United Keno Hill Mines Limited

Report No. UKH/96/01

# United Keno Hill Mines Limited

# Site Characterization

## Technical Appendices I - VI

June 3, 1996

ACCESS MINING CONSULTANTS LTD.

# Appendix I - Appendix VI

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# Appendix I

## Minerals of the Keno Hill - Galena Hill Area

# Appendix I

## United Keno Hill Mines Limited

## Elsa, Yukon Territory

## Minerals of the Keno Hill - Galena Hill Area

| ORE | CHEMICAL FORMULA | DESCRIPTION |
|---|---|---|
| Freibergite | $(Cu,Fe,Zn,Ag)_{12}(Sb, As)_4S$ | Silver rich variety of tetrahedrite, also known as "Grey Copper". One of the most important ore minerals in the district. Steel grey to black in colour. Contains 10 to 30% Ag in the Keno/Galena area. |
| Pyrargyrite | $Ag_3SbS_3$ | An important ore mineral, also known as "Ruby Silver". Occurs primarily as coatings in narrow fractures. Contains 59.7% Ag. Has a distinct deep red colour but tarnishes black on exposure to light. |
| Polybasite | $(Ag,Cu)_{16}Sb_2S_{11}$ | Rare silver mineral. Found at Husky Mine. Occurs as hexagonal, platy crystals and sometimes as iridescent rosettes. Contains 75.6% Ag. |
| Stephanite | $Ag_5SbS_4$ | Occurs as black, stubby crystals associated with polybasite and pyrargyrite. Contains 6.85% Ag. |
| Native Silver | $Ag$ | Occurs as plates and wires, rare in district. Silver white in colour but tarnishes black. Has been noted within ice in some mines. |
| Galena | $PbS$ | The most important ore minerals in the Keno-Galena Hill area. Varies from coarse crystalline to fine-grained (often due to shearing). Extremely fine-grained variety is known as "Steel Galena". Most galena in this area contains from 0.8 to 1.5% Ag. |
| Sphalerite | $ZnS$ | Abundant mineral in many mines (except Husky system). Varies in colour from reddish brown to black in the iron rich varieties |
| Jamesonite<br>Bournonite<br>Boulangerite | $Pb_4FeSb_6S_{14}$<br>$PbCuSbS_3$<br>$PB_5Sb_4S_{11}$ | Lead sulphosalts occurring in small quantities in siderite-galena veins. Lead grey fibrous in appearance and difficult to distinguish from each other. |
| Greenockite<br>Hawleyite | $CdS$ | Greenish-yellow, powdery cadmium minerals usually associated with sphalerite and siderite. |

## United Keno Hill Mines Limited
## Elsa, Yukon Territory
## Minerals of the Keno Hill - Galena Hill Area

| ASSOCIATED VEIN | CHEMICAL FORMULA | DESCRIPTION |
|---|---|---|
| Pyrite | $FeS_2$ | Common sulphide mineral occurring in all veins. Colour is pale brass-yellow, sometimes iridescent. Crystals cubic or octahedral. |
| Arsenopyrite | $FeAsS$ | Silver white to steel grey mineral found associated with quartz and pyrite but much less abundant. and pyrite but much less abundant. |
| Marcasite | $FeS_2$ | Pale bronze-yellow tabular crystals. Very similar to pyrite but much less abundant. |
| Chalcopyrite | $CuFeS_2$ | Brass-yellow copper mineral found in some siderite/galena veins. |
| **GANGUE** | **CHEMICAL FORMULA** | **DESCRIPTION** |
| Siderite | $FeCO_3$ | The most abundant gange mineral in vein faults on Keno/Galena Hills. Colour is usually cream to brown, maganiferous variety is black. |
| Quartz | $SiO_2$ | Widespread mineral in all rocks and vein zones. Occurs occasionally as hexagonal crystals (crystals not common in district). |
| Barite | $BaSO_4$ | Occurs in small quantities in some vein structures. Often as well formed crystals, white or colourless. well formed crystals; white or colourless. |
| Calcite | $CaCO_3$ | Widely occurring mineral in most rock types. Colourless or white. Rhombohedral crystals. |

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| SECONDARY | CHEMICAL FORMULA | DESCRIPTION |
|---|---|---|
| Cerussite | $PbCO_3$ | Found in oxidized zones of deposits containing galena. White to Grey, earthy. Occurs with anglesite. |
| Anglesite | $PbSO_4$ | Usually light to dark grey. Occurs as earthy coatings or concentrate bands around galena. |
| Malachite | $Cu_2(OH)_2(CO_3)$ | Found in oxidized zones usually as an alteration product of freibergite or chalcopyrite. Bright green in colour. |
| Azurite | $Cu_3(OH)_2(CO_3)_2$ | Associated with malachite as an alteration product of freibergite or chalcopyrite. Bright green in colour. |
| Copper Sulphates | $CuSO_4$, $5H_2O$<br>$Cu_4SO_4(OH)_6$ | Chalcanthite, Brochantite, Antlerite. Green to sky blue. Occur in upper oxidation zones from alteration of copper minerals. |
| Limonite | $HFeO_2$ | Yellowish brown to reddish brown earthy material. Oxidation product of minerals containing iron (pyrite, siderite, etc.). Most common oxidation mineral in area. |
| Pyrolusite | $MnO_2$ | Common manganese mineral found in oxidized parts of veins. Similar to manganite, wad, etc. |
| Bindheimite | $Pb_2Sb_2O_6(O,OH)$ | Occurs as earthy coatings on primary sulphosalts. Widely distributed in oxidized veins. |
| Beudantite | $PbFe_3(AsO_4)(SO_4)(OH)_6$ | Occurs as crusts, crystal coatings, cryptocrystalline aggregates and banded seams. Widely distributed in oxidized veins. |
| Scorodite | $(Fe,Al)(AsO_4)2H_2O$ | Yellowish green to greenish brown. Abundant in deeply oxidized quartz-pyrite-arsenopyrite-gold veins on Keno Hill as alteration product of arsenopyrite. |

# United Keno Hill Mines Limited
# Elsa, Yukon Territory
# Minerals of the Keno Hill - Galena Hill Area

| OTHER MINERALS | |
|---|---|
| **MINERAL** | **CHEMICAL FORMULA** |
| Acanthite | $Ag_2S$ |
| Aragonite | $CaCO_3$ |
| Argentite | $Ag_2S$ |
| Argentojarosite | $AgFe_3(SO_4)_2(OH)_6$ |
| Argyrodite | $Ag_8GeS_6$ |
| | |
| Aurichalcite | $(Zn,Cu)_5OH_6(CO_3)_2$ |
| Biotite | $K(Mg,Fe)_3(AlSi_3O_{10})(OH)_2$ |
| Bornite | $Cu_5FeS_4$ |
| Chalcocite | $Cu_2S$ |
| Chalcophanite | $ZnMn_3O_7.3H_2O$ |
| | |
| Chlorargyrite | AgC1 |
| Chlorite | $(Mg,Fe,Al)_6(Al,Si)_4O_{10}(OH)_8$ |
| Covellite | $CuS$ |
| Corkite | $PbFe_3PO_4SO_4(OH)_6$ |
| | |
| Coronadite | $Pb(Mn^{2+},Mn^{4+})_5O_{16}$ |
| Digenite | $Cu_{2-x}S$ |
| Dolomite | $CaMg(CO_3)_2$ |
| Dundasite | $PbAl_2(CO_3)_2(OH)_4.2H_2O$ |
| Gold | Au |
| | |
| Graphite | C |
| Geothite | $HFeO_2$ |
| Gunningite | $ZnSO_4.H_2O$ |
| Gypsum | $CaSO_4.2H_2O$ |
| Ice | $H_2O$ |
| | |
| Ilesite | $(Mn,Fe,Zn)SO_4.4H_2O$ |
| Indium | In |
| Kaolinite | $Al_2Si_2O_5(OH)_4$ |
| Massicot | $PbO$ |
| Meneghinite | $Pb_{13}Sb_7S_{23}$ |
| | |
| Miargyrite | $AgSbS_2$ |
| Mimetite | $Pb_5(AsO_4)_3Cl$ |
| Mimium | $Pb_3O_4$ |
| Montmorillonite | $(Na,Ca)_{0.33}(Al,Mg)_2Si_4O_{10}(OH)_2.nH_2O$ |
| Muscovite | $KAl_2(AlSi_3O_{10})(OH)_2$ |

## United Keno Hill Mines Limited
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## Minerals of the Keno Hill - Galena Hill Area

| OTHER MINERALS | |
|---|---|
| **MINERAL** | **CHEMICAL FORMULA** |
| Pavonite | $AgBi_3S_5$ |
| Pharmacosiderite | $Fe_3(AsO_4)_2(OH)_3.5H_2O$ |
| Plumbojarosite | $PbFe_6(SO_4)_4(OH)_{12}$ |
| Psilomelane | $BaMn^{2+}Mn^{4+}{}_8O_{16}(OH)_4$ |
| Pyromorphite | $Pb_5(PO_4)_3Cl$ |
| | |
| Pyrrhotite | $FeS$ |
| Rhodochrosite | $MnCO_3$ |
| Rozenite | $FeSO_4.4H_2O$ |
| Senarmonite | $Sb_2O_3$ |
| Serpentine | $(Mg,Fe)_3Si_2O_5(OH)_4$ |
| | |
| Smithsonite | $ZnCO_3$ |
| Sphene | $CaTiSiO_5$ |
| Stibnite | $Sb_2S_3$ |
| Sulphur | $S$ |
| Szmikite | $MnSO_4.H_2O$ |
| | |
| Szomolnokite | $FeSO_4.H_2O$ |
| Tennantite | $Cu_{12}As_4S_{13}$ |
| Tetrahedrite | $Cu_{12}Sb_4S_{13}$ |
| Tourmaline | $Na(Mg,Fe)_3Al_6(BO_3)_3(Si_6O_{18})(OH)_4$ |
| Zinc | $Zn$ |

# Appendix II

# Design of a Passive System for Treatment of Discharges from the Galkeno 900 Adit at the United Keno Hill Mine Camp

Microbial Technologies

United Keno Hill Mines Ltd. Closure Plan

# Design of a Passive System for Treatment of Discharges from the Galkeno 900 Adit at the United Keno Hill Mine Camp.

Draft Technical Report

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MICROBIAL
TECHNOLOGIES

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# EXECUTIVE SUMMARY

Considerable anecdotal information indicates that wetlands can effectively neutralize and remove metals from contaminated mine drainage. As far back as 1965, Boyle (1965) noted that "(a bog) into which the mine water from the Hector-Calumet mine flows, effectively removes all of the zinc (40 ppm) in less than 2,000 feet." A review of the technical literature corroborates this view: natural wetlands have been documented to neutralize acidic discharge and remove metals and metalloids such as aluminum, arsenic, copper, iron, lead, manganese, radium, and zinc.

It is generally recognized that wetland plants play a supportive role in metal removal by providing the environment favouring important chemical and microbial processes. Thus, they produce detritus which can adsorb and retain certain metals. This organic matter also sustains microbial activity which injects alkalinity into the water. Microbes catalyse oxidation and hydrolysis reactions causing iron and manganese to precipitate. These oxides provide surfaces which interact with dissolved metal, leading to their removal from mine water. Finally, anaerobic microbes respiring on sulphate produce hydrogen sulphide, consume acidity, and raise water pH. The sulphide ion reacts with many metals, including cadmium, copper, iron, lead, nickel, and zinc, forming insoluble precipitates that remain buried in the anaerobic sediments.

The use of wetlands to treat mine drainage has been exploited since the early 80's in North America. Initial successes with wetlands treating coal-generated acid mine drainage in the Eastern States has resulted in the construction of over 300 wetland treatment systems (WTS). These systems treat water on a year-round basis, neutralizing water with pH as low as 2.5, flows as high as 35 L/sec., and reducing aluminum, iron and manganese from initial concentrations as high as 100, 300, and 100 mg/L, respectively (R.P.L. Kleinmann and D. Kepler, personal communication). Extensive monitoring experience has resulted in the derivation of standardized design criteria (Hedin *et al.*, 1994):

1. Net acid mine drainage is pre-treated with an anoxic limestone drain (at 7,800 $kg/L.min^{-1}$ of flow), followed by an aerobic wetland, or is treated in a compost-based wetland [minimum size ($m^2$) = acidity loading ($g.day^{-1}$)/7].

2. Net alkaline mine drainage is treated to remove iron at a rate of 20 $g/m^2$/day and manganese at a rate of 0.5 $g/m^2$/day.

Additional criteria have been developed for aluminum or for water containing a combination of contaminants to be treated, based on consideration of metal geochemistry and on knowledge of wetland processes. Similar design criteria are unavailable for mine drainage other than from coal mines. Therefore, data necessary for their design must be generated through field studies. Such a field program was instituted in the summer of 1995.

Investigations of natural wetlands in the vicinity of the United Keno Hill camp revealed that they are able to improve the quality of contaminated mine drainage. One small swamp near the Husky adit was shown to increase water pH from 1.06 to 6.56 within a distance of fifteen feet! Another swamp was shown to reduce zinc concentrations from 3 mg/L to 0.3 mg/L.

Plants from two wetlands receiving contaminated mine drainage did not take up metals accumulated in sediments. An analysis of the metal species retained in these sediments revealed that metals were largely retained by sorption onto iron and manganese oxides, and by precipitation as sulphides. These metals resisted leaching by low pH water (pH 4), indicating that they were stably retained in these sediments.

A 9 x 18.5 metre pilot wetland was constructed in May 1995 near the Galkeno 900 adit to determine whether it could improve the quality of its discharge. Zinc was shown to be removed by the wetland from an initial concentration of 25 mg/L to 4-5 mg/L, on flows of 3 L/min. A concurrent study using *in situ* microcosms indicated that zinc concentrations could be reduced to less than 0.3 mg/L. The rate of zinc removal calculated from the *in situ* microcosms data was in good agreement with rates estimated for the Galkeno constructed wetland and a natural wetland. Cadmium, manganese and nickel were also reduced to low concentrations. Sulphate reduction in sediments and formation of insoluble metal sulphides appeared to be the primary process responsible for their removal.

These data provide the basis for designing a wetland system to treat the discharge from the Galkeno 900 adit. For the past 10 years, this discharge has averaged 29 ppm zinc and flows of 7.4 L/sec. For design purposes, flows of 10 L/sec containing 33 ppm were assumed. While discharges limits in the water license are set to 0.5 mg/L, the design objective has been set at 0.25 mg/L. Using the above rate equation and design criteria, a retention time of 26 days will be required to treat a discharge of 864 $m^3$/d. This necessitates building a series of wetlands averaging approximately 450 x 20 x 0.5 metre. A gently sloping area downgradient of the Galkeno 900 adit could accommodate these wetlands. This design assumes that treatment would be provided on a year-round basis. An alternative option would be to store water in the adit during the winter months and release it for treatment during the summer. Regardless of the option eventually selected, the current treatment with lime will need to be continued for the next 3-4 years to give time for the wetlands to be constructed, planted, and for biomass to accumulate sufficiently for effective treatment.

# 1. Introduction

Exploration geologists have long known that wetlands (swamps, bogs, etc) act as sinks for metals in the environment. Occasionally, their casual observations have been documented in reports published in the technical and scientific literature. For instance, Boyle (1965) reported that:

> "Streams and springs that dissipate their water into bogs have their zinc (as well as other metals) largely removed as a result of adsorption on decaying vegetation, humic compounds, and other organic colloidal substances. Initially, this zinc is loosely bound and can be removed by acid or citrate solutions. With aging, however, the zinc partakes of the organic colloidal complexes and is then relatively tightly bound and unavailable to most extractants...Numerous bogs that extract zinc from surface waters were observed in the Keno Hill area. One of these into which the mine water from the Hector-Calumet mine flows, effectively removes all of the zinc (40 ppm) in less than 2,000 feet."

Developments in the past 10-15 years have shown that wetland treatment systems (WTS) provide a viable option for the treatment of metal-contaminated mine drainage, as well as contaminated discharges from other industries (Moshiri, 1993). The objectives for this technical document are to present technical information validating this concept and to provide field data supporting the design of a WTS to passively remediate water produced from the Galkeno 900 adit.

Information from the scientific literature and other sources documenting the performance of and processes occurring in WTS will first be reviewed. Elements of design will also be discussed in general terms. This information is presented to provide the reader with the technical knowledge necessary to evaluate subsequent work performed at the United Keno Hill (UKH) camp.

Results from field work performed during the summer of 1995 will be presented next. A number of natural wetlands which ameliorate the quality of mine drainage at UKH will be described. Laboratory tests conducted on samples collected from these wetlands provide additional information on the fate of metals accumulated in wetland sediments. In addition to this field work, a pilot wetland was constructed below the Galkeno 900 adit in May 1995 to demonstrate the applicability of the WTS concept at UKH. Data collected from this study are used to generate the parameters necessary to design a full-scale treatment system. Information from these laboratory and field studies is presented in this report in summary form. However, all the original data and field notes are attached in Appendix II. Instructions for the laboratory work are also included to facilitate the verification of the results presented herein.

# 2. Technical Background

The design of any passive treatment system is based on knowledge of the performance of existing WTS and on a good understanding of processes acting within them. Considerable information on these systems has been published in the scientific literature, in conference proceedings and in government reports. This information will be reviewed in some detail, as it provides the scientific basis for evaluating the laboratory and field work, and the subsequent design of a passive treatment system for UKHM. In addition to reviewing performance results and design parameters, the main processes acting toward metal removal within wetlands will be discussed.

## *2.1 Existing Wetland Treatment Systems*

### 2.1.1 Natural Systems

The amelioration of coal generated acid mine drainage by natural wetlands in the Eastern States was first documented by Huntsman and co-workers and Wieder and Lang in the late 1970's (Huntsman *et al.*, 1978; Wieder and Lang, 1982). Their ability to neutralise high acidity and to remove toxic metals was subsequently described for a variety of different wetlands. A large number of metals has been reported to be retained in natural wetlands, including arsenic, copper, iron, lead, silver, uranium, and zinc (Owen and Otton, 1995). Several reports describing such natural wetlands will be presented below.

Bob Boyle encountered numerous bogs and swamps retaining metals during his work for the Canadian Geological Survey (Boyle, R.W., personal communication). These metals had been present in springs and streams draining mineralised areas and flowing through the wetlands. Boyle indicated that copper, lead, zinc and uranium were among the toxic metals most commonly retained. The sediments in one swamp in New Brunswick had as much as 2% copper! Other metals or minerals which he found include pyrite (often abundant), vivianite, and various manganese oxides. The presence of pyrite indicates that sulphate reduction (and formation of hydrogen sulphide) occurs in these wetlands.

An environmental survey of the Panel wetlands area in Elliot Lake, Ontario, indicated that a natural wetland effectively controls acidity, iron and radium released by tailings produced by Rio Algom's Quirke mine in the 1950's (Davé, N.K., 1993). The tailings were deposited in a basin with a total area of 14.5 ha, forming an average layer of 0.92 m over an area of 12.9 ha. Only 12% of the tailings are exposed, at the western end of the basin. However, the exposed tailings were shown to produce low pH (3.4 to 5.5) surface drainage and sub-surface water. This water flows eastward through an extensive wetland, where it is neutralised as it mixed with ponded water and groundwater. In addition, oxidation of pyrite in these tailings releases iron at a rate of 183.7 kg Fe/yr. This iron is retained or recycled at a high rate (96%) in the wetland, with no observable impact on wetland function. Similarly, radium (Ra-226) produced by the tailings is effectively retained. Significant plant uptake of radium was noted, but iron and aluminium concentrations were at background levels. The storage time of iron and radium in the wetland is estimated to be 926 x $10^3$ and 40 x $10^3$ years, respectively.

A natural wetland in Western Montana receiving acid mine drainage from an abandoned lead/zinc mine effectively removed iron and lead, and neutralised acidity (pH 4.0) for 55 years (Dollhopf *et al.*, 1988). Copper was removed moderately well, and zinc, cadmium, and manganese were poorly removed. The effectiveness of metal removal was estimated from present and historical loadings and from concentrations of metals deposited in wetland sediments. These estimates are certain to be inaccurate, and likely underestimate removal efficiency. Nonetheless, they underscore the potential of natural wetlands to afford long-term treatment of mine drainage. The above study also showed that plants (*Carex rostrata*) in the impacted wetland took up some metals (aluminium, copper, iron, and lead), but not others (arsenic, cadmium, manganese, nickel, zinc) when compared with matched species growing in a nearby unimpacted wetland.

A wetland receives and treats zinc-contaminated discharges at the Silver Queen mine, in Smithers, B.C. (Higgs, T.W., personal communication). The mine water emerges from an adit, and flows through a ditch into a vegetated (cattails, *Typha latifolia*) tailings pond. From there, the overflow is discharged into a wetland covering several hectare. Zinc concentrations in the mine drainage vary during the year, from a high of 50-60 ppm during a 2-3 week spring flush to a low of about 2 ppm during the summer. Zinc concentrations reported at 0.05-0.1 ppm in the decant from the wetland. While the processes responsible for metal retention are not fully elucidated, it appears that formation of insoluble carbonates plays a significant role (Higgs, T.W., personal communication). The wetland has a large water storage capacity, as is typical of wetlands in general, such that the high flows occurring in the spring can still be contained and treated properly.

Cominco's Con Operations decanted tailings water flows into a series of lakes and muskegs, ultimately discharging into Great Slave Lake (Cominco Ltd, 1979). Metals of concern (arsenic and copper) and cyanide in the tailings water are effectively attenuated by these lakes. The muskeg appear to play a particularly important role in removing metals. Field investigations by Cominco staff indicated that considerable hydrogen sulphide production occurred in the muskeg (due to bacterial sulphate reduction). Laboratory investigations confirmed that sulphidogenic muskeg samples removed arsenic from tailings water (Lorne Ball, personal communication). Undoubtedly, this is similar to the reported precipitation of arsenic (III) as an iron-arsenic-sulphide in sulphidogenic sediments (Rittle *et al.*, 1995).

The ability of natural wetlands to remove metals from mine drainage briefly described above is corroborated with similar descriptions of natural wetlands removing metals from stormwater runoff, landfill leachate, and from other sources (Stockdale, 1991). In a number of cases, the processes responsible for metal removal, such as partitioning onto organic matter or formation of insoluble sulphides, has been documented. This information supports the concept of WTS as long-term solutions for the treatment of contaminated mine drainage, and is highly relevant to their design.

### 2.1.2 Constructed Wetlands

The impetus to develop constructed wetlands to treat mine drainage, instead of natural wetlands, has come for several reasons:

1. Wetlands are not always present where they are required;

2. Sizing can be tailored to the characteristics of the water to be treated;

3. Better control over the flow path is typically achieved, particularly in attaining the desired 5:1 length:width ratio which maximises contact between the substrate and the water to be treated; and,

4. Design elements, such as anoxic limestone drains for injection of alkalinity, waterfalls or rip rap ditches for aeration, quiescent areas for settling of metal oxides, etc, can be incorporated to promote certain treatment processes.

The first uses of constructed wetlands in North America arose in the Eastern States in the early 1980's for treatment of coal-generated acidic mine drainage, (Stone and Pasavento, 1982; Hammer, 1990). They were principally designed to neutralise water pH and to remove dissolved aluminium, iron and manganese. Since then, many systems have been developed throughout the world, ranging in size from a few square meters to several hectares, and with variety of metals concentrations and loadings to treat, and with flows from a few Litres per minute up to 2,000 Litres per minute. As an example, one of the largest, most complex waste streams for which a WTS is currently being designed is at the Wheal Jane tin mine, in Cornwall, U.K. The treatment system must be designed to treat flows of 10 L/sec containing principally iron (300 mg/L), zinc (120 mg/L), and associated aluminium, arsenic, cadmium, copper, and manganese, as well as ameliorate the water pH of approximately 3.5 (Dodds-Smith *et al.*, 1995).

There are over 200 constructed wetlands treating coal-generated acid mine drainage in the Appalachian region (Bastian and Hammer, 1993). Some of these have been operating satisfactorily for many years, such as an Ohio wetland that has treated iron-contaminated mine drainage effectively for twenty years (Stark *et al.*, 1990), and six Tennessee Valley Authority (TVA) wetlands that have produced compliant water for at least eight years (Brodie, 1991). Most of these wetlands are cattail- (*Typha latifolia*) or bulrush-based (various *Scirpus* species) surface flow systems. Recent elaborations of these systems includes the incorporation of components such as anoxic limestone drains (Turner and McCoy, 1990), Successive Alkalinity Producing Systems (SAPs) (Kepler and McCleary, 1994), etc. In addition, systems treating large flows are beginning to appear. Thus, the firm Damariscotta (Clarion, PA) has assisted or developed one wetland treatment system treating 600+ gallons per minute (gpm) and four systems treating 500+ gpm, low pH water (Doug Kepler, personal communication). This firm is currently working on a pilot system to treat a 1000+ gpm discharge.

Knowledge gained in the past fifteen years from operating these wetland systems in the Eastern States has been synthesised into formal guidelines for their design (Brodie, 1993; Hedin *et al.*, 1994). Recall that these systems are strictly concerned with removal of aluminium, iron, and manganese, as well as neutralisation of water pH. The US Bureau of Mines has developed empirical sizing criteria, based on iron removal, that takes into account water chemistry as well as flow rates. For influent water with a pH > 6 and excess alkalinity, 1 $m^2$ is predicted to remove about 10 g of iron per day. For manganese, the criteria is set at 0.5 $g/m^2/day$. For net acid water, pre-treatment using anoxic limestone drains or use of compost-based systems is recommended. The minimum size ($m^2$) of a compost-based wetland to remove acidity is sized to acidity load (mg/L)/5.

Criteria to determine the number of wetland cells have also been elaborated. Since aeration only provides enough dissolved oxygen to oxidize about 50 mg/L $Fe^{2+}$, one cell is required for each 50 mg/L $Fe^{2+}$ present in mine drainage. In addition, this necessitates that channels connecting each wetland cell (such as rock-lined ditches) re-aerate the water sufficiently to remove the specified amount of iron.

The design of WTS should also considers the following issues (R.P.L. Kleinmann, personal communication):

1. "What composition(s) of AMD have to be treated and what unit treatment operations are appropriate to treat the AMD? What are the incoming chemical loads that have to be treated or may, as in the case of net alkalinity, aid in the treatment processes? Is there appreciable ferrous iron concentrations that need to be oxidized to ferric iron?

2. Is there enough area available to treat the AMD flow given the appropriate area requirements based on the chemical nature of the AMD?

3. Is there enough hydraulic potential between the AMD discharge point(s) and the permit boundary elevation or proposed discharge point to drive water through the wetland system and avoid backflow at the discharge point? If aeration structures are to be used in the wetland system, then their consumption of hydraulic potential should be considered.

4. What must be done to keep the water to be treated in the wetland system and have it exit at the proper discharge point(s) instead of through the wetland floor or cell walls? Will compaction of on-site materials be sufficient or will materials (clay/silt) have to be imported? Will a liner be a cost-effective alternative?

5. Will there be any uncontrolled inflows to the wetland system such as seeps (surface and subsurface), surface runoff, and AMD inflow surges? These may cause an underdesign of the wetland system or erroneous conclusions to be drawn concerning the performance of a wetland.

6. How will water be routed through the wetland system? Rock-lined ditches are common low maintenance flow paths. Pipes have a bad track record for this unless oxygen can be excluded.

7. How will supplies and equipment have access to the construction area? How will the site be secured from uninvited visitors, both human and animal?"

The above checklist is broadly applicable to any wetland design. It makes it clear that designing a WTS accounts for more than just rate equations for metal removal.

There are fewer examples of wetland treatment systems designed other than for coal mine drainage. Three of these have been examined in some detail and will next be presented: the Big Five Pilot Wetland in Idaho Springs, CO, the Bell Copper experimental wetlands at the former Bell Copper Mine, in Smithers, BC, and wetlands at LTV's Dunka Mine, in northeastern Minnesota. Two other wetlands receiving gold mill effluents in Saskatchewan (Star/Jasper and Jolu operations) are also potentially relevant, because of their setting in a northern environment (Gormely *et al.*, 1990). However, these treatment systems are based on the deployment of sprinklers discharging effluents onto muskegs which are natural, not constructed. For this reason, these systems will not be considered, other than to indicate that they remove cyanide and copper by about 90-95% on maximum flows of approximately 250 gpm (Star/Jasper) and 600 gpm (Jolu) during the ice-free period (May-October). Another passive treatment system that has researched in detail is the Makela test cell system at the INCO Copper Cliff tailings near Sudbury, Ontario (Fyson *et al.*, 1995). However, the characteristics of this system are so unique, and unlike those of wetland treatment systems, that it will not be discussed.

The Big Five Pilot Wetland consisted of three cells (18.6 $m^2$) designed to neutralised acidic mine drainage (water pH 2-3) and to remove metals with concentrations exceeding 900 mg/L (Wildeman, 1992). The cells had a mushroom compost of manure-based substrate, onto which cattails were planted. The system increased water pH and reduced copper, iron, and zinc concentrations in proportion to the flow rate ($<1$ to 4 L/min). The fact that decreases in sulphate concentrations and in $E_h$ were also correlated with flow rate suggested that sulphate reduction played an important role in mine water neutralisation and metal removal (Wildeman *et al.*, 1990). Flow rate was not directly correlated with rates of metal removal, indicating that other processes were also involved in metal removal. Subsequent laboratory investigations identified adsorption onto organic matter as another important removal process, particularly for copper and iron (Machemer and Wildeman, 1992). However, bacterial production of sulphide ultimately controlled effluent concentrations of copper and zinc, effecting their complete removal (effluent concentrations $<$ 0.05 mg/L). Effective year-round operation has been documented for this system, but the relatively warm water temperature (12-16° C) is certainly uncharacteristic of Canadian mine effluents.

The Bell Copper experimental wetlands consisted of two membrane-lined cells (nominal surface areas of 300 $m^2$ and 75 $m^2$) with a peat-based substrate vegetated with cattails (*Typha latifolia*) or sedges (*Carex aquatilis/C. laeviculmis*) (Sobolewski *et al.*, 1995). For the first two years of operation, the wetlands successfully treated circumneutral mine drainage, reducing copper concentrations of 0.5-2 ppm to below 0.02 ppm. Introducing low pH (3-3.5), high copper (45-50 ppm) mine water resulted in effective, but transient metal removal. It appeared that the system had been overloaded, but this explanation is clouded by the fact that the system failed shortly before the onset of winter and that it was not restarted the following year.

