	0.022		4	S
#190	951028	19	0		0.05		0.019	0.464		0.23	0.005		6.64	G
#209	951028	20	0		0.14		0.04	0.666		0.29	0.008	5.3	5.78	G
#207	951029	2	0		0.27		0.078	0.149		0.73	0.007		6.47	S
#86	950813	3	1		4.1	0.4	0.595	20.2		1.1	0.01		5.15	G
#140	950813	5	1		2.46	0.11	1.06	2.24		1.21	0.023		4.08	G
#97	950813	7	1		1.78	0.13	0.539	5.37		0.96	0.008		5.41	S/G
#129	950813	8	1		2.61	0.23	1.67	5.58	0.1	2.21	0.034		4.49	G/S
#126	950813	9	1		0.41		0.122	3.24		0.99	0.005		6.21	S
#177	950813	10	1		0.27		0.088	0.457		1.36	0.007		5.87	S
#117	950813	11	1		7.97	0.09	2.25	30.5	0.2	29.6	0.124		4	S
#90	950813	13	1		1.44		1.37	1.23		18.7	0.059		4.22	G
#119	950813	15	1		11.5	0.83	7.62	69.5		13.9	0.096		4.19	G/S
#85	950813	17	1		3.7	0.9	2.98	41.9		3.2	0.056		4.9	S
#109	950813	20	1		16.3	2.7	2.35	97.4		3.6	0.15	5.86	4.17	G
#134	950820	3	1		0.5		0.129	0.629		1.26	0.013	5.1	6.65	G
#73	950820	5	1		0.38		0.135	1.05		0.74	0.007	5.26	6.53	S
#106	950820	7	1		0.28		0.086	0.612	0.1	0.84	0.006	5.49	6.45	S
#108	950820	9	1		0.29		0.114	3.66		1.97	0.014	5.62	6.36	S
#146	950820	11	1		3.05		2.67	1.52		30.9	0.108	4.28	4.02	S
#147	950820	13	1		0.67		0.454	11.5		19.4	0.033	5.18	3.89	G/S
#195	950820	15	1		0.65	0.16	0.21	40.6	0.3	8.72	0.038	5.83	3.96	G/S
#118	950820	17	1		0.55	0.12	0.362	8.41		1.21	0.009	5.59	6.19	S
#272	950923	8	1		0.41		0.142	1.2		0.9	0.01	5.46	6.41	S/G
#306	950923	9	1		0.27		0.11	2.01		1.19	0.012	5.47	6.79	S
#277	950923	10	1		0.16		0.105	1.55		5.61	0.009	5.52	6.44	S

Fen and Background Waters PESC ICP-AES
Concentrations in ppm (mg/l)

SAMPLE#	DATE	STATION#	TRANSECT #	BGRD ID	Al	As	Cu	Fe	P	S	Zn	pH	pH 2	Sur/Grnd
#210	950924	8	1		0.19		0.036	0.097		0.62	0.004	5.46	5.34	S
#243	950924	12	1		1.66		2.93	0.051		35.5	0.063		4.23	S
#240	950924	13	1		0.56		0.85	0.044		20.4	0.035	4.1	4.28	G/S
#244	950924	13	1		2.32		2.42	0.11		40.7	0.126		4.04	G
#275	950924	14	1		2.28		1.67	1.72		29.6	0.091	3.93	4.07	S
#236	950924	15	1		0.17		0.426	4.62		4.22	0.049		4.67	G
#208	951028	7	1		0.27		0.058	0.269		0.92	0.008		6.1	S
#201	951028	9	1		0.26		0.062	2.17		0.67	0.008	6.02	6.31	S
#197	951028	11	1		6.19		5.64	2.66		45.1	0.193	3.71	3.66	S
#167	951028	12	1		0.2		0.091	1.7		4.02	0.014	5.78	6.67	S
#202	951028	13	1		2.68		2.19	1.93		29	0.093	4.1	3.97	S
#172	951028	14	1		5.06		4.36	1.74		39.5	0.159	3.79	3.73	S
#199	951028	15	1		0.85		0.259	40.9		3.07	0.015	5.8	6.73	S
#194	951028	17	1		0.49	0.07	0.18	16		3.59	0.017	5.29	5.29	S
#203	951028	18	1		0.19		0.336	2.47		4.51	0.011		4.95	S
#173	951028	19	1		0.44	0.14	0.159	16.5		7.2	0.01	4.27	3.71	G
#161	951028	20	1		0.25	0.06	0.266	4.84		7.56	0.023	5.3	3.56	G
#235	951029	3	1		0.11		0.05	0.125		0.67	0.004		5.78	G
#259	951029	4	1		0.2		0.086	0.181		0.79	0.005		5.21	S
#260	951029	5	1		0.13		0.044	0.046		0.65	0.007		6.06	S
#237	951029	6	1		0.55	0.1	0.13	4.37		0.54	0.007	5.46	5.34	S
#125	950813	1	2		6.25	2.3	0.05	33.4		2.7	0.01	5.22	5.94	G
#127	950813	2	2		39.1	2	0.32	266		3.6		5.53	5.31	G
#111	950813	4	2		0.81	0.27	0.108	12.3	0.7	1.62	0.008	5.99	6.33	G
#120	950813	6	2		8.48	0.11	2.81	14.1	0.2	28.2	0.124	4.6	4.18	S
#138	950813	8	2		2.89		2.44	1.23		27	0.095	4.51	4.18	S
#128	950813	10	2		12		6.03	204		40.5	0.3	4.07	3.77	S
#139	950813	12	2		13		3.04	712		47.4	0.2	4.14	3.63	S
#154	950813	14	2		6.91	0.12	2.89	16.8	0.2	27.5	0.115	4.37	4.1	S
#136	950813	16	2		3.35		2.3	3		28.1	0.106	4.62	4.1	S
#89	950813	18	2		3.26		2.06	2		28.6	0.107	4.65	4.02	S
#131	950813	20	2		1.4	0.05	0.314	2.31		0.81	0.024	4.74	4.53	G
#181	950820	1	2		0.59	0.14	0.038	0.372	0.3	1.03	0.019	5.6	7.3	G
#184	950820	5	2		0.22		0.102	0.435		0.66	0.009	5.38	7.04	S
#133	950820	7	2		3.07		2.61	0.99		29.9	0.107	4	4.07	S
#180	950820	9	2		3.33		2.71	1.97		30.7	0.108	4.04	4	S
#183	950820	13	2		3.14		2.68	2.39		30.1	0.109	3.98	3.87	S
#81	950820	15	2		2.79		2.46	1.52		28.4	0.105	4.14	4.08	S
#179	950820	17	2		3.39		2.67	3.53		29.6	0.107	4.03	4.03	S
#169	950820	19	2		2.92		2.34	2.19		27.6	0.097	4.07	4.02	S
#238	950924	2	2		0.14		0.009	0.097		2.88			5.89	S
#311	950924	5	2		0.17		0.153	0.167		8.07	0.019	5.43	6.68	S
#231	950924	6	2		5.99		4.84	0.152		41.5	0.176		3.78	S
#278	950924	6	2		4.9		3.55	0.593		53.5	0.163	3.8	3.99	S
#241	950924	7	2		5.29		4.62	0.069		43.4	0.17		3.8	S
#276	950924	7	2		4.26		2.91	1.75		46.9	0.141	4.07	4.08	S
#281	950924	8	2		4.87		3.29	2.1		51.2	0.152		3.95	S
#280	950924	9	2		4.84		3.38	3.36		52.3	0.156	4.12	3.92	S
#253	950924	13	2		5.14		3.48	0.163		52.4	0.166		3.95	S
#242	950924	14	2		4.55		3.33	0.148		56.6	0.166		3.94	S
#230	950924	15	2		5.38		3.19	0.171		54.1	0.17		3.89	S
#258	950924	16	2		0.08		0.054	393	0.3	212	0.011		5.66	
#301	951029	3	2		0.4	0.09	0.047	8.31	0.6	0.53	0.003		5.4	G
#304	951029	4	2		0.62	0.67	0.121	42.7	1.8	1.21	0.009		5.67	G/S
#289	951029	5	2		0.31		0.134	1.3		3.93			6.56	S
#286	951029	9	2		5.36		4.74	0.108		45.8	0.168		3.77	S
#233	951029	10	2		0.16		0.076	111	0.1	23.8	0.016		5.41	S
#252	951029	11	2		1.93		1.69	0.159		44.7	0.223		3.85	S
#287	951029	12	2		1.22		1.21	0.211		45.8	0.219		3.9	G
#264	951029	13	2		5.76		4.66	0.173		43.1	0.181		3.81	S

Table A2-1: Fen and Background Water PESC ICP-AES Analyses

SAMPLE#	DATE	STATION#	TRANSECT #	BGRD ID	Al	As	Cu	Fe	P	S	Zn	pH	pH 2	Sur/Grnd
#265	951029	14	2		5.41		4.58	0.089		41.5	0.172		3.83	S
#229	951029	15	2		5.76		4.9	0.13		42.9	0.182		3.78	S
#228	951029	16	2		6.38		4.58	0.203		47.9	0.186		3.82	S
#189	951029	17	2		6.02		4.82	0.139		42.4	0.192		3.86	S
#255	951029	17	2		1.02		0.096	6.63		53.6	0.066		3.26	S
#248	951029	18	2		5.87		4.74	0.118		45.4	0.186		3.78	S
#232	951029	19	2		6.61		5.27	0.119		48.9	0.21		3.85	S
#234	951029	20	2		0.07		0.106	0.091		2.39	0.025		4.69	G
#38	950813	4	3		16.3	4.4	3.69	363	1	29.8	0.21	4.96	4.38	S
#44	950813	6	3		3.8		2.75	5.11		25.1	0.109	5.13	4.15	S
#43	950813	8	3		64.4	4.6	2.48	533	1	9.3	0.04	5.1	4.64	G
#17	950813	10	3		20.7	0.36	2.76	84.3	0.5	29	0.162	4.52		S
#42	950813	12	3		22	0.41	2.7	107	0.6	27.9	0.159	4.2	3.71	S
#31	950813	16	3		4.43	0.18	0.752	16	0.3	5.01	0.067	4.45		G
#26	950819	7	3		3.15		2.35	2.71		23.8	0.094	4.11		S
#27	950819	9	3		4.83	0.07	2.43	11.6		25.1	0.102	4.32		S
#53	950819	11	3		4.13		2.44	4.13		23.8	0.099	4.16	4.05	S
#55	950819	13	3		5.07	0.05	2.6	8.82		23.2	0.115	4.06	4.09	S
#29	950819	14	3		10	0.1	2.94	12.8	0.2	28.1	0.132	4.19		S
#41	950819	15	3		4.87	0.07	2.57	8.4	0.1	23.4	0.113	4.21	4.04	S
#54	950819	16	3		2.16		0.102	0.614	0.4	1.99	0.029	4.98	6.85	S/G
#32	950820	3	3		1.45		0.352	3.31	0.2	9.07	0.039	4.94		S
#132	950924	6	3		5.24		3.34	3.77		51	0.157		3.85	S
#188	950924	6	3		5.3		3.36	3.84		51.1	0.158		3.85	S
#218	950924	7	3		3.4		2.04	4.8		46.7	0.109		3.66	S
#224	950924	8	3		5.62	7.09	0.469	111	0.3	1.29	0.014		4.77	G
#143	950924	9	3		4.96		2	1.73		49	0.131		3.81	S
#217	950924	9	3		4.97		1.99	1.78		49.1	0.131		3.81	S
#178	950924	10	3		4.81		2.12	1.03		48	0.131		3.91	S
#313	950924	10	3		4.63		2.19	0.997		49.8	0.13			S
#150	950924	11	3		4.54		1.77	2.03		48.5	0.127		3.83	S
#256	950924	11	3		4.59		1.8	2.08		49	0.131		3.83	S
#212	950924	12	3		5.59		3.41	12.4		47.8	0.186		3.9	S/G
#211	950924	13	3		5.9	0.76	0.419	60.2	0.3	16.7	0.008		4.49	G
#219	950924	14	3		5.24		3.21	1.65	0.2	50.9	0.156		3.99	S
#254	950924	14	3		5.32		3.27	1.62		51.3	0.16		3.99	S
#171	950924	15	3		5.21		3.52	11.4		45.4	0.15			
#226	950924	15	3		5.31		3.63	12.1		46.5	0.156		3.94	S
#65	951029	2	3		0.18	0.05	0.079	5.43	0.5	0.67	0.007		4.88	G
#35	951029	3	3		3.7	0.8	0.34	467		3.5	0.05		6.7	G
#261	951029	3	3		1.24		1.51	0.082		27.2	0.037		4.06	G
#70	951029	4	3		6.39		4.66	7.44		34.5	0.174		3.85	S
#250	951029	4	3		1.67		3.15	0.114		44.7	0.157		4.13	S
#64	951029	5	3		6.01		4.56	8.02		35.7	0.171		3.88	S
#56	951029	6	3		7.31	0.05	4.94	11.6		39.4	0.19		3.83	S
#24	951029	7	3		7.38	0.05	5.05	9.74		40.2	0.187			S
#4	951029	9	3		5.91		4.76	4.4		40.6	0.177			S
#69	951029	10	3		5.99		4.68	3.95		37.4	0.18		3.84	S
#50	951029	11	3		6.61	0.05	4.78	9.14		38.6	0.183		3.82	S
#11	951029	12	3		5.61		4.46			38.9	0.172			S
#67	951029	13	3		6.01		4.68	3.58		37	0.179		3.86	S
#52	951029	14	3		6.3		4.71	4.19		38.3	0.176		3.8	S
#10	951029	15	3		7.72	0.1	4.68	10.9	0.1	39	0.177			S
#14	951029	15	3		5.51		4.52	0.043		40.5	0.182			S
#62	951029	16	3		3.54		2.58	1.23		18.6	0.097		4.02	S
#76	950819	2	4		0.61		0.239	2.52	0.3	1.17	0.026	5.29	6.43	S
#80	950819	3	4		0.25		0.105	0.629		1.36	0.014	4.54	6.39	S
#83	950819	4	4		1.07		1.16	1.32	0.3	14.5	0.067	4.33	4.42	S
#100	950819	5	4		2.46		2.33	0.473		23.7	0.0108	4.08	4.3	S
#78	950819	6	4		2.39		2.24	0.718		23.4	0.095	4.19	4.24	S

Fen and Background Waters PESC ICP-AES
Concentrations in ppm (mg/l)

SAMPLE#	DATE	STATION#	TRANSECT #	BGRD ID	Al	As	Cu	Fe	P	S	Zn	pH	pH 2	Sur/Grnd
#74	950819	7	4		2.41		2.25	0.634		23.3	0.097	4.09	4.18	S
#99	950819	8	4		2.38		2.34	0.461		24.3	0.095	4.08	4.23	S
#110	950819	9	4		0.46		0.285	1.03		5.98	0.027	5.22	4.63	S
#160	950820	10	4		2.1	0.29	0.305	1.03	0.2	2.29	0.03	5.43	5.36	G
#245	950924	2	4		3.87		2.73	0.031		48.7	0.143		3.84	S
#225	950924	4	4		3.6		2.49	1.72		45.1	0.131		3.96	S
#166	950924	5	4		4.98		2.74	0.579		49.8	0.144		3.6	S
#205	950924	5	4		5		2.77	0.593		50.2	0.146		3.6	S
#79	950924	6	4		5.7		3.25	2.41		50.3	0.156			S
#141	950924	6	4		5.88		3.28	2.5		51.8	0.16		3.85	S
#105	950924	7	4		5.47		3.34	1.56		50.9	0.163			S
#186	950924	7	4		5.69		3.29	1.65		52	0.165		4.01	S
#152	950924	8	4		11.2	0.12	3.43	16.9	0.2	51.2	0.173		3.97	S
#196	950924	8	4		11.3	0.1	3.42	17	0.2	50.6	0.172		3.97	S
#312	951029	2	4		0.23		0.16	0.35		0.8	0.005		5.99	S
#257	951029	3	4		0.71		0.741	1.6		9.45	0.045		4.85	S
#298	951029	3	4		0.69		0.76	1.65		9.89	0.04		4.85	S
#296	951029	4	4		2.25		2.08	0.605		20.8	0.086		4.28	S
#297	951029	5	4		5.48		4.72	1.96		41.5	0.165		3.82	S
#284	951029	6	4		5.43		4.65	1.83		41.1	0.163		3.84	S
#300	951029	6	4		5.52		4.74	2.1		41.3	0.168		3.84	S
#249	951029	7	4		5.55		4.68	1.85		40	0.169			S
#292	951029	7	4		5.47		4.67	2.07		41.2	0.164		3.81	S
#285	951029	8	4		5.03		4.31	1.96		38.3	0.159		3.85	S
#293	951029	8	4		5		4.26	2.15		37.9	0.152		3.85	S
#283	951029	9	4		5.4		4.29	3.2		38.6	0.153		3.85	S
#291	951029	9	4		5.44		4.3	3.55		39	0.152		3.85	S
#305	951029	10	4		2.09		1.86	0.403		15.2	0.07		4.27	S
#187	950812	7	5		1.29	0.08	0.115	0.592	0.2	1.89	0.016	4.91	4.87	G
#30	950819	1	5		0.29		0.13	0.294	0.3	0.73	0.019	5.08		G
#40	950819	2	5		2.43		2.35	0.6		21.4	0.093	4.09	4.12	S/G
#46	950819	2	5		2.41	0.15	0.205	2.35	0.4	3.05	0.053		4.79	S/G
#23	950819	3	5		1.51		1.53	0.61		19.2	0.077	4.39		S
#28	950819	4	5		0.4	0.12	0.099	16.6	0.2	11.3	0.023	5.16		S
#22	950819	5	5		2.51		2.44	0.709		23.5	0.1	4.21		S
#18	950819	6	5		0.81		0.586	9.98	0.1	22	0.078	4.83		S
#144	950924	2	5		1.44	0.06	0.61	12		2.75	0.013		4.62	G/S
#227	950924	2	5		1.44		0.624	12.5		2.83	0.013		4.62	G/S
#223	950924	3	5		3.21	0.35	3.47	20.1	0.2	8.54	0.052		4.41	S
#185	950924	4	5		5.62		3.22	4.68		50.6	0.152		3.93	S
#220	950924	4	5											
#13	950924	5	5		4.77		3.08	1.36		50	0.158			S
#7	950924	6	5		15		3.19	74.7		15.2	0.1			G
#63	951029	1	5		1.05		0.102	0.251		0.83	0.086		6.38	S
#60	951029	2	5		4.14		3.28	2.45		26	0.13		4.22	S
#49	951029	3	5		4.34		3.8	2.28		30.8	0.144		3.92	S
#61	951029	5	5		6.15		4.48	2.17		38.5	0.179		3.85	S
#59	951029	6	5		6.26	0.05	3.75	7.14		29.4	0.143		3.93	S
#47	951029	7	5		3.41		2.26	3.88		19	0.094		4.32	S
#66	951029	8	5		0.44		0.055	0.156		0.36	0.007		4.74	G
#72	950819	1	6		0.48	0.5	0.372	1.13	0.2	0.8	0.021	5.16	6.32	G
#153	950819	2	6		0.83	0.36	0.134	5.37	0.2	1.84	0.03	5.39,5	6.05	G/S
#88	950819	3	6		2.49		2.32	0.628		23.7	0.087	4.08	4.12	S
#104	950819	4	6		2.5		2.34	0.641		23.8	0.088	4.06	4.14	S
#155	950819	5	6		1.26	0.16	0.323	3.64		1.67	0.019	5.27	5.82	G/S
#170	950819	6	6		0.9		0.056	0.287		1.1	0.005	4.96	5.6	G
#158	950924	2	6		3.6	1.3	0.61	72		3.9	0.04		4.81	G
#204	950924	2	6		3.74	1.39	0.643	83.5		4.23	0.019		4.81	G
#34	950924	3	6		1.1		0.509	0.123		8.01	0.027		3.6	S
#36	950924	4	6		5.44		3.12	1.17		48.8	0.158		3.6	S

Fen and Background Water
Table A2-1: PESC ICP-AES Analyses

Fen and Background Waters PESC ICP-AES
Concentrations in ppm (mg/l)