Although there was twice more copper in aboveground plant tissues of sedges from one experimental wetland relative to a control site[1], plants contributed insignificantly to metal removal. The presence of sulphate-reducing bacteria (SRB) and detection of hydrogen sulphide in peat during the summer implicated formation of insoluble sulphides as a potential metal removal process. This was corroborated by the identification of copper sulphide minerals in peat (Sobolewski, In Press). However, effective copper removal in winter months – when both SRB and hydrogen sulphide were nearly undetectable – indicate that other processes were also be involved. An analysis of metal species present in the peat from the experimental wetlands indicated that organically-bound copper was the most prevalent species, with insoluble copper carbonate and iron/manganese oxide-bound copper also being significant (Sobolewski, In Press). However, other data indicated that these species would eventually be transformed into copper sulphides, which appears to be the final, permanent form of copper accumulating in the peat.

Wetland treatment systems were constructed (four cells, each 183 $m^2$) at LTV's Dunka Mine, in northern Minnesota. They were modelled after a natural wetland which removed 92% of the copper and 84% of the nickel released from drainage from a rock stockpile (Eger and Lapakko, 1988). The test wetlands effectively removed nickel in circumneutral mine water (average flow rate of 4 L/min.), reducing its concentrations from approximately 2 to 0.1 ppm (Eger *et al.*, 1994). Other metals (copper, cobalt, and zinc) were also reportedly removed, but their low initial concentrations were environmentally inconsequential. Sulphate was present in the stockpile drainage in large concentrations (approximately 2,300 ppm), and there were indications that sulphate reduction played an important role in metal removal. This was observed by a gradual shift in the nickel species with increasing depth in the wetland substrate, from organically-bound dominating near the surface, to (apparently) insoluble sulphides dominating at

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[1] Copper concentrations were below the mean of aquatic forbs and grasses in non-impacted environments (Hutchinson, 1975). Uptake by the cattails was no greater than for control plants.

greater depth. Carbonates were also present, representing from 10-20% of the total metal species. This shift in metal species is suggestive of the gradual ageing process reported for the Bell Copper wetlands.

## *2.2 Wetland Elements and Processes*

Many wetland elements contribute to their function as treatment systems. These elements will be review in this section, focusing on their relation to metal removal.

### 2.2.1 Vegetational Aspects

Plants play important roles in WTS, but their role in metal removal is only indirect. Their uptake of metal is insignificant in relation to other metal-removal processes acting in wetlands. However, they produce detritus and root exudates which provide the habitat and organic matter required by micro-organisms involved in these processes. In particular, this maintains anaerobic conditions in wetland sediments, which are necessary for the production of alkalinity and hydrogen sulphide. Plant-mediated evapotranspiration increases the effective hydraulic retention time of mine water flowing through a wetland. This effect, and their "filtering" capacity (see Section **Error! Reference source not found.**) increases the settling of particulates suspended in the water column. Furthermore, the detritus they produce binds sediments, preventing the loss of metals deposited therein.

Requirements for the establishment of wetland vegetation are relatively minimal. The wetland soil must be continually saturated or covered with water to a depth tolerated by the species selected. While a wide range of soil types, water pH and salinity are often tolerated, these parameters can influence the final species composition in a wetland. Cattails (*Typha latifolia*) are most commonly planted in Canada and the U.S.A., but success has been obtained (or observed) with various rushes (e.g., *Carex rostrata*, *C. Aquatilis*, etc). Regardless of the species initially used, a mixed vegetation typically develops as the system matures.

Initial planting is usually required to establish a wetland. This is accomplished by transplanting roots stocks from a donour site or a nursery, or by broadcasting seeds. Planting is usually done at a low density, typically 1 plant/$m^2$. Fertilization typically helps, as does addition of an organic substrate (manure and mushroom compost are commonly used in the U.S.A.). Depending on the growth habit (e.g., growth as tussocks or rhizomes) and on the growth rate of the selected species, the nascent wetland fills in within 1-3 years. The system matures with successive growth periods from the deposition and accumulation of detritus. Concomitantly, treatment performance improves for the first 5 years following wetland construction, at which time the system reaches maturity.

### 2.2.2 Microbiological Processes

Unlike the vegetation of wetlands, microbiological processes play a central role in metal removal. Microorganisms are primarily located in the wetland detritus layer and sediments, where sources of organic matter (used as nutrients) are abundant. There, they catalyze a number of reactions which significantly affect the composition of surface and sediment pore water.

Microbial decomposition (breakdown of organic matter) maintains anaerobic conditions in sediments by consuming oxygen faster than it can be replenished.

Anaerobic mineralization (degradation of organic matter to its inorganic constituents) generates bicarbonate alkalinity (Vile and Wieder, 1993). For instance, sulphate reduction proceeds according to the reaction shown below:

$$CH_3COO^- + SO_4^{2-} \rightarrow HS^- + 2\ HCO_3^-$$

Similarly, reduction of iron and manganese oxides under anaerobic conditions consumes acidity and generates alkalinity:

$$CH_3COO^- + 8\ Fe(OH)_3 + 15\ H^+ \rightarrow 2\ HCO_3^- + 8\ Fe^{2+} + 20\ H_2O$$

$$CH_3COO^- + MnO_2 + 7\ H^+ \rightarrow 2\ HCO_3^- + 4\ Mn^{2+} + 4\ H_2O$$

This alkalinity neutralizes acidic mine drainage, as demonstrated in Section 3.1.1. Notice that in all the above cases, there is a requirement for organic carbon (in the above examples, acetate) for these microbial reactions. These reactions are thus much less likely to occur in open water or in creeks and rivers than in swampy areas, where organic matter accumulates and is decomposed anaerobically.

The above reactions indicate that reduction of iron and manganese oxides and hydroxides contribute substantially to acid neutralization. However, their actual contribution tends to be limited by the location of mineral oxides near the surface of sediments, which are typically aerobic. On the other hand, sulphate reduction contributes considerable alkalinity because of the continuous supply of sulphate in anaerobic sediments.

Some products of anaerobic mineralization, such as bicarbonate and hydrogen sulphide, react directly with dissolved metals to form insoluble precipitates that are retained in wetland sediments. Thus, metal carbonates and sulphides have been reported to accumulate in sediments of wetlands treating mine drainage (Machemer and Wildeman, 1992; Eger *et al.*, 1994; Sobolewski *et al.*, 1995).

Microbial oxidation of iron sulphides results in its dissolution and in the production of acidity. This reaction only under aerobic conditions, so it is typically not expected to occur in wetland sediments, where insoluble iron sulphides are retained. However, a system overloaded with acidic water may so reduce decomposition (due to unfavourable pH conditions) that oxygen consumption no longer keeps up with its diffusion into sediments. Oxidation of iron sulphides may occur under these circumstances. Moreover, the acidity produced by this reaction will further exacerbate the conditions which caused it in the first place.

### 2.2.3 Metals Geochemistry in Wetlands

A variety of wetland processes play a role in removing metals from mine water. Several of these have been identified and will be discussed below. Others are not yet fully understood and undoubtedly play a significant role as well. For instance, the observations of Boyle and others indicate that metals are initially "loosely bound" in sediments. They subsequently become "fixed" after a (poorly understood) ageing process[2]. Bearing in mind the currently incomplete state of our knowledge, the geochemistry of metals in wetlands will be reviewed, in relation to their function as treatment systems.

Seven processes effecting metal removal in wetlands can be distinguished. These are:

1. pH-controlled precipitation reactions

2. Sorption onto organic matter, both dissolved and particulate

3. Oxidation and hydrolysis reaction, such as formation of iron and manganese oxides

4. Sorption onto the surface of iron and manganese oxides

5. Formation of insoluble carbonates

6. Formation of insoluble sulphides

7. Co-precipitation reactions

These processes may occur concurrently or be mutually exclusive. Each of these will be reviewed below.

### *2.2.3.1 pH-Controlled Precipitation Reactions*

All precipitation reactions are influenced by water pH. However, the dissolved concentrations of some metals is almost entirely controlled by it. For example, the removal aluminium in wetlands is essentially controlled by pH, being primarily determined by the solubility of $Al(OH)_3$ (Nordstrom and Ball, 1986). Similarly, copper concentrations are quickly reduced as water approaches neutrality, though its solubility at those pHs may still exceed environmentally-acceptable concentrations. While the solubility of most metals increases under acidic conditions, there are exceptions. Molybdenum follows the reverse pattern, as it becomes more soluble under alkaline conditions, but forms insoluble compounds at the water pH decreases below 6.

Certain metals, notably zinc and cadmium, are quite soluble under neutral conditions. Other removal processes must operate for these metals.

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[2] Three possible examples of this ageing process are given. Metals may initially bind to organic matter because this is a kinetically-favoured reaction. However, slower processes, such as reaction with sulphide, may eventually displace the organically-bound metals and form more stable species. Alternatively, metals released from the mineralization of organic matter may form the more stable sulphides. Lastly, amorphous iron or manganese oxides formed in the presence of dissolved organic matter may incorporate it into their insoluble flocs. While these mixtures are better metal scavengers than the oxides alone (Warren and Zimmerman, 1994; Düker *et al.*, 1995), they are likely to be further transformed as the associated organic matter becomes mineralized by microbial action. This transformation may be an element in the ageing process.

### 2.2.3.2 *Sorption onto Organic Matter*

The abundance of detritus in wetlands means that sorption of metals onto organic matter will be a significant process. Metal ions can also be captured through processes involving ion exchange, complex formation and precipitation with living or dead cells (e.g., Ferris *et al.*, 1985; Duggan *et al.*, 1992; Vatcharapijarn *et al.*, 1994). The latter process does not appear to be useful in practice because any metal sorbed by living cells is apt to be released when the cells die.

While organic matter clearly interacts with metals, its overall function in terms of metal removal is still unclear. Earlier design based on the ion-exchange capacity of peat (e.g., *Sphagnum* moss) were found to fail when this capacity became saturated (Hedin *et al.*, 1994). Still, there are indications that organic matter plays other roles in wetland treatment system. For instance, metals may initially be removed by organic matter until all available sites are saturated, at which time other removal processes become more important (Machemer and Wildeman, 1992). Alternatively, metal removal by organic matter may proceed in concert with other processes (Sobolewski, In Press). According to this view, interactions with organic matter proceed rapidly, but organically-bound metals eventually become converted to thermodynamically more stable forms. This may be an important process relating to the ageing of metals in wetland sediments. Finally, a totally opposing view suggests that dissolved organic matter can prevent formation of insoluble carbonates, hydroxides, and sulphides, and that it can even extract metals from such insoluble forms (Rashid and Leonard, 1973). Regardless of these different views, it is important to note that sorption onto organic matter is entirely abiotic, meaning that it can still function at temperatures when biotic processes are negligible (Gormely *et al.*, 1994).

There is a clear order of preference for metals by organic matter, with some minor disagreements between authors (Kadlec and Keoleian, 1986). For most peats and humic acids investigated, copper and iron form the most stable complexes. Lead and aluminium are reported to form stronger complexes by some authors, and weaker complexes by others. Intermediate strength complexes are formed by cadmium, cobalt, nickel, and zinc (Spear, 1981; Machemer and Wildeman, 1992). Finally, the weakest associations are formed by manganese, magnesium, and calcium. From a design standpoint, this means that sorption of zinc onto organic matter will be prevented by iron and copper in solution, and that organically-bound zinc will be displaced by these metals if their concentration suddenly increase in mine water (Abboud, 1987). Therefore, exploitation of the sorptive capacity of detritus to retain zinc and cadmium requires that a wetland be preceded by a settling pond to take dissolved iron out of solution.

Metals, particularly copper, can also form soluble complexes with dissolved organic matter (van den Berg *et al.*, 1987). These complexes will not settle from solution, potentially making it difficult to remove (Gormely *et al.*, 1992). However, it is also well known that such soluble metal complexes are less toxic compared with the free metal ion (Nor, 1994). In fact, it is likely that a large proportion of the "dissolved" metals in the discharge from a wetland is complexed with humic acids and other soluble organic matter. Thus, wetlands probably produce a less toxic effluent than indicated by analysis of dissolved metal concentration.

### 2.2.3.3 *Formation of Iron and Manganese oxides*

Iron and manganese are most typically removed by oxidation and hydrolysis, at least for wetland designs most commonly favoured in the Eastern States.

Iron precipitation occurs according to the reactions:

$$Fe^{2+} + ¼O_2 + H^+ \rightarrow Fe^{3+} + ½H_2O$$

and

$$Fe^{3+} + 2H_2O \rightarrow FeOOH + 3H^+$$

which generates net acidity (i.e., increase water pH). The reaction is pH-dependent, occurring most readily as water pH rises above 3-4. The flocs of iron hydroxide resulting from the above (and additional) reactions are bulky and can easily be resuspended in the water column after deposition.

Like iron, manganese undergoes oxidation and hydrolysis, resulting in the precipitation of manganese oxyhydroxides, according to the reaction:

$$Mn^{2+} + ¼O_2 + 3/2H_2O \rightarrow MnOOH + 2H^+$$

The specific mechanism for latter reaction in aerobic mine water is presently uncertain. However, it appears likely that the oxyhydroxide oxidizes over time to the more stable $MnO_2$. The formation of carbonates, followed by formation of the stable oxide, is also considered possible in alkaline environments, according to the reactions:

$$Mn^{2+} + HCO_3^- \rightarrow MnCO_3 + H^+$$

and

$$MnCO_3 + ½O_2 \rightarrow MnO_2 + CO_2$$

Manganese oxidation essentially stops when the pH falls below 6.

An interaction between manganese and iron in mine water has been uncovered, whereby ferrous iron reduces manganese oxides, according to the probable reactions:

$$MnO_2 + 2Fe^{2+} + 2H_2O \rightarrow 2FeOOH + Mn^{2+} + 2H^+$$

or

$$MnOOH + Fe^{2+} \rightarrow FeOOH + Mn^{2+}$$

These reactions, and the decrease in pH which iron hydrolysis causes, explain why manganese oxidation only occurs after most of the dissolved iron is removed from mine water, as has been observed in many wetlands. Accordingly, the design of passive treatment systems must account for their *sequential* removal: that is, iron must be mostly removed before manganese can be removed (oxidatively).

#### *2.2.3.4 Sorption of Trace Metals onto the Surface of Iron and Manganese Oxides*

The sorption of metals, such as cadmium, copper, lead and zinc, on the surface of iron and manganese (hydr)oxides and oxyhydroxides is now well documented (Spear, 1981; Allen *et al.*, 1990; Osaki *et al.*, 1990). These interactions are very important in relation to metal removal in wetland treatment systems. It is accepted that manganese oxides are the dominant phase for cadmium and zinc in wetlands in circumneutral waters (Balikungeri and Haerdi, 1988; L. Bendell-Young, personal communication). These oxides can contribute significantly to metal removal. Iron and manganese oxides are either stably formed in a wetland at the oxic-anoxic interface, or form encrustations on the bottom of small streams. Wetland designs exploit this processes by promoting contact between mine water and these surfaces, for instance by maintaining shallow water depths. An example of this process is presented later in this report (Sections 3.1.3 and 3.2).

#### *2.2.3.5 Formation of Insoluble Carbonates and Sulphides*

Formation of insoluble carbonates and sulphides are potentially very important processes operating in wetlands. Dissolved metals react with dissolved carbonate or sulphide, both of which are produced in anaerobic sediments by sulphate-reducing bacteria. The low solubility products of metals sulphides indicates that they can potentially be reduced to very low concentrations, if the reaction is allowed to proceed to completion (Table 1).

**Table 1. Solubility products of selected metal sulphides.**

| Metal sulphide | Solubility product[1] |
|---|---|
| CdS | $1.4 \times 10^{-23}$ |
| CuS | $4.0 \times 10^{-38}$ |
| FeS | $1.0 \times 10^{-19}$ |
| MnS | $5.6 \times 10^{-16}$ |
| NiS | $3.0 \times 10^{-21}$ |
| PbS | $1.0 \times 10^{-29}$ |
| ZnS | $4.5 \times 10^{-24}$ |

[1] Ehrlich, 1981.

These insoluble compounds are susceptible to oxidation, usually under acidic conditions. However, they will remain stably in sediments as long as they are able to exclude oxygen. Treatment systems based on this process have been reported (Dvorak *et al.*, 1992).

Wetlands which exploit this process are termed anaerobic. These wetlands are designed to promote this condition in sediments, for instance by minimizing re-aeration of water entering the wetlands, and by maintaining a comparatively high water depth and slow retention time. Given the critical role of sulphate-reducing bacteria in this process, their requirement for circumneutral water must also be respected.

Although carbonates are more generally soluble than sulphides and more susceptible to dissolution, they still play an important role in WTS. In particular, calcium carbonate may accumulate in wetland sediments, creating a reservoir of buffering capacity that can neutralise incoming acidic mine water. In addition, some metals, such as copper or nickel, may be retained in substantial quantity as carbonates (Eger *et al.*, 1994; Sobolewski *et al.*, 1995).

One important aspect of these two processes is that they are not expected to take place during period of low temperature (Section 2.2.2). On the other hand, they will continue as long as mine water entering the wetlands maintains sulphate concentrations greater than approximately 100 mg/L. Since these sulphate concentrations would be associated with the cessation of mineral sulphide oxidation, it can be argued that metal removal by these processes can continue for as long as there is a problem to treat.

#### *2.2.3.6 Co-precipitation Reactions*

Chemistry is never quite as simple as presented above. For many metals, precipitation in wetlands occurs to more complicated processes. For example, arsenic can be removed by co-precipitation with an iron oxide under aerobic conditions, or with iron sulphide under anaerobic conditions (Rittle *et al.*, 1995). In this case, a wetland design would ensure that iron is present in mine water containing arsenic, and structures would be designed to promote its aerobic or anaerobic precipitation[3]. Similarly, copper was shown to form chalcopyrite ($CuFeS_2$) in sediments of an anaerobic wetland (Sobolewski *et al.*, 1994).

## *2.3 Wetland Design*

Several elements of wetland design have been discussed above. It should be clear that many factors are considered during the design of a wetland treatment system. In general, the following sequence is followed in designing a WTS:

1. The composition of the mine water is examined to determine which metals require treatment.

2. Processes involved in removing these metals from solution are identified. Conditions necessary for these processes (e.g., specific pH conditions, requirements for alkalinity or sulphate or other metals) are examined to determine if can be met. Elements of system design may be incorporated to modify mine water composition until these conditions are met (e.g., an anoxic limestone drain can made to precede a wetland to increase water pH and alkalinity).

3. Kinetic data are generated to determine rates of metal removal. Sizing parameters are used to develop a preliminary system design, based on average and maximum metal loadings.

4. The preliminary system design is refined to provide (if possible) year-round treatment, as well as long-term (20-50 years) treatment. The environmental-acceptability of the treatment system is examined (e.g., will metals be stably retained in sediments, or are they susceptible to future release). The requirement for long-term care-taking are examined, with a view to modify the system design to eliminate as much of this as possible. These consideration produce a final system design.

5. A start-up and monitoring program is then established to ensure that the system evolves and performs as expected. The program is designed to identify the need for modifications and to adjust the system for continued, long-term performance.

The remainder of this report follows the steps outlined above in developing the design of a WTS to treat the discharge from the Galkeno 900 adit at UKH.

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[3] This decision would also be based, for instance, on whether sulphate is present, in which case the design would favour anaerobic precipitation, or absent, in which case the choice would be to favour aerobic precipitation.

# 3. Review of Field Data

Field data were obtained during two site visits: in mid-May and mid-August, 1995. The objective of these site visits was to establish the feasibility of developing a passive treatment system which could treat the mine drainage at UKH to environmentally acceptable levels. These data will be presented below, discussing separately natural ecosystems which ameliorate mine drainage and a pilot-scale constructed wetland to treat discharges from the Galkeno 900 adit.

## *3.1 Natural Restoration of Water Quality for Mine Drainage at UKH*

During a site visit in August 1995, several areas were identified in which natural restoration of water quality was recorded. While these areas are inherently of interest in validating the use of passive treatment systems, they are also important because some of their elements responsible for metal removal can be incorporated into the design of a full-scale system.

### 3.1.1 Amelioration of water quality at the Husky adit

The first example is of a small seep emerging from a waster rock dump at the Husky adit. The partly oxidized pyritic material in this dump appeared to impart the poor quality to this water. The obvious rusty colour of this seep and its pH of 1.06 substantiated this view (see Photograph 1, bottom photograph, in Appendix I). Its flow rate was small, estimated at slightly less than 1 Litre/min. Approximately 3-4 feet away from this site, the water flowed through a mossy patch (middle photograph). Concomitantly, its pH increased to 3.34 and it became clear. A further 3-4 feet away (top photograph), its pH increased to 6.56 as it flowed through a grassy swamp. No other water mixed with this seep, implicating the mossy and grassy areas as the sources for this improvement in water quality. Thus, within a distance of less than 10 feet, the pH of this small seep increased by 5.5 units, and its quality appeared (without further analysis) to be acceptable.

### 3.1.2 Zinc removal along No Cash Creek

An earlier report by Kwong and co-workers documented the attenuation of zinc along the course of No Cash Creek (Kwong *et al.*, 1994). Zinc concentrations were reported to decrease from approximately 15 - 25 ppm (dissolved metal) to 5 ppm at a culvert where No Cash intersects Highway 2. This attenuation was attributed in large part to the formation of solid hydrozincite, a zinc carbonate [$Zn_5(OH)_6(CO_3)_2$] formed under slight alkaline conditions (although simple zinc carbonate, $ZnCO_3$, would also be favoured under the pH measured at No Cash; Stumm and Morgan, 1981, pp. 278-281). The authors reported that further attenuation was expected in a swampy area downstream from where they sampled the creek, and it is this area which was further investigated.

Zinc concentrations measured from the culvert at Highway 2 down to valley bottom (See Map 1) are indicated in Figure 1. The data clearly show that most of the zinc is present in particulate form, and that its removal is essentially a matter of settling suspended solids. Numerous patches of creamy-white deposit were observed on the creek bed between Station 1 and Station 3. This deposit is similar to that reported by Kwong and co-workers, and is presumed to be hydrozincite.

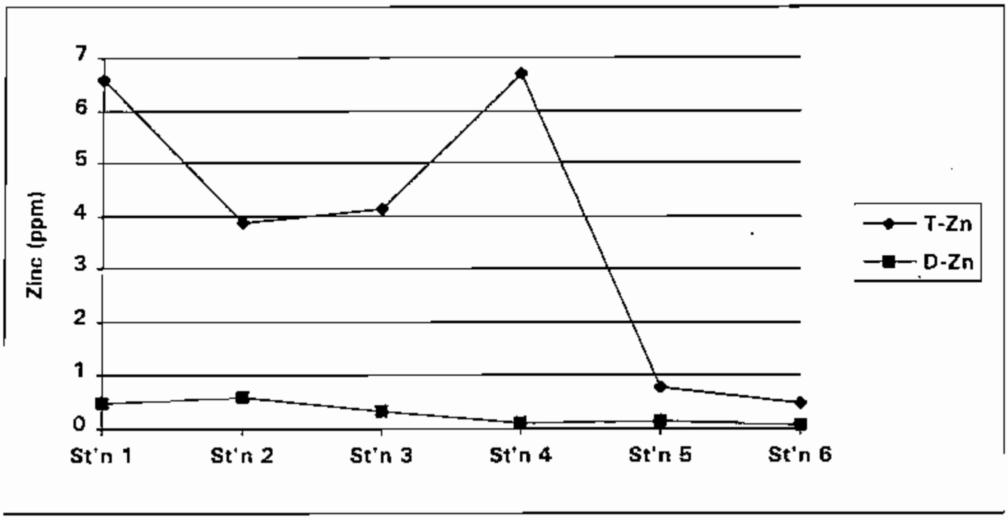

**Figure 1. Zinc concentrations along the course of No Cash Creek.**

The increase in Total Zinc concentrations recorded in Station 4 deserves a comment. Approximately 200 metres from Station 3, the bulk of the water disappeared below the muskeg (see Photograph 2, Appendix I). Once below ground, it entered a large subsurface reservoir of silt-laden water (see Photograph 3). This reservoir discharged (presumably entirely) into a small creek located approximately 100 metres from the disappearance of No Cash Creek, as indicated by the injection of silt-laden water into the small creek (see Photograph 4). The water sampled at Station 4 is this silt-laden water. This silt was brownish and settled easily, clearly different from the creamy-white material found suspended in the water column upstream from Station 3. The water sampled at Station 5 was obtained approximately 35 metres below this spring, from water that appeared to have dropped its silt load. The final sample was obtained a further 100 metres away, where the water was sparkling clean and with environmentally acceptable zinc concentrations (D-Zn = 0.011 ppm).

The above observations indicate that some metal attenuation can be expected to occur along the course of some impacted creeks, apparently from the formation of insoluble zinc compounds.

### 3.1.3 Amelioration of water quality downgradient from the Galkeno 900 adit

The abandoned road to the old Galkeno mill, by Christal Lake, has been partly revegetated. Some areas where water stagnates support small wetlands, at least one of which receive zinc-containing mine drainage. This naturally revegetated area and wetlands were tested for their ability to ameliorate water quality.

A small wetland measuring 11.6 x 3.7 x 0.23 m a few metres from the Galkeno constructed wetland was found to receive zinc-contaminated mine water (see Photograph 5). This wetland had only one source of water and one point of discharge, which means that any change in water quality arose from processes occurring within it. The water flowing into the wetland had a pH of 6.60, an alkalinity of 227 mg $CaCO_3$ eq/L, and contained 3.2 ppm zinc (D-Zn). At the point of discharge, the water had a pH of 6.45, alkalinity of 323 mg/L, and had 0.27 ppm zinc (D-Zn). Within this natural wetland, water had similar pH (6.43), alkalinity (358 mg/L) and zinc levels (0.20 ppm D-Zn).

The level of zinc removal evident from these data substantiates the notion that a wetland can treat mine water to an environmentally-acceptable quality. The increase in water alkalinity indicates that anaerobic mineralization was taking place in the sediments. While data on sulphate concentrations were not obtained, some sediment sampled from this wetland had a sulphur odour, indicative of sulphate reduction. Moreover, sulphate-reducing bacteria (SRB) were found to be present in the sediments at 1.1 x $10^7$ cells/g. These data suggest that these bacteria were active in the sediments and undoubtedly played an important role in metal removal.

At the time of sampling, the water flowed into the wetland at an estimated rate of 0.01 L/sec., giving a nominal retention time of 11.4 days. This number is consistent with that calculated for a similar degree of zinc removal measured in the Galkeno constructed wetland, presented elsewhere in this report (Section 3.3.2.3).

An important question is whether treatment is possible during the winter. Part of the question is simply to determine whether water flows through the wetland when it is covered with ice. In late November 1995, staff from Access Mining Consultants Ltd. dug a whole in the ice covering the Galkeno natural wetland and found that water was indeed flowing through it. However, the -35° C ambient temperature made it impossible to keep the hole unfrozen long enough to obtain a water sample and determine its metal concentrations. Thus, the effectiveness of treatment under the ice in a sub-arctic climate remains to be determined.

Another interesting observation was made in an unvegetated area 20-25 metres downstream from the Galkeno natural wetland. The bottom of the small creek was extensively covered with a thick black deposit covered with a veneer of orange deposit (see Photograph 6). The orange deposit is undoubtedly iron, but the black deposit turned to be manganese-rich, 9.2% by dry weight. Similar black deposits have been reported downstream of wetlands treating coal-generated acid mine drainage (Bob Kleinmann, personal communication). This material also contained 1.7% iron and 1.3% zinc, which confirms the well-established complexing capacity of hydrous manganese oxides (Balikungeri and Haerdi, 1988). Metal concentrations in water sampled approximately 10 metres before and after the deposit were determined, as shown in Table 2:

**Table 2. Metal concentrations before and after manganese deposit.**

| Location | Cadmium | Manganese* | Nickel | Zinc* |
|---|---|---|---|---|
| Before Deposit | 0.018 | 28 | 0.14 | 6.5 |
| After Deposit | <0.002 | 12 | 0.019 | 0.78 |

*Metal concentrations are in mg/L.

The above data clearly show that these manganese deposits are effective scavengers of trace metals. The promotion of such deposits could be a useful element in the design of a WTS. The reported requirement for their formation are (Hedin *et al.*, 1994, Kleinmann, personal communication):

1. Low dissolved iron concentrations

2. Water pH greater than 6

3. Water aeration, or good dissolved oxygen concentrations

4. Location downgradient from a wetland

While the first two conditions are required for the chemical reaction to proceed, the last requirement is for the supply of organic matter which sustains the microbially-mediated oxidation of dissolved manganese[4]. Thus, this process is expected to be seasonal in nature.

## *3.2 Fate of Metals Retained in Natural Wetlands*

Concerns about the stability and bioavailability of metals retained in wetlands must be addressed, as part of the overall design process. While it seems reasonable to obtain this information directly from the constructed wetland during the field program (Section 3.3), it turns out to be impractical because of the low levels of metals that accumulate in a single field season. In contrast, the natural wetlands discussed in this section have been accumulating metals from contaminated mine drainage for several years. Identifying the form and fate of the accumulated metals is far more relevant, as it informs on the long-term environmental acceptability and performance of these treatment systems. To this end, a number of laboratory studies and analyses were performed to determine the form of metals retained in wetland sediments, their bioavailability and plant uptake, and their susceptibility to being remobilized should the water become more acidic (e.g., lower pH).

### 3.2.1 Metal Uptake by Plants

Samples from wetland sediments and plant tissues (aboveground) were collected from a variety of sources to determine the extent of metal uptake by plants. Sources of material included:

- South McQuesten swamp, donour site for the Galkeno constructed wetland
- Small natural swamp fed by No Cash creek
- Small natural swamp adjacent to the Galkeno constructed wetland, receiving drainage apparently associated with the Galkeno 900 adit
- Old Galkeno mill tailings in Christal Lake and plants growing upon it

Sediments and plants were not collected from the Galkeno constructed wetland because too little metal was expected to be present in either the sediments or the plants. Conversely,

Total metal concentrations measured in these material are presented in Table 3:

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[4] This oxidation is postulated to be microbially-mediated because it is not favoured chemically (abiotically) under the temperature and concentrations measured in this water.

**Table 3. Metal concentrations in wetland sediments and plants in the Keno Hill area[a].**

| | S. McQuesten swamp[b] | No Cash swamp | Galkeno natural swamp | Galkeno tailings | Non-enriched[c] sites | Non-enriched sites |
|---|---|---|---|---|---|---|
| **Metal** | Sediments/Plants<br>*n*=2 | Sediments/Plants<br>*n*=*1* | Sediments/Plants<br>*n*=2 | Sediments/Plants<br>*n*=2 | Plant tissues<br>Range | Plant tissues<br>Mean |
| Cadmium | 23/<0.50 | 227/0.78 | 66/<0.50 | 2,140/3.1 | 2.6-28 | 8.0 |
| Copper | 46/4.27 | 238/3.19 | 110/2.81 | 251/3.42 | 2.5-243 | 48 |
| Lead | <50/4.7 | 1,760/7.2 | 98/<2.5 | 553/34 | 2.0-53 | 11 |
| Zinc | 1,114/132 | 12,200/185 | 10,345/102 | 123,000/237 | 26.5-1,000 | 143 |

[a] Data expressed as mg/dry kg

[b] Refer to text for identification

[c] Background metal concentrations in aquatic grasses and forbs, reported by Hutchinson, 1975

The data in Table 3 indicate that metals concentrations in sediments and plant tissues are not directly correlated. Data from the South McQuesten swamp can be considered to provide background metal concentrations for the area, since the wetland is drained by the South McQuesten river and since it is directly connected to the source of drinking water for Elsa. Metals clearly accumulate in the sediments of the No Cash and Galkeno natural swamps. However, they do not accumulate in plant tissues, with the possible exception of zinc in plants from the No Cash swamp, where it is enriched by a factor of 0.3-0.4 relative to plants from the donour site and non-enriched sites. Significant accumulation of cadmium and lead is seen in tissues of plants growing on Galkeno tailings in Christal Lake, while zinc accumulates somewhat and copper does not.

Note that zinc concentrations in the Galkeno tailings are 100X greater than in the South McQuesten swamp, but zinc concentrations in plant tissues are only about 2X greater. These data either indicate that metals are not bioavailable, and hence not taken up by plants, or that metals uptake by plants is actively regulated. The latter explanation appears to be favoured by the cadmium and lead data, because it would be expected that geochemical conditions making zinc biologically-unavailable should also make cadmium unavailable. However, the fact that Galkeno tailings are not truly representative of typical wetland sediments must be borne in mind when evaluating these data. For example, they lack the typically high organic matter levels found in the wetland sediments. Moreover, Christal Lake does not have high sulphate concentrations, which could support significant sulphate reduction and retention of metals as sulphides in sediments, unlike the other two wetlands.

When considering the lead data, it is apparent that metal uptake occurs in plants growing on Galkeno tailings, while little or no uptake occurs in the No Cash swamp, in spite of nearly 3X higher lead concentrations in the latter sediments. Some uptake of cadmium by plants from the No Cash swamp may be indicated by the data, but this uptake appears to be marginal. This lack of metal uptake argues that metals are biologically-unavailable in wetland sediments, since lead would have been expected to be found in higher concentrations in No Cash plants than in Galkeno tailings, given the lead higher concentrations in No Cash sediments.

### 3.2.2 Metal Accumulation in Sediments

While plant uptake of metals entering wetlands does not significantly contribute to their removal, retention in wetland sediments does. two important question to resolve become:

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While plant uptake of metals entering wetlands does not significantly contribute to their removal, retention in wetland sediments does. two important question to resolve become:

1. Will metal removal continue throughout the life of the wetland, or will it cease in a few years?
2. Will the metals retained in sediments be remobilized easily, or only under radically different conditions?

These questions can be answered by identifying the forms of metals retained in wetland sediments. Specifically, it is necessary to determine whether a metal is retained as a species which will quickly reach saturation in the system (e.g., organically-bound) or whether it is likely to be produced for a long (e.g., carbonates, iron and manganese oxide-bound, and sulphides). In addition, it gives some indication of the potential to treat mine drainage on a year-round basis, since some processes, such as the formation of sulphides, only occurs during the growing season.

An analytical sequential leach was performed on sediments from the Galkeno natural wetland (2 samples, tested in duplicate) and the No Cash natural wetland (1 sample, tested in duplicate) to answer these questions. This analysis can be used to identify the main metal species present in wetland sediments (Hall *et al.*, 1990; Kwong, *et al.*, 1994; Sobolewski, In Press). This information, when supplemented with results from leach tests, can also indicate whether the metals will be stably retained or whether they are susceptible to remobilization with changes in inflow water chemistry.

Although it is a relatively difficult analysis, the sequential leach was judged to have been performed satisfactorily, based on a recovery in the leachates of 71% of the zinc in the head assay, with 1.9% of the initial zinc remaining in the spent residue (Appendix II). The test revealed that most of the zinc is bound to iron and/or manganese oxides in the two Galkeno natural wetland samples (Figure 2 and Table 4), whereas it is more equally distributed among these oxides and sulphide species. Similarly, cadmium was mostly (89%) retained on iron and/or manganese oxides in the Galkeno natural wetland, whereas it was predominantly (66%) present as a sulphide in the No Cash sediments (the remaining being associated with metal oxides). These findings suggest that removal of these metals will continue for several years.

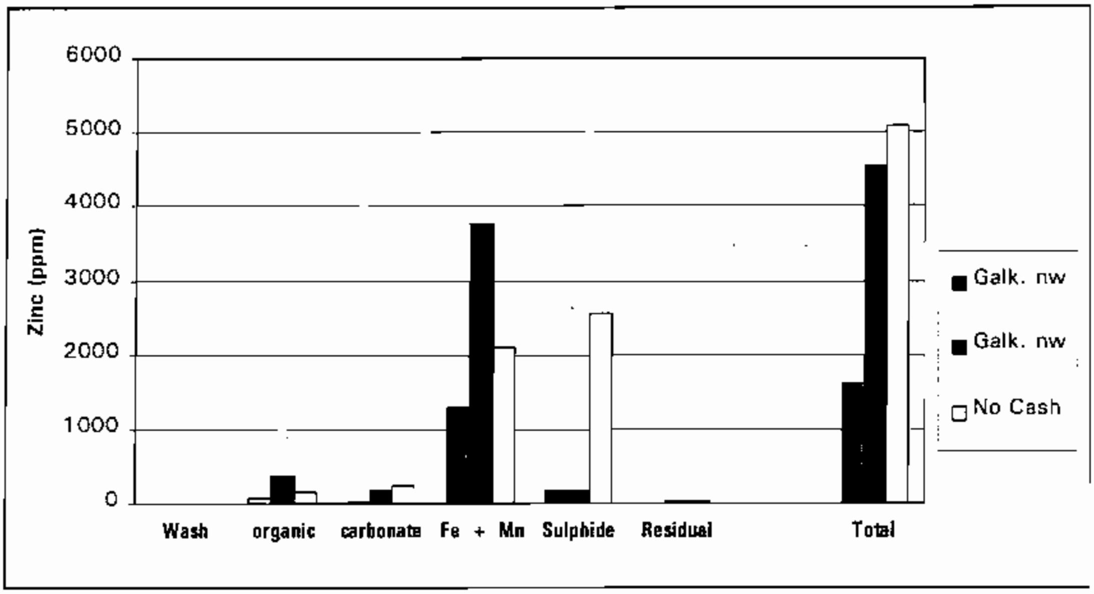

**Figure 2. Zinc species in sediments of natural wetlands in the Keno Hill area.**

Further speciation of iron and manganese in these sediments revealed that manganese was predominantly (78%) present as an oxide in the Galkeno natural wetland, whereas iron was less abundant as an oxide (28%) than as a sulphide (57%) (Table 4). This result suggests that zinc and cadmium were likely associated with manganese oxides formed within the wetland. In contrast, iron and manganese were retained as sulphides more readily in the No Cash wetland sediments (68% and 38%, respectively) than in the Galkeno wetland, consistent with the behaviour of zinc and cadmium.

For most of the metals listed in Table 4, association of metals with organic matter and carbonates was minor. Only copper had a significant (38%) association with organic matter, in the Galkeno wetland sediments. However, copper was mostly (58%) present as a sulphide in the No Cash wetland. This finding indicates that even if metals are originally retained on detritus or as carbonates in wetland sediments, they will ultimately be transformed into another, presumably more stable form.

**Table 4. Concentrations of selected metal species in sediments of the Galkeno and No Cash natural wetlands*.**

| | Wash | Organic | Carbonates | Fe + Mn | Sulphides | Residue | Total |
|---|---|---|---|---|---|---|---|
| **Galkeno** | | | | | | | |
| Cd | <0.5 | <0.5 | <5 | 15.2 | 1.07 | 0.29 | 17 |
| Cu | 2.1 | 33 | 36 | 27 | 27 | 3.9 | 129 |
| Fe | 11 | 1394 | 630 | 10637 | 19862 | 3284 | 35818 |
| Mn | 3 | 491 | 259 | 4816 | 128 | 44 | 5741 |
| Pb | <1 | <27 | <14 | 8.17 | 7.74 | 6.95 | 23 |
| Zn | 0.99 | 221 | 116 | 2,532 | 192 | 18 | 3080 |
| **No Cash** | | | | | | | |
| Cd | <0.5 | <0.5 | <5 | 18.9 | 37.4 | <0.5 | 56 |
| Cu | 1.9 | 55 | 9.5 | 19 | 103 | 1.7 | 190 |
| Fe | 2 | 1127 | 95 | 2712 | 16812 | 4115 | 24863 |
| Mn | 1 | 342 | 190 | 1530 | 1297 | 56 | 3416 |
| Pb | <1 | 72.73 | <10 | 193 | 567 | 8.42 | 841 |
| Zn | 0.86 | 209 | 314 | 2693 | 3290 | 39 | 6546 |

*Data are expressed as mg/dry kg

Kwong and co-workers (1994) suggested that acid mine drainage may develop on the property once the "galvanic protection" of pyrite by sphalerite and galena becomes exhausted. Moreover, they speculated that "(metals in sediments) can readily be remobilized upon subtle changes in pore fluid composition" (Kwong *et al.*, 1994). The potential environmental implication of their work are that acidic discharges could develop in the future and release metals retained in wetland sediments. Therefore, it was important to determine whether metals retained in wetland sediments if the mine drainage acidified.

The stability of metals was first tested by leaching sub-samples of wetland sediments in a shake flask with water of increasingly low pH, using South McQuesten water as a proxy for mine water[5]. However, the strong buffering capacity of the wetland sediments prevented their acidification and any significant metal leaching (Table 5). Thus, only 0.2% and 2% of the total zinc could be leached from sediments of the Galkeno and No Cash wetland, respectively. Clearly, zinc retained in these sediments resists simple exposure to acidified water.

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[5] Obviously, South McQuesten water does not contain much metals, and is thus an improper proxy of acidified mine drainage. However, leaching wetland sediments with water containing metals would obscure the results of the test. It would be impossible to determine whether metals were leached from the peat, sorbed onto peat, or interact between the two media. Since interpretation of test results is much simpler with water initially void of metals, this approach was adopted.

Table 5. Shake flask leach test for Galkeno and No Cash natural wetland sediments[1].

| | Galkeno | | Galkeno (dupl.) | | No Cash | |
|---|---|---|---|---|---|---|
| | pH[2] | Zinc | pH | Zinc | pH | Zinc |
| **Wash** | 7.74 | 2.8 | 7.90 | 7.5 | 7.74 | 5.9 |
| **pH 6** | 7.44 | 11 | 7.91 | 4.3 | 7.51 | 7.9 |
| **pH 5** | 7.50 | 3.7 | 8.05 | 2.3 | 7.41 | 33 |
| **pH 4** | 7.35 | 5.3 | 7.69 | 2.0 | 7.22 | 43 |
| **pH 3** | 7.01 | 11 | 7.45 | 3.2 | 6.96 | 55 |

[1] Data are expressed as mg zinc leached per dry kg peat. For initial zinc concentrations in peat, see Table 4.
[2] Refers to water pH after leaching overnight approximately 7.5g (dw) peat in 100-150 mL acidified South McQuesten water (initially washed with 500 mL South McQuesten water, pH 7.1).

Prolonged exposure to acid mine drainage might eventually exhaust the buffering capacity of the wetland sediments. Consequently, the test was modified to titrate out the buffering capacity and determine whether this enhances metal leaching. Fifteen gram subsamples (ww) of the Galkeno wetland sediments were initially suspended in 300 mL distilled water. Subsequently, the suspension was titrated with 0.1 N HCl until the water pH was reduced to 6.0 ± 0.1, then 5.0 ± 0.1, then 4.0 ± 0.1. After each titration, the sediment suspension was stirred for 1 hour to allow mineral dissolution and metal desorption. Despite this, little zinc was released from the sediments (Table 6). These results clearly show that metals retained in wetland sediments are stable and will not be remobilized following acidification of mine drainage.

Table 6. pH and zinc concentrations of leachate from wetland sediments titrated with 0.1 N HCl.

| | Galkeno | | Galkeno (dupl.) | |
|---|---|---|---|---|
| | pH[1] | Zinc[2] | pH | Zinc |
| **pH 6** | 6.40 | 0.019 | 6.36 | 0.088 |
| **pH 5** | 5.45 | 0.10 | 5.44 | 0.78 |
| **pH 4** | 4.63 | 0.62 | 4.45 | 3.4 |
| **Residue[3]** | NA | 8354 | NA | 7362 |

[1] The pH of the suspension measured one hour after washing with distilled water, then titrating to pH 6.0, 5.0, and 4.0.
[2] Total mass of zinc (mg) solubilized after leaching for one hour, following titration with 0.1 N HCl.
[3] Zinc concentration (mg/dry kg) remaining in the filtered solid residue following the leach procedure.

### *3.3 Pilot Wetland Treatment System*

In the summer of 1995, a pilot wetland treatment system was constructed downgradient from the Galkeno 900 adit. This system included a settling pond receiving untreated Galkeno 900 water and a small wetland located downgradient from and fed by the settling pond. They were fed mine water starting in July 1995 and monitored until late September for their effect on water quality. Additional on-site tests, including a settling test with untreated Galkeno 900 water and the establishment of *in situ* microcosms (i.e., columns holding cores of wetland sediments and plants), were conducted to generate more precise kinetic data on metal removal. Results from this test program provided the basis for designing a full-scale treatment system. These results are presented below.

### 3.3.1 Performance of Settling Pond

Historical data on the composition of Galkeno 900 water indicated that some metals (iron, manganese, and zinc) were present in particulate form which could be retained by a 0.45 µm filter. To determine how quickly and/or whether this material could settle out, a 4 Litres plastic cubitainer completely filled with untreated Galkeno 900 water was left to stand within the Galkeno 900 adit. Over a seven day period, the water pH (6.5), alkalinity (204 mg/L as $CaCO_3$), and most metal concentrations remained unchanged. However, iron concentrations decreased by half during this time, as shown in Figure 3:

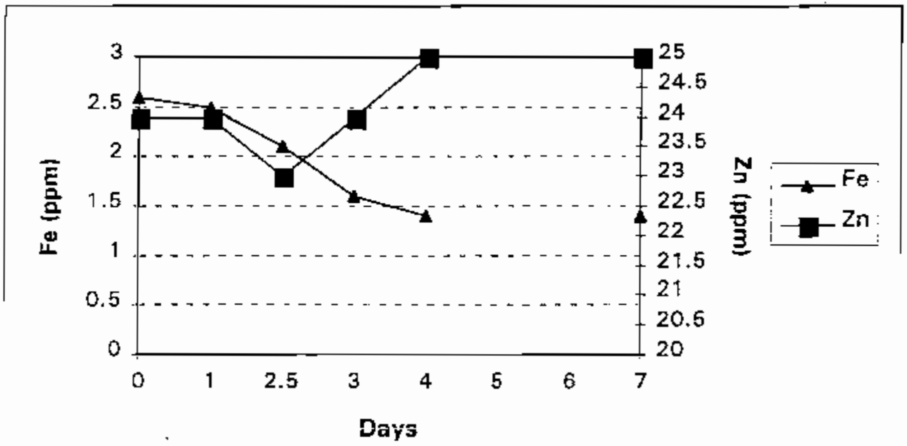

**Figure 3. Iron and zinc concentrations (Total metal) in standing Galkeno 900 water.**

The apparent increase in zinc concentrations on Figure 3 simply reflects sampling and analytical error: in fact zinc concentrations remained unchanged during the test. The residue filtered from the incubated mine water was found to contain some iron, minor amounts of zinc, and some calcium.

These data indicate that little removal of zinc could be achieved by letting particulates settle out of Galkeno 900 water. However, the removal of iron was of interest, as it would compete with zinc in binding onto organic matter. Therefore, a settling pond was constructed between the Galkeno 900 adit and the pilot Galkeno constructed wetland to remove iron.

The plastic-lined 7.6 x 7.0 x 2.0 m settling pond was excavated and filled with Galkeno 900 water (see Photograph 7). A pipe inserted just below the water surface supplied water to the Galkeno constructed wetland. A flow rate of 3 L/min. was used during the monitoring phase of the test program, giving a retention time of approximately 20 days. Unfortunately, no data are available to establish its effect on metal concentrations. Data from 1994 and 1995 indicate that total iron concentrations in Galkeno 900 water average approximately 4.1 ± 1.3 ppm, whereas water entering the Galkeno constructed wetland averaged 1.0 ± 0.11 ppm, consistent with its anticipated effect. Total zinc concentrations in Galkeno 900 water averaged 27 ± 1.2 ppm when measured in 1994 and 1995, but they averaged 24 ± 0.61 ppm[6] in the water entering the Galkeno constructed wetland. This indicates that only low amounts of zinc were

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[6] There is an outlier in the data set for zinc concentrations in the wetland inflow: eliminating this outlier yields an average of 25 ± 0.19 ppm.

retained in the settling pond before entering the constructed wetland. An orange deposit, obviously an iron oxide, was seen to accumulate in the settling pond, again consistent with its anticipated effect.

This indirect evidence indicates that iron concentrations are substantially decreased, and zinc concentrations are little decreased when Galkeno 900 water is retained in the settling pond. Thus, the settling pond was effective in attaining its stated objective of decreasing concentrations of iron entering the Galkeno constructed wetland.

### 3.3.2 Performance of the Galkeno Constructed Wetland

A pilot-scale wetland was constructed to treatment water from the Galkeno 900 adit. The specific purposes for building this wetland were:

1. To establish the feasibility of constructing a wetland in a sub-arctic climate
2. To determine its effectiveness in improving the quality of water produced by the Galkeno 900 adit
3. To develop performance parameters for the design of a full-scale system that would discharge water of a quality that does not impact on the receiving environment
4. To determine its long-term effectiveness in removing metals

This part of the field program was successful in meeting these specific objectives, as described below.

#### *3.3.2.1 Wetland construction and plant growth*

Construction of the test wetland (from hereon referred to as the Galkeno constructed wetland) was initiated on May 17th 1995. A bare, exposed, South-facing plot below the Galkeno 900 adit was marked and excavated to approximately 9 x 18.5 x 0.5 metres. See and Photograph 8 Appendix I. A very small trickle of groundwater could be seen to emerge from the excavated bank, but too little water was produced to obtain a sample for analysis. It was felt that this input of groundwater would not significantly influence the results from the test.

A donour site with a stand of the sedge *Carex aquatilis* (Taylor, 1983, or *C. Stans*, Porsild, 1973) (see Photograph 9) for the Galkeno constructed wetland was identified. This site was located in the reservoir providing drinking water to the hamlet of Elsa, which is fed by the South McQuesten River and is judged to be uncontaminated by mine drainage. On May 19, 1995, sods of sedges and underlying soil/peat were dug out (down to permafrost, approximately 30 cm below the surface), loaded onto flatbed trucks, and immediately placed into the excavated plot. Fertilizer (21-7-7) was broadcast at a rate of approximately 185 kg/ha onto the ground prior to transplanting the sods. The excavated plot was filled as completely as practical with sods and filled with lime-treated mine water (see Photograph 10). Contaminated mine water was not introduced until good plant growth was seen.

Plant growth in the constructed wetland was compared with that at the donour site. Individual *Carex* clumps were demarcated at four stations in the constructed wetland and five stations in the donour site, and the height of the tallest shot at each station was measured. These measurements indicated that the onset of plant growth was slightly delayed in the Galkeno constructed wetland, but that it was otherwise comparable with that at the donour site (see Figure 4). By mid-August, (after having received contaminated mine water) plant coverage varied from 30% to 70% (see Photograph 11). Numerous side shoots were observed, indicative of healthy vegetative growth. Moreover, many plants had fruit-bearing spikelets, indicating that plant reproduction was unaffected. These data and observations indicate that a wetland could be constructed which sustains normal plant growth and reproduction in a mining environment.

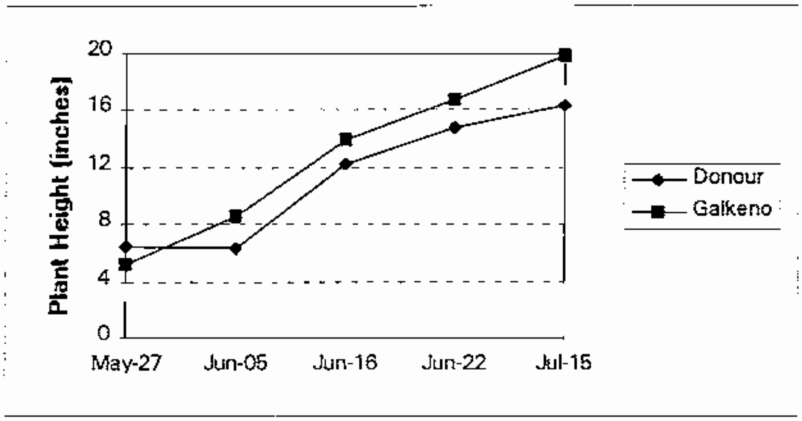

**Figure 4. Plant growth at the donour site and Galkeno constructed wetland.**

#### *3.3.2.2 Metal removal*

Lime-treated Galkeno 900 mine water was circulated into the constructed wetland until good plant growth was established. Starting in July 1995, untreated water was circulated first throughout the settling pond (Section 3.3.1), thence to the constructed wetland. The flow rate was established at 0.3 L/sec (18 L/min.), giving a nominal retention time in the wetland of approximately 3 days. Until mid-August 1995, water sampled periodically indicated that little metal removal occurred in the wetland. Typical zinc concentrations in the inflow and decant measured approximately 25 and 18 ppm (mg/L), respectively. These results indicated that water probably had an insufficient retention time, since earlier tests indicated that letting the mine water sit for seven days decreased zinc concentrations to approximately 15 ppm (Section 3.3.1).

A site visit in mid-August indicated that the inflow was likely by-passing a portion of the wetland as well[7]. Measurements of water characteristics further confirmed this view. Ten stations were established in the wetland, five on the inflow side and five on the decant side of the wetland, as shown in Figure 5. Examination of the water pH, Eh, and temperature reveals that Stations 4 and 5, and probably Station 3

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[7] This is not unusual during the first year, as sods transplanted in the excavated cell slow settle.

on the inflow side were different from the other stations (Table 7). Their distinctly higher temperature and lower Eh were indicative of stagnating water[8].

The low Eh at Stations 4 and 5 indicated that reducing substances (such as hydrogen sulphide) were produced in the water column. To corroborate this hypothesis, sediment samples were collected near these stations and tested for the presence of hydrogen sulphide (by smell), for Eh, and for the presence of sulphate-reducing bacteria (SRB). One sediment sample near Station 5 had an Eh of -147 mV (moderately reduced), had a characteristic sulphur odour and pitch black colour, indicating that sulphate reduction was occurring. Analysis of this sample for SRB indicated that it harboured a healthy population of $2.9 \times 10^6$ MPN[9]/dry g. For a comparison, sediments from an experimental constructed wetland at the former Bell Copper mine harboured SRB populations averaging $5 \times 10^3$ MPN/dry g at the onset of the growing season, and $4 \times 10^7$ MPN/dry g before the onset of the dormant season (Gormely *et al.*, 1994). Another sample taken nearby Station 3 also had a low Eh (-127 mV), but not other characteristics typical of sulphate reduction. In contrast, a sediment sample taken from the centre of the wetland had an Eh of 42 mV. Thus, the wetland was functioning as an anaerobic treatment system.

**Table 7. Water characteristics in constructed wetland, before installation of baffles.**

| | | *Station 1* | *Station 2* | *Station 3* | *Station 4* | *Station 5* |
|---|---|---|---|---|---|---|
| | **Inflow** | | | | | |
| pH | | 6.45 | 6.76 | 6.80 | 6.86 | 6.5 |
| Eh | | 54.7 | 85.4 | 41.0 | -28.9 | -18 |
| Temperature (° C) | | 12.5 | 12.6 | 14.3 | 15.6 | 15.0 |
| Alkalinity (mg/L as $CaCO_3$) | | 176 | 160 | 150 | 356 | 218 |
| Zinc (ppm) | | 22.6 | - | 19.8 | - | 0.33 |
| | **Decant** | | | | | |
| pH | | 6.69 | 6.76 | 6.69 | 6.61 | 6.78 |
| Eh | | 83.2 | 72.3 | 75.8 | 76 | 92.3 |
| Temperature (° C) | | 13.1 | 13.0 | 13.9 | 13.9 | 13.7 |
| Alkalinity (mg/L as $CaCO_3$) | | 158 | 155 | 147 | 140 | 141 |
| Zinc (ppm) | | 19.3 | - | 19.7 | - | 17.5 |

The data on zinc concentrations are noteworthy. The decrease in zinc concentrations between the wetland inlet and outlet is not very large, decreasing from 22.6 to 17.5 ppm. The short-circuiting suggested by the above arguments likely accounts for this poor performance. However, zinc concentrations sampled in Station 5 decreased to 0.33 ppm. Repeat sampling the following day yielded zinc concentrations of 1.44 ± 0.87 ppm (0.58 ± 0.095 ppm if one outlier is excluded), which are nearing environmentally acceptable discharge concentrations. Given the above arguments that water sampled in Station 5 stagnated (i.e., had a long retention time), these results provided the first indication that the constructed wetland could remove zinc, given enough time.

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[8] The higher temperature would result from a greater warming from sunlight (temperature was measured at the surface in all cases), whereas the lower Eh would result from the lower mixing and more complete consumption of oxygen, both of which occur when water stagnates.

[9] MPN stands for Most Probable Number, and is essentially equivalent to the cell number in a sample.

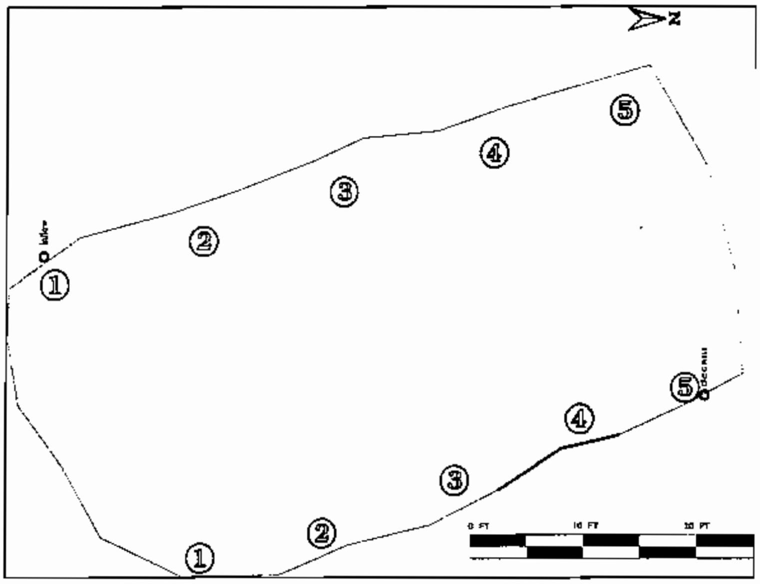

**Figure 5. Sampling stations to characterize water flowing through wetland.**

To remedy the problem of short-circuiting, plywood baffles were inserted across the wetland, redirecting water to flow past the high point in the wetland (Station 5 in Figure 5). These baffles (shown in Figure 6) were installed on August 22 and 23. With the baffles in place, water from the Galkeno adit was redirected to be retained within the first baffle, and its flow was re-established at 3 L/min. This gave a nominal retention time of 19.3 days.

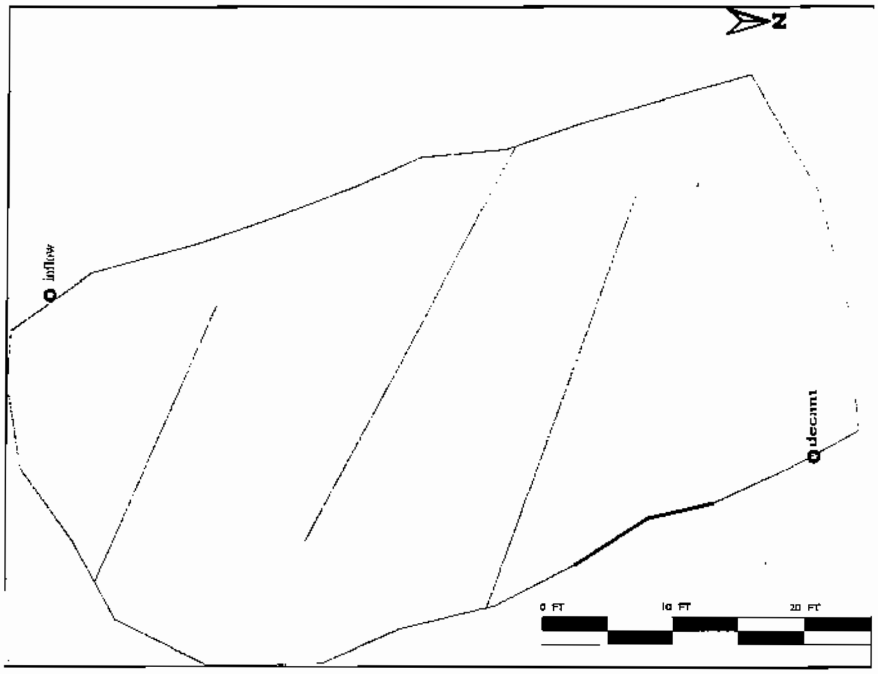

Figure 6. Placement of baffles in Galkeno constructed wetland.

Installing the baffles did not completely establish the desired flow of the water across the wetland. A zone of high permeability was found below the inflow which allowed water to escape out of the wetland. On August 24, this zone of high permeability was covered with soil and the flow of water was again redirected away from it and around the first baffle. From that time onward, water flowed around the baffles and decanted out as planned.

Zinc concentrations (total metal) measured at the wetland inflow and decant from August 26 to September 20 are shown in Figure 7.