SAMPLE#	DATE	STATION#	TRANSECT #	BGRD ID	Al	As	Cu	Fe	P	S	Zn	pH	pH 2	Sur/Grnd
#74	950819	7	4		2.41		2.25	0.634		23.3	0.097	4.09	4.18	S
#99	950819	8	4		2.38		2.34	0.461		24.3	0.095	4.08	4.23	S
#110	950819	9	4		0.46		0.285	1.03		5.98	0.027	5.22	4.63	S
#160	950820	10	4		2.1	0.29	0.305	1.03	0.2	2.29	0.03	5.43	5.36	G
#245	950924	2	4		3.87		2.73	0.031		48.7	0.143		3.84	S
#225	950924	4	4		3.6		2.49	1.72		45.1	0.131		3.96	S
#166	950924	5	4		4.98		2.74	0.579		49.8	0.144		3.6	S
#205	950924	5	4		5		2.77	0.593		50.2	0.146		3.6	S
#79	950924	6	4		5.7		3.25	2.41		50.3	0.156			S
#141	950924	6	4		5.88		3.28	2.5		51.8	0.16		3.85	S
#105	950924	7	4		5.47		3.34	1.56		50.9	0.163			S
#186	950924	7	4		5.69		3.29	1.65		52	0.165		4.01	S
#152	950924	8	4		11.2	0.12	3.43	16.9	0.2	51.2	0.173		3.97	S
#196	950924	8	4		11.3	0.1	3.42	17	0.2	50.6	0.172		3.97	S
#312	951029	2	4		0.23		0.16	0.35		0.8	0.005		5.99	S
#257	951029	3	4		0.71		0.741	1.6		9.45	0.045		4.85	S
#298	951029	3	4		0.69		0.76	1.65		9.89	0.04		4.85	S
#296	951029	4	4		2.25		2.08	0.605		20.8	0.086		4.28	S
#297	951029	5	4		5.48		4.72	1.96		41.5	0.165		3.82	S
#284	951029	6	4		5.43		4.65	1.83		41.1	0.163		3.84	S
#300	951029	6	4		5.52		4.74	2.1		41.3	0.168		3.84	S
#249	951029	7	4		5.55		4.68	1.85		40	0.169			S
#292	951029	7	4		5.47		4.67	2.07		41.2	0.164		3.81	S
#285	951029	8	4		5.03		4.31	1.96		38.3	0.159		3.85	S
#293	951029	8	4		5		4.26	2.15		37.9	0.152		3.85	S
#283	951029	9	4		5.4		4.29	3.2		38.6	0.153		3.85	S
#291	951029	9	4		5.44		4.3	3.55		39	0.152		3.85	S
#305	951029	10	4		2.09		1.86	0.403		15.2	0.07		4.27	S
#187	950812	7	5		1.29	0.08	0.115	0.592	0.2	1.89	0.016	4.91	4.87	G
#30	950819	1	5		0.29		0.13	0.294	0.3	0.73	0.019	5.08		G
#40	950819	2	5		2.43		2.35	0.6		21.4	0.093	4.09	4.12	S/G
#46	950819	2	5		2.41	0.15	0.205	2.35	0.4	3.05	0.053		4.79	S/G
#23	950819	3	5		1.51		1.53	0.61		19.2	0.077	4.39		S
#28	950819	4	5		0.4	0.12	0.099	16.6	0.2	11.3	0.023	5.16		S
#22	950819	5	5		2.51		2.44	0.709		23.5	0.1	4.21		S
#18	950819	6	5		0.81		0.586	9.98	0.1	22	0.078	4.83		S
#144	950924	2	5		1.44	0.06	0.61	12		2.75	0.013		4.62	G/S
#227	950924	2	5		1.44		0.624	12.5		2.83	0.013		4.62	G/S
#223	950924	3	5		3.21	0.35	3.47	20.1	0.2	8.54	0.052		4.41	S
#185	950924	4	5		5.62		3.22	4.68		50.6	0.152		3.93	S
#220	950924	4	5											
#13	950924	5	5		4.77		3.08	1.36		50	0.158			S
#7	950924	6	5		15		3.19	74.7		15.2	0.1			G
#63	951029	1	5		1.05		0.102	0.251		0.83	0.086		6.38	S
#60	951029	2	5		4.14		3.28	2.45		26	0.13		4.22	S
#49	951029	3	5		4.34		3.8	2.28		30.8	0.144		3.92	S
#61	951029	5	5		6.15		4.48	2.17		38.5	0.179		3.85	S
#59	951029	6	5		6.26	0.05	3.75	7.14		29.4	0.143		3.93	S
#47	951029	7	5		3.41		2.26	3.88		19	0.094		4.32	S
#66	951029	8	5		0.44		0.055	0.156		0.36	0.007		4.74	G
#72	950819	1	6		0.48	0.5	0.372	1.13	0.2	0.8	0.021	5.16	6.32	G
#153	950819	2	6		0.83	0.36	0.134	5.37	0.2	1.84	0.03	5.39,5	6.05	G/S
#88	950819	3	6		2.49		2.32	0.628		23.7	0.087	4.08	4.12	S
#104	950819	4	6		2.5		2.34	0.641		23.8	0.088	4.06	4.14	S
#155	950819	5	6		1.26	0.16	0.323	3.64		1.67	0.019	5.27	5.82	G/S
#170	950819	6	6		0.9		0.056	0.287		1.1	0.005	4.96	5.6	G
#158	950924	2	6		3.6	1.3	0.61	72		3.9	0.04		4.81	G
#204	950924	2	6		3.74	1.39	0.643	83.5		4.23	0.019		4.81	G
#34	950924	3	6		1.1		0.509	0.123		8.01	0.027		3.6	S
#36	950924	4	6		5.44		3.12	1.17		48.8	0.158		3.6	S

Table A2-1: Fen and Background Water PESC ICP-AES Analyses

Fen and Background Waters PESC ICP-AES
Concentrations in ppm (mg/l)

SAMPLE#	DATE	STATION#	TRANSECT #	BGRD ID	Al	As	Cu	Fe	P	S	Zn	pH	pH 2	Sur/Grnd
#290	950924	5	6		0.26		0.313	0.097		0.96	0.032		4.5	S
#294	951029	1	6		0.2		0.086	0.313		0.34			5.65	S
#246	951029	2	6		1.52		1.29	0.404		11.1	0.053		4.58	S
#302	951029	2	6		1.49		1.3	0.418		11.5	0.05		4.58	S
#295	951029	3	6		5.66		4.94	1.93		42.8	0.17		3.82	S
#58	951029	4	6		6.22		4.83	3.01		38.7	0.182		3.81	S
#299	951029	4	6		5.45		4.77	1.8		41.3	0.166		3.84	S
#303	951029	5	6		4.72		3.88	0.563		33.9	0.141		4.05	S
#221	950606			10N+15E	2.64	0.1	2.04	22.1		15.8	0.059		3.97	S
#222	950606			10N+20E	2.13	0.92	1.43	50.6		5.84	0.033		4.61	S
#266	950606			10N+01W	18.7	0.82	2.98	126	0.2	1.78	0.065		4.86	S
#19	950813			Z	2.65		2.38	0.614		25.9	0.097	4.39		S
#20	950813			21	1.47		0.075	2.48		1.34	0.019	5.26		S
#21	950813			Y	3.44		3	1.22		32.4	0.122	3.98		S
#39	950813			20	0.31		0.06	0.59	0.2	1.84	0.017	4.94	5.59	S
#45	950813			12	2.33		0.028	0.82	0.3	1.22	0.011		3.63	S
#95	950813			16	0.76		0.063	0.653		0.47	0.006	4.47	4.37	S/G
#98	950813			18	2.5		0.586	2.77		2.11	0.025	4.86	4.68	S/G
#101	950813			10	2	0.1	0.379	25.1	0.2	2.01	0.011	5.92,5	6.26	S/G
#112	950813			11	0.3		0.025	0.282		0.2	0.003	4.81	5.93	S
#121	950813			13	0.23		0.024	0.26		0.22	0.005	6.41	4.43	S
#122	950813			5	0.14		0.042	1.21		2.02	0.01		5.1	S
#124	950813			19	2.05		0.381	1.61		0.49	0.016	5.1	4.73	S
#137	950813			9	0.46	0.05	0.052	2.92	0.1	0.53	0.004	5.34	6.61	S
#148	950813			8	0.47		0.064	0.832		0.78	0.003	6	6.95	S
#176	950813			15	0.34		0.115	0.439		2.57	0.012	5.23	4.89	S
#71	950819			3	0.26		0.046	2.03	0.1	1.9	0.025	4.28		G
#75	950819			Y	2.91		2.49	0.895		27	0.099	3.95	4.1	S
#91	950819			Z	2.49		2.31	0.655		23.4	0.087	4.04	4.12	S
#92	950819			2	0.13		0.016	0.009		0.84	0.003	5.68	6.5	S
#102	950819			4	0.38		0.149	1.49	0.1	3.69	0.022	4.73	4.83	S
#113	950819			5	0.69		0.099	1.7		8.15	0.032	4.24	4.44	S
#114	950819			6	0.31		0.03	0.37	0.2	0.81	0.012	4.58	6.57	S
#156	950819			10	0.31	0.1	0.051	2.78	0.1	0.41	0.021	5.63,5	7.29	S
#162	950819			1	0.79		3.2	0.298		17.6	0.102	4.63	4.72	S
#157	950820			8	0.18		0.051	0.616		0.79	0.004	6.95	7.14	S
#164	950820			9	0.37		0.052	1.08	0.1	0.57	0.018	5.42	7	
#15	950923			Y	7.02		4.83	1.29		66.9	0.227	4.15		S
#93	950923			X	8.06		5.48	1.12		75.9	0.243	3.63	4.22	S
#214	950923			X	8.32		5.59	1.18		77.9	0.252	3.63	3.81	S
#8	950924			11	0.11		0.01	0.023		0.55	0.004	4.67		S/G
#9	950924			13						0.07		4.82		S/G
#16	950924			Z	4.68		3.02	1.24		49.7	0.155			S
#116	950924			8	0.34		0.059	4.75		0.32	0.003		7.34	S
#168	950924			8	0.35	0.05	0.061	4.72		0.33	0.005	6.51	7.34	S
#174	950924			12	0.34		0.021	0.353		0.22	0.007			
#200	950924			12	0.33		0.019	0.367		0.2	0.008		4.3	S
#239	950924			3	0.19		0.094	1.27		1.3	0.015		5.05	S
#247	950924			Z	5.54		4.78	0.073		41.9	0.177		3.76	S
#267	951024			9	0.56		0.06	14.4		1.33	0.007		5.7	S
#216	951028			Y	6.45		5.98	3.29		47.6	0.201		3.66	S
#48	951029			18	0.7		0.144	1.27		1.17	0.029		5.2	S
#57	951029			21	1.29		0.057	1.98		0.97	0.007		6.12	S
#68	951029			20	0.19		0.042	0.492		1.54	0.008		5.89	S
#251	951029			21	2.21		0.217	0.052		2.64	0.042		3.86	G
#262	951029			10	0.41		0.019	0.565		1.11	0.003		4.94	G
#268	951029			8	0.12		0.35	0.137		0.86			6.91	S
#269	951029			15	0.2		0.44	0.779		0.97	0.007		6.14	G
#271	951029			19	7.13		0.584	9.1		0.42	0.013		4.99	S
#273	951029			17	7.98		0.202	5.07		0.89	0.016		4.57	S

Table A2-1: Fen and Background Water PESC ICP-AES Analyses

Fen and Background Waters PESC ICP-AES
Concentrations in ppm (mg/l)

SAMPLE#	DATE	STATION#	TRANSECT #	BGRD ID	Al	As	Cu	Fe	P	S	Zn	pH	pH 2	Sur/Grnd
#274	951029			100	22	0.8	1.85	124		0.2	0.096		6.27	S
#288	951029			9	0.54	0.05	0.057	14.5		1.4	0.004		5.7	S
#2	951103			Z	1.67		1.11	0.668		26.7	0.048			S
#37	951104			Y	9.08		4.93	1.3		76.3	0.219			S
#51	951104			2	5.04		0.151	4.24		0.79	0.024		6.12	S
#3	960921			Y	5.25		3.45	1.14		47.4	0.159			S
#5	960921			X	6.11		4.57	0.68		63.2	0.206			S
#1	960927			Z	4.21		3.22	1.23		44.3	0.151			S
#6	961220			W		0.1	0.104	0.013		0.61	0.101			S/G
#12	961220			W		0.09	0.105			0.6	0.103			
#25	961220			W		0.08	0.108	0.009		1.34	0.019			S
#135														
#263					22	0.8	1.78	133		0.18	0.094			

Table A2-1: Fen and Background Water PESC ICP-AES Analyses

SAMPLE	DATE	STATION#	TRANSECT	BGRD ID	Al	As	Cu	Fe	P	S	Zn	N	%Protein
#133	950819	1	0		73		31.3	146.6	760	2126	30.5		
#214	950729	2	0										
#223	950729	2	0										
#134	950819	2	0		44		37.5	178.4	760	2154	41.5		
#27	950922	2	0		47		21.7	258.1	350	1509	27.5		
#407	951022	2	0										
#216	950729	3	0										
#135	950819	3	0		74		22.5	182.1	1480	1983	28.6		
#28	950922	3	0		21		9.42	105.8	590	1727	29.6		
#217	950729	4	0										
#140	950819	4	0		66		64.3	281.3	670	2653	37.2		
#29	950923	4	0		28		23.1	209.8	310	1711	26.8		
#408	951021	4	0										
#218	950729	5	0										
#137	950819	5	0		133		45.5	591.1	730	2165	17.2		
#30	950923	5	0		121		44.6	574.1	310	1843	28.3		
#409	951021	5	0										
#138	950819	6	0		100		41.4	877.2	600	3438	35.9		
#31	950923	6	0		587		282.2	2798	490	4353	57.4		
#219	950729	7	0										
#139	950819	7	0		93.3		53.1	357.9	983	3616	28.2		
#32	950923	7	0		84		37.8	313.4	470	1852	21.8		
#230	950723	8	0										
#220	950729	8	0										
#141	950819	8	0		95		45.6	431.6	1000	6993	26.2		
#34	950923	8	0		92.3		38.5	380.3	620	6007	52.8		
#38	950923	8	0		111		44.1	418.9	640	6117	15.5		
#410	951021	8	0										
#221	950723	9	0										
#142	950819	9	0		183		70.9	611.7	760	4846	52		
#146	950819	9	0		141		42.4	514.3	770	3845	45.7		
#148	950819	9	0		247		59.3	703.8	750	4973	55.7		
#35	950923	9	0		837	13	250.1	2973	520	6721	52.8		
#222	950723	10	0										
#143	950819	10	0		545	8.5	74.4	1138	1170	4555	45		
#144	950819	11	0		237		64.3	409.1	1020	3530	41.9		
#36	950923	11	0		441		198.3	657.5	570	2969	27.4		
#224	950723	12	0										
#145	950819	12	0		439	5	71.3	905.2	1250	8589	37.5		
#37	950923	12	0		267		61.5	737.1	857	6321	11.1		
#225	950723	13	0										
#39	950923	13	0		4078	64	212.5	7829	1390	2602	40.7		
#226	950723	14	0										
#147	950819	14	0		2799	45	145	4999	2020	2788	51.7		
#40	950923	14	0		3459	44	167.3	5898	1420	3768	37.8		
#411	951021	14	0										
#414	951021	14	0										
#227	950723	15	0										
#149	950819	15	0		103		90.29	338.8	1410	2983	51.3		
#53	950923	15	0		114		18.5	390.9	955	1580	67.2		
#412	951021	15	0										
#228	950723	16	0										
#150	950819	16	0		53		30.9	205	1850	2858	56.9		
#41	950923	16	0		126		51.3	427.9	720	1973	28.5		
#229	950723	17	0										
#151	950819	17	0		61		41.4	206.8	1180	4701	30		
#157	950819	17	0		64		41.5	203.3	1150	4718	29.5		
#42	950923	17	0		76		27.4	232.6	560	4914	19.5		
#231	950723	18	0										
#152	950819	18	0		679	11	59.8	1379	1710	2547	30.9		
#43	950923	18	0		820	14	49.3	1421	1060	2256	30.5		
#413	951021	18	0										

Table A2-2: Fen and Background Plant Samples from Mt. Washington PESC ICP-AES

SAMPLE	DATE	STATION#	TRANSECT	BGRD ID	Al	As	Cu	Fe	P	S	Zn	N	%Protein
#232	950723	19	0										
#153	950819	19	0		71		23.3	696.8	2710	2369	63.8		
#44	950923	19	0		112	6	27.1	552	1360	1465	59		
#415	951021	19	0										
#233	950723	20	0										
#154	950819	20	0		36		11.8	372.3	2420	1932	53.4		
#45	950923	20	0		125	8	30.6	1659	1170	1334	58.9		
#416	951021	20	0										
#417	951021	20	0										
#366	951021	1	1										
#234	950730	2	1										
#367	951021	2	1										
#235	950729	3	1										
#178	950819	3	1		82		42.5	191.9	1850	3394	62.6		
#46	950923	3	1		26		19.7	108.6	450	1400	28.7		
#368	951021	3	1										
#236	950729	4	1										
#136	950819	4	1		60		26.4	125.3	1410	2178	36.2		
#179	950819	4	1		90.3		62	187.7	1330	2169	35.9		
#47	950923	4	1		25		33.4	122.6	925	1800	44		
#237	950729	5	1										
#242	950729	5	1										
#180	950819	5	1		125		71.5	227.1	1470	2263	38.2		
#48	950923	5	1		36		13.7	99.27	887	1623	39.9		
#369	951021	5	1										
#375	951021	5	1										
#238	950729	6	1										
#181	950819	6	1		134		57.9	320.2	1300	2103	37.3		
#49	950923	6	1		29		13.9	137.4	856	1678	34.8		
#370	951021	6	1										
#239	950729	7	1										
#182	950819	7	1		316	13	62.2	762.9	1410	2613	45.1		
#50	950923	7	1		76		13.8	187.7	710	1902	39.9		
#371	951021	7	1										
#240	950729	8	1										
#183	950819	8	1		186	6	92.6	443	1190	2551	44.8		
#187	950819	8	1		184	5	86.93	410.1	1190	2588	42.8		
#54	950923	8	1		60		25.1	152.5	740	2117	41.9		
#372	951021	8	1										
#241	950729	9	1										
#55	950923	9	1		828	22	98.68	2579	906	1545	39.1		
#373	951021	9	1										
#243	950729	10	1										
#184	950819	10	1		1881	29	244.9	7983	2000	2049	36.4		
#56	950923	10	1		1223	26	140	4560	2260	2488	36.8		
#374	951021	10	1										
#244	950729	11	1										
#250	950729	11	1										
#185	950819	11	1		1036	15	126.5	3051	2360	3383	46.9		
#51	950923	11	1		1438	20	135.1	4374	921	1672	14.5		
#59	950923	11	1		1066	16	108.8	3412	999	1624	12.9		
#376	951021	11	1										
#245	950729	12	1										
#186	950819	12	1		1146	1.8	102.1	2729	1980	3492	39.5		
#52	950923	12	1		73		15.6	227.3	700	3078	19		
#377	951021	12	1										
#378	951021	12	1										
#246	950729	13	1										
#188	950819	13	1		598	10	74.7	1631	1730	4139	39		
#57	950923	13	1		553	11	42	1728	1280	3061	30.8		
#247	950729	14	1										
#189	950819	14	1		4845	83.8	280.6	10910	2720	2909	43.1		

Table A2-2: Fen and Background Plant Samples from Mt. Washington PESC ICP-AES

SAMPLE	DATE	STATION#	TRANSECT	BGRD ID	Al	As	Cu	Fe	P	S	Zn	N	%Protein
#58	950923	14	1		2016	40	124.9	4287	1350	2635	29.3		
#379	951021	14	1										
#385	951021	14	1										
#248	950729	15	1										
#190	950819	15	1		414	8.5	53	1261	1320	4598	24.9		
#60	950923	15	1		1187	17	83.11	1993	898	5002	16.5		
#380	951021	15	1										
#249	950729	16	1										
#191	950819	16	1		158		68	527.6	854	2546	23		
#61	950923	16	1		91.1		37.1	368.5	430	2038	11.2		
#381	951021	16	1										
#251	950729	17	1										
#192	950819	17	1		414	31	98.12	3515	1470	2532	32.2		
#252	950729	18	1										
#193	950819	18	1		78		23.6	636.1	1600	2328	15.7		
#62	950923	18	1		246		66.1	1068	710	1885	9.14		
#382	951021	18	1										
#253	950729	19	1										
#194	950819	19	1		47		24.4	463.2	1250	2712	57		
#63	950923	19	1		84.1		23.5	347.2	620	2569	63.6		
#383	951021	19	1										
#254	950729	20	1										
#195	950819	20	1		443	6	60	1361	1010	2023	18.2		
#64	950923	20	1		264		59	1020	670	2146	16.2		
#196	950819	21	1		1115	19	95	2614	1970	2103	38.7		
#197	950819	21	1		1129	20	88.6	2550	1990	2152	38.6		
#384	951021	21	1										
#158	950819	1	2		113		4.6	162.2	1320	2484	46		
#80	950923	1	2		41		2.8	88.66	790	1547	35.7		
#255	950730	2	2										
#159	950819	2	2		21		3.7	132.4	1350	2126	36		
#81	950923	2	2		28		2.5	69.6	993	1934	27.4		
#325	951021	2	2										
#256	950730	3	2										
#160	950819	3	2		34		6	216.7	1640	1752	29.4		
#82	950923	3	2		40	6	9.26	355.6	1210	1553	25.2		
#86	950923	3	2		53	8	9.02	431.2	1180	1537	29.1		
#326	951021	3	2										
#333	951021	3	2										
#257	950730	4	2										
#269	950730	4	2										
#161	950819	4	2		112	14	27.4	966.6	1700	1734	27.5		
#174	950819	4	2		133	17	27.2	1080	1770	1733	27.5		
#327	951021	4	2										
#258	950730	5	2										
#162	950819	5	2		285	9.3	110.7	1052	1880	2072	28.1		
#83	950923	5	2		258	8.6	82.7	805.1	1440	3764	19.5		
#84	950923	5	2		1002	16	195.1	2011	1420	2671	42.1		
#328	951021	5	2										
#259	950730	6	2										
#347	950819	6	2										
#329	951021	6	2										
#260	950729	8	2										
#163	950819	8	2		1408	23	250.8	4369	3350	4475	47.5		
#261	950729	9	2										
#164	950819	9	2		766	13	120.7	2183	2310	2994	35.8		
#177	950819	9	2		934	16	131	2644	2260	3000	36.4		
#108	950922	9	2		1179	19	143.3	2541	1340	3120	34.6		
#330	951021	9	2										
#335	951021	9	2										
#262	950729	10	2										
#165	950819	10	2		1151	24	121.2	3155	2290	3489	53.7		

Fen and Background Plant Samples from Mt. Washington

Table A2-2: PESC ICP-AES

SAMPLE	DATE	STATION#	TRANSECT	BGRD ID	Al	As	Cu	Fe	P	S	Zn	N	%Protein
#109	950922	10	2		1200	20	89.51	2500	1660	3269	39.6		
#331	951021	10	2										
#263	950729	11	2										
#166	950819	11	2		1505	47	208	6900	1840	2759	40.2		
#85	950923	11	2		1315	27	118.2	3637	1320	2260	35.4		
#89	950923	11	2		2059	57	162.6	7112	1340	2421	36.4		
#332	951021	11	2										
#264	950729	12	2										
#274	950729	12	2										
#167	950819	12	2		914	25	111.3	3168	2270	3381	48.6		
#87	950923	12	2		970	16	92.06	2247	1360	2487	39.7		
#334	951021	12	2										
#265	950729	13	2										
#168	950819	13	2		2326	42	239.1	6654	2440	4013	53.7		
#169	950819	13	2		1091	19	124.1	2413	2230	3331	42.2		
#88	950923	13	2		2815	52	224	7051	2040	3575	42.8		
#336	951021	13	2										
#266	950729	14	2										
#90	950923	14	2		1648	32	128.1	3926	1430	2799	30		
#337	951021	14	2										
#267	950729	15	2										
#170	950819	15	2		1167	29	134.4	3460	1810	3084	32.4		
#91	950923	15	2		1716	35	143.5	4520	1800	2925	27.6		
#338	951021	15	2										
#268	950729	16	2										
#171	950819	16	2		613	16	97.11	2268	1690	2659	31.1		
#33	950822	16	2		984	15	79.7	1989	1300	2451	15.5		
#26	950922	16	2		795	16	71.5	2015	1330	2526	23.3		
#339	951021	16	2										
#270	950729	17	2										
#172	950819	17	2		555	14	117.2	1992	1810	3126	36.8		
#92	950923	17	2		1279	21	81.4	2455	1300	2939	26.7		
#340	951021	17	2										
#271	950729	18	2										
#173	950819	18	2		1108	26	199.2	3652	2170	3445	48.3		
#93	950923	18	2		3296	54	183.2	6287	1660	3242	39.2		
#341	951021	18	2										
#272	950729	19	2										
#175	950819	19	2		1809	37	236.5	4756	2220	3991	50		
#94	950923	19	2		2094	31	145.5	3403	1500	3153	28.2		
#342	951021	19	2										
#273	950729	20	2										
#176	950819	20	2		499	11	76.8	1603	1870	2990	65.2		
#95	950923	20	2		9999	20	155.4	1991	1170	2186	50.4		
#343	951021	20	2										
#97	950923	4	3		1008	23	243.4	3183	1700	4842	25.8		
#291	950716	5	3										
#132	950819	5	3		2227	28	181.6	3576	2900	5362	53.4		
#275	950716	6	3										M
#21	950819	6	3		1397	22	109.5	2919	2380	2648	38.4	25000	15.7
#292	950716	8	3										
#156	950820	9	3		1152	21	138.9	3292	2700	3895	60.9		
#344	951021	9	3										
#22	950820	10	3		945	20	96.5	3061	2180	3367	50.3	18000	11.3
#96	950923	11	3		622	13	39.4	1141	905	2811	36.6		
#2	960805	11	3		254		46	1041	2300	2978	49.4	15000	9.4
#5	960805	11	3		188	6	44.8	1027	2120	3270	37.9	17000	10.6
#8	960805	11	3		349	7	68.7	1238	2080	3092	42.2	16000	10
#20	960805	11	3		394	10	59.1	1217	2280	2988	50.9	16000	10
#155	950819	12	3		987	18	77.3	2103	1970	3155	41.4		
#313	951021	12	3										
#276	950716	15	3										

Fen and Background Plant Samples from Mt. Washington

Table A2-2: PESC ICP-AES

SAMPLE	DATE	STATION#	TRANSECT	BGRD ID	Al	As	Cu	Fe	P	S	Zn	N	%Protein
#305	950716			19									
#306	950716			20									
#307	950716			21									
#308	950716			13									
#298	950720			12									
#4	950722			20	671	11	61.8	2283	3520	3992	36.3	24000	15
#123	950812			13	64		13.8	265.5	2440	2314	38.7		
#126	950812			11	96.8		11.8	436.4	2030	1819	22.7		
#127	950812			12	525		8.3	895	1690	1768	31.8		
#359	950812			minesite									
#361	950812			minesite									
#115	950819			1	105		19.7	215.3	1680	1434	34.7		
#116	950819			3	66		10.1	113.7	1420	2151	35		
#117	950819			4	159		17.3	632.4	2220	2918	40.7		
#118	950819			7	198	5	17.9	719.3	2690	1940	42.9		
#122	950819			11	22		9.64	53.1	1630	1567	40.1		
#124	950819			3	185		19	730.6	2360	2992	40.9		
#125	950819			7	161		17.1	632.2	2520	1975	42.5		
#128	950819			14	52		9.52	99.09	2040	2316	76.6		
#130	950819			16	103		8.86	293.3	1030	1102	39.2		
#131	950819			19	84		39.4	904.4	1640	1503	37.4		
#350	950819			6									
#352	950819			12									
#353	950819			13									
#360	950819			18									
#362	950819			18									
#405	950819			19									
#119	950820			8	142		16.6	297.7	1820	1398	37.4		
#120	950820			9	32		4.8	369.5	820	1773	35.3		
#121	950820			10	106		21.2	509.9	1840	1735	35.9		
#129	950820			15	29		18.9	121.8	1350	2231	54.2		
#355	950920			13									
#356	950920			20									
#65	950923			2	44		8.39	83.66	800	1872	42.3		
#66	950923			1	616	9.3	41	949.8	1420	1579	33.8		
#67	950923			4	80		7.9	141.6	1270	2756	27.8		
#68	950923			5	31		5.8	126.6	810	1322	25.4		
#69	950923			7	30		9.98	107.4	780	1029	21.3		
#70	950923			8	292	8.8	18.3	540.3	1040	1136	52.9		
#71	950923			9	95.8		6.1	177.9	470	1352	29.6		
#72	950923			10	108		6.9	275.2	1120	1238	30		
#73	950923			11	49		6.3	71	830	993.5	40.2		
#74	950923			14	60		8.38	91.72	1420	1687	109.7		
#75	950923			15	98.4		9.15	127	923	1362	51.1		
#76	950923			16	58		6.4	241.9	590	888.8	46.1		
#77	950923			19	76		20.6	132.8	893	1070	37.2		
#78	950923			9	44		3.1	134.6	490	1362	29.7		
#79	950923			21	43		6.1	204.9	650	1230	58.4		
#349	950923			3									
#357	950923			20									
#358	950923			18									
#351	950924			6									
#354	950924			12									
#418	951021			10N+1W									
#363	951022			2									
#364	951022			3									
#365	951022			5									
#387	951022			3									
#388	951022			4									
#389	951022			6									
#390	951022			7									
#391	951022			8									
#392	951022			9									
#393	951022			10									
#394	951022			11									
#395	951022			12									
#396	951022			13									
#397	951022			14									
#398	951022			15									
#399	951022			16									
#400	951022			18									
#401	951022			19									
#402	951022			20									
#403	951022			21									
#404	951022			21									
#406	951022			9									
#25	951023			2	663	11	94.6	1106	1250	1088	33.1		
#1	960805			21	364		58.9	1426	3910	4082	53.1	21000	13.1
#7	960805			3	69		15.5	181.4	2050	2948	33.3	12000	7.5
#9	960805			minesite	32		26.1	200.4	1550	6511	27.2		
#10	960805			minesite	25		39.4	190.3	2130	8586	46.8		
#12	960805			minesite	68		38.3	171	1610	4325	32.9		
#14	960805			minesite	34		27.1	213.3	1480	8900	23		
#15	960805			minesite	30		54	275.4	1900	12420	73.5		
#16	960805			minesite	92	10	70.9	1208	1900	4495	32.7	18000	11.3
#18	960805			minesite	106	7	99.3	854.7	1980	5065	29.2	22000	13.8

SAMPLE ENV #	Cu in soil	Cu (Pesc)	Zn (ppm)	Zn	Fe %	Fe(Acme)	Fe(Pesc)	As (Acme)	As(Pesc)	P %	P (Acme)	P	Al %	Al (Acme)	Al (Pesc)	S	%H2O	TRANSECT	STATION	DEPTH	LENGTH (cm)	DESCRIPTION -Characteristics of Sample (most medium to dark to dark chocolate brown & moderately fibric peat unless otherwise stated).	DATE
-2	3494																	3	15	1.50	5.0/3.5	Umber sediment, many roots, much cotton grass leaves, peat and twigs.	Oct-95
-1	757																	3	2	1.50	3.5/2.0	Dark brown, no umber sediment, many twigs and needles, very crumbly.	Oct-95
0																		3	6			Channel full, no soil sample taken(ran out of sampler/corer)	Oct-95
1	2243		57		4.5	45000		735		0.076	760		2.94	29400				3	8	1.00	5.0/4.0	Wet, slightly gritty, fine grained.	Jul-95
2	1664		31		3.6	36000		604		0.153	1530		2.02	20200				3	11	1.00	6.0/5.0	Some roots, dk. brown, crumbly.	Jul-95
3	3350		79		3.67	36700		323		0.111	1110		1.94	19400				3	15	2.00	8.0/6.0	Fine and coarse roots, fine peat.	Jul-95
4	2597		54		3.74	37400		625		0.12	1200		2.26	22600				3	12	1.00	6.0/5.0	Medium brown, peaty, crumbly.	Jul-95
5	47		353		2.23	22300		36		0.068	680		0.48	4800				3				Standard LKSD 4	Jul-95
6	2949		67		0.93	9300		93		0.102	1020		0.59	5900				3	3	2.00	6.0/4.0	Very Fibrous, Carex spectabilis fibres, peat	Jul-95
7	2,387		87		4.66	46600		587		0.051	510		2.83	28300				3	5	0.00	3.0/3.0	Coarse fibres & fine sediment.	Jul-95
8	3608		112		6.14	61400		961		0.064	640		2.89	28900				3				Replicate of # 11(3-7)	Jul-95
9	1175		11		3.13	31300		456		0.205	2050		2.12	21200				3	10	1.00	5.1/4.1	Fine roots and very fine fibres.	Jul-95
10	3178		18		2.04	20400		177		0.191	1910		1.39	13900				3	14	1.00	6.0/5.0	Very fine textured peat, with fine roots, very wet.	Jul-95
11	3,608	3571	108	92.3	6.03	60300	65180	947	1010	0.064	640	820	2.86	28600	41270	6574		3	7	0.00	5.0/5.0	Many needles and fine brown sludge	Jul-95
12	3525		41		3.5	35000		646		0.161	1610		2.08	20800				3	13	1.00	6.0/5.0	Dark brown needles and roots.	Jul-95
13	249		11		0.31	3100		33		0.071	710		0.12	1200				3	2	1.00	5.0/4.0	Very crumbly, many root and leaf fibres, twigs	Jul-95
14	2648	2623	50	40.8	4.14	41400	42080	654	676	0.094	940	1100	2.87	28700	35130	3551		3	9	1.00	6.0/5.0	Slightly gritty, fine roots and small fibres.	Jul-95
15	4661		152		6.14	61400		715		0.058	580		3.23	32300				3	6	0.00	6.5/6.5	Needles, fibres, peat, wood bits, fine umber sediment.	Jul-95
16	2308		27		1.43	14300		114		0.107	1070		1.05	10500				3	16	1.50	5.5/4.0	Coarse fibres, wood bits, peat.	Jul-95
17						0					0			0									
18	3700		44		0.24	2400		11		0.092	920		0.43	4300				3	1	0.05	6.0/5.5	Needles, roots, ends in wood, materials not identifiable like old dry tea leaves. Layered appearance	Jul-95
19	4452		90		2.66	26600		356		0.105	1050		1.98	19800				3	4	1.00	5.0/4.0	V. fibrous, some roots, Cotton grass, leaves, mixed vertically	Jul-95
20	3739	3957	101	107	6.92	69200	76260	886	966	0.072	720	990	2.99	29900	42180	6401		3	7	2.00	4.5/2.5	Much umber sediment, cotton grass leaves and rhizomes.	Oct-95
21	4286		82		4.68	46800		483		0.089	890		2.52	25200				3	4	3.00	6.0/3.0	Cot G, rhizomes, roots, some twigs and brown peat.	Oct-95
22	3469		72		5.22	52200		519		0.094	940		2.36	23600				3	16	2.00	4.0/2.0	Ruddy sediments, many leaves, roots, and other plant pieces.	Oct-95
23	45		73		5.18	51800		515		0.094	940		2.37	23700				3	LKSD4			Certified Standard	Oct-95
24	2629		363		2.29	22900		35		0.068	680		0.48	4800				3	10	2.00	4.0/2.0	Umber sediment, many roots, rhizomes, and some C.G. leaves.	Oct-95
25	4203		49		4.3	43000		667		0.1	1000		2.93	29300				3	3	2.00	6.0/4.0	Dark brown, many needles an twigs, peaty.	Oct-95
26	2962		64		3.77	37700		347		0.122	1220		0.095	950				3	13	1.00	5.0/4.0	Dark umber, slightly gritty, roots, rhizomes, plant fibres	Oct-95
27	2376		93		7.04	70400		721		0.084	840		3.22	32200				3	8			Replicate of 35(3-8)	Oct-95
28	7979		53		4.96	49600		793		0.084	840		2.95	29500				3	5	0.00	2.0/2.0	Cot G. leaves, umber coloured sediment.	Oct-95
29	3954	3923	224	50.5	8.62	86200	44550	925	574	0.074	740	1200	3.41	34100	42070	5377		3	14	1.50	4.0/2.5	Dark grey, many roots and much sediment.	Oct-95
30	2766		57		4.36	43600		554		0.098	980		2.49	24900				3	12	1.50	3.5/2.0	Dark grey sediment, slightly gritty, roots, rhizomes, plant fibres.	Oct-95
31	3487		64		4.19	41900		661		0.075	750		2.89	28900				3	1	1.00	3.0/2.0	Brown, woody humus, little peat, not gritty, very crumbly.	Oct-95
32	2371		37		0.3	3000		15		0.104	1040		0.46	4600				3	9	0.50	4.0/3.5	Cotton grass leaves and grey sediment, some fine peat.	Oct-95
33			70		6.33	63300		676		0.083	830		3.08	30800				3					Oct-95
34	2779		50		4.39	43900		612		0.086	860		2.9	29000				3	11	2.00	4.0/2.0	Grey-umber sediment. brown peat, roots, rhizomes, plant fibres.	Oct-95
35	2376	2391	50	4605	4.96	49600	52520	802	846	0.084	840	1100	2.98	29800	43080	2753		3	8	2.00	4.0/2.0	Some gray sediment, many roots, rhizomes, and some C.G. leaves.	Oct-95
36		1341	115	62.2	4.52	45200	1706	433	9	0.11	1100	980	2.22	22200	2864	2156		4	15	2.00			Oct-95
37		2994	9	60.7	0.24	2400	3001	15	10	0.072	720	1300	0.16	1600	4768	2126		4	11	6.00		Standard (ppm% of 5) 58/133/3.79/420.102/1.93	Oct-95

ppm/dry weight
or as stated

Table A2-3: Fen and Background soils
PESC ICP-AES analyses

SAMPLE ENV #	Cu in soil	Cu (Pesc)	Zn (ppm)	Zn	Fe %	Fe(Acme)	Fe(Pesc)	As (Acme)	As(Pesc)	P %	P (Acme)	P	Al %	Al (Acme)	Al (Pesc)	S	%H2O	TRANSECT	STATION	DEPTH	LENGTH (cm)	Sample(most medium to dark to dark chocolate brown & moderately fibric peat	DATE
38		3149		45.4			24040		220			1200			35960	2983		4	3	2.00		Dark brown, lots of needles and roots	Oct-95
39		1735		20.5			16080		177			1400			22560	3698		4	3	6.00		"	Oct-95
40		4730		39			18600		160			1700			13350	2959		4	2	2.00		Very dark, lots of needles and roots (wet)	Oct-95
41		2356		40.9			6672		45			1100			5860	4144		4	2	6.00		"	Oct-95
42		2048		65.9			42110		497			670			42560	2942		4	4	2.00		Gyttja, cotton grass leaves and roots	Oct-95
43		2506		69.2			43730		863			740			45910	3496		4	4	6.00		Gyttja, cotton grass leaves and roots	Oct-95
44		3254		59.6			38770		625			1000			45550	5280		4	6	2.00		Very dark, crumbly, lots of needles, cotton grass roots	Oct-95
45		3239		63.2			41950		682			870			36660	4886		4	6	6.00		"	Oct-95
46		3034		71.8			44370		672			870			39270	5052		4	6	2.00		Gyttja, dark, some root	Oct-95
47		2656		58.5			43700		655			960			38570	4705		4	6	6.00		"	Oct-95
48		3218		120			64040		682			800			41820	5245		4	7	2.00		Very dark brown, bits of twigs, dark brown sludge	Oct-95
49		2920		94			63850		722			820			44030	4885		4	7	6.00		"	Oct-95
50		2847		75.9			47890		497			930			42180	4300		4	8	2.00		V. dk. brown, lots of roots	Oct-95
51		3476		63.9			3625		376			1100			34850	7946		4	8	6.00		V. dk. brown, lots of roots	Oct-95
52		2393		67.8			46000		530			1100			37650	3739		4	9	2.00		V. dk. brown, lots of roots and needles	Oct-95
53		3358		73.8			45380		548			990			35960	4779		4	9	6.00		V. dk. brown, lots of roots and needles	Oct-95
54		2783		15			10410		76			1500			19360	2043		4	10	2.00		V. dk. brown, roots and needles, crumbly	Oct-95
55		2401		36.7			46920		485			1300			24640	1660		4	10	6.00		V. dk. brown, roots and needles, crumbly	Oct-95
56		3386		29.6			31610		302			1300			21010	1600		6	1	2.00		Dk. crumbly, many roots	Oct-95
57		3217		30			29810		261			1200			21060	1540		6	1	6.00		Dk. crumbly, many roots	Oct-95
58		2230		47.2			35680		516			970			34730	2825		6	2	2.00		Many needles and roots, reddish laminae and dark brown	Oct-95
59		2213		39.2			42700		504			1000			29880	2779		6	2	6.00		"	Oct-95
60		1865		45.6			3120		685			1100			32810	2110		6	5	2.00		V. dk. crumbly, wet, some roots	Oct-95
61		1862		43.7			40910		625			1100			38970	1962		6	5	6.00		"	Oct-95
62		59.7		23.8			9960		52			1100			5208	2115		2	1	2.00		Dk., many roots, dry	Oct-95
63		55.5		28.7			9225		52			1000			5206	1972		2	1	6.00		Dk., many roots, dry	Oct-95
64		69.4		20.4			15010		160			1400			5656	2589		2	2	2.00		V. dk., many roots, fibrous	Oct-95
65		56.6		19			12330		100			1400			7192	2650		2	2	6.00		V. dk., many roots, fibrous	Oct-95
66		60.4		8.4			4431		33			1200			4354	2962		2	3	2.00		V. dk. wet, crumbly, many roots	Oct-95
67		63.6		10			5325		40			1300			4185	2842		2	3	6.00		V. dk. wet, crumbly, many roots	Oct-95
68		644.1		19.6			11440		232			1400			6174	3366		2	4	2.00		V. fibrous, dk. brown	Oct-95
69		636		19.7			12650		273			1400			7647	3404		2	4	6.00		V. fibrous, dk. brown	Oct-95
70		825		16			9956		140			1300			6616	4558		2	5	2.00		V. dk. fibrous roots, wet	Oct-95
71		885.3		18.2			11970		160			1200			8157	4193		2	5	6.00		V. dk. fibrous roots, wet	Oct-95
72		3280		76.6			39250		617			1000			33330	5498		2	6	2.00		Dk. brown, cotton grass, roots	Oct-95
73		3762		86.4			39320		576			960			40790	4497		2	6	6.00		Dk. brown, cotton grass, roots	Oct-95
74		3487		73.3			48330		638			1000			42140	4727		2	7	2.00		Dk. brown, cotton grass, roots and needles	Oct-95
75		3170		76.1			47790		566			960			43210	4837		2	7	6.00		Dk. brown, cotton grass, roots and needles	Oct-95
76		2588		81			70080		817			970			40470	4235		2	9	2.00		V. dk. cotton grass, wet	Oct-95
77		2452		86.4			74780		804			890			38600	4843		2	9	6.00		V. dk. cotton grass, wet	Oct-95
78		1950		46.7			63000		890			830			35560	2900		2	12	2.00		V. dk. cotton grass, roots and needles	Oct-95
79		2342		65.8			71200		784			850			35680	3120		2	12	6.00		V. dk. cotton grass, roots and needles	Oct-95
80		2659		96.4			73700		757			870			45380	3868		2	13	2.00		V. dk, lots of cotton grass.	Oct-95
81		2407		76.3			69420		817			850			41810	3484		2	13	6.00		V. dk, lots of cotton grass.	Oct-95
82		1739		43.9			53990		790			740			37120	2347		2	18	2.00		Dk. brown, cotton grass, dry	Oct-95
83		2140		42.6			58300		838			780			41220	1822		2	18	6.00		Dk. brown, cotton grass, dry	Oct-95
84		2287		76.5			63080		749			890			48010	2991		2	14	2.00		V. dk, cotton grass roots, wet	Oct-95
85		2164		66.8			61350		808			860			44170	2976		2	14	6.00		V. dk, cotton grass roots, wet	Oct-95
86		2486		73			50710		634			880			49330	3828		2	15	2.00		Dk brown, lots of cotton grass	Oct-95
87		2656		80.6			25670		640			880			45230	3786		2	15	6.00		Dk brown, lots of cotton grass	Oct-95
88		2040		55.7			40600		452			1500			29650	4493		2	16	2.00		Dk. brown, cotton grass roots	Oct-95
89		2599		61.4			42280		477			1200			33010	4736		2	16	6.00		Dk. brown, cotton grass roots	Oct-95
90		3362		73.2			36210		665			1300			29680	6420		2	17	2.00		Brown, many roots, some needles	Oct-95
91		3160		106			41660		644			980			39110	6386		2	17	6.00		Brown, many roots, some needles	Oct-95
92		3039		111			40170		560			950			34610	4655		2	19	2.00		V. dk., roots, needles, cotton grass	Oct-95
93		2948		96.6			48720		585			1000			38220	4512		2	19	6.00		V. dk., roots, needles, cotton grass	Oct-95
94		2179		48.2			4294		10			1000			9091	1570		2	21	2.00		V. fibrous, needles, dk. brown	Oct-95
95		2053		40.4			3604		10			1000			8246	1650		2	21	6.00		V. fibrous, needles, dk. brown	Oct-95
96		139906.6																1	6	2.00		Dk. brown, fibrous, roots	Oct-95
97	102021																	1	6	6.00		Dk. brown, fibrous, roots	Oct-95