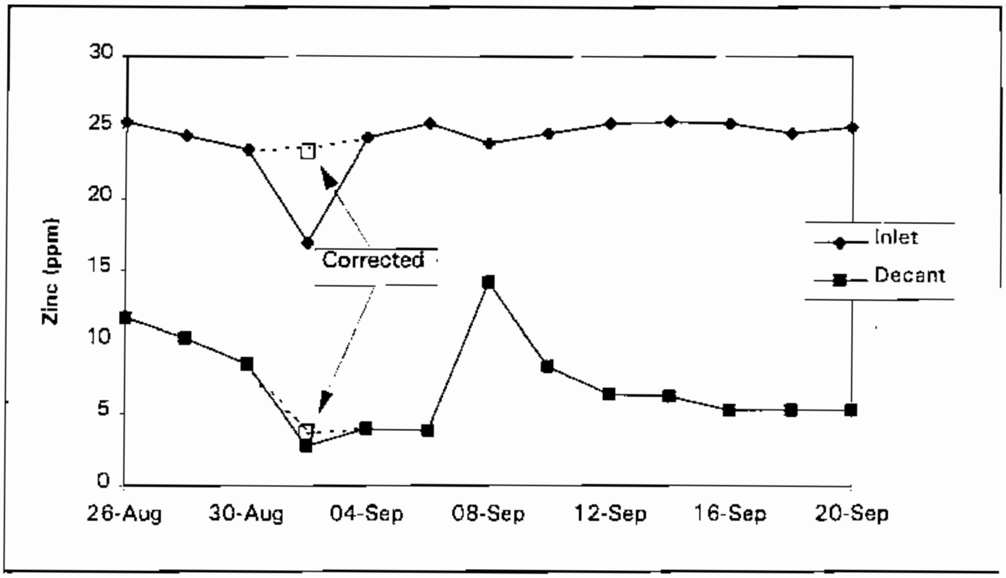

**Figure 7. Zinc concentrations in inflow and decant of the Galkeno constructed wetland.**

Figure 7 shows that zinc concentrations in the inflow were largely constant at 25 ppm. Concentrations in the decant initially decreased to 3-4 ppm. However, conditions in the wetland changed in early September, causing a release of zinc which peaked around September 8. Zinc concentrations in the decant decreased thereafter, but never to less than 5 ppm. Such upsets are not uncommon for newly established systems, because sediments are not completely vegetated and flow pattern are not fully developed (i.e., water chanellization is common). Nonetheless, these data show that zinc concentrations were consistently reduced in the wetland by approximately 90%. They also show that the system had not yet reached a steady state, otherwise *constant* zinc concentrations would have been obtained in the decant. This precludes calculation of a metal removal rate.

A noticeable decrease in inflow concentrations of zinc occurred on September 2. This can be explained by noting a similar decrease in magnesium concentrations in the wetland inflow and decant (Figure 8)[10]. All other element concentrations decreased similarly in the inflow and decant (e.g., Figure 9 to Figure 12). Assuming that magnesium behaves as a conservative tracer, these data suggest that heavy rainfall diluted the mine water. A dilution factor was calculated and applied to the inflow and decant zinc concentrations on September 2 (Figure 7). This correction shows somewhat more readily that zinc concentrations were leveling off at approximately 4 ppm before September 8.

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[10] The steady increase observed in late September is likely due to its release by senescing plants, and other related events associated with the end of the growing season.

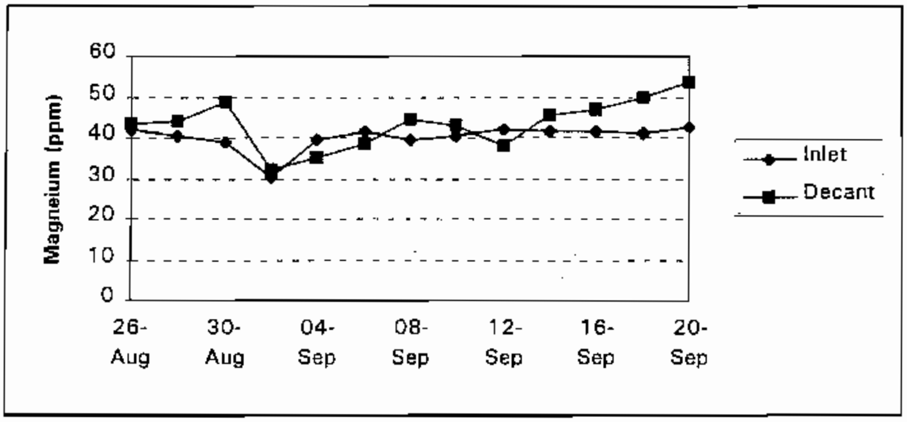

**Figure 8. Magnesium concentrations in the inflow and decant of the Galkeno constructed wetland.**

Nickel was also removed in the wetland (Figure 9). Inflow concentrations remained nearly constant at approximately 0.44 ppm, whereas decant concentrations appeared to stabilize at approximately 0.1 mg/L. Interestingly, the same pattern as for zinc was observed for nickel concentration in the decant: they leveled off to below 0.1 ppm until September 8, whereupon they suddenly increased. Subsequently, decant concentrations leveled off at slightly more than 0.1 ppm.

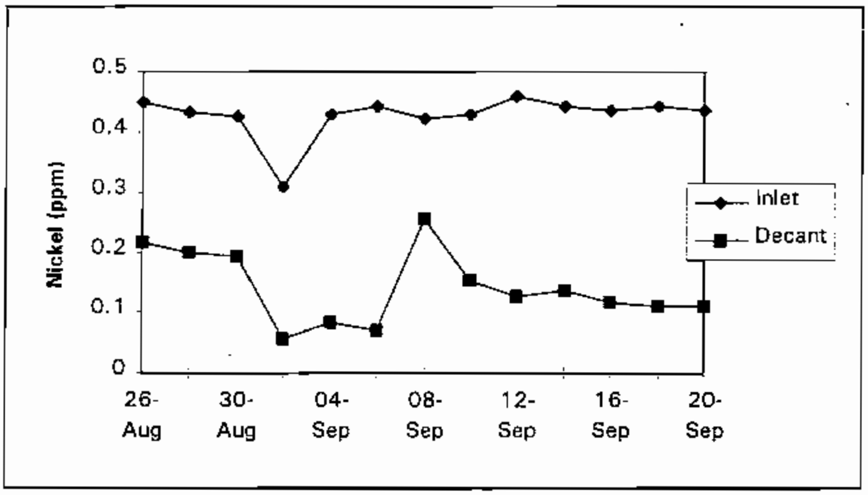

**Figure 9. Nickel concentrations in inflow and decant of the Galkeno constructed wetland.**

Manganese concentrations (total metal) also decreased in the wetland (Figure 10). Manganese concentrations in the decant also showed the same pattern as zinc concentrations. That is, they initially decreased to about 13 ppm until early September, whereupon they increased to a peak on September 8, levelling to about 20 ppm by the end of the sampling period.

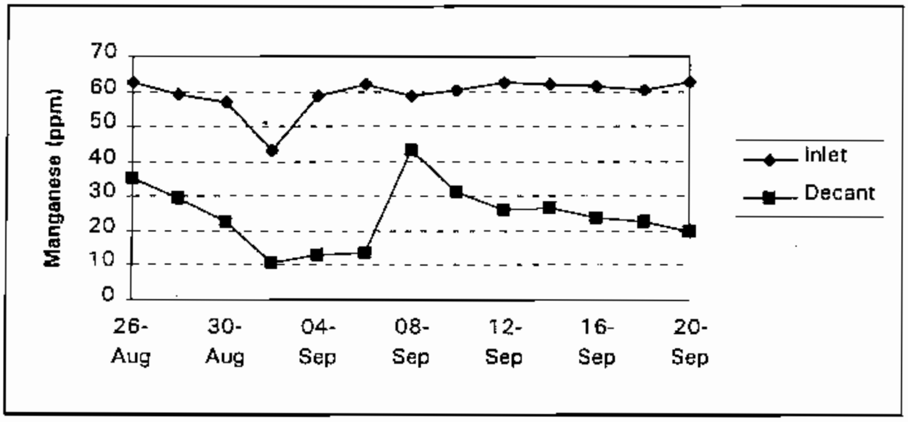

**Figure 10. Manganese concentrations in inflow and decant of the Galkeno constructed wetland.**

Information about some of the processes responsible for removing these metals was obtained by conducting additional water analyses on site. The data presented in Table 7 indicated that the water pH increased slightly as it flowed across the wetland, increasing from approximately 6.5 to 6.8. Water alkalinity exhibits a decreasing trend as it flows to the decant, indicating that it is consumed. Since the water pH increases in this interval, these data suggest that acidity is being neutralised or that carbonates are retained in wetland sediments.

Another important treatment process is the formation of insoluble sulphide minerals, as indicated earlier (Sections 2.2.3 and 3.2.2) and as suggested by the data presented in Table 7. Sulphate concentrations were measured at the inflow and decant to assess how much sulphate was reduced to hydrogen sulphide and retained in the wetland (Figure 11).

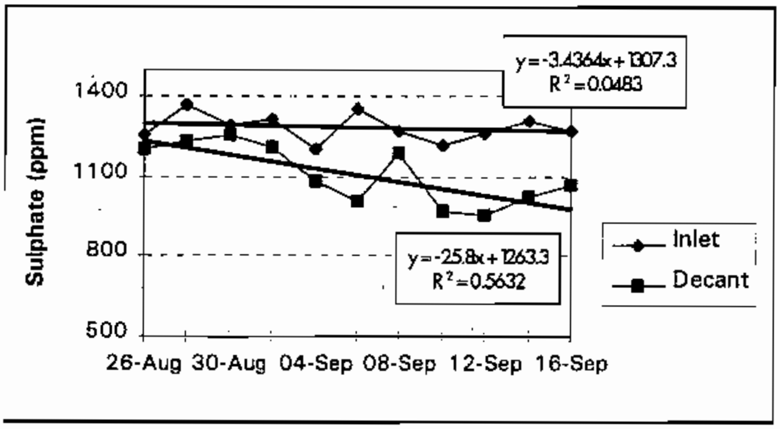

**Figure 11. Sulphate concentrations in inflow and decant of the Galkeno constructed wetland.**

Two observations can be made from these data.

1. Sulphate concentrations in the decant were gradually decreasing during the test period, indicating that insoluble sulphides (or, less likely, sulphur) were increasingly being retained in the wetland. This indicates that steady state conditions had *not* yet been attained, otherwise, lower, but *constant* sulphate concentrations would be expected in the decant.

2. A sudden jump of the decant sulphate concentrations observed on September 8. Such an increase in sulphate concentrations can only mean that anoxic sediments were stirred up and that sulphides were resuspended in the water column[11]. This explanation appears quite reasonable, given that the area near the decant is relatively unvegetated and sediments there are prone to being disturbed.

The latter observation provides a reasonable explanation for the jump in zinc and manganese concentrations in the decant observed on September 8. These metals were probably retained as sulphides in sediments and they became reoxidized – and redissolved – when the sediments were stirred up.

The fact that steady state conditions were not attained probably reflects the slow maturation of the system. In this instance, the capacity to retain sulphate (as sulphur or sulphides) was increasing during the test. SRB populations were probably still increasing in the wetland sediments during the test, which would explain this increasing capacity to retain sulphate (i.e., the overall rate of sulphate reduction to sulphide was increasing throughout the test period). These observations strongly suggest that metals were (partly) retained in the Galkeno constructed wetland as insoluble sulphides.

Given that sulphate reduction produce two moles of bicarbonate for each mole of sulphate reduced (c.f. Section 2.2.2), a concomitant increase in alkalinity in the decant would have been expected. The fact that a *decrease* was found instead (Table 7) suggests that insoluble carbonates were also retained within the wetland. A previous leachate test with sediments from natural wetlands indicated that they accumulated substantial quantities of carbonate (Table 5). A comparison of calcium concentrations in the inflow and decant of the Galkeno constructed wetland indicated that it was also retained in the wetland (See Figure 12). Note that, again, the system was perturbed in early September. Specifically, a peak of calcium in the decant is measured on September 8, as was observed for zinc, manganese, and sulphate. These observations suggest that sediments were disturbed on that date, resuspending sulphates and carbonates previously deposited therein.

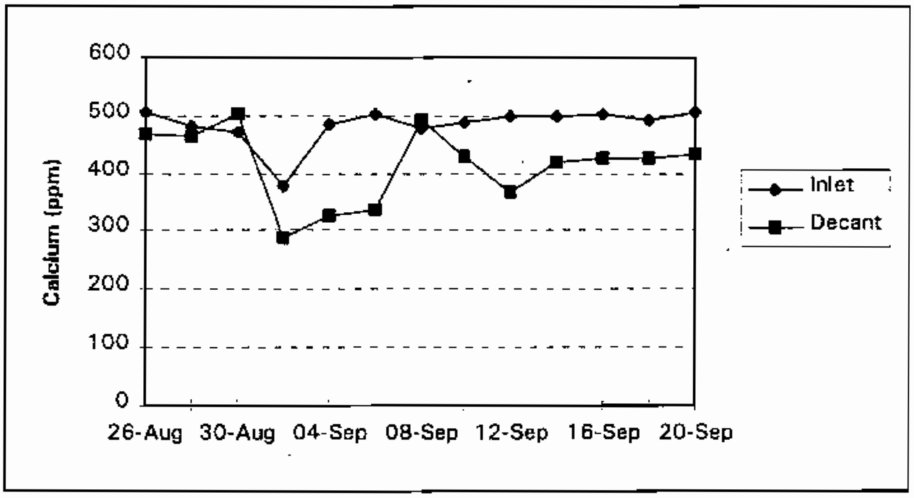

**Figure 12. Calcium concentrations in inflow and decant the Galkeno constructed wetland.**

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[11] Unfortunately, the samples collected in September were not filtered, and it is impossible to determine whether the increased metal and sulphate concentrations measured in the decant arise from resuspended particles dissolved by the nitric acid added to preserve the sampled water or truly dissolved species.

These data not only confirm that the Galkeno constructed wetland functioned similarly to the natural wetlands, they indicate that a full-scale wetland treatment system is likely to store a tremendous buffering capacity in sediments. Such a buffering capacity may be important in mitigating potential increases in the acidity of the mine drainage being treated.

Cobalt and nickel concentrations at the wetland decant exhibited a pattern similar to that of zinc and manganese: and initial decrease, followed by a transient increase which peaked on September 8, and finally declining gradually until the end of the test period. Cadmium was also removed by the wetland, but it did not show the same pattern as the other metals. This is presumed to result from its low inflow and decant concentrations (15 and 5 ppb, respectively). The low inflow concentrations (in the ppb range) for cobalt and nickel indicated that they were of no environmental significance. However, the same pattern of removal observed for all these metals (except cadmium) indicate that:

1. Similar processes affected metals present in the Galkeno mine water, and

2. Metal removal was upset by some event(s) occurring in early September.

The lower metal removal rate in the later part of September could also have resulted from lower temperatures, which would slow biological processes. These processes undoubtedly play an important role in metal removal, as mentioned earlier (see Section 2.2.2). Temperature data from the Mayo airport for September 1995 confirm this[12]. The mean temperature remained above 10° C from September 1-3, 6-13, and 19-26. The period of September 14-19 exhibited low temperatures, which would be expected to result in lower microbial activity, such as reduced sulphate reduction by SRB.

The 1995 field program has not allowed to address the question of treatment performance during the winter. A survey of the Galkeno natural wetland, nearby the pilot wetland, indicated that water was flowing under the ice in mid-November. Unfortunately, the temperature at the time was -35° C, which thwarted attempts to sample the water to determine metal concentrations. Despite this low temperature, it is expected that some metal removal will occur through sorption onto organic matter and onto precipitated iron and manganese oxides. The lack of data prevent prediction of metal removal rates, and it is recommended that such data be developed in the future.

### *3.3.2.3 Column Study Results*

One drawback anticipated with the Galkeno constructed wetland was that the short snow-free season limited the amount of data that could be collected during the field program. Several *in situ* microcosms were established on August 18 within the Galkeno constructed wetland to augment data from the pilot

---

[12] The temperatures at Elsa for the same month were significantly lower, as seen in the table below:

| | Mayo | Elsa |
|---|---|---|
| Max Temp. | 12.3 | 9.9 |
| Mean Temp. | 6.5 | 5.1 |
| Min. Temp. | 0.7 | 0.3 |

wetland. These microcosms consisted of translucent plastic columns (13.1 cm inner diameter x 25 cm height) containing cores of wetland sediments and vegetation (see Photograph 12). The cores were sealed at the bottom, drained, and replenished with 1.4 Litres of untreated Galkeno 900 water (Columns 4, 5, and 6) or Galkeno 900 water diluted 1:2 with South McQuesten water (Columns 1, 2, and 3). Microcosms thus prepared were re-introduced into the wetland where they were originally obtained (see Photograph 13).

Overall zinc (total metal) removal measured in the columns was better than in the Galkeno constructed wetland (Figure 13). Metal removal during the first 6 days was recorded, but the field technician (and the sampling procedure) changed on August 26, such that the results prior to this date are not comparable with the later results. Therefore, only the data from August 26 onwards are presented and discussed.

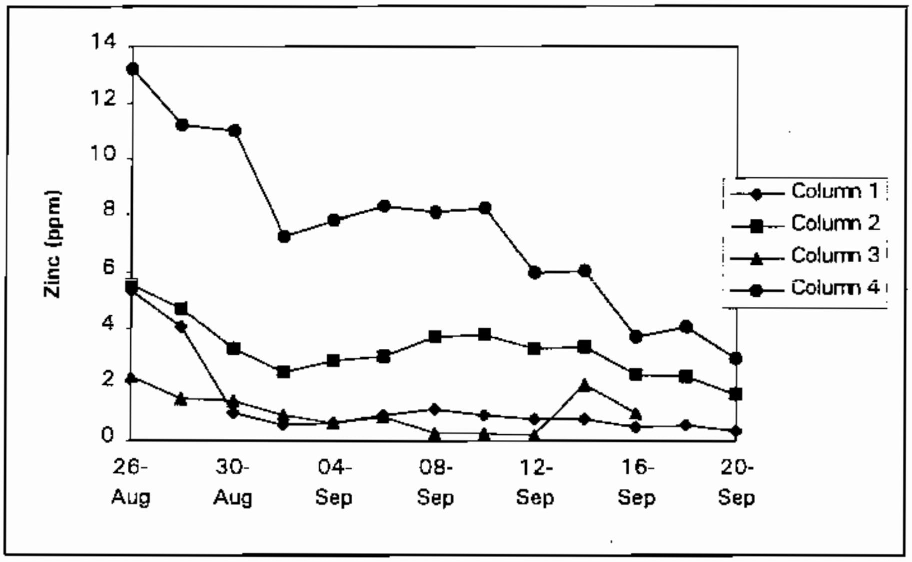

**Figure 13. Zinc removal in the Galkeno constructed wetland *in situ* microcosms.**

Data from columns 5 and 6 were lost because they were damaged midway through the study. In addition, the data from Column 2 are suspect, because of the increase in zinc concentrations in early September, which persisted until the end of the study. Results from these columns were removed from the data set, and only the data from Columns 1, 3, and 4 were considered further.

The results from Column 4 indicate that zinc was removed at a steady rate through the study. Similarly, zinc was constantly removed from Columns 1 and 3, except for the last two sample points for Column 3. These data were combined into a single, continuous data set to compute a zinc removal rate, and are plotted in Figure 14. That is, the zinc data from Column 4 were merged with those averaged from Columns 1 and 3 at the point where zinc concentrations coincided[13].

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[13] This approach is justifiable if the zinc removal processes operating at high and low concentrations are the same. Data presented later in the section suggest that this is a valid assumption.

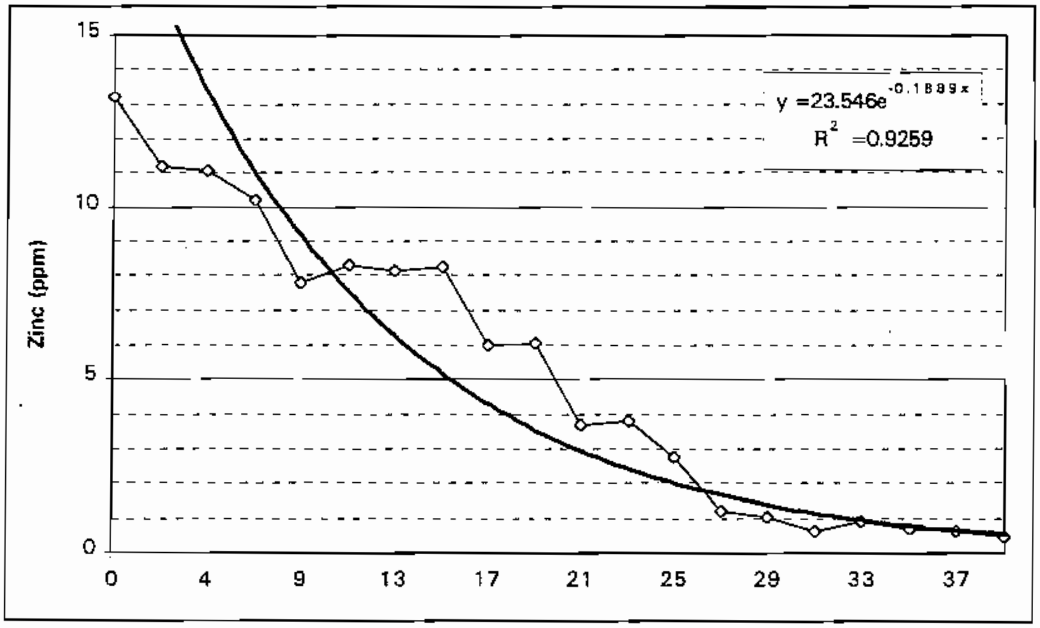

**Figure 14. Combined data from Columns 1, 3, and 4 for zinc removal.**

Despite the different waters used in the columns, the data obtained from combining the available data set produced a curve which fitted very well with an exponentially-decaying trendline ($R^2$ = 0.93). Applying the same removal rate to the zinc concentration data from the Galkeno natural wetland (Section 3.1.3), the predicted retention time should be approximately 14 days *vs* an retention time of 11.4 days estimated from field data. This close agreement suggests that the above rate of zinc removal is reasonable. Applying this removal rate to the data from the Galkeno constructed wetland[14] indicated that it had a retention time of approximately 14.7 days *vs* a nominal retention time of 19.3 days. This is again in reasonably close agreement, considering that the flow rate was changed on August 19, and that its pattern was modified by the placement of baffles in the wetland.

Water samples collected from the columns were analyzed for sulphate to determine whether sulphate reduction was taking place in the enclosed sediments. The data shown in Figure 15 indicate that cores with untreated Galkeno water and diluted Galkeno:South McQuesten water both sustained considerable levels of sulphate reduction. It is worth noting that the sudden increase in sulphate concentrations observed on September 8 in the pilot wetland (Figure 11) was not observed in the columns, indicating that sulphate reduction was relatively unperturbed for the duration of the test.

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[14] Inflow concentrations of 25 ppm; decant concentrations of 3.95 ppm, before September 8.

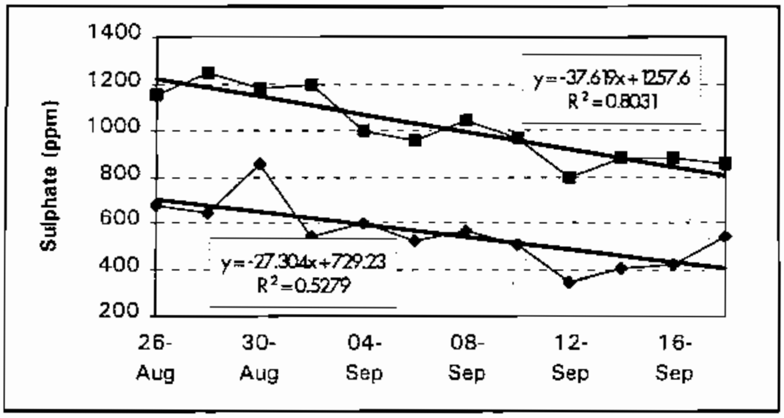

**Figure 15. Sulphate concentrations in columns in the Galkeno constructed wetland.**

The rate of sulphate reduction computed from the trendline fitted to the data is approximately 25 mmol/m$^2$/day. This rate compares favourably with rates of sulphate reduction published in the scientific literature. For instance, the average rate of sulphate reduction for 27 marshes on the Atlantic Coast and in the U.K. was 77.4 mmol/m$^2$/day (minimum 1.8, maximum 280 mmol/m$^2$/day) (Skyring, 1987).

From the rate of sulphate reduction computed above, it is predicted that bicarbonate alkalinity will be generated from wetland sediments are a rate of 50 mmol/m$^2$/day. Therefore, sediments in the columns are predicted to inject 41.5 mg $HCO_3^-$/day, as in Equation 1:

$$50 \text{ mmol } HCO_3^-/m^2/\text{day} \times 0.013 \text{ m}^2 \times 61 \text{ mg/mol} = 41.5 \text{ mg } HCO_3^-/\text{day} \qquad \textbf{Eq. 1}$$

With a volume of 1.4 Litre/column, an increase in alkalinity of approximately 20 mg/L/day would be expected. The alkalinity measured in the columns two days after adding the mine water increased as predicted by Equation 1 (Table 8). However, the alkalinity remained at these levels thereafter, indicating that it was removed from the mine water. Some alkalinity was undoubtedly lost as $CO_2$[15], but some is likely to have reacted with calcium and metals, forming insoluble carbonates. However, calculating the amount of metals lost from the water column as carbonates is very difficult (see footnote 15).

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[15] This was counteracted by the production of $CO_2$ from the decomposition of detritus. $CO_2$ concentrations measured in the columns concurrently with the measurements presented in Table 8 are as follows:

| | Galkeno | 1:2 Galk:McQ |
|---|---|---|
| | $CO_2$(aq) mg/L | $CO_2$(aq) mg/L |
| Day 0 | 40 | 18 |
| Day 2 | 40 | 43 |

While no there was no increase in dissolved $CO_2$ concentration in the [Galkeno] columns, there was a considerable increase in the [1:2 Galkeno:McQuesten] columns. Moreover, the system is clearly very dynamic: both $CO_2$ and $HCO_3^-$ are continually produced microbiologically and lost physically (volatilization) and chemically (equilibration the carbonate system, reaction with dissolved species). This complicates any attempt at modelling the carbonate system or the formation of insoluble carbonates based on these data.

Table 8. Bicarbonate production in columns in the Galkeno constructed wetland.

| | Galkeno | | 1:2 Galk:McQ | |
|---|---|---|---|---|
| | pH | Alkalinity mg/L as $CaCO_3$ | pH | Alkalinity mg/L as $CaCO_3$ |
| Day 0 | 6.02 | 139 | 6.04 | 95 |
| Day 2 | 6.55 | 175 | 6.24 | 125 |
| Day 5 | 7.01 | 162 | 6.97 | 130 |
| Rate of $HCO_3^-$ production from sediments by Day 2 | 25.2 mg $HCO_3^-$/day | | 21.0 mg $HCO_3^-$/day | |

Nonetheless, these results indicate that a significant amount of alkalinity will retained in the wetland sediments, as has been noted by others (Hedin *et al.*, 1994). This alkalinity will buffer water pH, which might be important in case the mine drainage gradually becomes acidified. For instance, it would preserve the pore water pH to a level that permits continued activity of sulphate-reducing bacteria.

The information presented above provides the basis for designing a wetland treatment system. While the field work focused on (and assumed the need for) treatment of the discharge from the Galkeno 900 adit, it is clear that such a design could be applied to other discharges on the property, should there be need for treatment.

# 4. Design of a WTS

The design for a full-scale WTS to treat the Galkeno 900 water will be developed in this section. First, historical water quality data for the discharge from the Galkeno 900 adit will be reviewed to indicate which metals are most of concern. Environmentally-acceptable discharge concentrations for each metal of concern will next be derived to provide the design objectives. An overall design will be elaborated, and a treatment system will be sized to achieve these objectives. Removal processes will then be considered for each of these metals, and the overall system design will be verified to determine whether it can accomplish the treatment objectives. Finally, this design will be refined through consideration of anticipated seasonal loads and performance, and system longevity.

## *4.1 Metals of Concern*

Metals potentially of concern in the Galkeno 900 adit discharge are initially screened by comparing their concentrations in the discharge from the Galkeno 900 adit with the CCREM Water Quality Guideline for the protection of freshwater aquatic life (1987).

**Table 9. Comparison between CCREM Water Quality Guidelines for protection of freshwater aquatic life and dissolved metal concentrations in the discharge from the Galkeno 900 adit.**

| | **CCREM**[1] | **Galkeno 900 adit** |
|---|---|---|
| | (hardness > 180 mg/L) | (mean diss. conc. for 1994-95) |
| **Cadmium** | 1.8 | 15 |
| **Copper** | 4 | < 2 |
| **Iron** | 300 | 2,105 |
| **Lead** | 7 | <10 |
| **Nickel** | 150 | 506 |
| **Zinc** | 30 | 25,000 |

[1] Metal concentrations expressed in µg/L.

Table 9 shows that cadmium, iron, nickel, and zinc concentrations in discharges from the Galkeno 900 adit exceed the CCREM Guidelines. These exceedances ranges from approximately three-fold for nickel, to approximately eight-fold for cadmium and iron, to more than eight hundred-fold for zinc. However, all but zinc were at or below concentrations stipulated by the Yukon Territory water license for UKHM. Clearly, reducing zinc concentrations in the discharge must be the primary treatment objective. Therefore, it can be reasonably argued that reducing zinc concentrations to an environmentally-acceptable level will eliminate all potential environmental impacts from the Galkeno 900 adit discharge[16].

Considering the extensive historical mining activity in the region and the existing discharge criteria, it is neither reasonable nor practical to reduce the zinc concentration to that recommended as the CCREM

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[16] It is worth noting in this regard that cadmium, iron, and nickel concentrations were significantly reduced when wetlands remove zinc from the mine water (Sections 3.2.2, 3.3.2 and 3.3.2.3).

guideline. Accordingly, the existing discharge limit of 0.5 mg/L might be adopted as the treatment objective for the wetland treatment system. However, designing the system to a zinc concentration 0.25 mg/L will insure that this discharge limit is never exceeded. Therefore, the wetland treatment system will be designed to produce a discharge with a maximum zinc concentration of 0.25 mg/L.

## *4.2 Overall Design of a Wetland Treatment Systems*

Having defined a treatment objective, a WTS can be designed, based on anticipated metal loadings and on their removal rates.