Table A2-3:

Fen and Background soils
PESC ICP-AES analyses

ppm/dry weight
or as stated

SAMPLE ENV #	Cu in soil	Cu (Pesc)	Zn (ppm)	Zn	Fe %	Fe(Acme)	Fe(Pesc)	As (Acme)	As(Pesc)	P %	P (Acme)	P	Al %	Al (Acme)	Al (Pesc)	S	%H2O	TRANSECT	STATION	DEPTH	LENGTH (cm)	Sample(most medium to dark to dark chocolate brown & moderately fibric peat	DATE
98	2419.276																77.3	1	6	9.00		Dk. brown, fibrous, roots	Oct-95
99																	77.4	1	7	2.00		V. wet, roots, wood, fibrous mat.	Oct-95
100																	77.6	1	7	6.00		V. wet, roots, wood, fibrous mat	Oct-95
101																	82.1	1	8	2.00		Brown, reddish blotches, cotton grass, needles, large roots	Oct-95
102																	82.3	1	8	6.00		Brown, reddish blotches, cotton grass, needles, large roots	Oct-95
103																	82.6	1	8	9.00		Brown, reddish blotches, cotton grass, needles, large roots	Oct-95
104																	86	1	9	2.00		V. dk., needles , roots, fibrous	Oct-95
105																	80.9	1	9	6.00		V. dk., needles , roots, fibrous	Oct-95
106																	79.5	1	10	2.00		V. dk., cotton grass roots, v. wet.	Oct-95
107																	73.4	1	10	6.00		V. dk., cotton grass roots, v. wet.	Oct-95
108																	68.8	1	11	2.00		V. dk., needles, roots, fibrous	Oct-95
109																	65	1	11	6.00		V. dk., needles, roots, fibrous	Oct-95
110																	65.8	1	13	2.00		V. dk., needles, roots, fibrous, rocks, wet	Oct-95
111																	60.6	1	13	6.00		V. dk., needles, roots, fibrous, rocks, wet	Oct-95
112																	62.4	1	14	2.00		Dk. brown, roots and needles, fibrous, large roots	Oct-95
113																	63.5	1	14	6.00		Dk. brown, roots and needles, fibrous, large roots	Oct-95
114																	64.2	1	14	9.00		Dk. brown, roots and needles, fibrous, large roots	Oct-95
115																	71.5	1	15	2.00		V. dk, fibrous, roots and needles	Oct-95
116																	58.5	1	15	6.00		V. dk, fibrous, roots and needles	Oct-95
117																	52.5	1	15	9.00		V. dk, fibrous, roots and needles	Oct-95
118																	66.2	1	16	2.00		Dk. brown, fibrous, cotton grass	Oct-95
119																	65.8	1	16	6.00		Dk. brown, fibrous, cotton grass	Oct-95
120																	76.5	1	17	2.00		Reddish brown, fibrous, large roots	Oct-95
121																	74.3	1	17	6.00		Reddish brown, fibrous, large roots	Oct-95
122																	81.4	1	18	2.00		Dk. brown, fibrous, wet, roots	Oct-95
123																	77.6	1	18	6.00		Dk. brown, fibrous, wet, roots	Oct-95
124																	79.6	1	18	9.00		Dk. brown, fibrous, wet, roots	Oct-95
125																	74	1	19	2.00		Many roots, crumbly, dark	Oct-95
126																	74	1	19	6.00		Many roots, crumbly, dark	Oct-95
127																	83.1	1	20	2.00		V. dk., roots and needles	Oct-95
128																	83.3	1	20	6.00		V. dk., roots and needles	Oct-95
129																	63.6	1	20	2.00		Reddish brown, fibrous, crumbly	Oct-95
130																	62.5	1	20	6.00		Reddish brown, fibrous, crumbly	Oct-95
131																	62.4	1	20	9.00		Reddish brown, fibrous, crumbly	Oct-95
132																	64.7	1	21	2.00		Dk brown, roots, cotton grass	Oct-95
133																	65.8	1	21	6.00		Dk brown, roots, cotton grass	Oct-95
134																	70.3	1	21	9.00		Dk brown, roots, cotton grass	Oct-95
135																	93	BK		2.00		Dk., fibrous, roots, grit	Oct-95
136																	79.4	3	1	2.00		crumbly, wood, roots	Aug-95
137																	88.2	3	2	2.00		V.dk., fibrous, some needles	Aug-95
138																	84.6	3	2	6.00		V.dk., fibrous, some needles	Aug-95
139																	86.4	3	3	2.00		V. brown, cotton grass roots	Aug-95
140																	89.3	3	4	2.00		Dk. brown, wet, roots and fibres	Aug-95
141																	89.2	3	5	2.00		Mostly cotton grass	Aug-95
142																	58.1	3	6	2.00		V. dk. fibrous, cotton grass	Aug-95
143																	76.1	3	8	2.00		Dk brown, crumbly	Aug-95
144																	75.7	3	8	6.00		Dk brown, crumbly	Aug-95
145																	81.8	3	9	2.00		Light brown, fibrous	Aug-95
146																	77.5	3	10	2.00		Dk. brown, crumbly, some roots	Aug-95
147																	69.8	3	10	6.00		Dk. brown, crumbly, some roots	Aug-95
148																	75.4	3	10	9.00		Dk. brown, crumbly, some roots	Aug-95
149																	79	3	11	2.00		V. dk., roots, fibrous	Aug-95
150																	77.9	3	12	2.00		Dk. brown, cotton grass, roots	Aug-95
151																	76	3	12	6.00		Dk. brown, cotton grass, roots	Aug-95
152																	77.1	3	13	2.00		V. dk, crumbly, cotton grass	Aug-95
153																	74.9	3	13	6.00		V. dk, crumbly, cotton grass	Aug-95
154																	82.3	3	14	2.00		V. dk. fibrous, some cotton grass	Aug-95
155																	76.9	3	14	6.00		V. dk. fibrous, some cotton grass	Aug-95
156																	82.4	3	15	2.00		Dk. brown, fibrous, cotton grass, crumbly	Aug-95
157																	84.5	3	16	2.00		V. dk. cotton grass	Aug-95

Table A2-3: Fen and Background soils
PESC ICP-AES analyses

ppm/dry weight
or as stated

SAMPLE ENV #	Cu in soil	Cu (Pesc)	Zn (ppm)	Zn	Fe %	Fe(Acme)	Fe(Pesc)	As (Acme)	As(Pesc)	P %	P (Acme)	P	Al %	Al (Acme)	Al (Pesc)	S	%H2O	TRANSECT	STATION	DEPTH	LENGTH (cm)	DESCRIPTION -Characteristics of Sample (most medium to dark to dark chocolate brown & moderately fibric peat unless otherwise stated)	DATE
158																	39.4	1	1	2.00		Dry, crumbly, roots, light brown.	Jul-95
159																	36.9	1	1	6.00		Dry, crumbly, roots, light brown.	Jul-95
160																	56.5	1	2	2.00		Dry, crumbly, light brown.	Jul-95
161																	55	1	2	6.00		Dry, crumbly, light brown.	Jul-95
162																	69.4	0	2	2.00		Reddish brown, some rocks, fibrous	Jul-95
163																	49.4	0	2	6.00		Reddish brown, some rocks, fibrous	Jul-95
164																	64	1	3	2.00		V. dk., fibres, roots	Jul-95
165																	72.5	1	3	6.00		V. dk., fibres, roots	Jul-95
166																	86.9	1	3	9.00		V. dk., fibres, roots	Jul-95
167																	75.2	1	4	2.00		V. dk., fibrous, cotton grass, roots	Jul-95
168																	86.4	1	4	6.00		V. dk., fibrous, cotton grass, roots	Jul-95
169																	62.4	1	4	2.00		Light brown, fibres, cotton grass	Jul-95
170																	67.5	1	4	6.00		Dk. brown, fibres, cotton grass	Jul-95
171																	76.9	1	4	9.00		Dk. brown, fibres, cotton grass	Jul-95
172																	82.5	1	5	2.00		Dk. brown, fibrous, roots, cotton grass	Jul-95
173																	92.5	1	5	6.00		Dk. brown, fibrous, roots, cotton grass	Jul-95
174																	87.7	1	5	9.00		Dk. brown, fibrous, roots, cotton grass	Jul-95
175																	77.3	1	6	2.00		Brown, fibrous, roots	Jul-95
176																	91.8	1	6	6.00		Brown, fibrous, root	Jul-95
177																	89.9	1	6	9.00		Brown, fibrous, root	Jul-95
178																	66	1	7	2.00		Dk. brown, cotton grass, fibrous	Jul-95
179																	81.9	1	7	6.00		Dk. brown, cotton grass, fibrous	Jul-95
180																	80.3	1	8	2.00		V. dk, wet, cotton grass roots	Jul-95
181																	85.7	1	8	6.00		V. dk, wet, cotton grass roots	Jul-95
182																	70.4	1	9	2.00		V. dk, lots of cotton grass, wet.	Jul-95
183																	72.7	1	9	6.00		V. dk, lots of cotton grass, wet	Jul-95
184																	63.7	1	10	2.00		Reddish brown, cotton grass, dry, hard	Jul-95
185																	61.7	1	10	6.00		Reddish brown, cotton grass, dry, hard	Jul-95
186																	56.3	1	10	9.00		Reddish brown, cotton grass, dry, hard	Jul-95
187																	78	1	12	2.00		Dk. brown, cotton grass, roots	Jul-95
188																	85.6	1	12	6.00		Dk. brown, cotton grass, roots	Jul-95
189																	77.6	1	11	2.00		Dk. brown, cotton grass, fibrous	Jul-95
190																	78.5	1	11	6.00		Dk. brown, cotton grass, fibrous	Jul-95
191																	63.2	1	13	2.00		Reddish brown, cotton grass, large rocks	Jul-95
192																	63.2	1	15	2.00		Dk. brown, fibrous, roots and needles	Jul-95
193																	61.1	1	15	6.00		Dk. brown, fibrous, roots and needles	Jul-95
194																	73.3	1	16	2.00		Dk. brown, cotton grass roots	Jul-95
195																	82.4	1	17	2.00		V. dk., fibrous, roots and needles	Jul-95
196																	82.8	1	17	6.00		V. dk., fibrous, roots and needles	Jul-95
197																	73.1	1	17	9.00		V. dk., fibrous, roots and needles	Jul-95
198																	76.3	1	18	2.00		V. dk., cotton grass roots, fibres.	Jul-95
199																	73.2	1	19	2.00		V. dk., fibrous, roots and needles, cotton grass	Jul-95
200																	72.9	1	19	6.00		V. dk., fibrous, roots and needles, cotton grass	Jul-95
201																	74.4	1	19	9.00		V. dk., fibrous, roots and needles, cotton grass	Jul-95
202																	61.4	1	20	2.00		Dk. brown, crumbly, roots	Jul-95
203																	77.5	1	20	6.00		Dk. brown, crumbly, roots	Jul-95
204																	75.9	1	20	9.00		Dk. brown, crumbly, roots	Jul-95
205																	62.5	1	21	2.00		V. dk., crumbly, root and needles	Jul-95
206																	87.8	6	1	2.00		V. dk. wood, roots, fibrous	Jul-95
207																	89.7	6	1	6.00		V. dk. wood, roots, fibrous	Jul-95
208																	84.8	6	1	9.00		V. dk. wood, roots, fibrous	Jul-95
209																	79.4	6	2	2.00		V. dk., fibrous, dry, hard, some roots	Jul-95
210																	79.1	6	2	6.00		V. dk., fibrous, dry, hard, some roots	Jul-95
211																	76.4	6	2	9.00		V. dk., fibrous, dry, hard, some roots	Jul-95
212																	76.9	6	3	2.00		Light brown, extremely wet	Jul-95
213																	50.7	6	4	2.00		Dk. brown, fibrous	Jul-95
214																	69.6	6	5	2.00		Dk. brown, fine roots and small fibres	Jul-95
215																	80.2	6	5	6.00		Dk. brown, fine roots and small fibres	Jul-95

Table A2-3: Fen and Background soils
PESC ICP-AES analyses

ppm/dry weight
or as stated

SAMPLE ENV #	Cu in soil	Cu (Pesc)	Zn (ppm)	Zn	Fe %	Fe(Acme)	Fe(Pesc)	As (Acme)	As(Pesc)	P %	P (Acme)	P	Al %	Al (Acme)	Al (Pesc)	S	%H2O	TRANSECT	STATION	DEPTH	LENGTH (cm)	DESCRIPTION -Characteristics of Sample (most medium to dark to dark chocolate brown & moderately fibric peat unless otherwise stated).	DATE
216																	80.2	6	5	9.00		Dk. brown, fine roots and small fibres	Jul-95
217																	80.5	6	6	2.00		V. dk., cotton grass, rocks, dry	Jul-95
218																	57.7	6	6	6.00		V. dk., cotton grass, rocks, dry	Jul-95
219																	71.1	0	1	2.00		V. dk., roots, fibres, needles	Jul-95
220																	78.3	0	1	6.00		V. dk., roots, fibres, needles	Jul-95
221																	80.1	0	3	2.00		V. dk., crumbly, wood pieces, wet	Jul-95
222																	81.6	0	3	6.00		V. dk., crumbly, wood pieces, wet	Jul-95
223																	70.4	0	4	2.00		Dk. brown, roots and needles	Jul-95
224																	71.4	0	4	6.00		Dk. brown, roots and needles	Jul-95
225																	68.5	0	5	2.00		Dk. brown, coarser fibres	Jul-95
226																	44.6	0	6	2.00		Reddish, large rocks, wet	Jul-95
227																	78.7	0	7	2.00		V.dk., wood bits, cotton grass roots, fibres	Jul-95
228																	79.4	0	8	2.00		V. dk., fine fibres, wet	Jul-95
229																	77.4	0	9	2.00		Multicoloured, v.dk. -reddish brown, many roots, fine fibres	Jul-95
230																	65.3	0	9	6.00		Multicoloured, v.dk. -reddish brown, many roots, fine fibres	Jul-95
231																	77.3	0	9	9.00		Multicoloured, v.dk. -reddish brown, many roots, fine fibres	Jul-95
232																	64.9	0	10	2.00		Dk. brown, many roots and fibres.	Jul-95
233																	64.5	0	10	6.00		Dk. brown, many roots and fibre	Jul-95
234																	72.9	0	10	9.00		Dk. brown, many roots and fibre	Jul-95
235																	59.4	0	11	2.00		Dk. brown, some pebbles, wet	Jul-95
236																	60.7	0	12	2.00		V. dk, many roots, some fine fibres	Jul-95
237																	63.6	0	13	2.00		V. dk., roots, many fibres	Jul-95
238																	68.4	0	14	2.00		Light outside, dk. inside colour, roots, fibres.	Jul-95
239																	69.3	0	14	6.00		Light outside, dk. inside colour, roots, fibres.	Jul-95
240																	59.6	0	15	2.00		Dk. brown, roots and needles, cotton grass	Jul-95
241																	77.6	0	15	6.00		Dk. brown, roots and needles, cotton grass	Jul-95
242																	71.8	0	15	9.00		Dk. brown, roots and needles, cotton grass	Jul-95
243																	58.4	0	16	2.00		Dk. brown, many roots, pieces of wood	Jul-95
244																	82.1	0	16	5.00		Dk. brown, many roots, pieces of wood	Jul-95
245																	75.1	0	16	9.00		Dk. brown, many roots, pieces of wood	Jul-95
246																	65.7	0	17	2.00		Dk. brown, cotton grass roots.	Jul-95
247																	75.6	0	17	6.00		Dk. brown, cotton grass roots.	Jul-95
248																	64.2	0	18	2.00		V. dk., roots, needles, fibres	Jul-95
249																	74.1	0	19	2.00		V. dk., fibrous, some roots, wet	Jul-95
250																	83.2	0	19	6.00		V. dk., fibrous, some roots, wet	Jul-95
251																	73.2	0	20	2.00		V. dk., v. fibrous, some roots	Jul-95
252																	87.5	0	20	6.00		V. dk., v. fibrous, some roots	Jul-95
253																	86.3	0	20	9.00		V. dk., v. fibrous, some roots	Jul-95
254																	81.7	4	1	2.00		Dk. brown, cotton grass, roots	Aug-95
255																	88.5	4	2	2.00		Dk. brown, some roots, v. fibrous	Aug-95
256																	85.9	4	2	6.00		Dk. brown, some roots, v. fibrous	Aug-95
257																	82.4	4	3	2.00		Dk. brown, crumbly, very fine fibres, no roots or needles	Aug-95
258																	82.1	4	3	6.00		Dk. brown, crumbly, very fine fibres, no roots or needles	Aug-95
259																	80.7	4	3	9.00		Dk. brown, crumbly, very fine fibres, no roots or needles	Aug-95
260																	82.7	4	5	2.00		Dk. brown, soft and mushy gyttja	Aug-95
261																	80.5	4	6	2.00		Dk. brown, very fibrous, some cotton grass and roots	Aug-95
262																	80.5	4	6	6.00		Dk. brown, very fibrous, some cotton grass and roots	Aug-95
263																	74.9	4	6	9.00		Dk. brown, very fibrous, some cotton grass and roots	Aug-95
264																	83.8	4	7	2.00		Dk. brown, soft and mushy, fibrous, and wet	Aug-95
265																	83.2	4	7	6.00		Dk. brown, soft and mushy, fibrous, and wet	Aug-95
266																	64.1	4	4	2.00		Reddish brown, very fibrous	Aug-95
267																	80.9	4	4	6.00		Reddish brown, very fibrous	Aug-95

Table A2-3:

Fen and Background soils
PESC ICP-AES analyses

ppm/dry weight
or as stated

SAMPLE ENV #	Cu in soil	Cu (Pesc)	Zn (ppm)	Zn	Fe %	Fe(Acme)	Fe(Pesc)	As (Acme)	As(Pesc)	P %	P (Acme)	P	Al %	Al (Acme)	Al (Pesc)	S	%H2O	TRANSECT	STATION	DEPTH	LENGTH (cm)	DESCRIPTION -Characteristics of Sample (most medium to dark to dark chocolate brown & moderately fibric peat unless otherwise stated)	DATE
268																	83.9	4	8	2.00		Dk. brown, cotton grass, fine fibres, no roots	Aug-95
269																	78.7	4	8	6.00		Dk. brown, cotton grass, fine fibres, no roots	Aug-95
270																	77.6	4	8	9.00		Dk. brown, cotton grass, fine fibres, no roots	Aug-95
271																	81.1	4	9	2.00		Dk. brown, fine fibres, no roots	Aug-95
272																	78.9	4	9	6.00		Dk. brown, fine fibres, no roots	Aug-95
273																	83.7	4	10	2.00		Dk. brown, cotton grass, fine fibres	Aug-95
274																	75.5	4	10	6.00		Dk. brown, cotton grass, fine fibres	Aug-95
275																		2	1	2.00		V. dk., crumbly, very fibrous	Aug-95
276																		2	1	6.00		V. dk., crumbly, very fibrous	Aug-95
277																		2	2	2.00		V. dk., roots, fibres	Aug-95
278																		2	2	6.00		V. dk., roots, fibres	Aug-95
279																		2	3	2.00		V. dk., fine roots and fibres	Aug-95
280																		2	3	6.00		V. dk., fine roots and fibres	Aug-95
281																		2	3	9.00		V. dk., fine roots and fibres	Aug-95
282																		2	4	2.00		V. dk., fine roots and fibres, wet	Aug-95
283																		2	4	6.00		V. dk., fine roots and fibres, wet	Aug-95
284																		2	4	9.00		V. dk., fine roots and fibres, wet	Aug-95
285																		2	5	2.00		V. dk., cotton grass, small roots and fibres	Aug-95
286																		2	5	6.00		V. dk., cotton grass, small roots and fibres	Aug-95
287																		2	5	9.00		V. dk., cotton grass, small roots and fibres	Aug-95
288																		2	6	2.00		Dk. brown, cotton grass, wet	Aug-95
289																		2	6	6.00		Dk. brown, cotton grass, wet	Aug-95
290																		2	7	2.00		Dk. brown, cotton grass, needles	Aug-95
291																		2	7	6.00		Dk. brown, cotton grass, needles	Aug-95
292																		2	8	2.00		Dk. brown, reddish blotches, cotton grass	Aug-95
293																		2	9	2.00		V. dk. cotton grass, wet, fibrous	Aug-95
294																		2	9	6.00		V. dk. cotton grass, wet, fibrous	Aug-95
295																		2	10	2.00		Dk. brown, cotton grass, wet	Aug-95
296																		2	11	2.00		Dk. brown, cotton grass, dry, fine fibres	Aug-95

Table A2-3:

Fen and Background soils
PESC ICP-AES analyses

ppm/dry weight
or as stated

Appendix 3: 2-biquinoline Colorimetric Testing for Copper. Reagents, Preparation and Procedure.