Since the WTS is assumed to be treating all the Galkeno 900 water, flow rates measured before placement of the plug in the Galkeno 900 adit will be used for design purposes. Until 1994, its discharge in the summer averaged 8.1 L/sec. For the WTS design, flows of 10 L/sec will be assumed. Using this flow rate, the daily volume of water to treat is calculated as follows:

$$10\ \text{L/sec} \times (60\ \text{sec/min} \times 60\ \text{min/hr} \times 24\ \text{hr/day}) \times 1{,}000\ \text{L/m}^3 = 864\ \text{m}^3/\text{day}$$

The total concentrations of zinc in the Galkeno 900 water in the past decade averaged 29 ppm, with a maximum recorded of 34.3 ppm. For design purposes, it will be assumed that the total zinc concentration to be treated is 34 ppm.

Data from the column study (Section 3.3.2.3) provided a zinc removal rate given by the exponential equation $y = 23.55e^{-0.1889x}$, where y is the zinc concentrations in mg/L and x is the number of days. This exponential decay equation means that the rate zinc removal decreases as its concentration diminishes, which is intuitively sensible. It should be noted that this rate was obtained from a recently constructed wetland. It is expected that better removal rates will be obtained as the system matures[17]. Thus, the above rate likely represents a minimum.

Using this rate, a retention time of approximately 26 days will be required to meet treatment objective of 0.25 mg/L zinc. From this retention time, the volume of water to be treated is calculated as:

$$864\ \text{m}^3/\text{day} \times 26\ \text{days} = 22{,}464\ \text{m}^3$$

Assuming that the constructed wetlands have an average depth of 0.5 metre, they will need to cover an approximate surface area of 45,000 $\text{m}^2$ (22,464 $\text{m}^3$ x 0.5 m). This can be achieved by building 4-5 wetland cells downgradient from the Galkeno 900 adit. A gently sloping area downgradient from the adit is available to accommodate these wetlands, an example of which is shown on Map 2.

Having developed an overall design, each element of the proposed wetland treatment system will be considered in further detail in the following sections.

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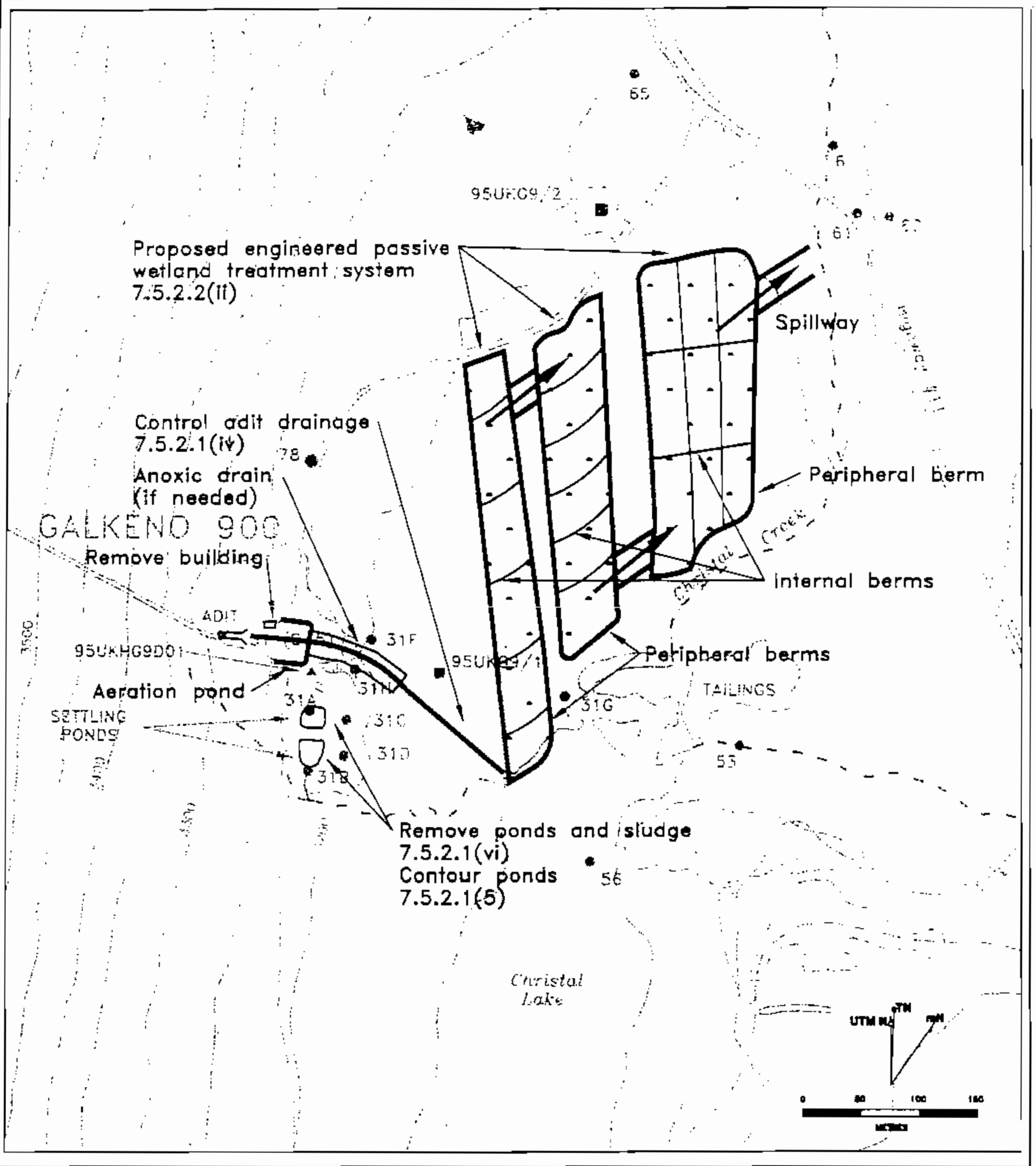
[17] For instance, higher populations of sulphate-reducing bacteria were expected in the wetland sediments, which would have resulted in faster rates of metal removal. Similarly, a gradual build-up of detritus would enhance metal removal.



## LEGEND

■ Soil test pit with piezometer
▲ Waste rock sample
● Water quality sample site
Disturbed area
▭ Building
Power Line
Telephone Line
Highway #11
Road
Trail
Stream or River
Underground Workings
Open pit, trench
Waste rock dump
Tailings area
Adit entrance
◪ Shaft location

**UNITED KENO HILL MINES LIMITED**

## GALKENO 900

## CLOSURE MEASURES

*Access Mining Consultants Inc.*

| | | |
|---|---|---|
| SCALE: 1 : 6,000 | FILE:[illegible].DWG | DATE: 26/04/96 |
| DRAWN: [illegible] | DWG: 96UK10C | FIGURE 7-6 |

### 4.2.1 Planting and Vegetational Aspects

The sedge *Carex aquatilis* used in the pilot wetland study is well suited for the full-scale Galkeno constructed wetlands. It is relatively abundant and accessible from the original donour site. It is a hardy plant, able to tolerate quite a range of water depths (estimated to be from -10 to +45 cm). The latter characteristic is important, as it is likely that the cells will settle unevenly after excavation and planting.

The large area (45,000 $m^2$) that needs to be planted presents a number of logistical problems. Nonetheless, there are reports of such large areas having been vegetated at mine sites in the arctic (Jorgenson *et al.*, 1992). It will not be possible to fully plant vegetate excavated cells, because there is probably not enough readily accessible sedges near the Galkeno 900 adit. Therefore, these areas will be partially planted, for example spacing plant clumps at one metre apart. This will be supplemented with seed broadcasting, using seeds collected the previous year (August-September collection). The fact that numerous rhizomes and side-shoots formed after being introduced into the pilot wetland suggests that transplanted plants will aggressively fill open spaces in the full-scale wetlands. Seed production, also observed in the pilot wetland, will also contribute to filling-in open spaces. These two modes of reproduction were undoubtedly promoted by the addition of fertilizer in the pilot wetland. Similar fertilization will be required when the full-scale system is vegetated.

The newly planted cells will need to be flooded to promote growth and prevent invasion by other plants. It will be necessary to circulate treated Galkeno 900 water into the newly vegetated cells. A period of 2-3 growing seasons is likely to be required before the cells are fully vegetated and the wetlands are ready to function as treatment systems. Plant growth and percent coverage will need to be monitored (measured yearly at peak standing crop) to determine when the wetlands are ready. Until then, the current lime treatment will need to be continued.

### 4.2.2 Wetland Design and Function

Several issues must be considered regarding the actual design of the full-scale WTS:

1. Can the surface area necessary for treatment be realistically accommodated within the space available?

2. Is the wetland shape compatible with treatment objectives under all the anticipated flow conditions?

3. Is the design compatible with its anticipated function (e.g. anaerobic system, acid loadings, etc)?

4. Will there be special requirements, such as the need to seal their bottom with synthetic liners?

These questions are considered in the following discussion.

The area drawn on Map 2 indicates that there is enough space below the Galkeno 900 adit to accommodate the full-scale wetland treatment system. Their tentative location was checked against a topographic map with 10-foot contour, which indicated that the wetland cells more or less follow the contours of the landscape. In addition, this map showed that there is sufficient height difference between the Galkeno 900 adit and Christal Creek to move the mine water through the wetlands.

One advantage of their proposed location is that its southern exposure on Galena Hill and relatively sheltered placement maximizes the effective ice-free period. This period is estimated to last approximately four months, from late May to late September.

During the summer, the wetlands will predominantly function anaerobically, due to the activity of sulphate-reducing bacteria (Sections 3.2.2, 3.3.2.2 and 3.3.2.3). Under these conditions, metals will be retained as insoluble sulphides. In the winter, when biological activity is negligible, metals will be retained through abiotic processes, such as sorption onto organic matter and metal oxides. During this time, flows and metal concentrations are expected to be reduced, making effective treatment is still possible.

The above design assumes that treatment will be provided on a year-round basis. An alternative option would be to store water in the Galkeno 900 adit during the winter and release it for treatment during the summer. Such an option can still be accommodated by the above design, insofar as the chosen flow rate of 10 L/sec would likely be sufficient to drain the water accumulated during the winter[18]. Treatment performance in the winter will have to be monitored in the first few years after start-up of the system, to determine whether this option is necessary.

The constructed wetlands are expected to continue removing metals for several (50+) years. This prediction is based on the data collected during the laboratory and field study, which indicate that metals are retained on the surface of metal oxides and as insoluble sulphides. These processes will remain active as long as iron, manganese and sulphate are present in the mine water. A different result would have been obtained, had the metals been retained predominantly by sorption onto organic matter. Thus, the cation exchange capacity of the system would have been saturated within a few years, whereupon metal removal would have ceased. The designed wetland depth (0.5 m) is high relatively to other systems, but it allows for substantial accumulation of detritus. The nominal retention time is expected to gradually decrease as the wetlands fill in, but a compensating increase in metal removal efficiency is expected. Thus, performance is expected to be maintained – or improve – over the long term.

One question which remains unresolved is whether the discharge from the Galkeno 900 adit will become altered over the years. The main concern is that its pH decreases over time. The US experience with WTS treating low pH mine drainage indicates that treatment is still possible, because alkalinity generated in wetland sediments neutralises the acidity in the mine drainage (Sections 2.1.2 and 2.2.2). However, there is a requirement to maintain the pore water pH within a range tolerable by sulphate-reducing bacteria (approximately pH 6-8). This requirement is met by designing the system to produce enough alkalinity to meet the maximum acidity load from the mine water.

The rate of alkalinity generation from sediments is 50 mmol/m$^2$/day (Section 3.3.2.3)[19]. The daily amount of alkalinity generated to match a daily load of acidity is calculated as follows:

1. The daily volume produced by the Galkeno 900 adit (assuming 10 L/sec) is 864 m$^3$/d.

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[18] This is based on the assumption of an average summertime flow rate of 6 L/sec and a wintertime flow rate of 2 L/sec. The water accumulated during the winter would correspond to an increased summertime flow rate of 4 L/sec (8 months accumulation discharged during a 4 month period), giving a total summertime flow of 10 L/sec.

[19] This is a low rate, which is expected to increase with time, as noted earlier.

2. This volume, spread over the wetland, will cover a surface area of 1728 $m^2$ (assuming 0.5 m depth).

3. The daily production of alkalinity from this surface area is 1728 $m^2$ x 50 $mmol/m^2/day$ = 86,400 mmoles, as $HCO_3^-$ (or 86,400 meq).

This amount of bicarbonate will neutralize an equivalent amount of acidity present in the Galkeno 900 water. Assuming this to be proton $[H^+]$ acidity, and given daily flows of 86,400 L/d, this corresponds to a capacity to neutralize 1 meq/L (or $10^{-3}$ mole $H^+$). Therefore, the wetlands will still perform satisfactorily with water of a pH as low as pH 3.5-4.

If the discharge from the Galkeno 900 adit is expected to reach such a low pH, it will be necessary to distribute it so as to maximize the contact with the substrate in the first wetland, so as to avoid localised overloads in acidity. This is done by allowing the water to flow into the wetland along its width, rather than its length, as depicted on the diagram in Figure 16.

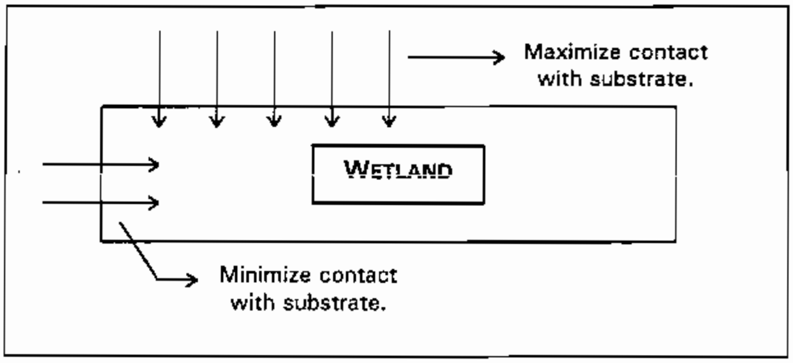

**Figure 16. Contrast between flow distribution to maximize and minimize contact with substrate.**

Such a distribution of water flow is achieved by constructing a distribution ditch along (part of) the width of the first wetland. Moreover, such a distribution system can easily be retrofitted or modified to suit changing circumstances.

### 4.2.3 Control of Water Flow in Wetlands

Several elements of constructed wetlands affect their hydrology, which in turn affects their performance. These elements are discussed in this section.

Initially, the settling ponds currently receiving treated Galkeno 900 water will be used as reservoirs feeding the wetland treatment system. However, the negligible effect on water quality noted from the settling pond feeding the pilot wetland indicates that they will not be necessary for the long-term. Even in their absence, the wetland system will be provided with a relatively constant inflow rate, because surges in flows will be smoothed within the Galkeno 900 adit. Therefore, integration of the settling ponds will be optional to the design of the WTS.

The wetlands must be designed to accommodate for low or high flow periods. Dikes will be built to retain and channel the water in the wetlands. They will be constructed using cell cuttings, adequately compacted and sloped minimally 2H:1V. They will also be covered with a layer of crushed rock to protect against damage by rodents. Since dikes tend to settle over the years, they will be constructed with 0.45-0.75 metre of freeboard to ensure at least a 0.3 metre freeboard over the long term. Surface runoff will be controlled through diversion ditches which direct its flow around the wetlands.

One common problem with wetlands is that water will not flow evenly across their surface, due to channelling, water stagnation, etc. Part of the solution is to design wetlands with a length-to-width ratio of 5:1. The wetlands drawn on Map 2 in the large measure adhere to this criterion. However, the local geometry of the wetland site will dictate their ultimate shape. Long wetlands are still subject to short-circuiting and they will be hydraulically chambered using simple, low or subsurface finger dike, riprap baffles or other structures. Another part of the solution is to minimize sloping and to keep the bottom relatively even. This is not entirely feasible, particularly in an environment where soil movement can be pronounced, but it can be promoted by carefully surveying the cells during excavation. Expertise available at the mine camp will be used for this purpose.

Spillways will be designed to pass the maximum probable flow. Spillways will consist of wide cuts in the dike with side slopes no steeper than 2H:1V. Proper attention will be paid to spillway design, to preclude high future maintenance costs due to erosion and/or failed dikes. They may be lined with non-biodegradable erosion control fabric and coarse riprapped. If possible, vegetated spillways overlaying erosion control fabric will be used, as they provide the most natural and stable spillways. Efforts will be made to incorporate structures to make flow measurements at the system outflow stations possible.

Channels connecting each wetland will prevent the build up of kinetic energy and minimize re-aeration of the water. Moreover, they will be designed to prevent high energy water from entering a wetland cell, causing erosion and/or the mobilization of sediments.

Soil movement induced by the wetlands is a potential concern. The wetlands drawn on Map 2 are designed to be narrow on the steeper part of the slope and comparatively wide on the flatter part of the slope. Spacing them as widely as possible is designed maximizes slope stability. However, many other factors affect soil stability. Qualified engineers will examined the final wetland design to insure that slope integrity is not jeopardized.

Wetlands commonly discharge or receive water through their bottom. This could potentially lead to the release of contaminated mine water in the environment. The bottom of the pilot wetland appeared to be relatively impermeable (except for an area with waste rock at the bottom), and it is expected that the full-scale wetlands will be similarly impermeable soil[20]. Nonetheless, the soil in the area planned for the wetlands will be characterized for thickness, composition, use as a construction material, drainage characteristics, and erosion potential prior to their construction.

It may become necessary to store water during the winter period if treatment performance in the winter is unacceptable. The simplest way to accomplish this would be to regulate water flow into the WTS from the plug in the Galkeno 900 adit. Water would be allowed to flow during the period of effective treatment, but it would be left to accumulate in the portal during periods when treatment in insufficient.

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[20] Such a flow through the wetland bottom would actually be favourable to the removal of metals because it would improve the contact between the mine water and the sediments, where sulphate reduction and formation of insoluble sulphides occurs.

The decision to proceed with this option will be made after treatment performance during the winter is determined.

## 4.3 System Start-up and Monitoring Program

There are special monitoring requirements associated with wetland treatment systems, in addition to those stipulated by the water license. These are particularly important in relation to the system start-up, because effective treatment can only begin when the wetland cells are sufficiently vegetated. In addition, the relative lack of experience with WTS in Canada dictates that enough information be gathered to gain confidence in these systems.

Plant growth and coverage must be monitored in the first 2-3 years following planting of the wetlands. Plant growth should be measured early during the growing season (early to mid-June) and later, during peak standing crop (mid-August). Plant survival, growth, and reproduction, and percent coverage will be recorded to monitor the progress of wetland maturation. Treatment of mine water may commence when plant growth is seen to be healthy and coverage reaches 67% (e.g., two-thirds vegetated).

While metal uptake by plants is not expected, it might be prudent to confirm this assumption. If this suggestion is implemented, sampling should be delayed for 3-5 years after treatment is initiated, because there will not be enough metal in the sediments to be detectable.

Fertilization is normally done during cell planting, but the advisability of follow-up fertilization will be determined during these bi-annual surveys. Evidence of plant damage due to browsing animal or disease will be sought, so that corrective measures and/or replanting can be promptly initiated. If necessary, animals may need to be trapped, removed, and barriers erected to prevent their access.

Similarly, dikes and spillways will be inspected so that damage to them can be repaired. Remedial work may arise from their deformation due to uneven settling or to damage caused by animals. The wetland cells may need to be modified, by creating baffles for instance, to ensure that water flows across evenly in spite of changes in shape. This is particularly important in the first few years of operation.

The monitoring plan for water quality should include measurement of a few parameters indicative of system function. In addition to metals, these would include pH, acidity, alkalinity, and sulphate concentrations. Measuring these parameters before treatment begins will also help in determining when to start up the system. For instance, an increase in effluent alkalinity and a gradual decrease in sulphate concentrations will indicate that sulphate reduction is occurring, a process necessary to metal removal. System start-up should be delayed in the absence of these indicators, even if the plant cover criterion is fulfilled. The reasons for a lack of sulphate reduction should then be identified, if indeed it is lacking.

At least once before start-up, a tracer study should be conducted to verify the nominal retention time. This test is quite easy, involving the addition of sufficient sodium bromide at the wetland inflow and measuring its progressive appearance in the decant. The test will diagnose if significant leakage from the wetlands occurs and may identify the need for remedial action. Quantitative recovery of the tracer will indicate the absence of leakage and will remove the need for any examination of groundwater impacts.

A weather station could provide additional data (temperature and rainfall). This is not mandated, but it might help to explain anomalous discharges. Close attention should be paid to water quality immediately after snow melt.

As this information is gathered, design can be improved to avoid future damage. A good monitoring effort during the early years will generate confidence in the long-term viability of the system. This will be beneficial to the regulator, the mining company, and others involved in the mining industry.

# 5. Data Gaps and Recommended Future Studies

There are some gaps in our current knowledge which could affect modifications to the proposed wetland treatment system. These deficiencies and the measures to correct them are briefly presented below.

A number of recommendations were made regarding monitoring requirements before and immediately after start-up of the treatment system (Section 4.3). Collecting the abovementioned information will validate or modify some of the assumptions made in this report.

The year-round performance anticipated for the treatment system is relatively uncertain and requires confirmation. The most effective way to do this is to sample the WTS during a winter of full operation. Data can still be obtained from the pilot-scale wetland, and it might be preferable to do this in the time before the full-scale system is started.

While the future changes in water quality of the discharge from the Galkeno 900 adit cannot be predicted with certainty, there may be some concern about its potential deterioration. It might be useful to test the prediction made in Section 4.2.2 concerning the ability of the wetlands to treat water of low pH. Again, this could be done in controlled tests using the pilot wetland (acidifying water in the settling pond by the Galkeno 900 adit, for example). This would give confidence in the long-term viability of the WTS.

It is not certain to what extent the results of the pilot wetland study can be generally applied to other discharges on the property. While they may be broadly applicable, and criteria may be produced for the design of WTS for these discharges, close monitoring would be required (in the absence of other data) to validate the assumptions used in their design.

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# APPENDIX I

## PHOTOGRAPHS

Photo 1. Measurement of water pH in small seep originating from waste rock dump at the Husky adit. Bottom right is nearest to the rock dump, top left is furthest away. See text for description.

Photo 2. Opening within muskeg where No Cash creek enters below the surface.

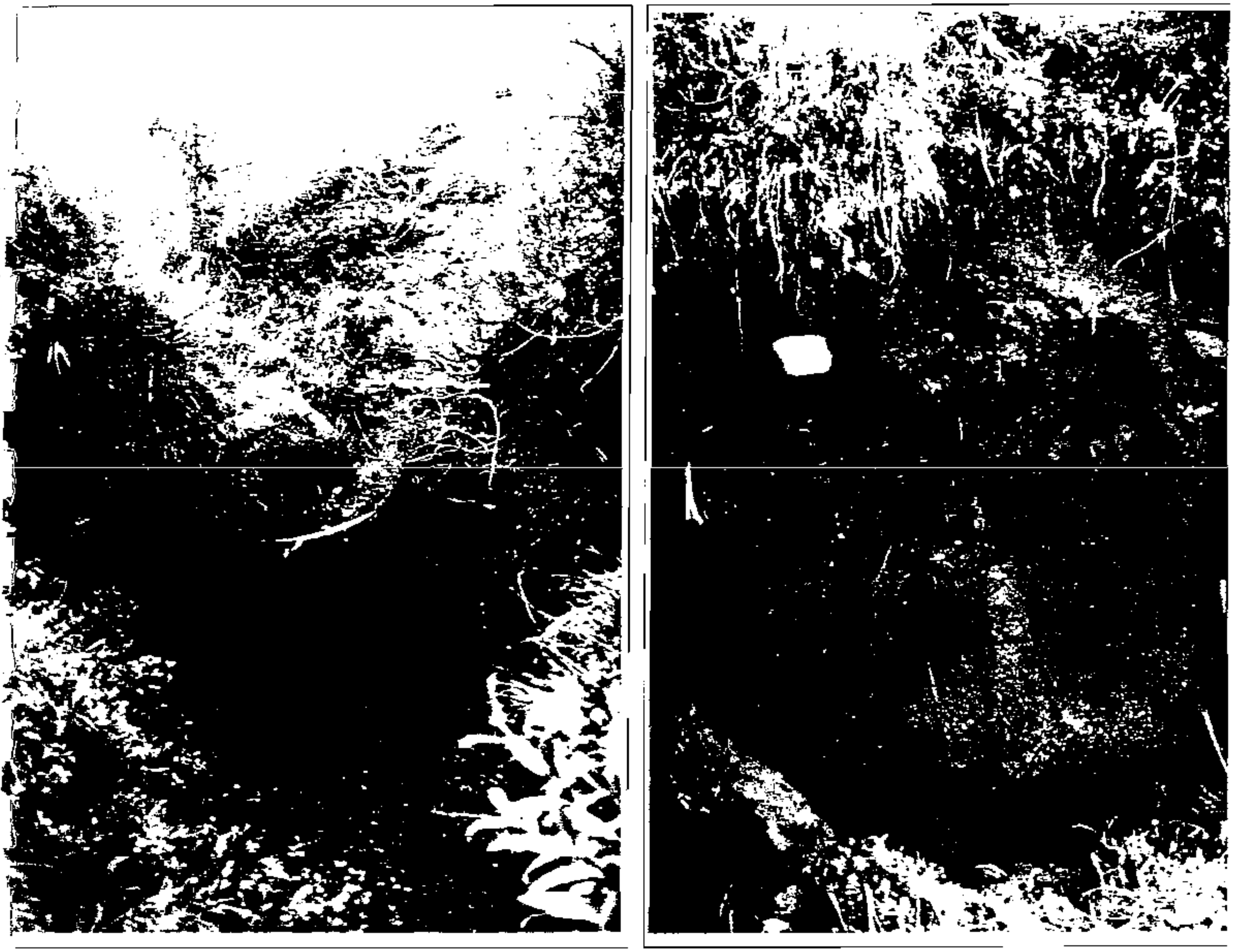


Photo 3. Opening within muskeg showing underground reservoir of water.

Photo 4. Emergence of underground, silt-laden water into a small creek. See text for description.

Photo 5. Small natural wetland, downgradient from the Galkeno constructed wetland. See text for description.

Photo 6. Black manganese deposit downstream from Galkeno natural wetland.

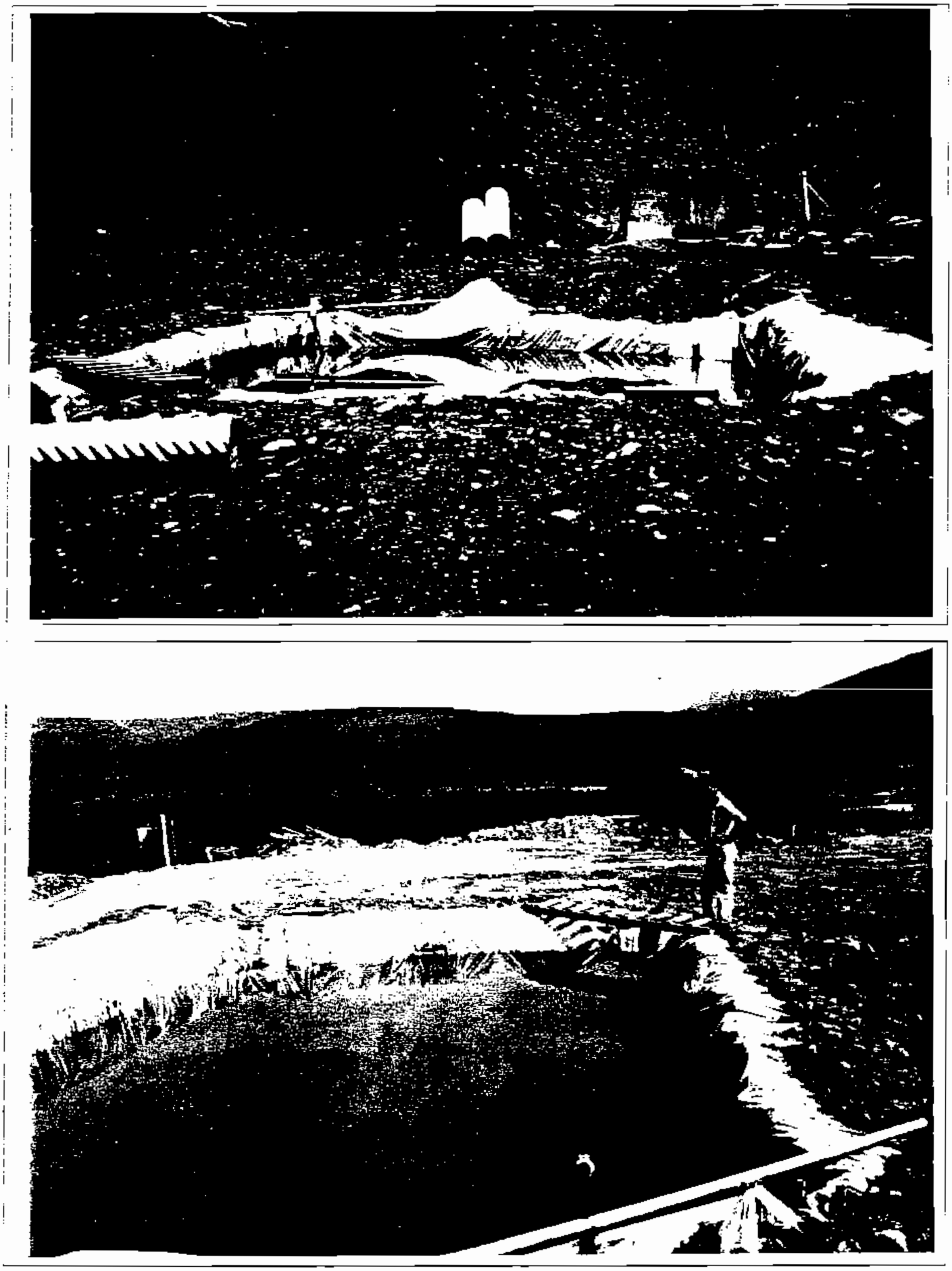


Photo 7. Plastic-lined settling pond below Galkeno adit.
Above: facing Galkeno adit. Below: opposite adit.

Photo 8. Excavation of the Galkeno constructed wetland.

Photo 9. Donour site of *Carex aquatilis* for planting of the Galkeno constructed wetland.

Photo 10. Galkeno constructed wetland shortly after planting.

Photo 11. View of the Galkeno constructed wetland after plants were fully grown, in mid-August. The inflow pipe is seen in the back, on the right, whereas the decant can be seen on the left.

Photo 12. Cores used as *in situ* microcosms in the Galkeno constructed wetland.

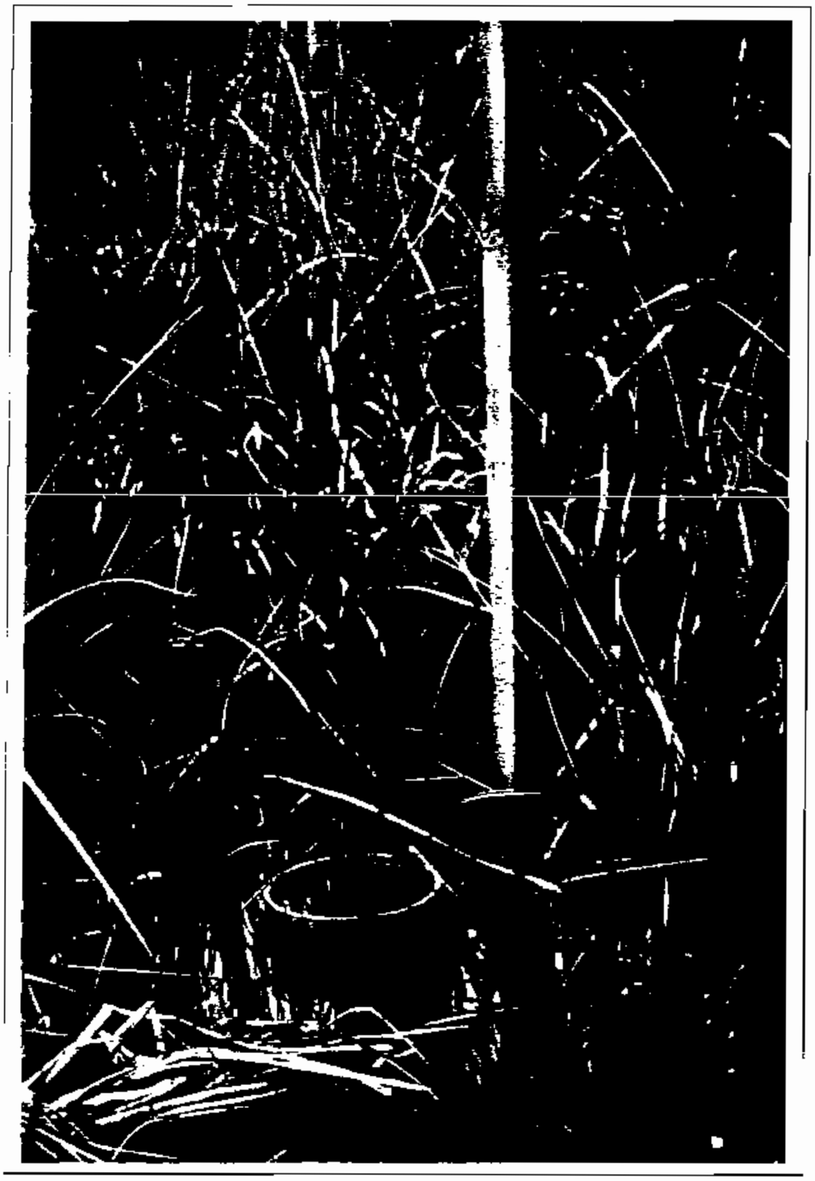
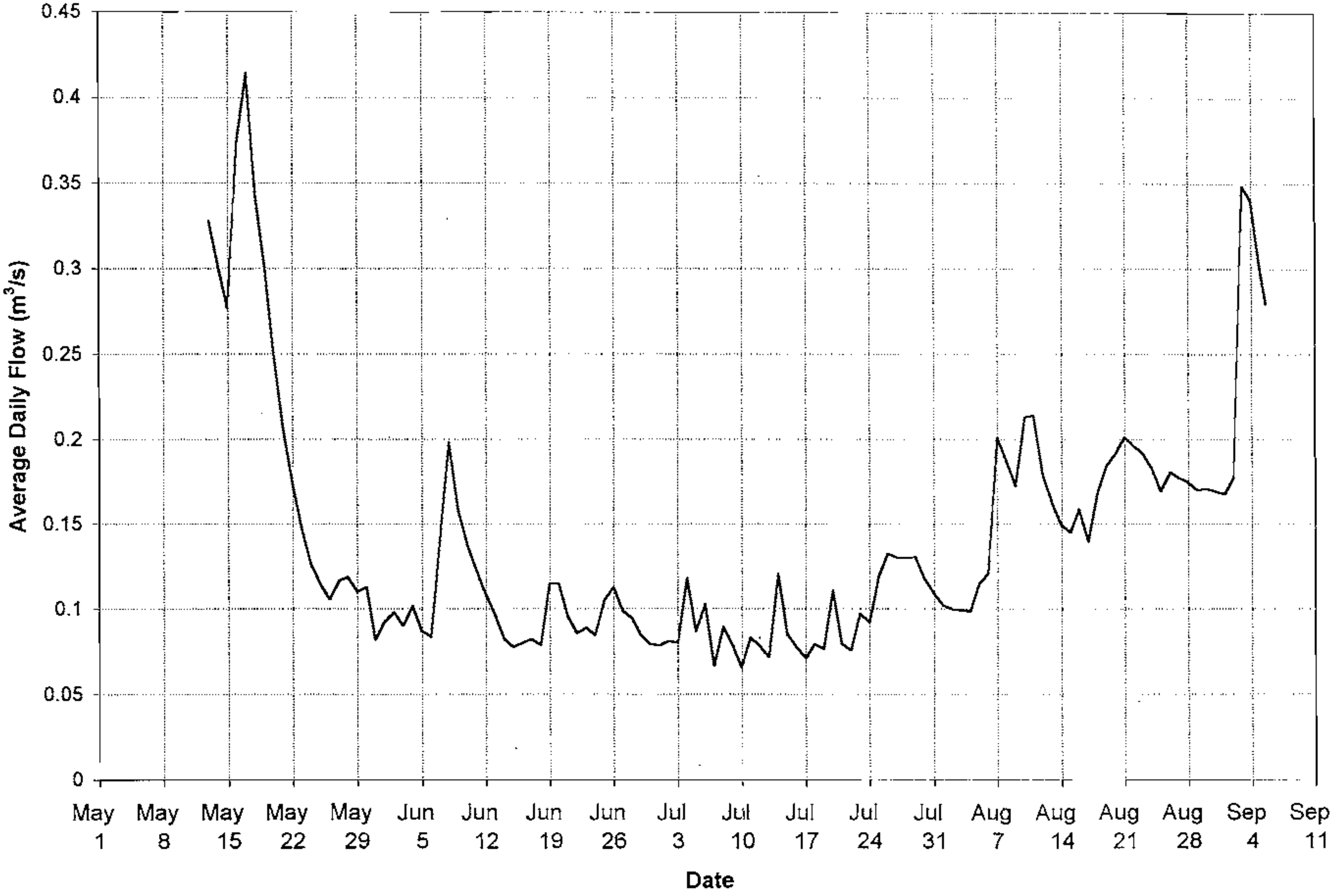


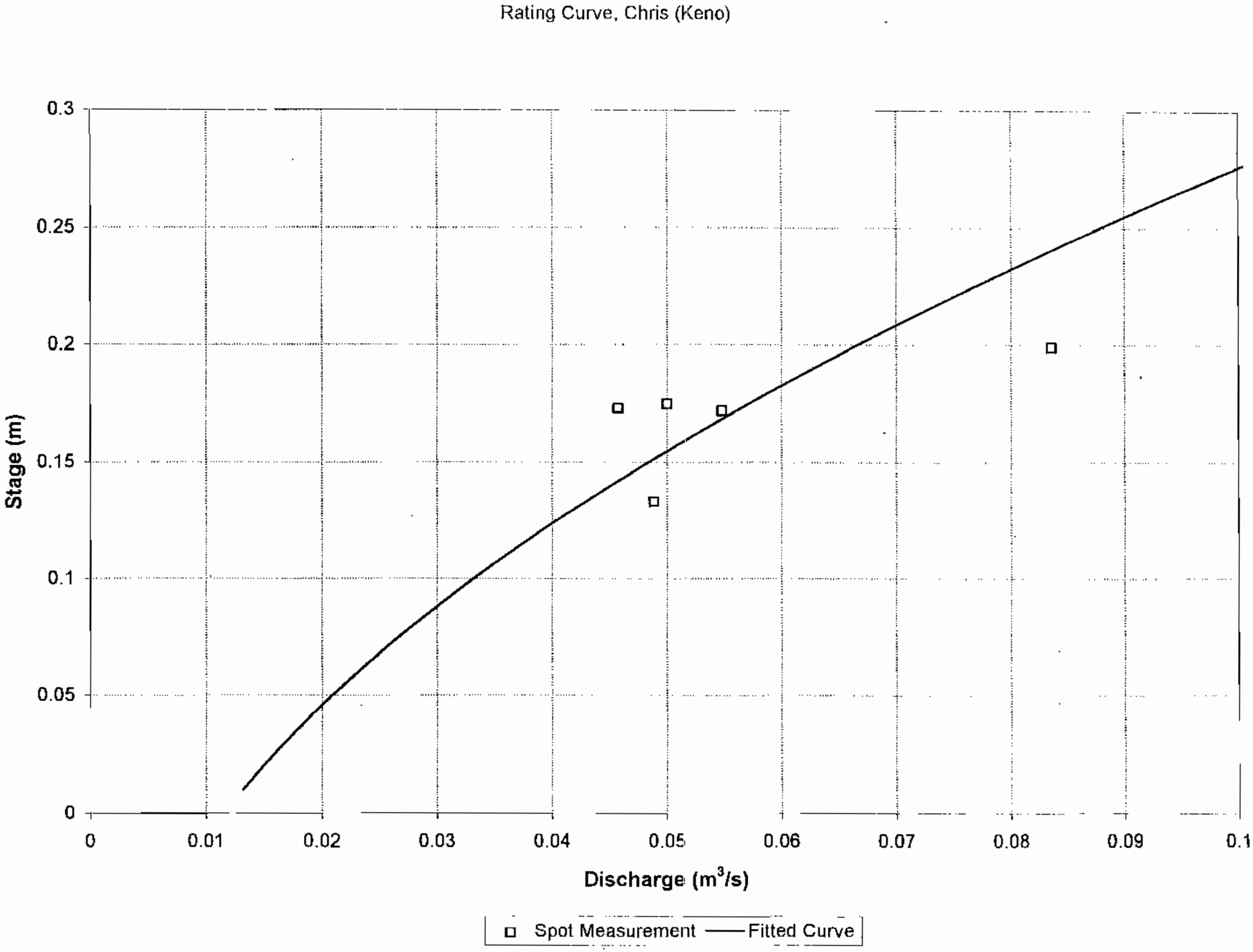
Photo 13. *In situ* microcosms in the Galkeno constructed wetland. Note the fruit-bearing culms on the wetland plants, to the right.

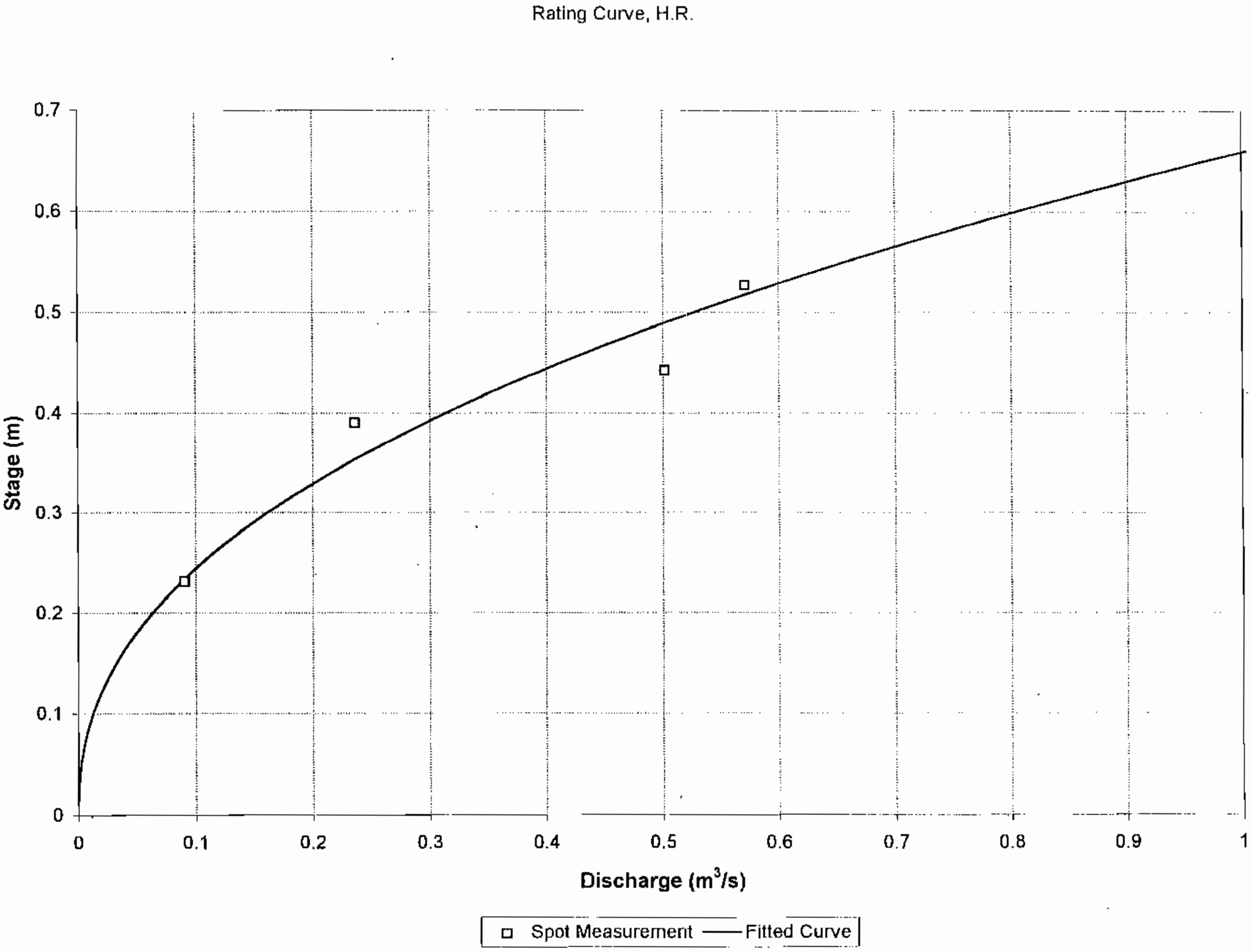
# Appendix III

## Hydrology Data

- Streamgauge Data
- Rating Curves
- Catchment Elevation, Area and Flow Data

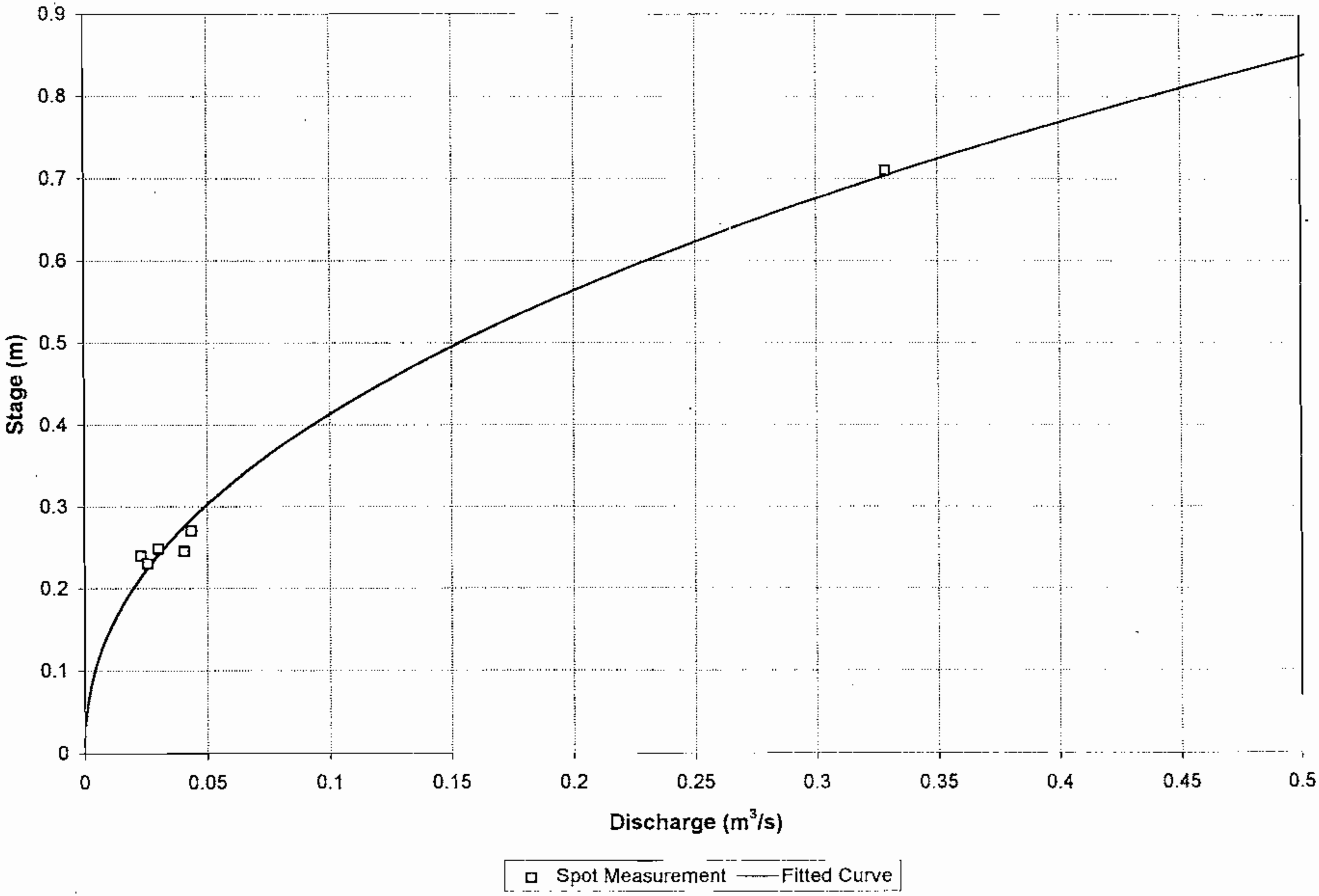

0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Average Daily Flow (m³/s)
May 1
May 8
May 15
May 22
May 29
Jun 5
Jun 12
Jun 19
Jun 26
Jul 3
Jul 10
Jul 17
Jul 24
Jul 31
Aug 7
Aug 14
Aug 21
Aug 28
Sep 4
Sep 11
Date


Rating Curve, Chris (Keno)
Stage (m)
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
Discharge (m³/s)
Spot Measurement
Fitted Curve

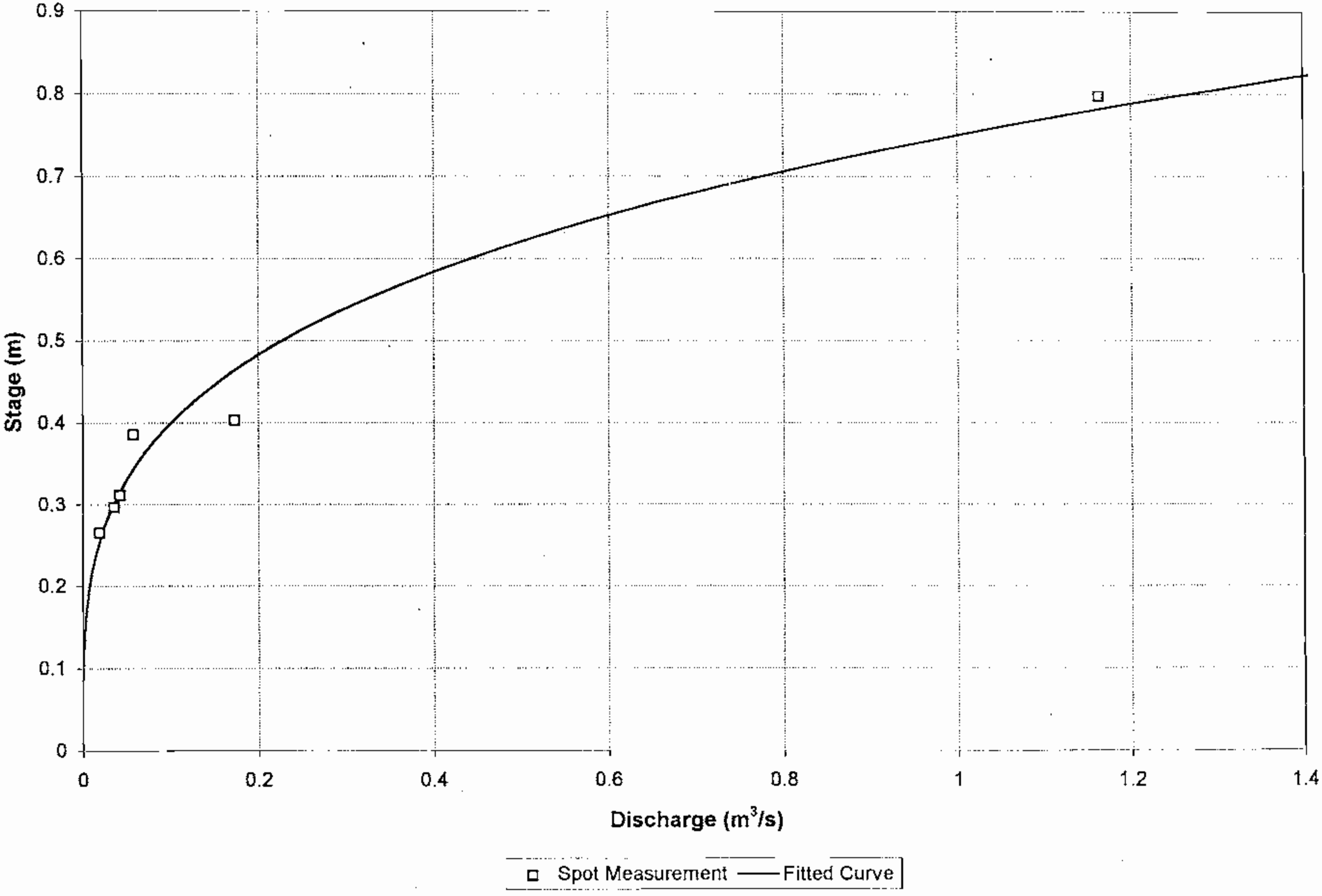


Rating Curve, H.R.
Stage (m)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Discharge (m³/s)
□ Spot Measurement
Fitted Curve

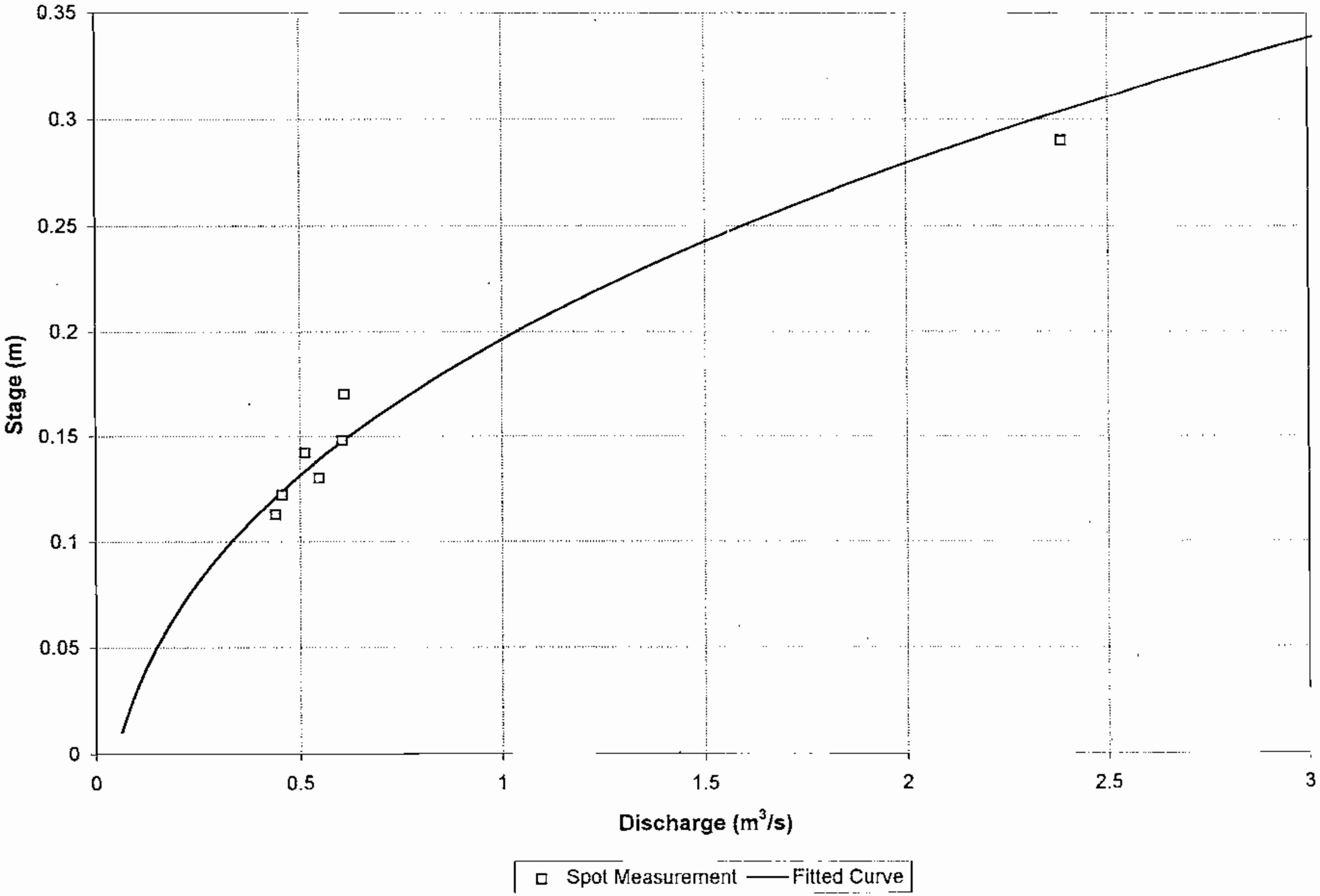
Rating Curve, Flat C.



Rating Curve, Flat (mouth)



Rating Curve, Lightning



**United Keno Hill Mines Ltd.**
**Present-Day Water Quality Model**

**Details of minesite catchments:**

| Catchment Description | Catchment Area (km$^2$) | Catchment Median Elevation (m.a.s.l.) | MAR - Mean Annual Runoff (mm) |
|---|---|---|---|
| Christal Creek above Station S18 | 7.7 | 990 | 240 |
| Christal Creek between Stations S19 and S18 | 35.8 | 970 | 230 |
| Sandy Creek above LES-63 | 2.3 | 1180 | 290 |
| No Cash Creek above LES-21 | 1.5 | 1200 | 300 |
| South McQuesten River above S10 and below LES-1, S19, LES-21, and LES-63 | 32.9 | 650 | 150 |
| South McQuesten River above LES-1 | 476 | 940 | 230 |
| Catchment of Dam No. 3 of Elsa Tailings Impoundment | 4.3 | 760 | 180 |
| Porcupine Creek Diversion Channel above LES-47 | 10.1 | 1110 | 270 |
| Galena Creek above the mouth | 10.9 | 970 | 240 |
| Flat Creek above S9 and below LES-57, LES-47, and S1 | 31.2 | 700 | 170 |
| South McQuesten River above S11 and below S10 and S9 | 29.9 | 670 | 160 |
| South McQuesten River above LES-5 and below S11 and LES-10 | 95.0 | 850 | 200 |
| Haldane Creek above South McQuesten Road | 88.8 | 830 | 200 |

**Details of enclosed basins created by open pits:**

| Enclosed Basin Description | Total Catchment Area (km$^2$) | Catchment Median Elevation (m.a.s.l.) | MAR - Mean Annual Runoff (mm) |
|---|---|---|---|
| Open pits within catchment of Element 1 (Calumet "C" and Onek) | 0.09 | 1180 | 290 |
| Open pits within incremental catchment of Element 2 (Sime 6, Sime 4, 35 Vein, and Miller) | 0.19 | 1280 | 320 |
| Open pits within catchment of Element 3 (Western portion of Calumet 4-11 Veins) | 0.05 | 1400 | 350 |
| Open pits within catchment of Element 4 (Bermingham and Bermingham SW) | 0.18 | 1350 | 340 |
| Open pits within incremental catchment of Element 5 (Calumet 3, Calumet 2, and part of Calumet 4-11 Veins) | 0.23 | 1380 | 350 |
| Open pits within catchment of Element 8 (Silver King) | 0.27 | 860 | 210 |

**Seasonal Distributions:**

| Description | Jan - Mar | Apr - Jun | Jul - Sep | Oct - Dec | Annual | Source of Data/ Comment |
|---|---|---|---|---|---|---|
| Number of days in period | 90.25 | 91 | 92 | 92 | 365.25 | |
| Average monthly flows for minesite streams (% of MAR) | 4.8 | 54.8 | 28.5 | 11.9 | 100 | Distribution of WSC Station 09DD004 (McQuesten R.) |
| Average discharge from Galkeno 900 Adit (L/s) | 5.5 | 8 | 8 | 6 | 6.9 | Average of measured flows (UKHM/Govt/LES data) |
| Average discharge from Onek Adit (L/s) | 0.23 | 0.32 | 0.35 | 0.32 | 0.31 | Average of measured flows (UKHM/Govt/LES data) |
| Average flow from natural spring near Christal Lake (L/s) | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | Average of two spot measurements taken in 1995 by LE |
| Average discharge from Galkeno 300 Adit (L/s) | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | One spot measurement taken in July 1994 by LES |
| Average discharge from UN Adit (L/s) | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | Average of measured flows (UKHM/Govt/LES data) |
| Average discharge from Bermingham Adit (L/s) | 1.2 | 3.6 | 1.6 | 1.5 | 2.0 | Average of measured flows (UKHM/Govt/LES data) |
| Average discharge from Ruby 400 Adit (L/s) | 1.2 | 1.5 | 1.9 | 1.5 | 1.5 | Average of measured flows (UKHM/Govt/LES data) |
| Average discharge from No Cash 500 Adit (L/s) | 4.1 | 4.1 | 5.1 | 4.1 | 4.4 | Average of measured flows (UKHM/Govt/LES data) |
| Seepage from Dam No.3 of Elsa Tailings Impoundment (L/ | 0 | 0 | 0 | 0 | 0 | No data available - assumed negligible |
| Average discharge from Silver King Adit (L/s) | 6 | 8 | 6 | 6 | 6.5 | Average of measured flows (UKHM/Govt/LES data) |
| Average discharge from Husky SW Adit (L/s) | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | Average of measured flows (UKHM/LES data) |
| Average discharge from Bellekeno 600 Adit (L/s) | 2 | 2 | 2.5 | 2.5 | 2.3 | Average of measured flows (UKHM/Govt/LES data) |
| Average discharge from Keno 700 Adit (L/s) | 0.3 | 3.5 | 3 | 1.5 | 2.1 | Average of measured flows (UKHM/Govt/LES data) |
| Average discharge from Lucky Queen Adit (L/s) | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | Average of measured flows (UKHM/Govt data) |
| Average discharge from Sadie Ladue Adit (L/s) | 9 | 11 | 11 | 11 | 10.5 | Average of measured flows (UKHM/Govt/LES data) |

# Appendix IV

# Biological Monitoring Survey
# at
# United Keno Hill Mine Area, 1994

### Laberge Environmental Services

*Laberge*
ENVIRONMENTAL SERVICES

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# BIOLOGICAL MONITORING SURVEY

# AT

# UNITED KENO HILL MINE AREA, 1994

For

**UKHM**

Prepared By

*Bonnie Bums*
**LABERGE ENVIRONMENTAL SERVICES**

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# 1.0 INTRODUCTION

Laberge Environmental Services (LES) was contracted by UKHM to conduct a biological monitoring survey in the Elsa area on Flat Creek, Christal Creek and the South McQuesten River in the field season of 1994. The following seven sites were sampled:

| Site # | Description |
|---|---|
| 1. | South McQuesten River approximately 1.5 kilometres upstream of Christal Creek |
| 3. | South McQuesten River approximately 20 metres upstream of Flat Creek |
| 4. | South McQuesten River approximately 100 metres downstream of Flat Creek |
| 5. | South McQuesten River approximately 9 kilometres downstream of Flat Creek |
| 6. | Christal Creek at the Keno Highway |
| 7. | Christal Creek at the Hanson Road Crossing |
| 9. | Flat Creek approximately 600 metres upstream of the South McQuesten River |

# 2.0 METHODS

## 2.1 Field Collection

Artificial substrate samplers were used for the benthic invertebrate sampling. The basket samplers were cylindrically shaped measuring 26 cm long and 17 cm in diameter constructed of galvanized wire with a 1 cm mesh. Each basket was filled with washed gravel and cobbles (3 to 12 cm in diameter) taken from the stream bed or bank. Total surface area provided by the artificial substrate samplers has been estimated to be approximately 6000 ± 1000 $cm^2$ (Baker 1979).