2, 2-biquinoline testing on water samples for ionic copper (after the method of Almond, discussed on pages 57-58, "Rapid methods of Trace Analysis", R. E. Stanton. 1966. Edward Arnold, London)

Procedure:

1 ml of filtered (0.45 m) and acidified (2 ml of concentrated nitric acid to 250 ml of filtrate) sample was added to a clean test tube and the volume brought up to 10 ml by the addition of 9 ml of deionized water. 10 ml of buffer solution was added, and then 2 ml of 2,2´biquinoline indicator solution. The test tube was corked tightly and shaken for 30 seconds, and allowed to sit for 5 minutes. Then it was compared to the standard series. If no colour was noticeable, or the colour was so faint as to be equivocal, the procedure was repeated with 10 ml of sample and no dilution. With the latter, the results were taken as read, but the former were multiplied by ten to give the concentrations of ionic copper in the water samples. Blanks and standards were run, and the samples randomized (including blanks, standards and duplicates) using a simple number to identify them, and a master list to refer back to the sample location or control type.

Solutions used:

To make up the buffer

200 g. of sodium acetate (trihydrate), 100 g of potassium sodium tartarate (tetra-hydrate) and 20 g of ascorbic acid is dissolved in water and diluted to 1 litre. Small amounts of a solution of 40 mg of dithizone in 400 ml of reagent grade mineral spirits (0.01% solution) was then added to the buffer solution until all the copper was extracted from the buffer. Using additional spirits, the dithizone was rinsed from the buffer.

To make up the indicator:

20 mg of 2,2´biquinoline was added to 50 ml of iso-amyl alcohol, the solution warmed until the 2,2´biquinoline dissolved, and the solution was brought up to 100 ml by the addition of further iso-amyl alcohol.

To make up the standards:

200 mg of copper sulphate (penta-hydrate) was dissolved in 500 ml. of 0.5 M hydrochloric acid. 1.0 ml of this solution was dissolved in 50 ml 0.5 M hydrochloric acid and brought up

to 100 ml by adding more 0.5 M hydrochloric acid, giving a 1 ppm solution. In a set of test tubes, thoroughly cleaned, small amounts of this solution was added, and brought up to 10 ml, to give a set of standards as follows: 10 ppb, 20 ppb, 40 ppb, 60 ppb, 75 ppb, 100 ppb, 125 ppb, 150 ppb, 175 ppb, 200 ppb, 250 ppb, 300 ppb, 350 ppb. These test tubes were labeled appropriately. To each of these solutions in their separate test tubes, 10 ml of buffer solution was added, and then 2 ml of indicator solution. The mixture was corked tightly and shaken vigorously for 30 seconds. They were then assembled in order in a test tube rack against a bright white background.

Appendix 4: Branch 126 Sedge Fen maps showing elemental concentrations in Water, Plants and Soils.

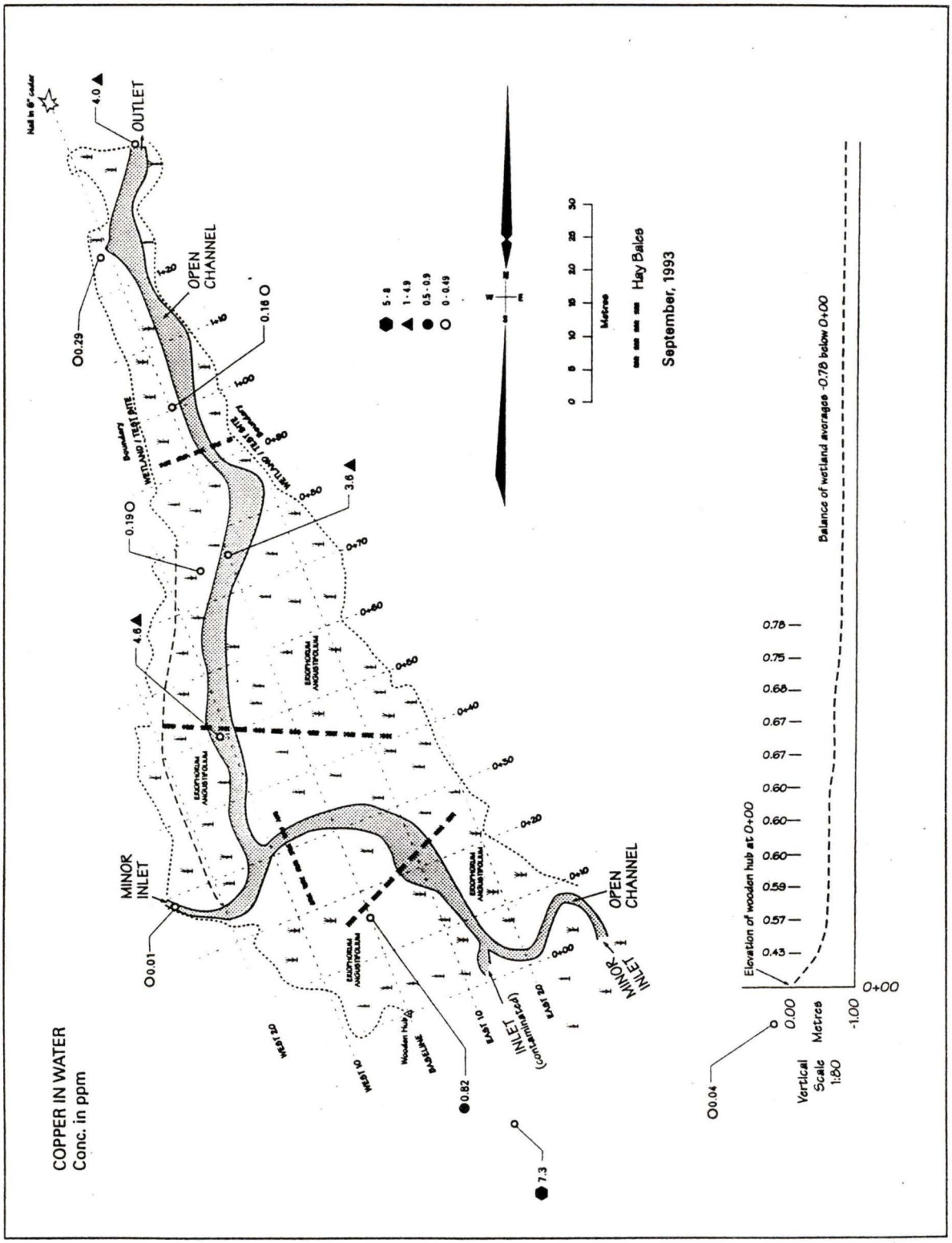


Figure A4-1: Copper in Water (September, 1993)

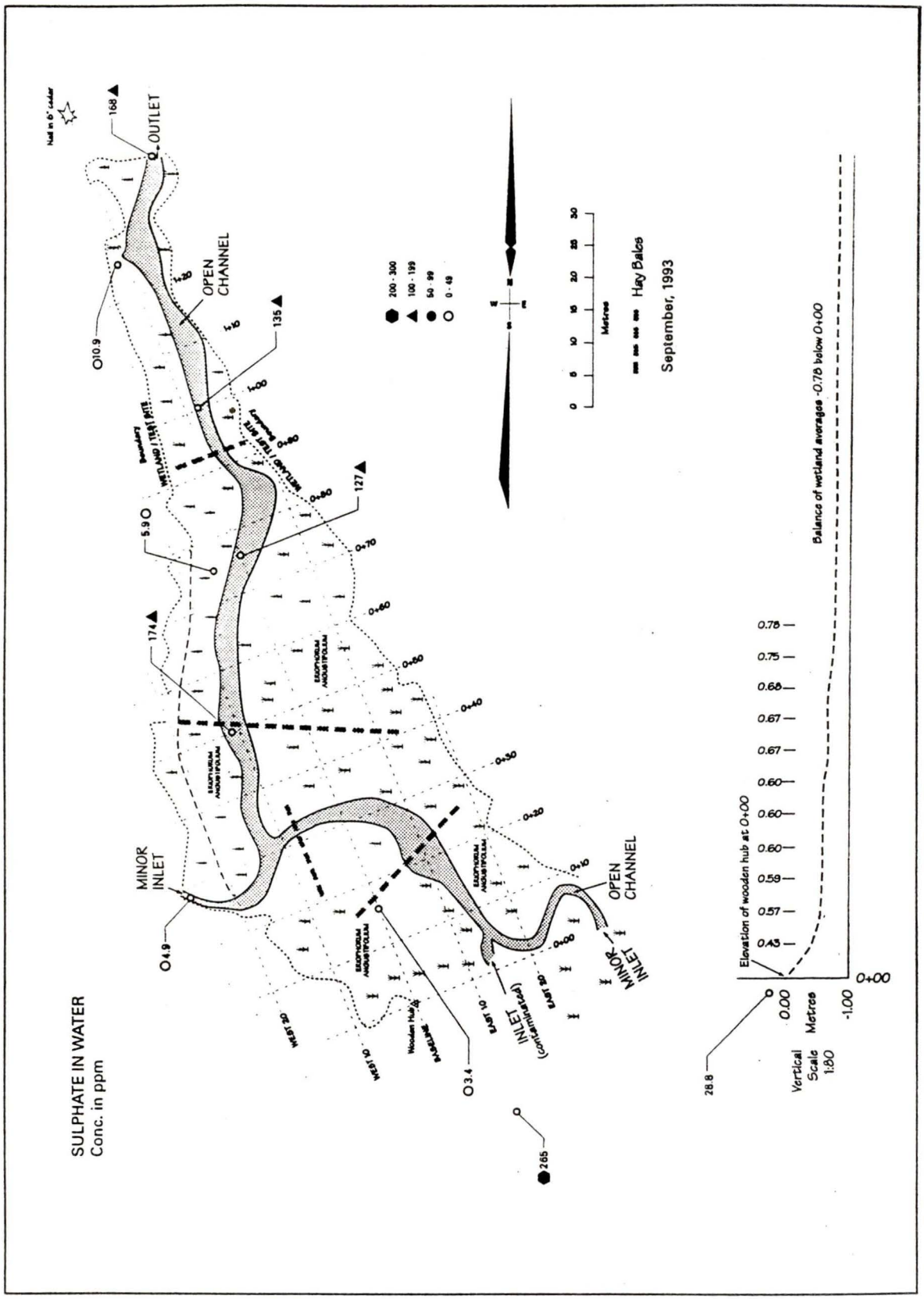


Figure A4-2: Sulphate in Water (September, 1993)

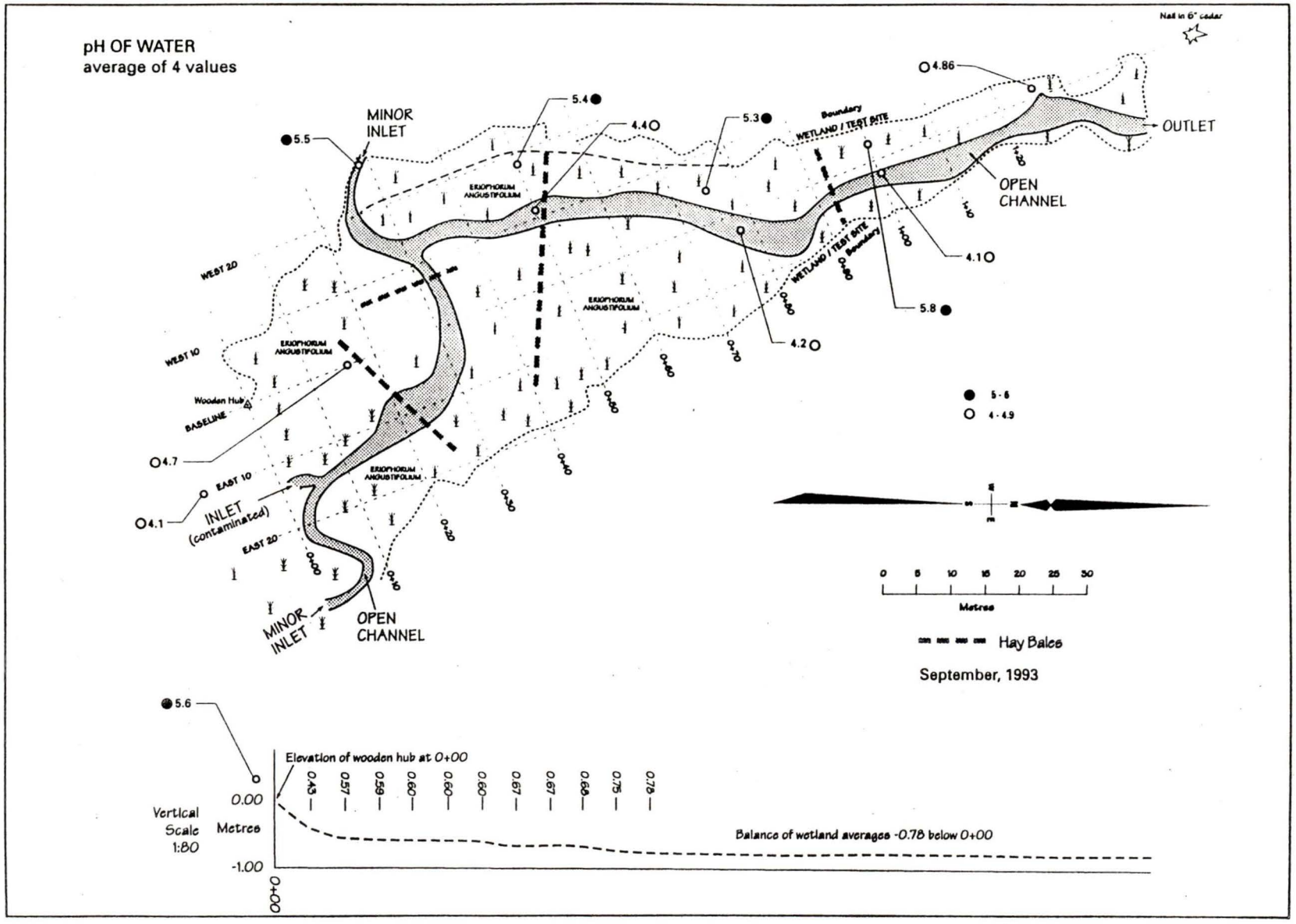


Figure A4-3: pH of Water (September, 1993)

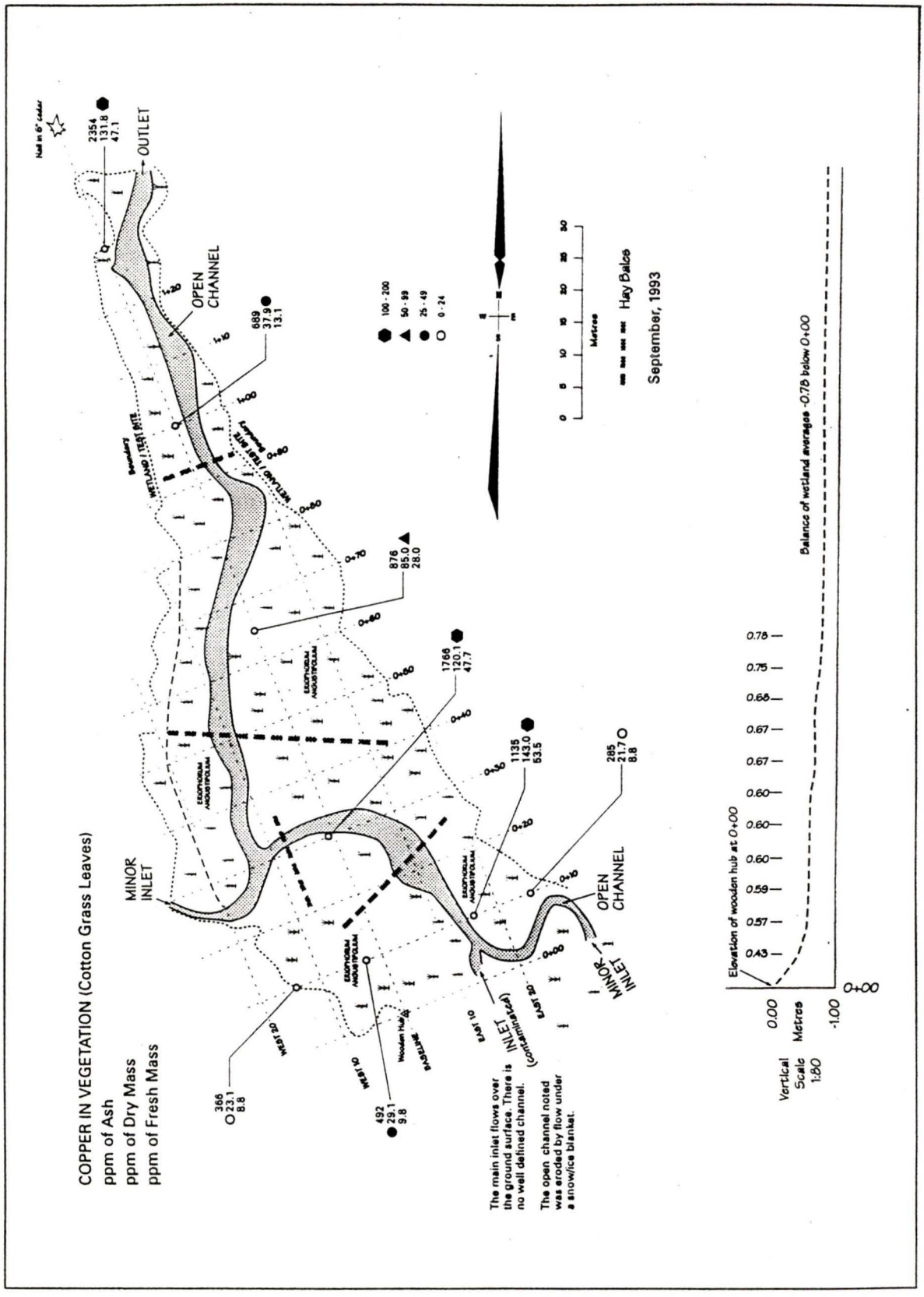


Figure A4-4: Copper in Vegetation (Copper Grass Leaves, September, 1993)

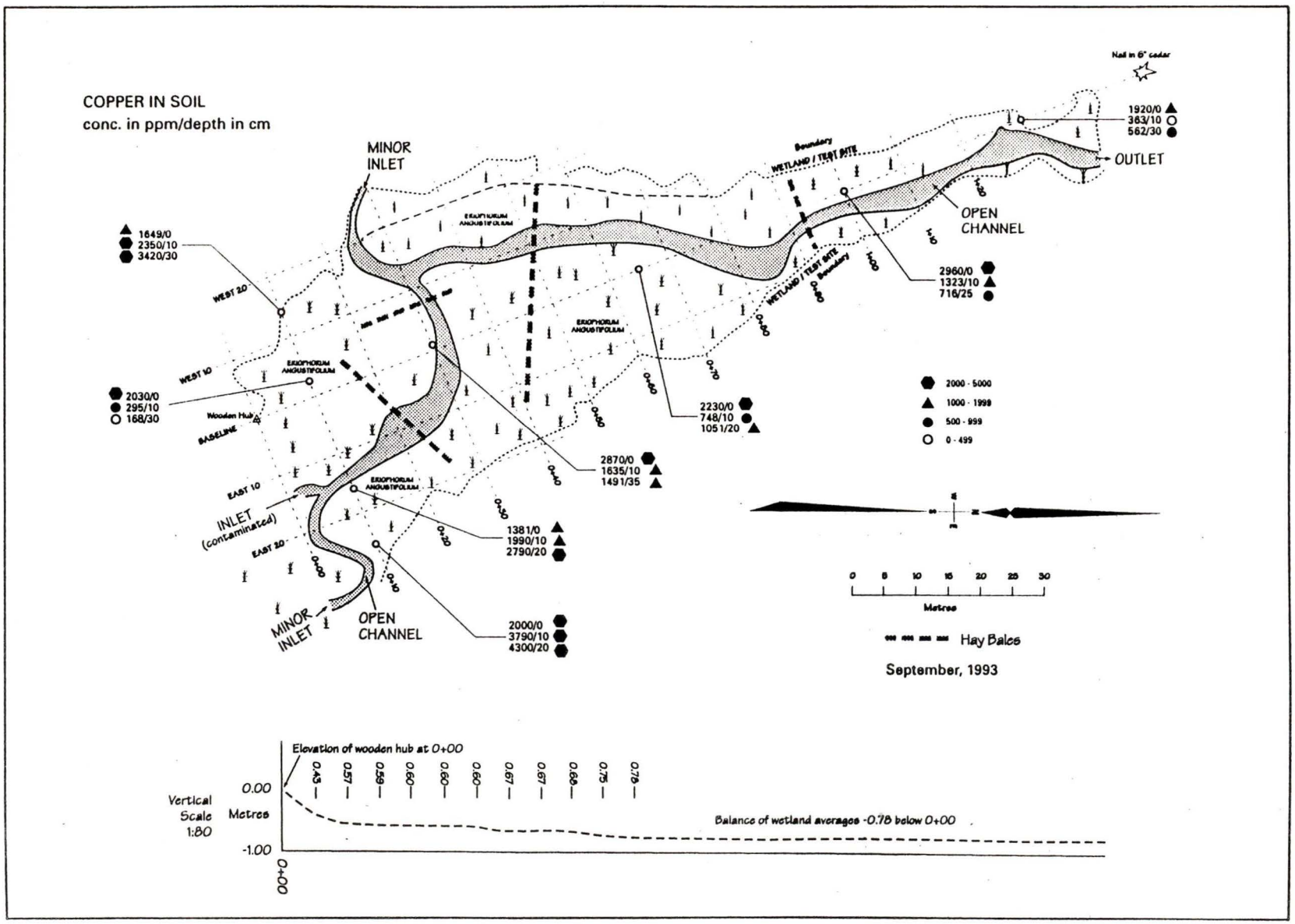


Figure A4-5: Copper in Soil (September, 1993)