Three replicate samplers were installed in riffle areas at the seven sites on July 26 to 29, 1994. The samplers were retrieved on September 5 to 7, 1994 after a colonization period of approximately five weeks. A screened-bottom bucket with a 300 micron mesh was placed downstream of each sampler during retrieval. The sampler was emptied into the screened bucket where the individual rocks were washed to remove and collect all invertebrates from the sample. The detritus and invertebrates remaining in the collection bucket were placed in a one litre nalgene bottle and preserved with 10% formalin

In-situ measurements were taken at each site during both surveys. Conductivity and temperature were determined with an Orion conductivity meter model 126. Dissolved oxygen readings were obtained using an Orion oxygen meter model 820 and pH measurements were taken using an Orion model 210A pH meter. The flow was measured where possible with a Price meter.

### 2.2 Laboratory Analysis

Analysis of the benthic invertebrate samples was conducted by Charles J. Low, PhD, an invertebrate biologist in Victoria, B.C. All samples were washed through two screens with mesh sizes 1 millimetre and 180 microns. All of the organisms retained by the coarse screen were counted and identified, whereas the organisms on the 180 micron screen were subsampled as necessary. Due to the large number of organisms in the samples from Site 5, the coarse fraction had to be split as well. The fine fractions for Site 5 were split to 1/64th and to no more than 1/8th for the rest. A Folsom plankton splitter was used for the subsampling.

## 3.0 RESULTS AND DISCUSSION

Seven sites were sampled for benthic invertebrates in the Elsa area. An eighth site had been established on the South McQuesten River at the pumphouse, which is downstream of Christal Creek but upstream of Flat Creek, but unfortunately the artificial substrate samplers were tampered with during the colonization period and this data could not be used.

Table 1 summarizes the in-situ measurements and physical characteristics of the sites.

## TABLE 1

## SUMMARY OF IN-SITU MEASUREMENTS AND PHYSICAL CHARACTERISTICS OF SITES

| Site # | Site Description | Temp oC | | D. O. mg/L | | Cond (us/cm) | | pH | | Width (m) | | Mean Velocity (m/s) | | Mean Depth (m) | | Flow (cms) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | July | Sept | July | Sept | July | Sept | July | Sept | July | Sept | July | Sept | July | Sept | July | Sept |
| 1 | S. McQuesten R u/s Christal Cr | 18.2 | 9.0 | 8.5 | 13.7 | 246 | 262 | 8.43 | 8.25 | 13 | 12.9 | 0.72 | 0.49 | 0.34 | 0.26 | 2.965 | 1.586 |
| 3 | S. McQuesten R u/s Flat Cr | | 8.0 | 8.6 | 12 | 278 | 303 | 8.26 | 8.06 | 19.7 | 17.7 | 0.35 | 0.32 | 0.44 | 0.35 | 3.334 | 1.953 |
| 4 | S. McQuesten R d/s Flat Cr | 12.6 | 8.0 | 8.8 | 12.1 | 313 | 355 | 8.22 | 8.08 | | | | | | | 3.370* | 1.995* |
| 5 | S. McQuesten R 9 km d/s Flat Cr | 16.8 | 9.3 | 10.4 | 13.9 | 292 | 331 | 8.23 | 8.18 | 17.7 | 16.8 | 0.47 | 0.34 | 0.43 | 0.42 | 3.683 | 2.208 |
| 6 | Christal Creek @ Keno Hwy | 15.0 | 7.1 | 8.8 | 13 | 840 | 799 | 7.95 | 7.95 | 2.8 | 2.5 | 0.11 | 0.11 | 0.18 | 0.21 | 0.049 | 0.050 |
| 7 | Christal Creek @ Hanson Road | 8.1 | 1.4 | 11.3 | 14.9 | 554 | 599 | 8.29 | 8.09 | 2.6 | 2.6 | 0.17 | 0.17 | 0.25 | 0.27 | 0.105 | 0.116 |
| 9 | Flat Cr u/s S. McQuesten R | 13.8 | 5.9 | 9.8 | 12.6 | 728 | 775 | 8.18 | 8.10 | 1.7 | 1.5 | 0.15 | 0.21 | 0.15 | 0.14 | 0.036 | 0.042 |

* Calculated flow by adding the flow at Site 3 and Site 9.

### 3.1 Abundance and Taxonomic Richness

Five phyla were found in the study area: Coelentrata, Nematoda, Annelida, Arthropoda and Mollusca. A total of 93 different taxonomic groups were identified within this phyla. This data is presented in Appendix A.

The total number of organisms of the triplicates for each site were summed to give a total abundance value for that site.

Taxonomic richness was determined for each site by enumerating all taxonomic groups identified from species to phylum, as a measure of community diversity.

The abundance and taxonomic richness values for the 1994 study were considerably higher than in past studies. Abundance ranged from 991 individual at Site 9, Flat Creek, to an abnormally high number of 242,839 individuals at Site 5 (South McQuesten River 9 kilometres downstream of the Flat Creek confluence). The same trend was followed for diversity with 36 different groups of organisms identified at Site 9 to 54 at Site 5.

The summer of 1994 was hot with very little precipitation. Warm temperatures were measured in the South McQuesten River. These warm temperatures probably enhanced productivity as very high abundance levels were found at all sites. The three baskets at Site 5 were coated in filamentous green algae. Excess algae was removed from the baskets and discarded, but the closely attached algae was included in the detritus. This algae was home to a great number of chironomids which accounts for the disproportionately high numbers of Diptera found at this site.

Abundance and diversity were plotted and are displayed in Figure 1. To aid in interpretation the stations were arranged on the x-axis to demonstrate where the tributaries Christal Creek and Flat Creek enter the South McQuesten River. The extremely high abundance values for Site 5 skew the graph so the Y-axis end value has been set at 25,000 instead of 250,000 so that the abundance values for the other sites could be visible on the graph. Figure 2 displays the sites on the South McQuesten River only. Populations and diversity decreased at Site 3 and gradually recovered to Site 5.

Figure 1

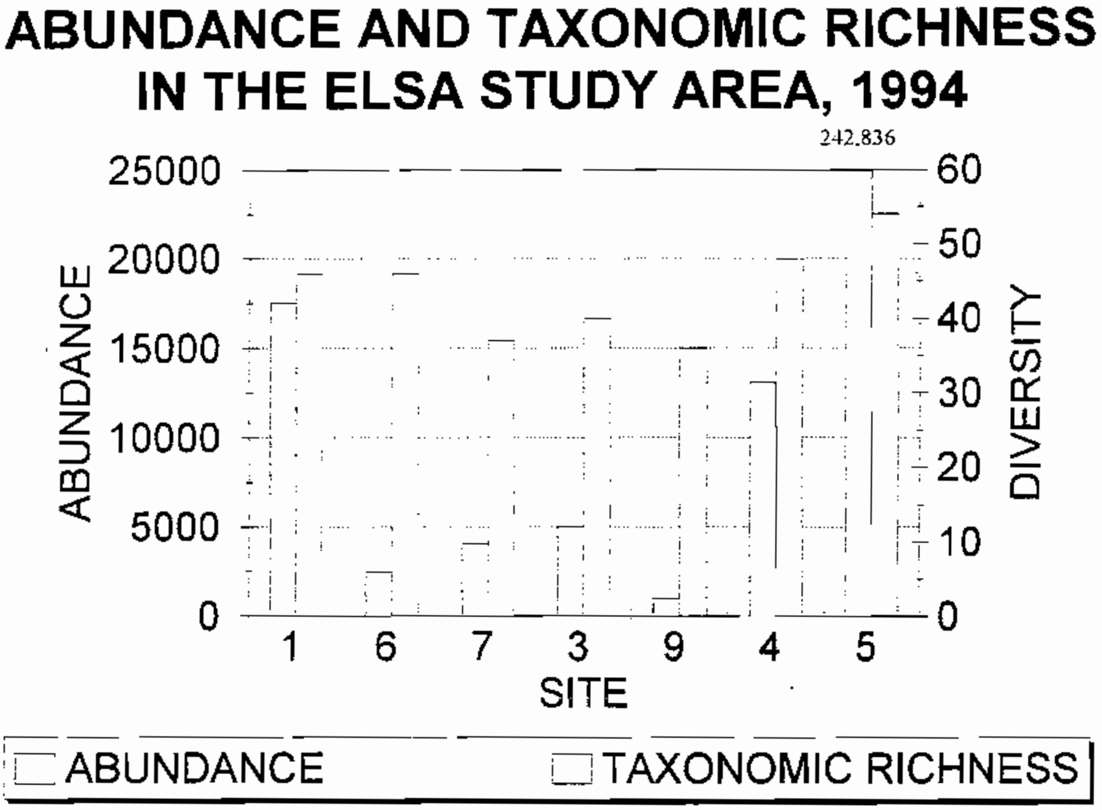
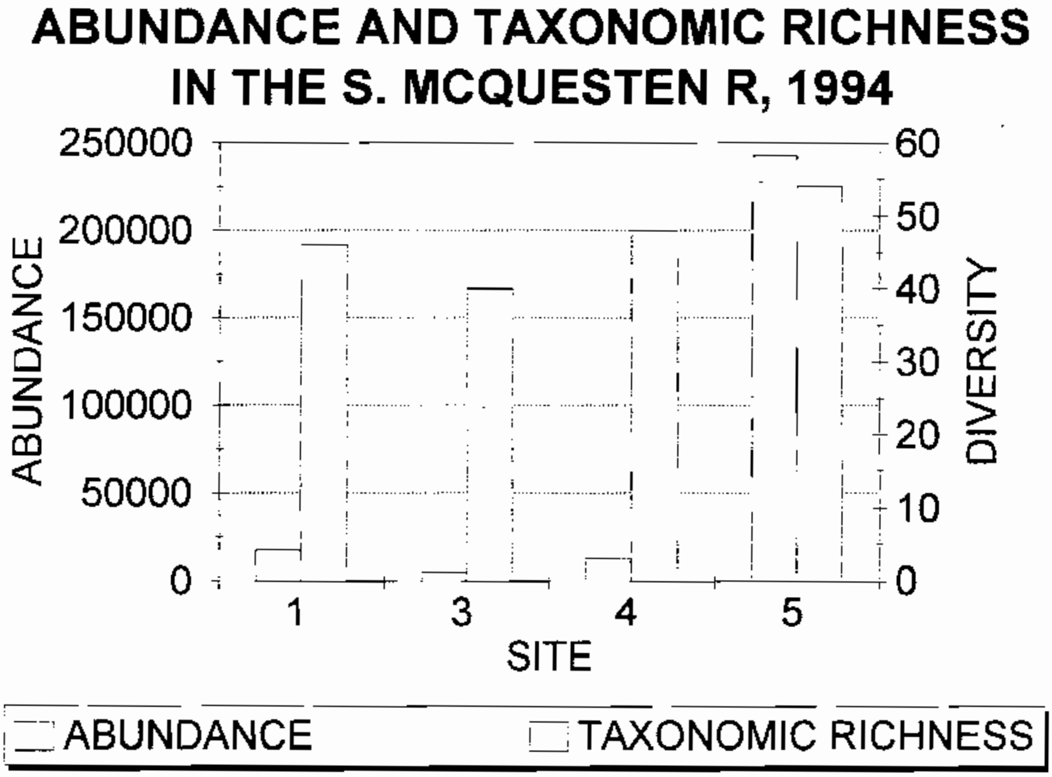


Figure 2



### 3.2 Distribution

The composition of the benthos communities was displayed as a percentage of the major taxonomic orders for each station (Table 2). Based on this, taxa were classified with respect to their dominance within the community (Table 3).

Diptera was the dominant or co-dominant group at all of the stations. For the first time since data has been collected at these sites, Oligochaeta (aquatic earthworms) formed a dominant group. This occurred at Christal Creek at the Keno Highway, Site 6, and at Flat Creek, Site 9.

Ephemeroptera, Trichoptera and Plecoptera are sensitive to most types of pollution (Rosenberg and Resh, 1993) and Lehmkuhl (1979) has identified several groups within these insect orders which have very low tolerance to chemical pollution. Thirteen of these taxa (seven taxa within Plecoptera, four taxa within Ephemeroptera and two taxa within Trichoptera) have been identified in the Elsa study area. Table 4 summarizes the presence or absence of each of these taxa per site. Sites 1,4 and 5 on the South McQuesten River had the highest number of sensitive taxa present, 11 out of 13. Christal Creek and Flat Creek had the lowest with a representation of 6 of the 13 sensitive taxa. These two sites are the most impacted by metals, although it is interesting to note that there is presence of these organisms here.

## 4.0 SUMMARY

There were very high numbers of benthos at most of the sites. Based on abundance and diversity, the benthic populations at the Flat Creek site were of the poorest quality. The site at Christal Creek near the Keno Highway also appeared to be impacted, although populations were diverse here. All sites had good to very good representation from the major groups of organisms, including those that are sensitive to heavy metal pollution, that are usually present in lotic waters.

## TABLE 2

## THE PERCENTAGE OF COMPOSITION OF DIFFERENT TAXONOMIC GROUPS AT EACH STATION, 1994

| TAXONOMIC GROUP | 1 | 3 | 4 | 5 | 6 | 7 | 9 |
|---|---|---|---|---|---|---|---|
| Ephemeroptera (mayflies) | 4.0 | 16.8 | 2.2 | 0.9 | 0.3 | 0.7 | 0.2 |
| Plecoptera (stoneflies) | 0.6 | 7.1 | 3.2 | 0.3 | 5.2 | 58.9 | 4.6 |
| Trichoptera (caddisflies) | 0.9 | 0.8 | 0.9 | 0.3 | 1.7 | 3.6 | 0.7 |
| Diptera (true flies) | 89.6 | 67.5 | 89.9 | 92.4 | 48.3 | 36.0 | 36.6 |
| Oligochaeta (aquatic earthworms) | 1.1 | 0.7 | 0.4 | 0.3 | 36.3 | 0 | 53.7 |
| Hydracarina (water mites) | 2.2 | 4.2 | 2.9 | 5.5 | 0.4 | 0.5 | 1.3 |
| Other * | 1.6 | 2.8 | 0.5 | 0.4 | 7.9 | 0.2 | 2.8 |

* Other includes one or more of the following taxonomic groups:

Coelenterata
Nematoda
Hirudinea
Cladocera

Copepoda
Peleycopa
Gastropoda
Ostracoda

Colembola
Homoptera
Thyansanoptera

## TABLE 3

## TAXONOMIC DISTRIBUTION OF BENTHIC INVERTEBRATES

| SITE | LOCATION | DOMINANT (≥25%) | SUBDOMINANT (10% to 24.9%) | COMMON (1.0% to 9.9%) | RARE (0.1% to 0.9%) | INCIDENTAL (<0.1%) |
|---|---|---|---|---|---|---|
| 1 | S. McQuesten R u/s Christal Cr | Diptera | | Ephemeroptera<br>Hydracarina<br>Other<br>Oligochaeta | Trichoptera<br>Plecoptera | |
| 3 | S. McQuesten R u/s Flat Cr | Diptera | Ephemeroptera | Plecoptera<br>Hydracarina<br>Other | Trichoptera<br>Oligochaeta | |
| 4 | S. McQuesten R d/s Flat Cr | Diptera | | Plecoptera<br>Hydracarina<br>Ephemeroptera | Trichoptera<br>Oligochaeta | |
| 5 | S. McQuesten R 9 km d/s Flat Cr | Diptera | | Hyracarina | Epemeroptera<br>Other<br>Plecoptera<br>Trichoptera<br>Oligochaeta | |
| 6 | Christal Cr @ Keno Hwy | Diptera<br>Oligochaeta | | Other<br>Plecoptera<br>Trichoptera | Hydracarina<br>Ephemeroptera | |
| 7 | Christal Cr @ Hanson Road | Plecoptera<br>Diptera | | Trichoptera | Ephemeroptera<br>Hydracarina<br>Other | Oligochaeta |
| 9 | Flat Cr u/s S. McQuesten R | Oligochaeta<br>Diptera | | Plecoptera<br>Other<br>Hydracarina | Trichoptera<br>Ephemeroptera | |

## TABLE 4

**Presence (+) and Absence (-) of Sensitive Taxa at S. McQuesten R and Christal and Flat Creeks**

| Sensitive Taxa | 1 | 3 | 4 | 5 | 6 | 7 | 9 |
|---|---|---|---|---|---|---|---|
| **Plecoptera** | | | | | | | |
| Nemouridae | + | + | + | + | + | + | + |
| Perlodidae | + | - | + | + | + | + | + |
| Capniidae | + | + | + | + | + | + | + |
| Perlidae | + | + | + | + | - | - | - |
| Chloroperlidae | + | + | + | + | + | - | - |
| Taeniopterigidae | - | - | - | - | - | + | + |
| Pteronarcidae | + | + | + | + | - | - | - |
| **Ephemeroptera** | | | | | | | |
| Epeorus | - | - | - | - | - | + | - |
| Ephemerellidae | + | + | + | + | - | - | - |
| Rithrogena | + | + | + | + | + | + | - |
| Paraleptophlebia | + | + | + | + | + | - | - |
| **Trichoptera** | | | | | | | |
| Brachycentriidae | + | + | + | + | - | - | + |
| Rhyacophilidae | + | - | + | + | - | + | + |
| Total # of sensitive taxa: | 11 | 9 | 11 | 11 | 6 | 7 | 6 |

After Lehmkuhl (1979)

## 5.0 REFERENCES

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APPENDIX A BENTHIC INVERTEBRATES AT UKHM, 1994

| | 1a | 1b | 1c | 3a | 3b | 3c | 4a | 4b | 4c | 5a | 5b | 5c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **PHYLUM COELENTERATA** | | | | | | | | | | | | |
| Order Hydroida | | | | | | | | | | | | |
| Hydra sp | 32 | 49 | 16 | | | | 8 | 1 | | | | |
| **PHYLUM NEMATODA** | | | | | | 4 | 8 | | | 67 | 65 | 69 |
| **PHYLUM ANNELIDA** | | | | | | | | | | | | |
| **Class Oligochaeta** | | | | | | | | | | | | |
| Order Haplotacida | | | | | | | | | | | | |
| Family Enchytraeidae | | | | | 2 | 1 | | | | | 64 | |
| Family Naididae | | | | | | | | | | | | |
| Nais sp | | | | | | 1 | | | | | | |
| Chaetogaster sp | | 136 | 64 | 8 | 8 | 16 | 32 | 8 | 8 | 128 | 138 | 320 |
| **Class Hirudinea** | | | | | | | | | | | | |
| Order Rhynchobdellida | | | | | | | | | | | | |
| Pisicola salmonsitica | | | | | | | | | 1 | | | 1 |
| **PHYLUM ARTHROPODA** | | | | | | | | | | | | |
| **Class Crustacea** | | | | | | | | | | | | |
| Order Cladocera | | | | | | | | | | | | |
| Alonella sp | 8 | 24 | | | | | | | | 192 | 128 | 128 |
| Eurycercus sp | 8 | | 16 | 8 | | | 8 | | | 64 | | |
| Sub Class Copepoda | | | | | | | | | | | | |
| Sub Order Cyclopoida | | | | | | | | | | | | |
| Sub Class Ostracoda | | | | | | | | | | | | |
| Candona sp | | 8 | | | | 4 | | | | | | |
| **Class Arachnida** | | | | | | | | | | | | |
| Order Hydracarina | | | | | | | | | | | | |
| Hydracarina, unid J/D | 137 | 48 | 128 | 48 | 88 | 68 | 64 | 240 | 32 | 4037 | 3845 | 4003 |
| Kawamuracarus sp | | | | | | | | | | 67 | 3 | |
| Lebertia sp | | | | | | | 4 | 16 | | 1 | 192 | 194 |
| Neumannia sp | 8 | 9 | | | | | | | | 2 | 64 | |
| Sperchon sp | 19 | 24 | 16 | | | 8 | 25 | | | 323 | 256 | 394 |
| Torrenticola sp | | | | | | | | | | | | |
| **Class Insecta** | | | | | | | | | | | | |
| Order Plecoptera | | | | | | | | | | | | |
| Plecoptera, Unid. J/D | 9 | | | 8 | 56 | 32 | 24 | 16 | 8 | | 64 | 64 |
| Family Capniidae | | | | | | | | | | | | |
| Capnia sp | 16 | | 32 | 81 | 106 | 44 | 32 | 169 | 56 | 129 | 133 | 1 |
| Family Perlidae | | | | | | | | | | | | |
| Classenia sabulosa | | 2 | 1 | 3 | 1 | | | 1 | | | 4 | 3 |
| Family Perlodidae | | | | | | | | | | | | |
| Isoperla sp | | | | | | | 1 | 1 | | 1 | 1 | |
| Megarcys sp | | | | | | | | | | | | |
| Skwala curvata | | | | | | | | | | 1 | | |
| Skwala paralella | 1 | | | | | | 1 | | | 5 | 5 | 4 |
| Family Nemouridae | | | | | | | | | | | | |
| Podmosta sp | | | | | | | | | | | | |
| Zapada sp | 3 | | 20 | 5 | | 1 | 50 | 31 | 11 | 94 | 29 | 160 |
| Family Pteronarcidae | | | | | | | | | | | | |
| Pteronarcella regularis | 2 | 1 | | 1 | 2 | 7 | | 10 | 1 | 18 | 14 | 20 |
| Pteronarcys californica | 4 | 2 | 6 | 4 | 2 | 2 | 2 | 2 | 1 | 1 | 3 | 2 |
| Pteronarcys dorsata | 1 | | | | | | | | | | | 1 |
| Family Chloroperlidae | | | | | | | | | | | | |
| Sweltsa sp gp | 1 | | | | 1 | | 1 | 1 | | 2 | | |
| Family Taeniopterigidae | | | | | | | | | | | | |
| Taenionema sp | | | | | | | | | | | | |
| Order Ephemeroptera | | | | | | | | | | | | |
| Family Siphlonuridae | | | | | | | | | | | | |

unid = unidentified J = juvenile L = larvae A = adult P = pupae D = damaged

# APPENDIX A BENTHIC INVERTEBRATES AT UKHM, 1994

| | 1a | 1b | 1c | 3a | 3b | 3c | 4a | 4b | 4c | 5a | 5b | 5c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ameletus sp | | | | | | | 8 | | | | | |
| Family Baetidae | | | | | | | | | | | | |
| Baetis sp | 190 | | 99 | 271 | 207 | 261 | 57 | 107 | 8 | 466 | 850 | 794 |
| Family Heptageniidae | | | | | | | | | | | | |
| Epeorus (Iron) sp | | | | | | | | | | | | |
| Heptagenia sp | 11 | 4 | 12 | | | | | | | | | |
| Rithrogena sp | 102 | 18 | 76 | 52 | 9 | 21 | 18 | 30 | 15 | 3 | 68 | 1 |
| Family Ephemerellidae | | | | | | | | | | | | |
| Ephemerella grandis | 3 | 3 | 1 | 4 | 2 | 3 | 13 | 2 | 2 | 11 | 26 | 37 |
| Ephemerella sp | 22 | 17 | 30 | | 10 | | 2 | 1 | 14 | 1 | | 2 |
| Family Leptophlebiidae | | | | | | | | | | | | |
| Paraleptophlebia sp | 4 | 17 | 91 | | 1 | 1 | 8 | 1 | 3 | 5 | | |
| | | | | | | | | | | | | |
| Order Colembola | | | | | | | | | | | | |
| Hypogastrura sp | | | | | | | | | | | | |
| Isotomurus sp | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| Order Homoptera | | | | | | | | | | | | |
| Aphididae | | | | | | | | | | | | |
| Cicadellidae | | | | | | | | | | 1 | | |
| | | | | | | | | | | | | |
| Order Thysanoptera A | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| Order Trichoptera | | | | | | | | | | | | |
| Trichoptera, Unid J/D | 9 | 1 | | | 1 | | 16 | 8 | 8 | 1 | 1 | 1 |
| Family Hydropsychidae | | | | | | | | | | | | |
| Arctopsyche sp | 8 | | 21 | 21 | 8 | 4 | 13 | 25 | 5 | 142 | 137 | 140 |
| Family Brachycentridae | | | | | | | | | | | | |
| Brachycentus sp | 4 | | 17 | | 2 | 4 | | 1 | | 23 | 30 | 30 |
| Micrasema sp | | | | | | | | | | 2 | 5 | 4 |
| Family Limnephilidae | | | | | | | | | | | | |
| Dicosmoecus sp | | | | | 1 | | 1 | | | | | |
| Ecclisomyia sp | | | | | | | | | | | | |
| Limnephilus sp | | | | | | | | | | | | |
| Nemotaulius sp | | | | | | | | | 1 | | | |
| | | | | | | | | | | | | |
| Grensia sp | | | | | | | | | | | 1 | |
| Family Hydroptilidae | | | | | | | | | | | | |
| Hydroptila sp | | | | | | | | 9 | | 39 | 50 | 91 |
| Oxyethira sp | | 63 | 24 | | | | 10 | 1 | 1 | 3 | 10 | 8 |
| Family Lepidostomatidae | | | | | | | | | | | | |
| Lepidostoma sp | | 1 | 1 | | | | 1 | | | | | |
| Family Rhyacophilidae | | | | | | | | | | | | |
| Rhyacophila sp J/D | 10 | | 3 | | | | 16 | 1 | | 7 | 14 | 13 |
| Rhyacophila (vao\acropedes) | 1 | | | | | | | | | 1 | | |
| | | | | | | | | | | | | |
| Order Diptera | | | | | | | | | | | | |
| Diptera, Unid adult | | | | | | | | | | 2 | | |
| Family Tipulidae | | | | | | | | | | | | |
| Tipulidae Unid J/D | | | | | | | | | | 1 | | |
| Dicranota sp | | | | | | | | | | | | |
| Family Simulidae | | | | | | | | | | | | |
| Simulidae Unid J/D | 16 | | 16 | | | | | | | | | |
| Prosimulium sp | | | | | | | | | | | | |
| Simulium sp | 8 | | 16 | 52 | 79 | 20 | | 9 | | 64 | 128 | 194 |
| Simulium sp P | | | | 3 | | 1 | | 1 | 1 | | 1 | 2 |
| Family Chironomidae | | | | | | | | | | | | |
| Chironomidae pupae | 8 | | | | | | 8 | | 8 | | 7 | 4 |
| Chironomidae unid J/D | 1689 | 2352 | 8081 | 984 | 1002 | 416 | 4344 | 1944 | 1521 | 34686 | 30542 | 32544 |
| Sub Family Tanypodinae | | | | | | | | | | | | |
| Procladius sp | | | | | | | | | | | | |
| Thienemannimyia sp | 63 | 152 | 217 | 40 | 33 | 26 | 189 | 213 | 162 | 3458 | 5048 | 5464 |
| Sub Family Orthocladiinae | | | | | | | | | | | | |
| Brillia sp | | | | | | | | | | | | |
| Cardiocladius sp | | | | | | | | | | 128 | 129 | 193 |
| Constempelina sp | | | | | | | | | | | | |
| Corynoneura sp | 46 | 160 | 224 | 24 | 73 | 10 | 272 | 40 | 184 | 64 | 64 | |

unid = unidentified J = juvenile L = larvae A = adult P = pupae D = damaged

APPENDIX A BENTHIC INVERTEBRATES AT UKHM, 1994

| | 1a | 1b | 1c | 3a | 3b | 3c | 4a | 4b | 4c | 5a | 5b | 5c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cricotopus sp | 78 | 72 | 272 | 16 | 48 | 8 | 224 | 89 | 97 | 838 | 996 | 844 |
| Eukiefferiella sp | 59 | 104 | 336 | 57 | 33 | 17 | 234 | 122 | 163 | 1286 | 1454 | 848 |
| Euryhapsis sp | | | | | | | | | | | | |
| Heleniella sp | | | | | | | | | | | | |
| Thienemanniella sp | 16 | 8 | 80 | 16 | 48 | | 24 | 8 | 24 | | 10 | |
| Sub Family Chironomiinae | | | | | | | | | | | | |
| Constempelina sp | | | | | | | | | | | | |
| Rheotanytarsus sp | 707 | 136 | 801 | 160 | 107 | 93 | 664 | 618 | 568 | 33834 | 33644 | 37732 |
| Sub Family Diamesinae | | | | | | | | | | | | |
| Diamesa sp | | | | | | | | | | | | |
| Monodiamesa sp | | | | | | | | | | | | |
| Family Ceratopogonidae | | | | | | | | | | | | |
| Palpomyia sp | | | | | | | | | | | | |
| Family Empididae | | | | | | | | | | | | |
| Chelifera sp | 11 | | | 8 | 8 | 4 | | 8 | | 70 | 15 | 17 |
| Clinocera sp | | | | | | | | | | | | |
| Weidemannia sp | | | | | | | | | | | | |
| Family Muscidae | | | | | | | | | | | | |
| Limnophora sp | | | | | | | | | | 1 | | |
| Family Psychodidae | | | | | | | | | | | | |
| Pericoma sp | | | | | | | | | | | | |
| **PHYLUM MOLLUSCA** | | | | | | | | | | | | |
| **Class Gastropoda** | | | | | | | | | | | | |
| Gastropoda, unid dam. | 4 | 15 | 5 | | 3 | 12 | 1 | | 2 | | | |
| Fossaria modicella | 8 | 35 | 20 | 9 | 18 | 18 | 4 | | 2 | | | |
| Gyraulus parvus | | 5 | 4 | | 1 | 2 | | | | | | |
| Physa gyrina | 3 | 7 | 6 | 1 | 6 | 1 | 10 | | 4 | 1 | | |
| Valvata sincera | 3 | | | | 23 | 25 | 9 | | 1 | | | 1 |
| **Class Pelecypoda (Bivalva)** | | | | | | | | | | | | |
| Pisidium sp | | | | | 8 | | 1 | | | | | |
| **Totals:** | 3332 | 3473 | 10752 | 1884 | 1997 | 1135 | 6407 | 3734 | 2912 | 80270 | 78238 | 84328 |