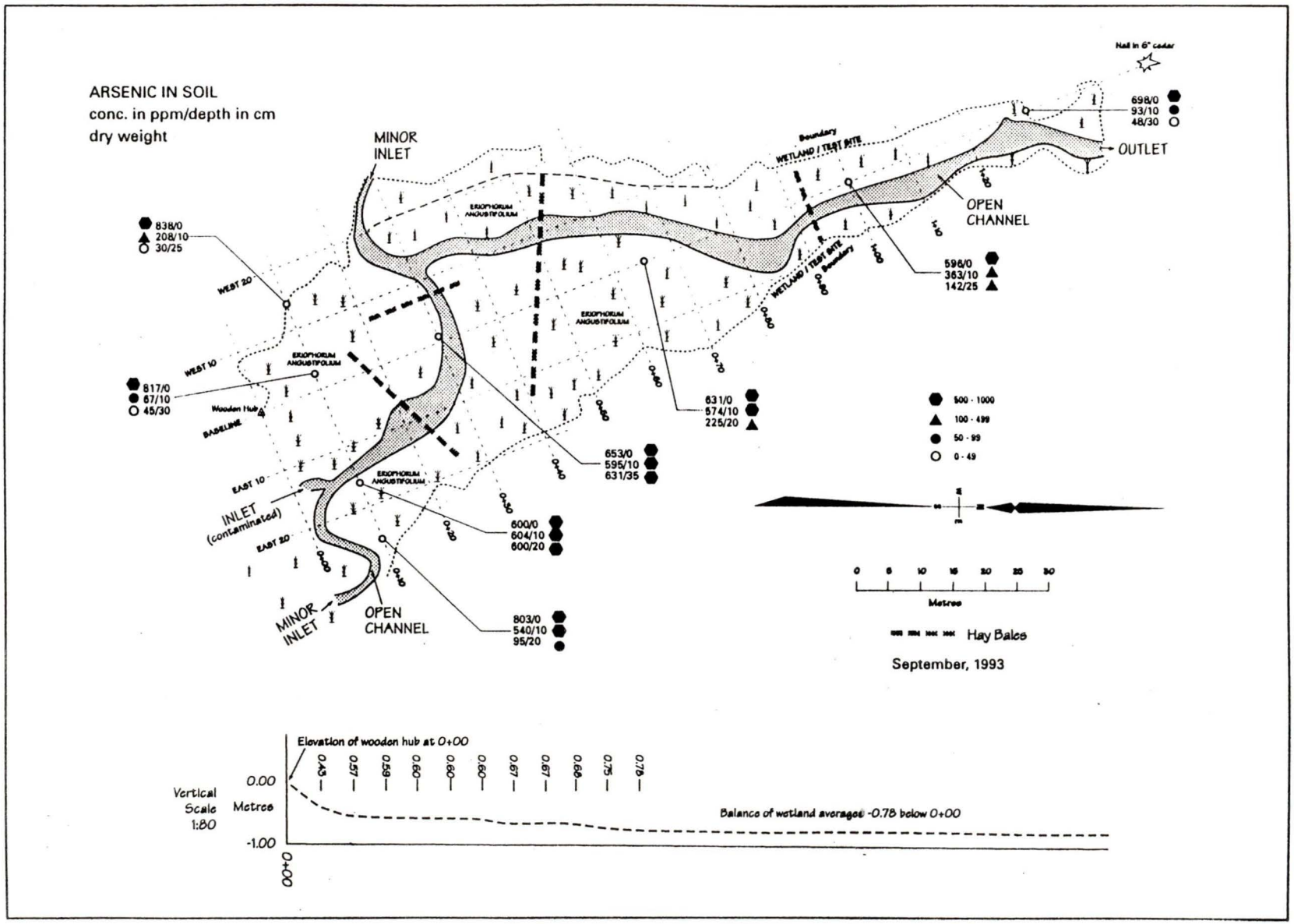


Figure A4-6: Arsenic in Soil (September, 1993)

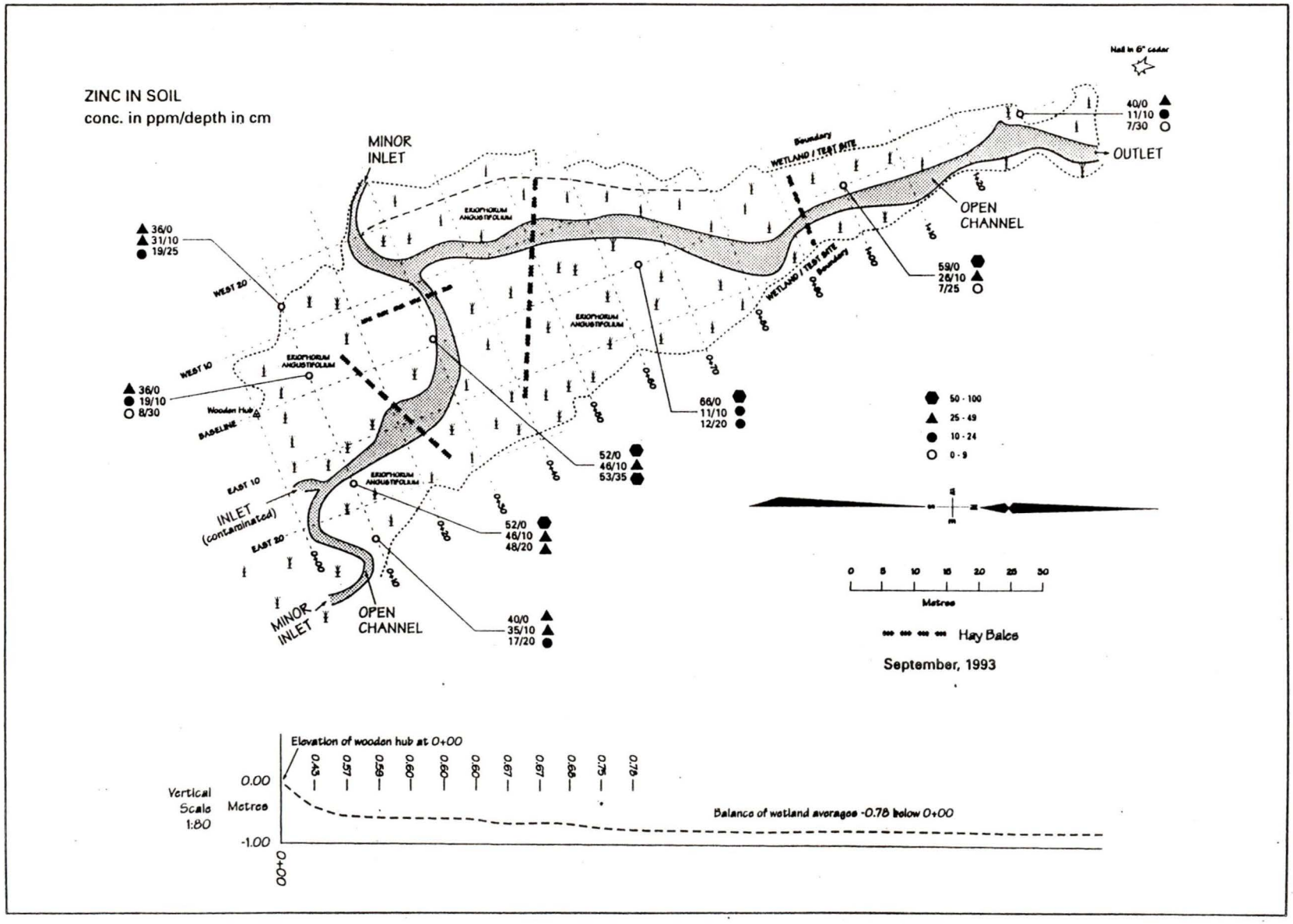


Figure A4-7: Zinc in Soil (September, 1993)

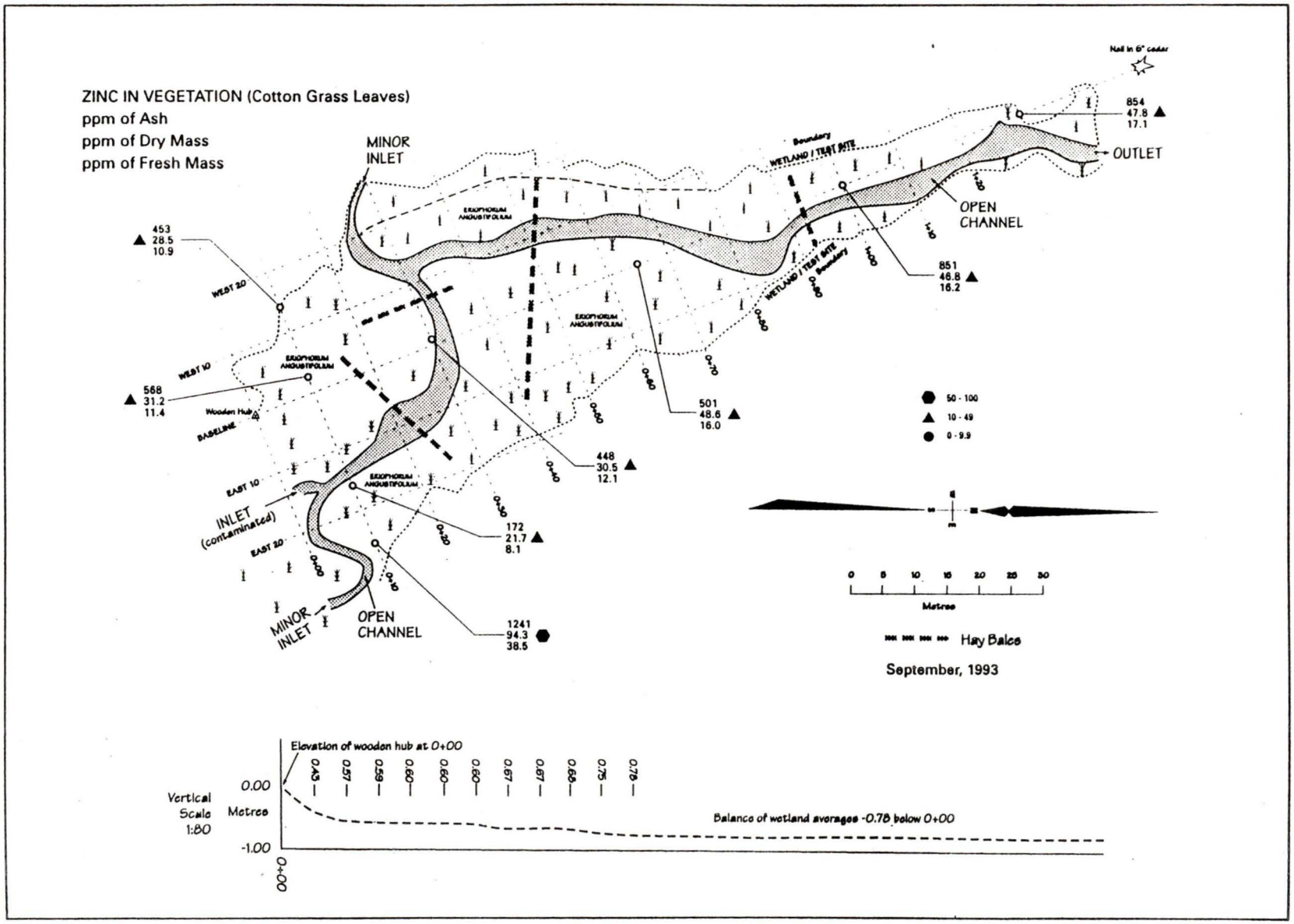


Figure A4-8: Zinc in Vegetation (September, 1993)

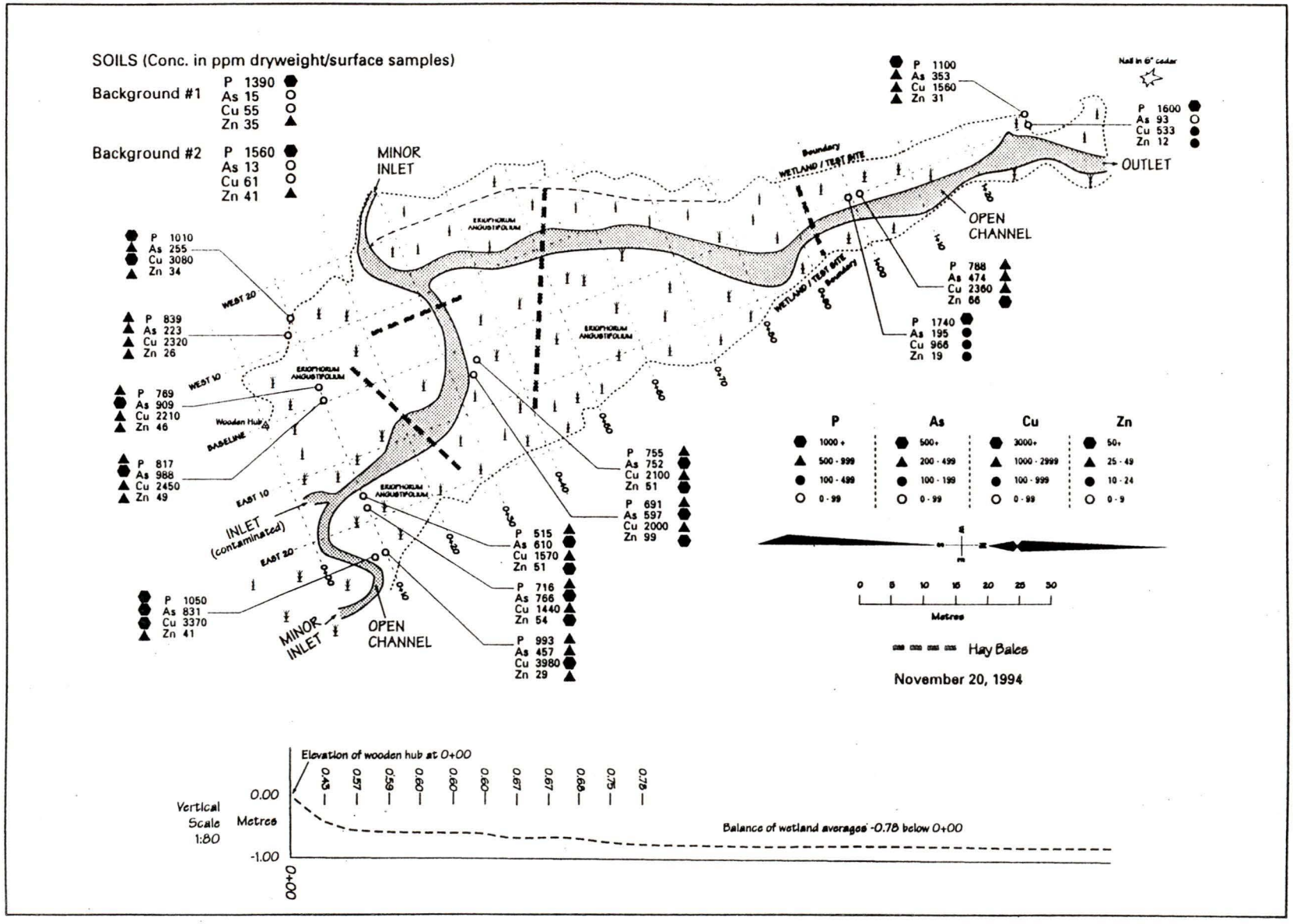


Figure A4-9: Soils (Elemental analysis for November, 1994)

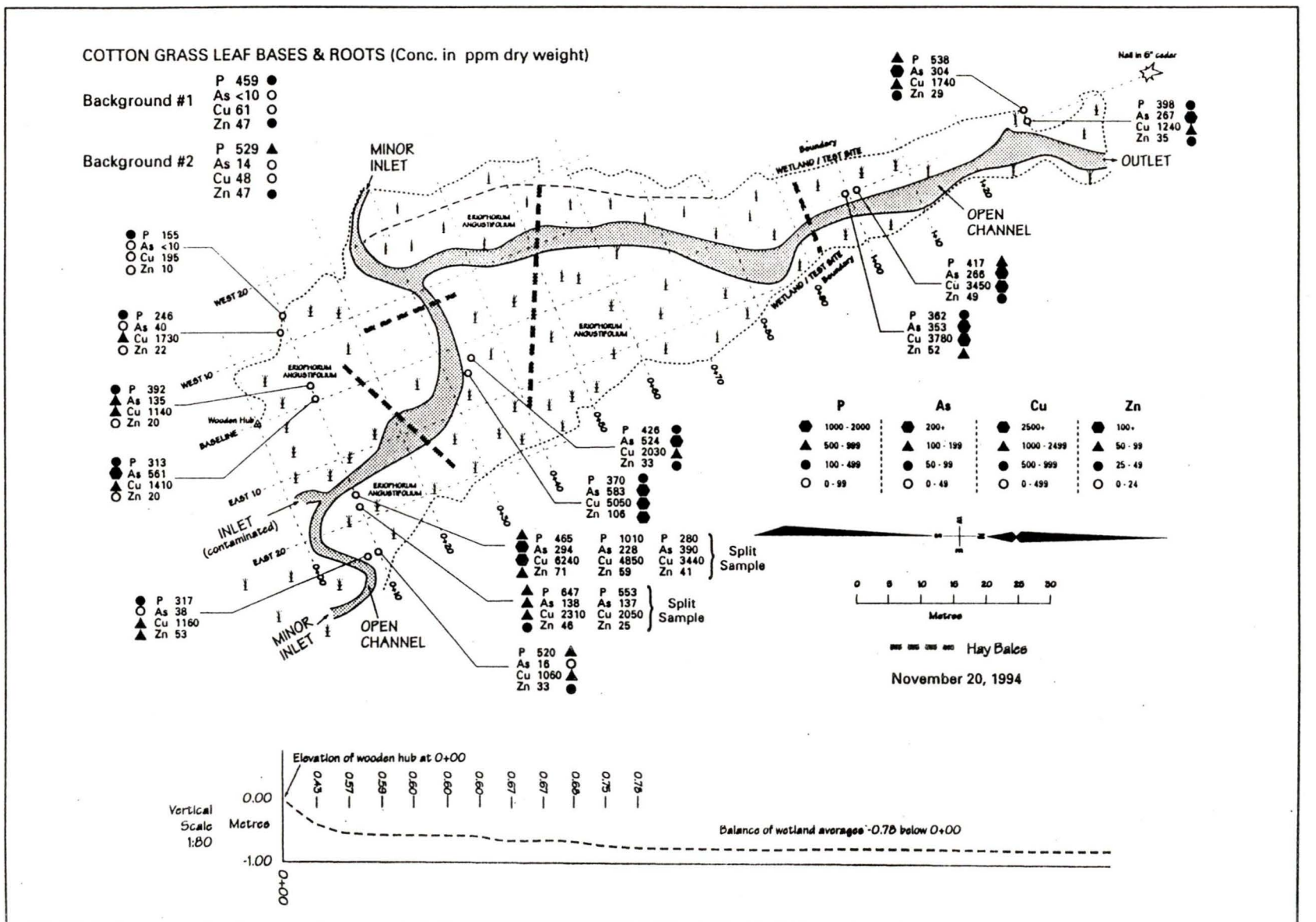


Figure A4-10: Cotton Grass Leaf Bases and Roots (Elemental analysis for November, 1994)

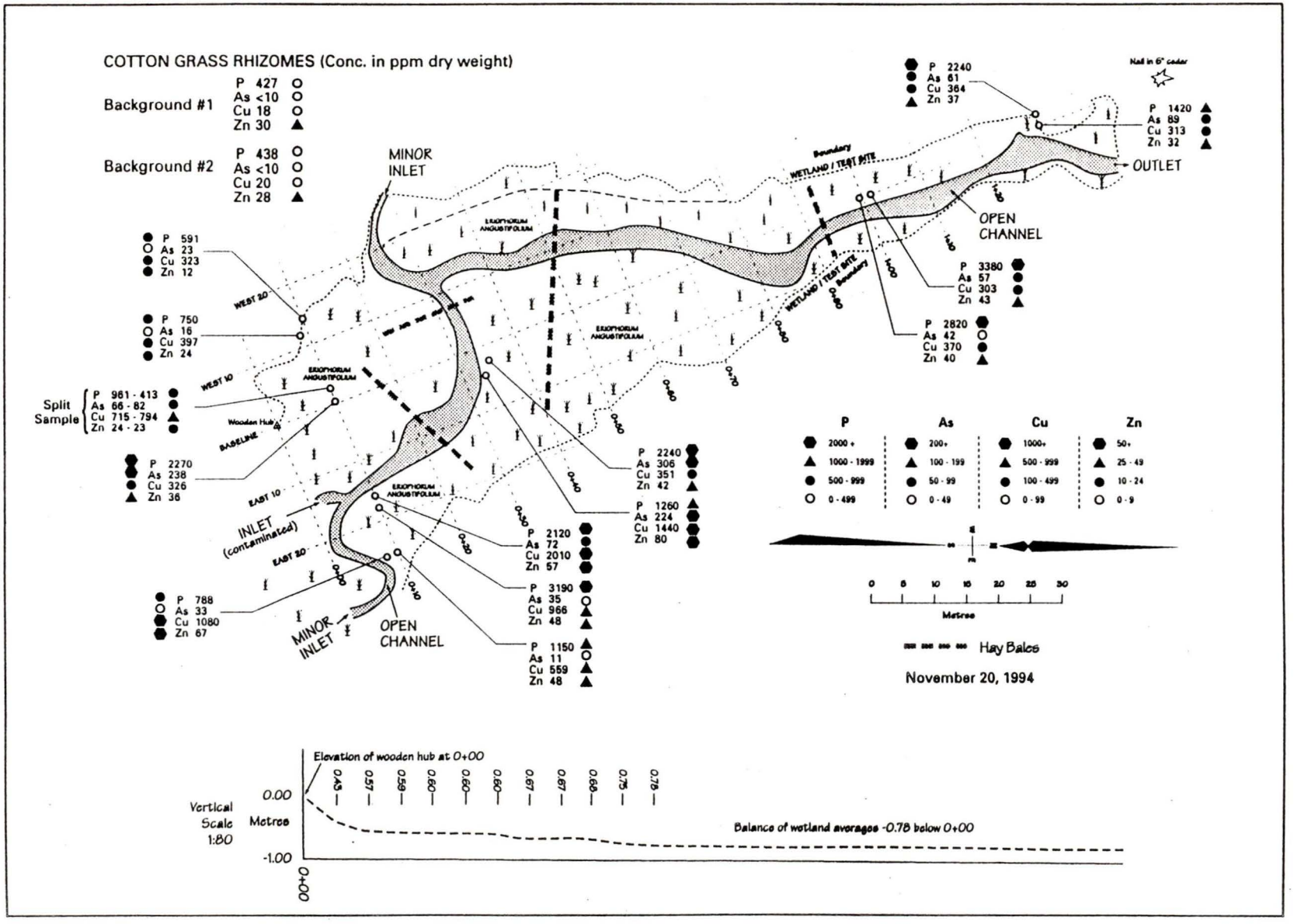


Figure A4-11: Cotton Grass Rhizomes (Elemental analysis for November, 1994)

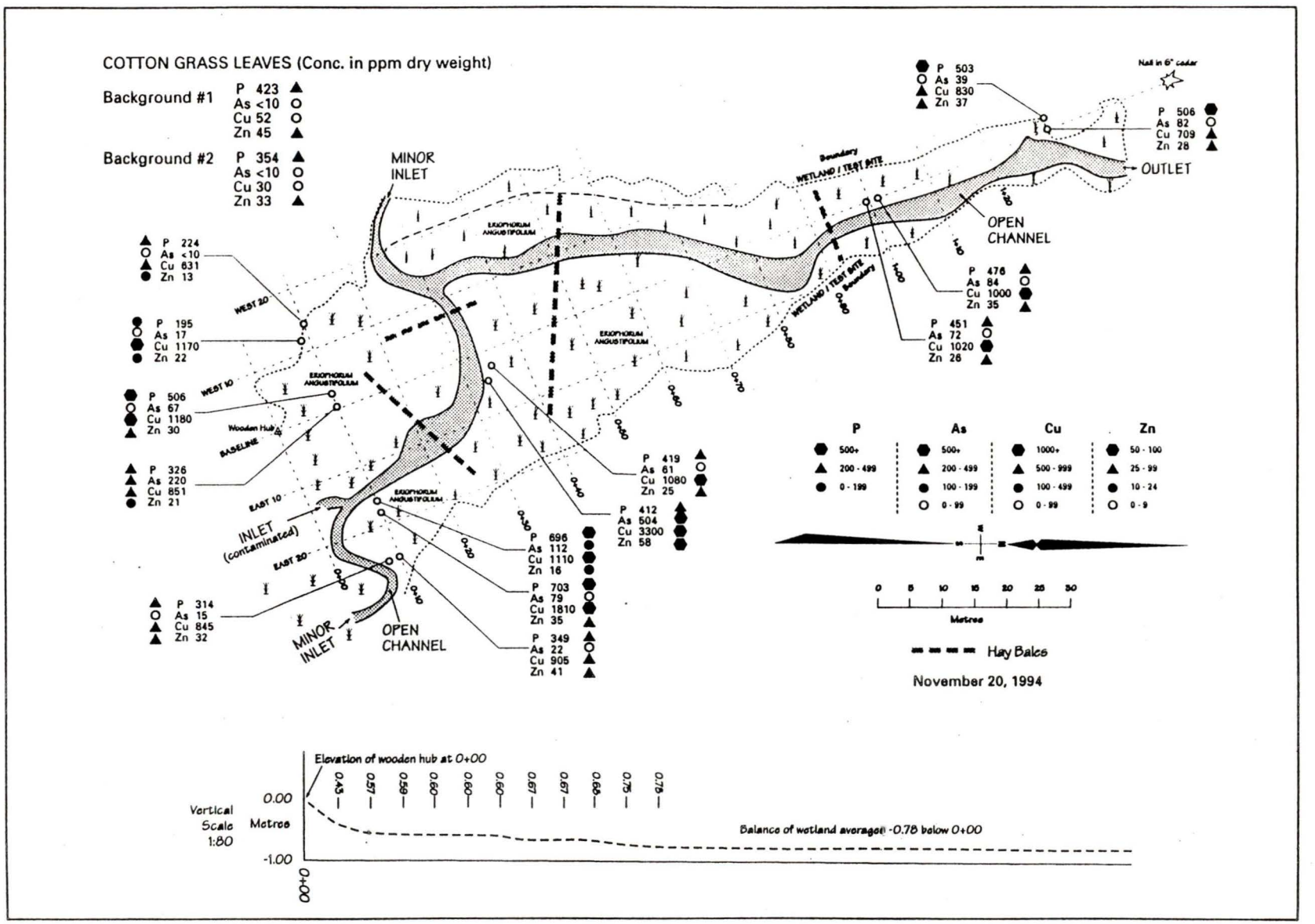


Figure A4-12: Cotton Grass Leaves (Elemental analysis for November, 1994)

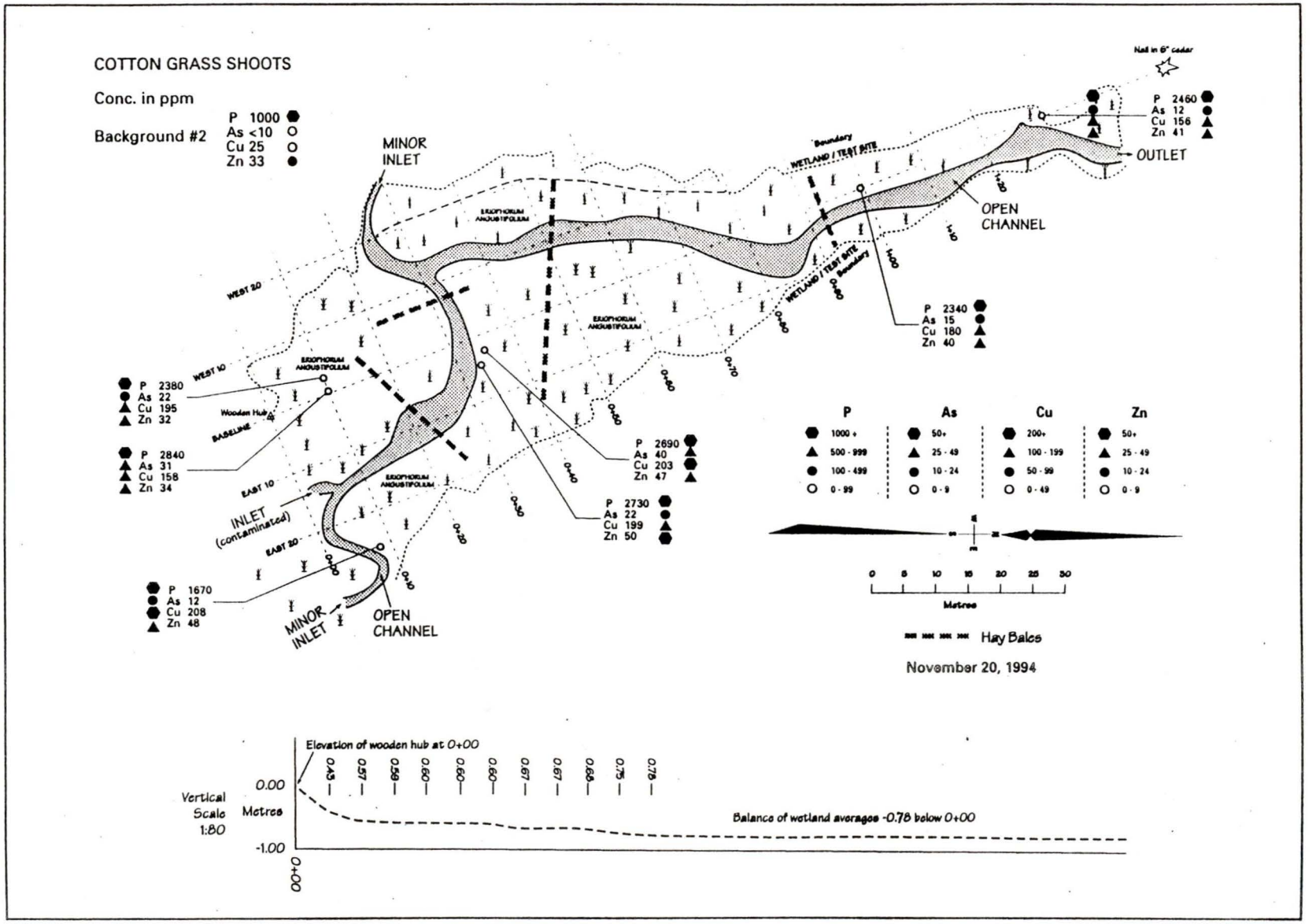


Figure A4-13: Cotton Grass Roots (Elemental analysis for November, 1994)

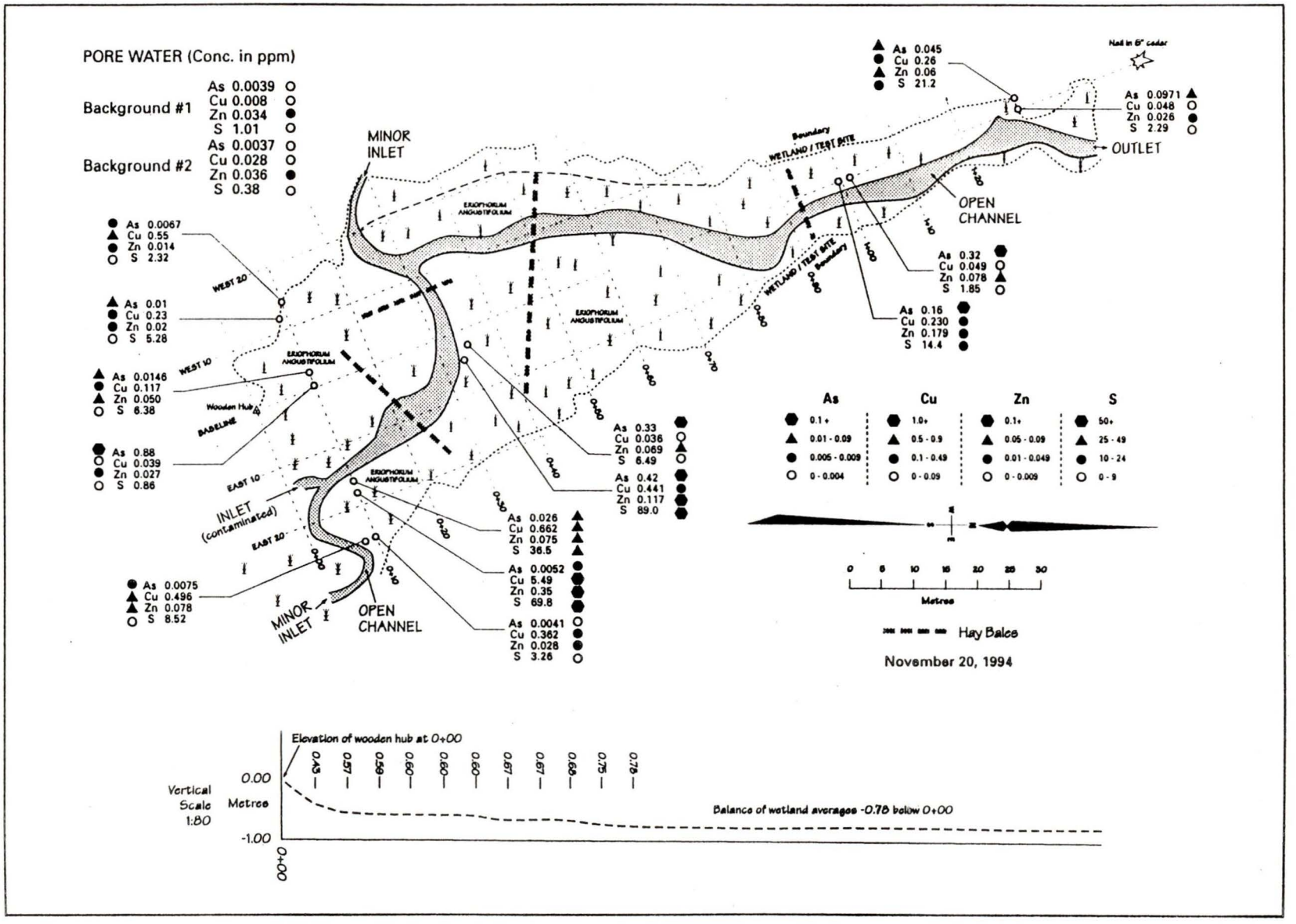


Figure A4-14: Pore Water (Elemental analysis for November, 1994)

Appendix 5: Review of Chemistry

Review of Chemistry

There are some general chemical reactions which are well studied, and influence the speciation of ions in an acid mine drainage situation. However, the presence of myriad species of bacteria belonging to different groups which are competing for some of the same resources and some of which release enzymes into their surroundings means that accurate and precise results are not very predictable at the present time. This is primarily because the bacterial enzymes can catalyze many of the reactions so that a straight comparison of phase diagrams will not predict the proportions of chemical species found. Even predicting which mines will and will not become acid-generating is not a certainty (Sobolewski, 1997).

The principal reaction, which starts off the problem, is the oxidation of pyrite by oxygen in the presence of water. In the equations below, it can be seen that this reaction, in the first line, leads to a further breakdown of the pyrite, as shown in the fourth equation. The ubiquitous *Thiobacillus ferrooxidans* further accelerates this reaction greatly, which in turn can raise the temperature of the substrate to the point were the reaction is proceeding fast enough to cause a fire to break out. Luckily, this does not occur at the minesite in question, but the bacillus is working to oxidize the pyrite there, and acid mine drainage is an environmental problem because of that.

Following are the initial reactions, which would be occurring at the minesite in the waste dump and in the wall rocks of the pit. Note that all but the second produce H^+ ions, increasing the acidity.

1. $2\ FeS_2\ (solid) + 7\ O_2 + 2\ H_2O \rightarrow 2\ Fe^{2+} + 4\ SO_4^{=} + 4\ H^+$

2. $4\ Fe^{2+} + O_2 + 4\ H^+ \rightarrow 4\ Fe^{3+} + 2\ H_2O$

3. $Fe^{3+} + H_2O \rightarrow Fe(OH)_3 = 3\ H^+$

4. $FeS_2 + 14\ Fe^{3+} + 8\ H_2O \rightarrow 15\ Fe^{2+}\ 2\ SO_4^{+} + 16\ H^+$

Oxidation of carbohydrates, such as cellulose (in our situation, found in all the plants and their remains, including the peat soil and the hay bales), also gives hydrogen ions (the glucose monomer is shown, the product of the hydrolysis of cellulose, see below in equation 7):

5. $6\ H_2O + C_6H_{12}O_6 \rightarrow 6\ CO_2 + 24\ H^+ + 24\ e^-$
(glucose)

Wetlands produce carbohydrate in the reverse of the above reaction (important in producing raw carbon-containing nutrient and raising pH).

6. HCO_3^- (aqueous) + 6 H2O $\rightarrow C_6H_{12}O_6 + 6\ O_2 + 6\ OH^-$
(glucose)

Under anaerobic conditions, microbial processes occur within the peat, some of which are using products of the top set of equations. These processes are: 7. Hydrolysis of the carbohydrates, notably cellulose, into glucose; 8. Fermentation of the glucose; 9. Methanogenesis; 10. Sulphate reduction; and 11. Iron reduction.

7. Hydrolysis

$(C_6H_{12}O_6)_n + n\ H_2O \rightarrow n\ C_6H_{12}O_6$
(cellulose) (glucose)

8. Fermentation (examples- many possibilities)

$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$
(ethanol)
$C_6H_{12}O_6 \rightarrow 2\ C_3H_4O_3 + 4\ H^+$
(pyruvic acid)

9. Methanogenesis

$CO_2 + 4\ H_2 \rightarrow CH_4 + 2\ H_2O$
(methane)

10. Sulphate Reduction:

$$6\ H^+ + 3\ SO_4^{=} + C_6H_{12}O_6 \rightarrow 3\ H_2S + 6\ H_2CO_3$$
(glucose)

11. Iron Reduction:

$$Fe^{3+} + e^- \rightarrow Fe^{2+}$$

The above reactions are reviewed in Wildeman *et al.* (1995).

Other non-toxic metals besides iron are present in sufficient amounts to affect the overall chemistry of the fen. Manganese is in the waters, and this metal can affect the pH in the following manner.

12. $2\ H_2O + Mn^{2+} \rightarrow MnO_2 + 3\ H^+ + 2\ e^-$

The metal of particular concern in the Mt. Washington situation is copper, since it is copper which is having the most deleterious effect on the Tsolum River. However, the amounts of other metals, such as zinc, aluminum and arsenic, in the waters or soils of the Pyrrhotite Creek drainage are of concern.

Aluminum

Aluminum solubility varies with pH. Aluminum compounds are least soluble close to neutral. Below pH 6 and above pH 8 their solubility increases dramatically (Schlesinger, 1991, p. 85).

Peat compounds appear to complex and/or adsorb quite large amounts of aluminum, in one experiment approximately 1% above the naturally occurring amount of ~0.3 %, when exposed to aluminum-rich water (Weider and Lang, 1986; Weider, 1990).

Most of the compounds associated with aluminum in acid drainage circumstances (Browne and Driscoll, 1992) are aluminum silicate complexes that correspond to the equation:

13. $pAl^{3+} + qH_4SiO_4 + rH_2O = Al_p(OH)_r(OSi(OH)_3)_q^{3p-q-p-r} + (q+r)H^+$

Browne and Driscoll (1992) investigated these complexes, and found species which corresponded to the values for p, q, and r of: 1, 1, 0; 2, 1, 2; and 2, 2, 2. The pH was between 4 and 5.5 in their experiments.

Investigating natural waters, they found up to 95% of the dissolved mononuclear Al was in these aluminum silicate complexes (Browne and Driscoll, 1992).

The aluminum and silicic acid comes from the weathering of feldspars, such as plagioclase and orthoclase:

14. $2\ KAlSi_3O_8 + 2\ H_2CO_3 + 9\ H_2O \rightarrow Al_2Si_2O_5(OH)_4 + H_4SiO_4 + 2\ K^+ + 2\ HCO_3^-$
(orthoclase) (kaolinite) (silicic acid)

The kaolinite can further decompose to gibbsite and silicic acid:

15. $Al_2Si_2O_5(OH)_4 + 7\ H_2O \rightarrow Al_2O_3{\cdot}3H_2O + 4\ H_4SiO_4$
(kaolinite) (gibbsite)

In regards to the situation on Mt. Washington, the single most important change that could reduce the amount of aluminum would be to increase the pH of the waters. Next, when this water is neutral, slow it down, as the reactions tend to be slow which precipitate the complexes. Raising their temperature will speed the reactions up dramatically, also, so holding the water until summer would allow the precipitations to occur.

Since the Al^{3+} when it precipitates as the hydroxide makes the water more acid, it is important to have ions which will react with the H^+, such as carbonate or processes which will use the hydrogen ions up.

16 a. $Al^{3+} + H_2O \Leftrightarrow Al(OH)^{2+} + H^+$

b. $Al(OH)^{2+} + H_2O \Leftrightarrow Al(OH)_2^+ + H^+$

c. $Al(OH)_2^+ + H_2O \Leftrightarrow Al(OH)_3 + H^+$

This is a flocculent precipitate, and bulky when compared to the clays.

Copper

The effects of copper on aquatic life are well-documented (Singleton, 1987). Toxic effects have been shown on rainbow trout fry at 0.0046 ppm (Marr *et al.*, 1996), and the limits as shown in Chapter 1, Table 1-1, set by the MOELP for freshwater is ≤0.002 ppm where the $CaCO_3$ concentration is ≤50 ppm.

Compounds of copper are readily soluble at low pH levels, but form insoluble oxides, carbonates (malachite and azurite), and sulphides at higher pH levels, depending on the environment and oxidation state of the copper ions.

For a solution containing 10 ppm Cu, 10 ppm Al, alkalinity 100 ppm, Ca 100 ppm, Fe 2 ppm, Mg 20 ppm, Mn 1.5 ppm, sulphate 80 ppm, Zn 0.5 ppm, an Eh of 100 mV, at a temperature of 8°C, and a pH of 6.4, precipitation products would include antlerite - $Cu_3(OH)_2CO_3$, brochantite - $Cu_4(OH)_6SO_4$, malachite - $Cu_2(OH)_2CO_3$ and azurite - $Cu_3(OH)_2(CO_3)_2$. These results were quoted by Sobolewski(1997b) from a simulation run under MINTEQA2. Lowering the temperature, increasing the pH, and increasing the copper concentration improves the proportion of copper precipitated.

From equation 6, the H_2S dissociates under more basic conditions to $HS^- + H^+$ and $S^=$. If the solution is too acid, the hydrogen sulphide is less soluble and may be lost through volatilization, also, if it is in an oxidizing environment, the hydrogen sulphide is readily oxidized to sulfurous acid, H_2SO_3. The formation of copper sulphides is as shown below, all the minerals shown have been found in wetlands. However, in the Bell mine project (there were two artificial wetlands, and a nearby lake served as a control), Sobolewski (1996) shows that most copper in the inlet areas of the wetlands was complexed with the organic materials of the wetlands (68% and 51%), much of the remainder (17% and 25%) was associated with the iron oxide phase of the wetlands, and the remainder as chalcocite (~5-10%) and chalcopyrite (~1% to ~13%). Grains of the latter mineral were found in the peat. The natural wetland at the lake had only chalcocite as a copper sulphide. Lett (1978) found chalcopyrite, chalcocite, and covellite in a Cascade Range bog, and noted that bornite was not found, although it should have been stable under the concentrations, oxidizing state, temperature, and other conditions in the wetlands he studied. See Figures A5-1 and A5-2.

17. a. $H_2S \Leftrightarrow HS^- + H^+$

b. $HS^- \Leftrightarrow S^= + H^+$

18. $2\ Cu^+ + S^= \rightarrow Cu_2S$

(Chalcocite)

19. $Cu^{2+} + Fe^{2+} + 2\ S^= \rightarrow CuFeS_2$

(Chalcopyrite)

20. $Cu^{2+} + S^= \rightarrow CuS$

(Covellite)

21. $2\ Cu^+ + 2\ OH^- \rightarrow Cu_2(OH)_2 \rightarrow Cu_2O + H_2O$

(Cuprite)

22. $5\ Cu^+ + Fe^{3+} \rightarrow Cu_5FeS_4$

Bornite

Depending on the environment, a drop in sulphate accompanied by an increase in oxygen can result in the formation of native copper, which also has been found in wetlands. Lett (1978) found some native copper grains rimmed with cuprite, together with covellite-chalcopyrite grains in a southern Cascade Mountain Range bog.

Figure A5-1: Simplified Eh-pH Diagram for Mineral Relationships in the Cu-Fe-S-O-H System at 25°C and 1 Atmosphere Pressure. Total dissolved sulphur concentration is 10^{-4}M and the light shaded area represents the approximate Eh-pH range of central bog waters in the southern Cascade Mountains. The diagram is based on that given by Garrels and Christ (1965) and modified by Lett (1978). Dark shaded area covers presumed range of this study.

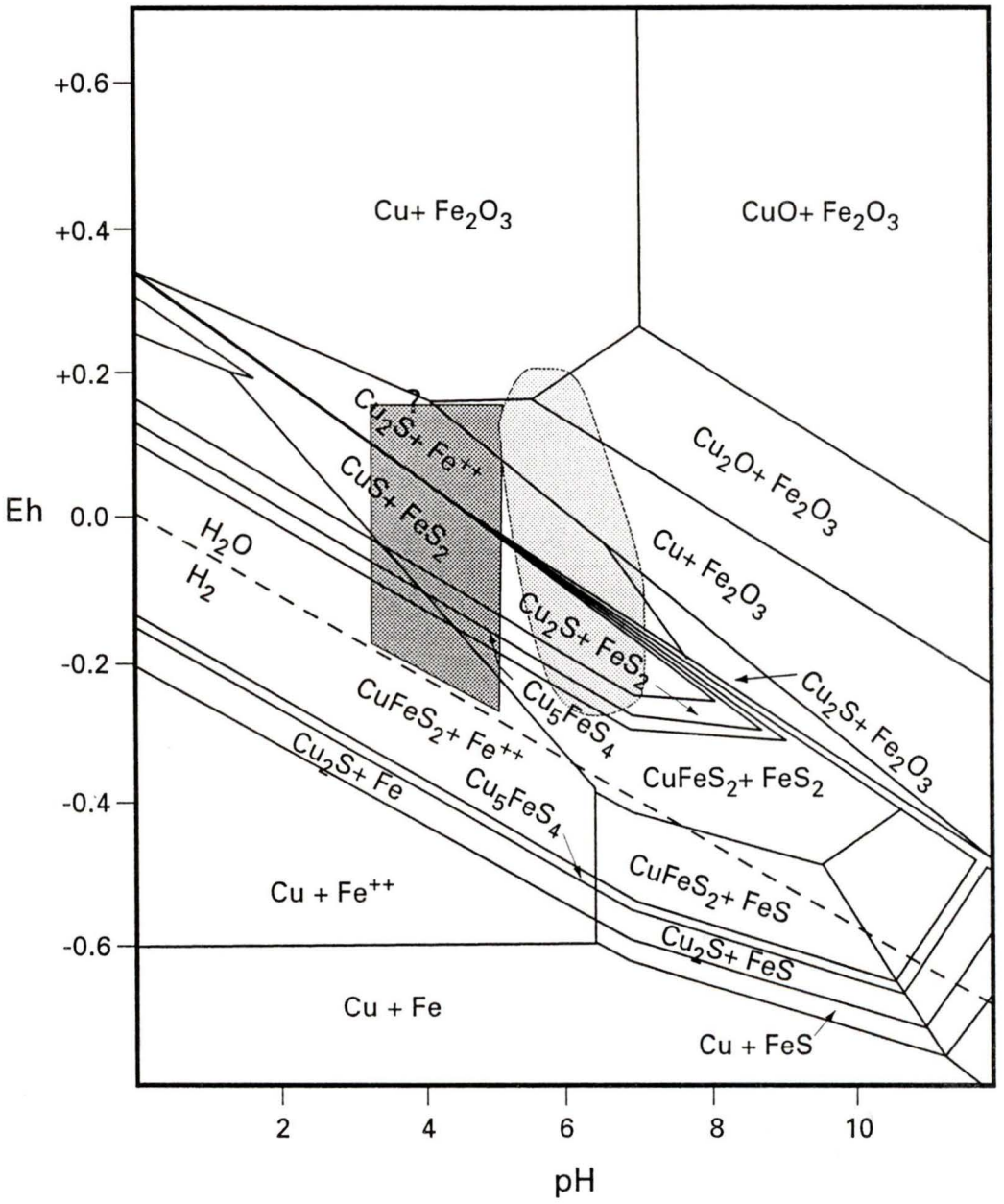
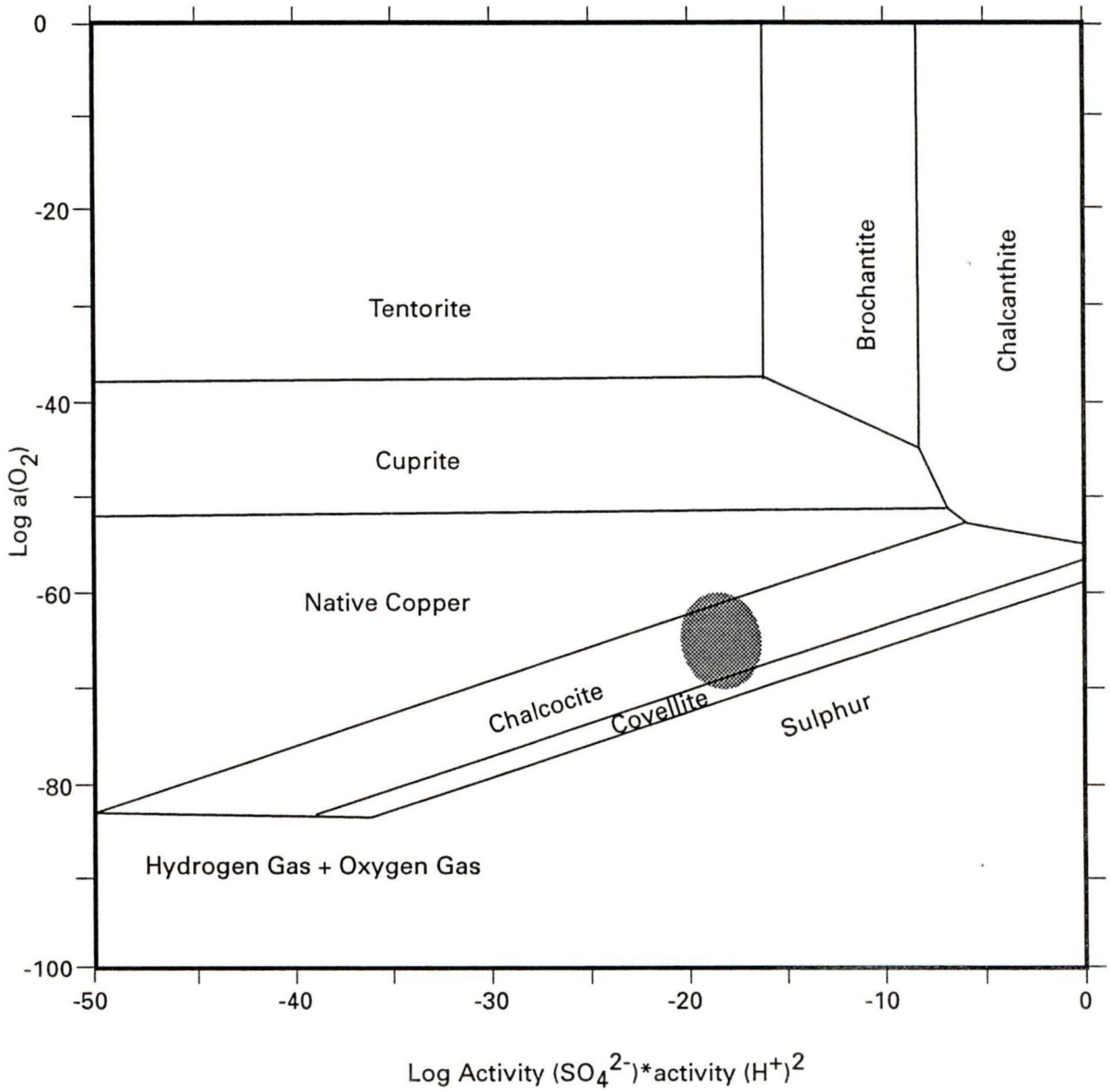


Figure 5A-1: Simplified Eh-pH diagram for mineral relationships in the Cu-Fe-S-O-H system at 25°C and 1 atmosphere pressure Total dissolved sulphur concentration is 10-4M and the shaded area represents the approximate Eh-pH range of central bog waters. The diagram is based on that given by Garrels and Christ (1965), modified by Lett, 1978.

Figure A5-2: Stability Relationships Between Copper Minerals in Water at 25°C and 1 Atmosphere Pressure as a Function of Log Activity Oxygen Gas and Log Activity Sulphate * Activity Hydrogen Ion^2. The shaded area indicates the approximate limits of subsurface bog water sample compositions (southern Cascade mountains) at pH 6.0 and Eh -100 mv. (from Lett, 1978).

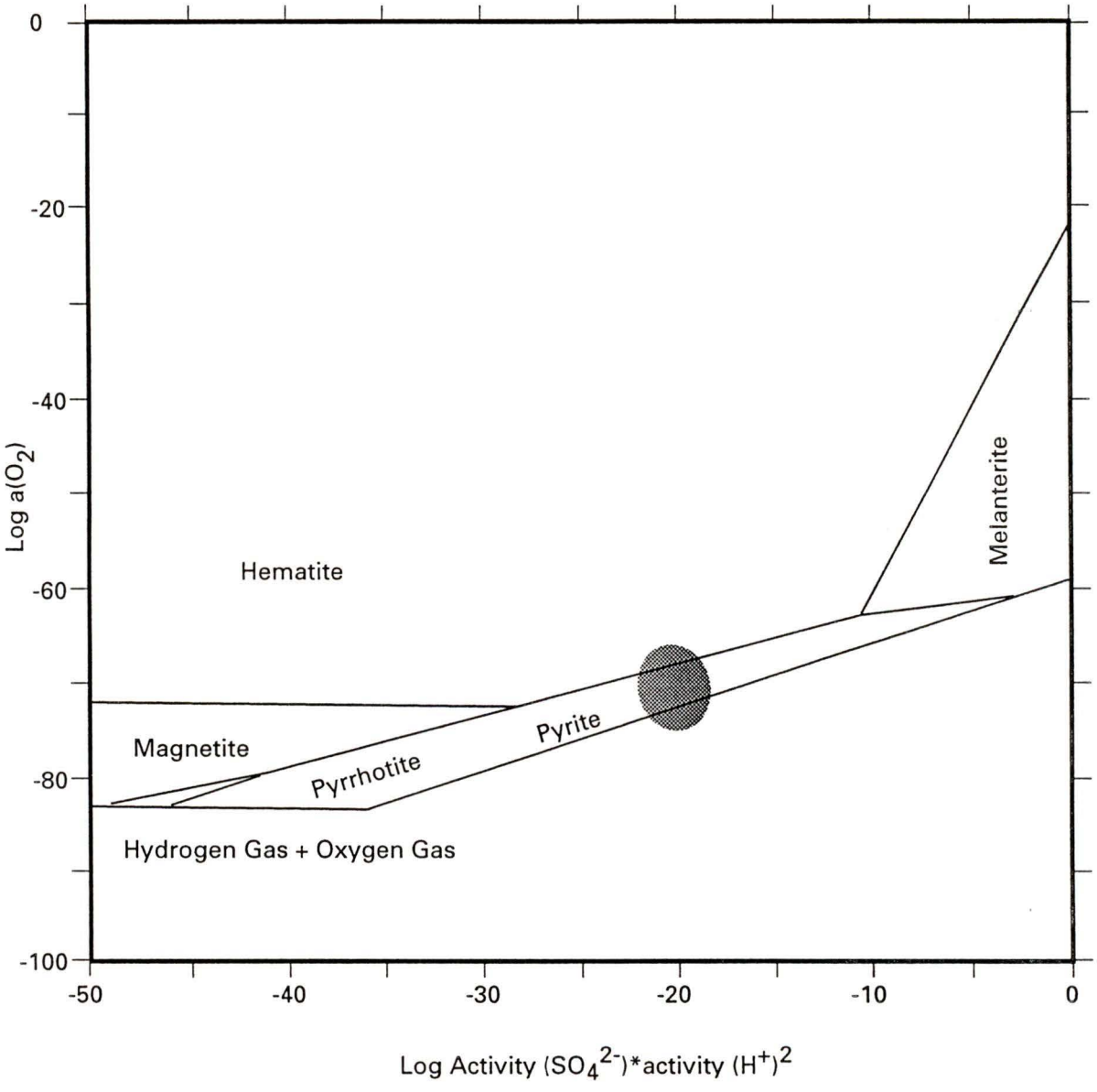


Iron

Iron is the metal in highest concentrations in most of our soil samples, although it is closely followed and occasionally exceeded by the aluminum concentrations. Under the appropriate conditions (strongly reducing, sulphide ion present, and basic water chemistry), the initial equations 1 and 4 (above) can be reversed, giving a precipitate of framboidal pyrite, which has been reported by Deniseger and Kwong (1996) in the Branch 126 sedge fen. Under oxidizing conditions, iron oxyhydroxides of very variable composition can be precipitated (goethite, limonite, etc.), and this can be seen on the surface of the alluvial fan at the south end of the wetland. A glance at some of the plates, especially Plate 12 in the lower right-hand corner, will bear this out. A somewhat flocculent scum of iron compounds (plus Al compounds?) is found throughout the wetland later in the summer, which could be easily transported in the summer rains from the area, and almost certainly in the winter rains.

Because of the buffering effect on pH (see equations 2 and 3), early iron and aluminum removal in any remediation situation will allow the pH to rise rapidly with the removal of H+ in sulphate reduction, which has the benefit of bringing more sulphide ions into solution from the reactions in equations 17. So, although iron is not normally toxic and aluminum is much less toxic than copper (see Table 1-1), removal of these metals is a priority in acid rock/acid mine drainage remediation.

FigureA5-3: Stability Relationships Between Iron Minerals in Water at 25°C and 1 Atmosphere Pressure as a Function of Log Activity Oxygen Gas and Log Activity Sulphate*Activity Hydrogen Ion^2.



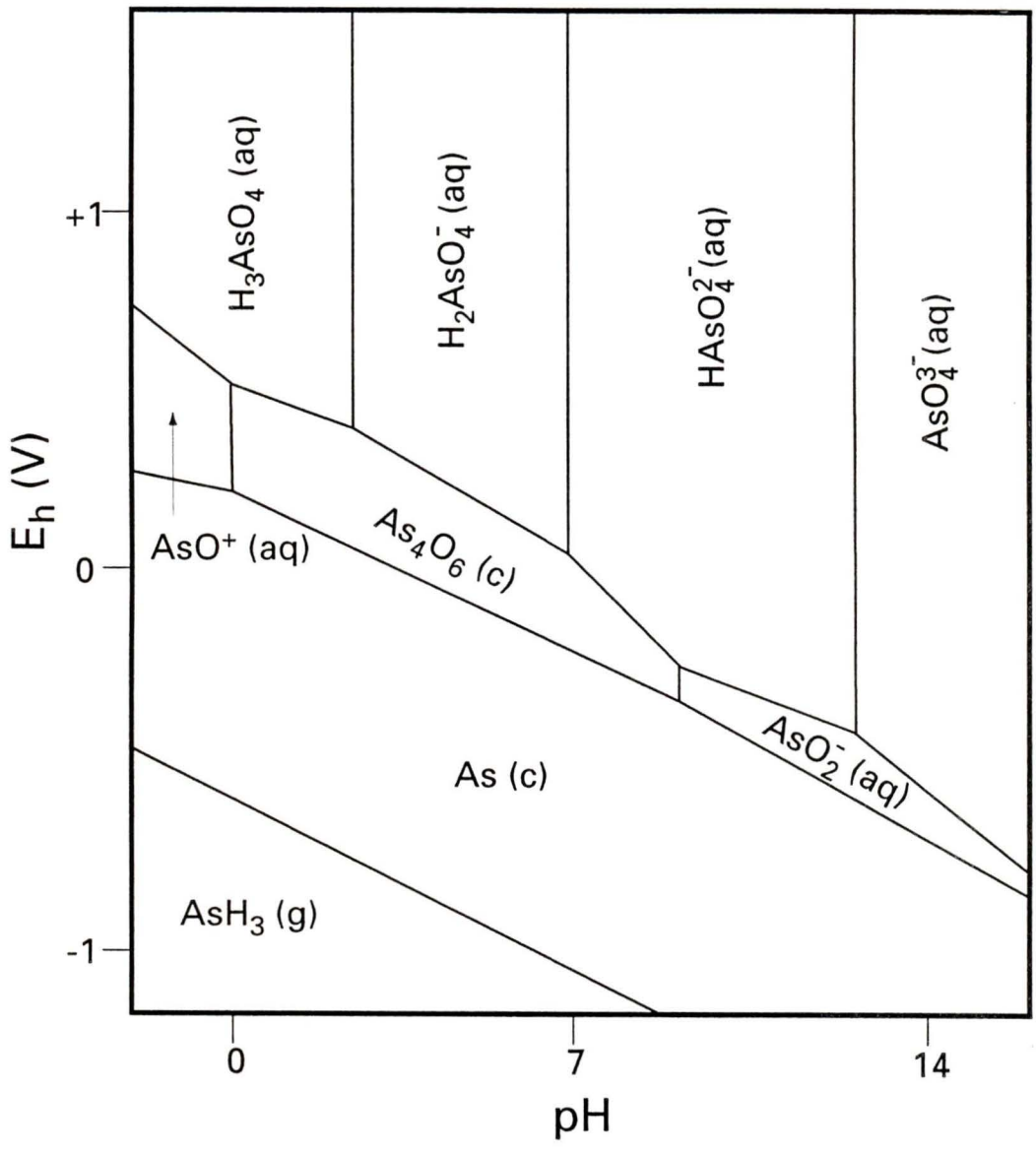
Stability relationships between iron minerals in water at 25°C and 1 atmosphere pressure as a function of Log activity oxygen gas and Log activity sulphate * activity hydrogen ion^2. The shaded area indicates approximate limits of subsurface bog water sample compositions at pH 6.0 and Eh -100mv (from Lett, 1978).

Arsenic

In natural waters, the important forms of arsenic are as As^{5+} in the species of arsenic acid H_3AsO_4 ($H_2AsO_4^-$, $HAsO_4^=$, AsO_4^{3-}) and as As^{3+} in the species of arsenious acid H_3AsO_3 ($H_2AsO_3^-$, $HAsO_3^=$, AsO_3^{3-}). The latter is a weak acid (the first dissociation constant $K= 6 \cdot 10^{-6}$). As(III) is more labile and more toxic than As(V) (Fergusson, 1991, p.551). Fergusson (1991, p.72) shows a standard Eh/pH diagram for arsenic species in aqueous systems.

Arsenic shares with aluminum an amphoteric nature, but its compounds are much less soluble at the lower pH ranges than it is closer to neutral. Arsenic can exist as As(V), As(III), As, and As(-III). Even so, so long as the pH is neutral or below, arsenic dissolution should not be a problem, as it is co-precipitated with iron oxyhydroxides (it is adsorbed by the positively charged ferric oxyhydroxides) (Golder, 1997). Also, "In acidic soils, the main forms of arsenic are aluminum and iron arsenates AlASO4 and FeAsO4, whereas in alkaline soils the main form is $Ca_3(AsO_4)_2$. The log Ksp of the three compounds are -15.8, -20.2 and -18.2 respectively, but because of their stochiometries, the aluminum and iron arsenates are less soluble than the calcium arsenate. " (Fergusson, 1991, p. 362). He also points out that under reducing conditions, the As(III) proportion increases. Almost all our soil samples have large amounts of iron and aluminum in them in a leachable form, which is likely where the arsenic is held. Arsenic(V) mimics the behaviour of phosphate somewhat, and interferes with the metabolism of that element, one of the reasons for its toxic properties (Fergusson, 1991, p. 552). Obviously, the amount of arsenic should be carefully monitored downstream of any wetland treatment installations.

Figure A5-4. Eh-pH Diagram for Aqueous Arsenic Species .



Eh-pH Diagram for Arsenic Species (from Fergusson, 1991)

Vita

Surname: Coombes

Given Names: David Mark Victor

Place of Birth: Bromborough, England

Educational Intstitutions Attended:

University of Victoria		1963-1972

Degrees awarded:

B.A.	University of Victoria	1969

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Author [redacted]

David Mark Victor Coombes

December 10, 1997