# APPENDIX A BENTHIC INVERTEBRATES AT UKHM, 1994

| | 6a | 6b | 6c | 7a | 7b | 7c | 9a | 9b | 9c |
|---|---|---|---|---|---|---|---|---|---|
| **PHYLUM COELENTERATA** | | | | | | | | | |
| Order Hydroida | | | | | | | | | |
| Hydra sp | 16 | 42 | 6 | | | | | | |
| **PHYLUM NEMATODA** | 1 | 6 | 2 | | | | | 1 | |
| **PHYLUM ANNELIDA** | | | | | | | | | |
| **Class Oligochaeta** | | | | | | | | | |
| Order Haplotacida | | | | | | | | | |
| Family Enchytraeidae | 1 | | | | | | | | |
| Family Naididae | | | | | | | | | |
| Nais sp | | 2 | | | | | | | |
| Chaetogaster sp | 189 | 225 | 482 | | | | 100 | 108 | 324 |
| **Class Hirudinea** | | | | | | | | | |
| Order Rhynchobdellida | | | | | | | | | |
| Pisicola salmonsitica | | | | | | | | | |
| **PHYLUM ARTHROPODA** | | | | | | | | | |
| **Class Crustacea** | | | | | | | | | |
| Order Cladocera | | | | | | | | | |
| Alonella sp | 7 | 16 | 6 | | | 2 | 5 | 7 | 4 |
| Eurycercus sp | | | | | | | | | |
| Sub Class Copepoda | | | | | | | | | |
| Sub Order Cyclopoida | 1 | 4 | 1 | | | | 2 | 2 | 4 |
| Sub Class Ostracoda | | | | | | | | | |
| Candona sp | 6 | 68 | 10 | | | | | | |
| **Class Arachnida** | | | | | | | | | |
| Order Hydracarina | | | | | | | | | |
| Hydracarina, unid J/D | 2 | 1 | | 12 | | | 3 | 1 | |
| Kawamuracarus sp | | | | | | | | | |
| Lebertia sp | 1 | | | | | | 2 | 2 | 1 |
| Neumannia sp | | | | | | | | | |
| Sperchon sp | 2 | 1 | | | | | | 1 | 1 |
| Torrenticola sp | 1 | 2 | | | 8 | 2 | | 1 | 1 |
| **Class Insecta** | | | | | | | | | |
| Order Plecoptera | | | | | | | | | |
| Plecoptera, Unid, J/D | | | 2 | 846 | 479 | 244 | 4 | 7 | 2 |
| Family Capniidae | | | | | | | | | |
| Capnia sp | | | 1 | 241 | 227 | 80 | 4 | 8 | 9 |
| Family Perlidae | | | | | | | | | |
| Classenia sabulosa | | | | | | | | | |
| Family Perlodidae | | | | | | | | | |
| Isoperla sp | | | 1 | 2 | 1 | 3 | | | |
| Megarcys sp | | | | 3 | 2 | 4 | | | |
| Skwala curvata | | | | | | | | | |
| Skwala paralella | 1 | | | 3 | 2 | 3 | 1 | | 2 |
| Family Nemouridae | | | | | | | | | |
| Podmosta sp | 13 | 10 | 6 | 4 | 1 | | | 1 | 1 |
| Zapada sp | 52 | 19 | 22 | 99 | 52 | 28 | 2 | 4 | |
| Family Pteronarcidae | | | | | | | | | |
| Pteronarcella regularis | | | | | | | | | |
| Pteronarcys californica | | | | | | | | | |
| Pteronarcys dorsata | | | | | | | | | |
| Family Chloroperlidae | | | | | | | | | |
| Sweltsa sp gp | | 2 | | | | | | | |
| Family Taeniopterigidae | | | | | | | | | |
| Taenionema sp | | | | 41 | 16 | 4 | 1 | | |
| Order Ephemeroptera | | | | | | | | | |
| Family Siphlonuridae | | | | | | | | | |

unid = unidentified J = juvenile L = larvae A = adult P = pupae D = damaged

# APPENDIX A BENTHIC INVERTEBRATES AT UKHM, 1994

| | 6a | 6b | 6c | 7a | 7b | 7c | 9a | 9b | 9c |
|---|---|---|---|---|---|---|---|---|---|
| Ameletus sp | | | | 3 | 4 | | | | |
| Family Baetidae | | | | | | | | | |
| Baetis sp | 5 | | | 1 | 4 | 4 | | 1 | 1 |
| Family Heptageniidae | | | | | | | | | |
| Epeorus (Iron) sp | | | | 4 | | | | | |
| Heptagenia sp | | | | | | | | | |
| Rithrogena sp | 1 | | | 4 | | 4 | | | |
| Family Ephemerellidae | | | | | | | | | |
| Ephemerella grandis | | | | | | | | | |
| Ephemerella sp | | | | | | | | | |
| Family Leptophlebiidae | | | | | | | | | |
| Paraleptophlebia sp | 1 | | | | | | | | |
| Order Colembola | | | | | | | | | |
| Hypogastrura sp | | | | | | | 1 | | |
| Isotomurus sp | 1 | | | | | | | | |
| Order Homoptera | | | | | | | | | |
| Aphididae | | | 1 | 1 | 6 | | | 1 | 1 |
| Cicadellidae | 1 | | | | | | | | |
| Order Thysanoptera A | | | | | | 1 | | | |
| Order Trichoptera | | | | | | | | | |
| Trichoptera, Unid J/D | | | | 3 | 9 | 7 | 1 | 1 | |
| Family Hydropsychidae | | | | | | | | | |
| Arctopsyche sp | 3 | 1 | | | | | | | |
| Family Brachycentridae | | | | | | | | | |
| Brachycentus sp | | | | | | | | 1 | |
| Micrasema sp | | | | | | | | | |
| Family Limnephilidae | | | | | | | | | |
| Dicosmoecus sp | | | | | 2 | | | | |
| Ecclisomyia sp | 1 | | | | | | | | |
| Limnephilus sp | 18 | 10 | 6 | | | | | | |
| Nemotaulius sp | | | | | | | | | |
| Grensia sp | | | | | | | | | |
| Family Hydroptilidae | | | | | | | | | |
| Hydroptila sp | 1 | | | | | | 1 | | |
| Oxyethira sp | | | 1 | | | | | 2 | |
| Family Lepidostomatidae | | | | | | | | | |
| Lepidostoma sp | | | | | | | | | |
| Family Rhyacophilidae | | | | | | | | | |
| Rhyacophila sp J/D | | | | 68 | 28 | 18 | | | |
| Rhyacophila (vao\acropedes) | | | | 6 | 1 | 4 | 1 | | |
| Order Diptera | | | | | | | | | |
| Diptera, Unid adult | 1 | | | | | | | | |
| Family Tipulidae | | | | | | | | | |
| Tipulidae Unid J/D | | | | | | | | | |
| Dicranota sp | | | | 1 | | | | | |
| Family Simulidae | | | | | | | | | |
| Simulidae Unid J/D | | | | | | | | | |
| Prosimulium sp | | | | 4 | 4 | 2 | | | |
| Simulium sp | 6 | | 4 | 287 | 206 | 160 | 2 | | 2 |
| Simulium sp P | | | | 1 | | | | | |
| Family Chironomidae | | | | | | | | | |
| Chironomidae pupae | 4 | 1 | 1 | | 4 | | 1 | 4 | 1 |
| Chironomidae unid J/D | 93 | 106 | 288 | 269 | 96 | 91 | 84 | 28 | 140 |
| Sub Family Tanypodinae | | | | | | | | | |
| Procladius sp | 1 | | | | | | | | |
| Thienemannimyia sp | 71 | 61 | 114 | 10 | 7 | 2 | 21 | 17 | 10 |
| Sub Family Orthocladiinae | | | | | | | | | |
| Brillia sp | | | | 2 | 13 | | | | |
| Cardiocladius sp | 36 | 2 | 48 | 12 | 4 | 2 | | | |
| Constempelina sp | | | | | | | | | |
| Corynoneura sp | | 2 | | | | | 2 | 2 | 1 |

unid = unidentified J = juvenile L = larvae A = adult P = pupae D = damaged

| | 6a | 6b | 6c | | 7a | 7b | 7c | 9a | 9b | 9c |
|---|---|---|---|---|---|---|---|---|---|---|
| Cricotopus sp | 35 | 40 | 96 | | 11 | | 8 | 6 | 11 | 4 |
| Eukiefferiella sp | 16 | 28 | 64 | | 69 | 51 | 18 | 1 | 7 | 5 |
| Euryhapsis sp | 2 | | | | | | | | | |
| Heleniella sp | | 2 | 4 | | | | | | | |
| Thienemanniella sp | | | | | 25 | 48 | 8 | | 2 | 1 |
| Sub Family Chironomiinae | | | | | | | | | | |
| Constempelina sp | | | | | | | | 1 | | |
| Rheotanytarsus sp | 19 | 19 | 30 | | 9 | 4 | 6 | 1 | | 1 |
| Sub Family Diamesinae | | | | | | | | | | |
| Diamesa sp | | | | | 1 | | | | | |
| Monodiamesa sp | | | 1 | | | | | | | |
| Family Ceratopogonidae | | | | | | | | | | |
| Palpomyia sp | | | 1 | | | | | | | |
| Family Empididae | | | | | | | | | | |
| Chelifera sp | | | | | 1 | | 1 | 3 | | 2 |
| Clinocera sp | | 1 | | | | | | | 1 | |
| Weidemannia sp | | | | | | | | | | 1 |
| Family Muscidae | | | | | | | | | | |
| Limnophora sp | | | | | | | | 1 | | |
| Family Psychodidae | | | | | | | | | | |
| Pericoma sp | | | | | 2 | 15 | 1 | | | |
| **PHYLUM MOLLUSCA** | | | | | | | | | | |
| **Class Gastropoda** | | | | | | | | | | |
| Gastropoda, unid dam. | | | | | | | | | | |
| Fossaria modicella | | | | | | | | | | |
| Gyraulus parvus | | | | | | | | | | |
| Physa gyrina | | | | | | | | | | |
| Valvata sincera | | | | | | | | | | |
| **Class Pelecypoda (Bivalva)** | | | | | | | | | | |
| Pisidium sp | | | | | | | | | | |
| **Totals:** | 609 | 671 | 1198 | 2478 | 2045 | 1294 | 707 | 251 | 221 | 519 |

unid = unidentified J = juvenile L = larvae A = adult P = pupae D = damaged

## United Keno Hill Mine Stream Sediment Samples Collected by Laberge Environmental Services

| Site # | Site Description | Date | Lab Reference # | %-100 Mesh % | Amount analysed | Aluminum ug/g | Antimony ug/g | Arsenic ug/g | Barium ug/g | Beryllium ug/g | Bismuth ug/g |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Stn #1 | S. McQuesten R u/s Christal Creek | 26 July 94 | 23885-001 | 75 | 0.509 g | 9880 | < 2. | 18 | 185 | 0.3 | < 5. |
| Stn #2 | S. McQuesten R @ Pumphouse | 28 July 94 | 23885-002 | 40 | 0.512 g | 6210 | 5 | 413 | 142 | < 0.1 | < 5. |
| Stn #3 | S. McQuesten R u/s Flat Cr | 28 July 94 | 23885-003 | 95 | 0.501 g | 12400 | 35 | 210 | 262 | 0.2 | < 5. |
| Stn #4 | S. McQuesten R d/s Flat Cr | 28 July 94 | 23885-004A | 11 | 0.502 g | 9430 | 41 | 166 | 190 | < 0.1 | < 5. |
| Stn #4 | Duplicate | 28 July 94 | 23885-004B | - | 0.507 g | 10200 | 43 | 170 | 199 | 0.2 | < 5. |
| Stn #5 | S. McQuesten R 9 km d/s Flat Cr | 29 July 94 | 23885-005 | 2 | 0.513 g | 10800 | 18 | 116 | 253 | < 0.1 | < 5. |
| Stn #6 | Christal Cr @ Keno Highway | 26 July 94 | 23885-006 | 25 | 0.517 g | 8970 | 8 | 128 | 223 | < 0.1 | < 5. |
| Stn #7 | Christal Cr @ Hanson Road | 26 July 94 | 23885-007 | 40 | 0.500 g | 8930 | 16 | 174 | 298 | < 0.1 | < 5. |
| Stn #8 | Flat Cr @ Keno Highway | 26 July 94 | 23885-008 | 5 | 0.514 g | 11700 | < 2. | 30 | 233 | 0.3 | < 5. |
| Stn #9 | Flat Cr u/s S. McQuesten R | 28 July 94 | 23885-009 | 5 | 0.509 g | 9020 | 150 | 395 | 394 | < 0.1 | < 5. |
| Stn #11 | Galena Cr u/s Silver King adit | 27 July 94 | 23885-010 | 39 | 0.499 g | 15500 | 11 | 62 | 413 | 0.4 | < 5. |
| Stn #21 | No Cash Cr @ Keno Highway | 27 July 94 | 23885-015A | 13 | 0.500 g | 11100 | 59 | 397 | 220 | < 0.1 | < 5. |
| Stn #21 | Duplicate | 27 July 94 | 23885-015B | - | 0.506 g | 11000 | 69 | 406 | 215 | < 0.1 | < 5. |
| Stn #34 | Erickson Gulch @ road to Lucky Queen | 27 July 94 | 23885-018 | 2 | 0.505 g | 16000 | 22 | 77 | 330 | 0.3 | < 5. |
| Stn #41 | Lightning Cr @ Keno City Rd X-ing | 26 July 94 | 23885-022A | 94 | 0.503 g | 13700 | 4 | 39 | 223 | 0.3 | < 5. |
| Stn #41 | Duplicate | 26 July 94 | 23885-022B | - | 0.499 g | 7830 | < 2. | 35 | 164 | 0.3 | < 5. |
| Stn #47 | Porcupine Diversion (Flat Cr) d/s of all inputs | 28 July 94 | 23885-023 | 63 | 0.508 g | 3200 | 300 | 1340 | 50.2 | < 0.1 | < 5. |
| Stn #48 | Hope Gulch | 28 July 94 | 23885-024 | 2 | 0.505 g | 11000 | 64 | 1460 | 172 | < 0.1 | < 5. |
| Stn #51 | Combine seepages in Porcupine Div u/s Brefault Cr | 6 Sept 94 | 24236-1 | 57 |  | 3400 | 260 | 950 | 162 | <0.1 | <5 |
| Stn #52 | Thunder Gulch u/s Bellekeno Adit | 8 Sept 94 | 24236-2A | 91 |  | 8040 | <2 | 32 | 120 | <0.1 | <5 |
| Stn #52 | Duplicate | 8 Sept 94 | 24236-2B | - |  | 8140 | <2 | 32 | 118 | <0.1 | <5 |
| Stn #53 | Old Galkeno freshwater pumphouse | 8 Sept 94 | 24236-3A | 41 |  | 6640 | <2 | 45 | 384 | <0.1 | <5 |
| Stn #53 | Duplicate | 8 Sept 94 | 24236-3B | - |  | 8080 | <2 | 44 | 402 | <0.1 | <5 |
| QA/QC | Sandy Soil | BCR Light | 23885-026 | - | 0.499 g | 20900 | < 2. | < 2. | 186 | 0.9 | < 5. |
| QA/QC | Sandy Soil | BCR Light | 23885-026A | - | - | 50100 | - | - | - | - | - |

## United Keno Hill Mine Stream Sediment Samples Co

| Site # | Site Description | Cadmium ug/g | Calcium ug/g | Chromium ug/g | Cobalt ug/g | Copper ug/g | Iron ug/g | Lead ug/g | Lithium ug/g | Magnesium ug/g | Manganese ug/g | Molybdenum ug/g |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stn #1 | S. McQuesten R u/s Christal Creek | 1.6 | 9450 | 16.7 | 10.4 | 22.4 | 21500 | 10 | 13.5 | 5820 | 602 | 3 |
| Stn #2 | S. McQuesten R @ Pumphouse | 26.3 | 8910 | 12 | 10.6 | 48.4 | 41500 | 1750 | 9 | 4650 | 10500 | < 1. |
| Stn #3 | S. McQuesten R u/s Flat Cr | 17 | 11000 | 22 | 11.5 | 49.4 | 34000 | 1100 | 13.9 | 5700 | 4530 | < 1. |
| Stn #4 | S. McQuesten R d/s Flat Cr | 17.7 | 8690 | 15.8 | 8.3 | 40.9 | 31000 | 980 | 11.5 | 4820 | 5800 | < 1. |
| Stn #4 | Duplicate | 18.5 | 8760 | 17.3 | 8.6 | 41.9 | 31300 | 980 | 12.3 | 5480 | 5840 | < 1. |
| Stn #5 | S. McQuesten R 9 km d/s Flat Cr | 8.6 | 11200 | 16.7 | 9.6 | 29.2 | 29800 | 344 | 12 | 6500 | 4390 | < 1. |
| Stn #6 | Christal Cr @ Keno Highway | 15.2 | 10800 | 16.1 | 11 | 34.5 | 27600 | 260 | 11.5 | 5600 | 5500 | < 1. |
| Stn #7 | Christal Cr @ Hanson Road | 12.4 | 13900 | 15 | 9.4 | 27.9 | 29000 | 680 | 10.6 | 5970 | 5380 | < 1. |
| Stn #8 | Flat Cr @ Keno Highway | 0.8 | 11400 | 19 | 7.9 | 29.4 | 23500 | 30 | 13.5 | 5420 | 465 | < 1. |
| Stn #9 | Flat Cr u/s S. McQuesten R | 51.3 | 9060 | 19 | 10.1 | 116 | 61000 | 4520 | 8.7 | 3500 | 29600 | < 1. |
| Stn #11 | Galena Cr u/s Silver King adit | 2.5 | 11200 | 24.4 | 11.2 | 41.4 | 26200 | 141 | 15.5 | 5950 | 978 | 1 |
| Stn #21 | No Cash Cr @ Keno Highway | 316 | 16500 | 21.4 | 40.7 | 243 | 62000 | 2650 | 11.7 | 6970 | 39700 | < 1. |
| Stn #21 | Duplicate | 295 | 16600 | 21.6 | 38.1 | 240 | 61000 | 2570 | 11.8 | 7170 | 35700 | < 1. |
| Stn #34 | Erickson Gulch @ road to Lucky Queen | 8.3 | 7880 | 21.8 | 15.4 | 50 | 30200 | 1070 | 15.3 | 6270 | 1900 | 3 |
| Stn #41 | Lightning Cr @ Keno City Rd X-ing | 2.7 | 6230 | 26.7 | 13.3 | 43.5 | 27900 | 70 | 16.8 | 4690 | 739 | < 1. |
| Stn #41 | Duplicate | 1.8 | 4110 | 17.6 | 12.4 | 51.1 | 22100 | 68 | 11.8 | 3790 | 650 | < 1. |
| Stn #47 | Porcupine Diversion (Flat Cr) d/s of all inputs | 67.2 | 3850 | 8 | 4.9 | 125 | 128000 | 11600 | 1.9 | 3840 | 48500 | < 1. |
| Stn #48 | Hope Gulch | 63.6 | 7540 | 19.4 | 12.9 | 113 | 45400 | 2440 | 12.5 | 4350 | 4480 | 2 |
| Stn #51 | **Combine seepages in Porcupine Div u/s Brefault Cr** | 68.4 | 12200 | 5 | 6.8 | 126 | 152000 | 10500 | 2.7 | 2300 |  | <1 |
| Stn #52 | Thunder Gulch u/s Bellekeno Adit | 0.8 | 3190 | 19.6 | 11.3 | 49.6 | 25800 | 77 | 12.8 | 3350 |  | 1 |
| Stn #52 | Duplicate | 0.8 | 3220 | 20 | 11.2 | 55.3 | 25600 | 74 | 13.1 | 3360 |  | 1 |
| Stn #53 | Old Galkeno freshwater pumphouse | 25.2 | 6480 | 12.6 | 7 | 32.8 | 20700 | 44 | 9.1 | 3270 |  | <1 |
| Stn #53 | Duplicate | 25 | 6890 | 14.1 | 7.1 | 34.8 | 21100 | 44 | 9.93 | 3490 |  | <1 |
| QA/QC | Sandy Soil | 0.3 | 35100 | 37.6 | 6.9 | 32.5 | 18800 | 34 | 19.7 | 6700 | 547 | < 1. |
| QA/QC | Sandy Soil | 0.25 | 35300 | 74.9 | 7.9 | 27.5 | 19600 | 37.8 | - | 6570 | 569 | - |

United Keno Hill Mine Stream Sediment Samples Co

| Site # | Site Description | Nickel<br>ug/g | Phosphorus<br>ug/g | Potassium<br>ug/g | Selenium<br>ug/g | Silicon<br>ug/g | Silver<br>ug/g | Sodium<br>ug/g | Strontium<br>ug/g | Sulfur<br>ug/g | Tin<br>ug/g | Titanium<br>ug/g |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stn #1 | S. McQuesten R u/s Christal Creek | 36.2 | 865 | 1090 | < 2. | 206 | < 0.5 | 149 | 31 | 570 | < 1. | 465 |
| Stn #2 | S. McQuesten R @ Pumphouse | 33.7 | 878 | 310 | < 2. | 142 | 5.1 | 102 | 22 | 3350 | < 1 | 104 |
| Stn #3 | S. McQuesten R u/s Flat Cr | 41.4 | 910 | 1760 | < 2. | 218 | 14.4 | 212 | 31 | 1600 | < 1. | 506 |
| Stn #4 | S. McQuesten R d/s Flat Cr | 28.5 | 829 | 940 | 2 | 194 | 14.2 | 147 | 23 | 1340 | < 1. | 415 |
| Stn #4 | Duplicate | 29.1 | 843 | 1160 | < 2. | 208 | 15.6 | 169 | 26 | 1430 | < 1. | 471 |
| Stn #5 | S. McQuesten R 9 km d/s Flat Cr | 47.5 | 817 | 1050 | < 2. | 193 | 6 | 169 | 32 | 780 | < 1 | 474 |
| Stn #6 | Christal Cr @ Keno Highway | 36.3 | 895 | 650 | < 2. | 231 | 4.2 | 120 | 26 | 1110 | < 1 | 380 |
| Stn #7 | Christal Cr @ Hanson Road | 30 | 1110 | 860 | < 2. | 243 | 7.3 | 137 | 30 | 1600 | < 1 | 349 |
| Stn #8 | Flat Cr @ Keno Highway | 19.6 | 702 | 1350 | < 2. | 222 | 0.5 | 141 | 43 | 450 | < 1 | 471 |
| Stn #9 | Flat Cr u/s S. McQuesten R | 36.8 | 575 | 1310 | < 2. | 303 | 55.2 | 162 | 26 | 2030 | < 1. | 301 |
| Stn #11 | Galena Cr u/s Silver King adit | 27.4 | 820 | 1770 | < 2. | 233 | 39.4 | 191 | 39 | 1240 | < 1. | 573 |
| Stn #21 | No Cash Cr @ Keno Highway | 136 | 864 | 1320 | < 2. | 1000 | 35.6 | 152 | 25 | 8500 | < 1. | 252 |
| Stn #21 | Duplicate | 91.6 | 890 | 1310 | < 2. | 916 | 30.9 | 152 | 26 | 9100 | < 1. | 261 |
| Stn #34 | Erickson Gulch @ road to Lucky Queen | 37.5 | 1800 | 1790 | < 2. | 269 | 5.5 | 140 | 33 | 420 | < 1. | 329 |
| Stn #41 | Lightning Cr @ Keno City Rd X-ing | 33.7 | 948 | 990 | < 2. | 283 | 0.5 | 153 | 29 | 140 | < 1. | 803 |
| Stn #41 | Duplicate | 30.7 | 909 | 390 | < 2. | 60 | < 0.5 | 266 | 18 | 170 | < 1. | 233 |
| Stn #47 | Porcupine Diversion (Flat Cr) d/s of all inputs | 7.5 | 321 | 340 | < 2. | 226 | 58.7 | 97 | < 1. | 32100 | 7 | 100 |
| Stn #48 | Hope Gulch | 32.7 | 848 | 860 | < 2. | 161 | 23.9 | 278 | 22 | 12500 | 13 | 648 |
| Stn #51 | Combine seepages in Porcupine Div u/s Brefault Cr | 8.3 | 516 | 300 | <2 | 678 | 139 | 94 | 21 | 14400 | 5 | 91.7 |
| Stn #52 | Thunder Gulch u/s Bellekeno Adit | 33.1 | 1060 | 370 | <2 | 255 | 1.7 | 144 | 15 | 50 | <1 | 405 |
| Stn #52 | Duplicate | 33.3 | 1050 | 380 | <2 | 257 | 1.2 | 116 | 15 | 50 | <1 | 417 |
| Stn #53 | Old Galkeno freshwater pumphouse | 17.5 | 1010 | 360 | <2 | 217 | 1 | 113 | 21 | 510 | <1 | 233 |
| Stn #53 | Duplicate | 17.7 | 1010 | 620 | <2 | 216 | 0.98 | 127 | 23 | 520 | <1 | 394 |
| QA/QC | Sandy Soil | 27.3 | 814 | 4240 | < 2. | 131 | < 0.5 | 494 | 77 | 960 | 3 | 371 |
| QA/QC | Sandy Soil | 29.2 | 961 | 20000 | 0.53 | 319000 | - | 7200 | - | - | - | 3720 |

## United Keno Hill Mine Stream Sediment  Samples Co

| Site # | Site Description | Thorium<br>ug/g | Uranium<br>ug/g | Vanadium<br>ug/g | Zinc<br>ug/g | Zirconium<br>ug/g |
|---|---|---|---|---|---|---|
| Stn #1 | S. McQuesten R u/s Christal Creek | 4 | < 5. | 31 | 310 | 6 |
| Stn #2 | S. McQuesten R @ Pumphouse | < 1. | < 5. | 15 | 2410 | 4.8 |
| Stn #3 | S. McQuesten R u/s Flat Cr | 4 | < 5. | 36 | 1610 | 6.9 |
| Stn #4 | S. McQuesten R d/s Flat Cr | 3 | < 5. | 27 | 1640 | 5 |
| Stn #4 | Duplicate | 4 | < 5. | 30 | 1640 | 5.7 |
| Stn #5 | S. McQuesten R 9 km d/s Flat Cr | 2 | < 5. | 30 | 1150 | 4 |
| Stn #6 | Christal Cr @ Keno Highway | 3 | < 5. | 27 | 2090 | 5.2 |
| Stn #7 | Christal Cr @ Hanson Road | 2 | < 5. | 25 | 1950 | 4.5 |
| Stn #8 | Flat Cr @ Keno Highway | 6 | < 5. | 32 | 108 | 5.4 |
| Stn #9 | Flat Cr u/s S. McQuesten R | < 1. | < 5. | 25 | 5180 | 0.6 |
| Stn #11 | Galena Cr u/s Silver King adit | 6 | < 5. | 43 | 182 | 5.7 |
| Stn #21 | No Cash Cr @ Keno Highway | < 1. | < 5. | 24 | 31700 | 3.3 |
| Stn #21 | Duplicate | < 1. | < 5. | 24 | 28800 | 4.6 |
| Stn #34 | Erickson Gulch @ road to Lucky Queen | 5 | < 5. | 31 | 684 | 7 |
| Stn #41 | Lightning Cr @ Keno City Rd X-ing | 7 | < 5. | 42 | 389 | 8.6 |
| Stn #41 | Duplicate | 6 | < 5. | 24 | 228 | 7.6 |
| Stn #47 | Porcupine Diversion (Flat Cr) d/s of all inputs | < 1. | < 5. | 8 | 7840 | < 0.1 |
| Stn #48 | Hope Gulch | 3 | < 5. | 31 | 6890 | 4.3 |
| Stn #51 | Combine seepages in Porcupine Div u/s Brefault Cr | <1 | <5 | 7 | 8960 | <0.1 |
| Stn #52 | Thunder Gulch u/s Bellekeno Adit | <1 | <5 | 26 | 180 | 7.9 |
| Stn #52 | Duplicate | <1 | <5 | 27 | 176 | 8.1 |
| Stn #53 | Old Galkeno freshwater pumphouse | <1 | <5 | 19 | 972 | 1.5 |
| Stn #53 | Duplicate | <1 | <5 | 24 | 967 | 2.1 |
| QA/QC | Sandy Soil | 3 | < 5 | 32 | 90.2 | 3.9 |
| QA/QC | Sandy Soil | - | - | - | 92.4 | - |

# Appendix V

# Fish and Fish Habitat Assessment Conducted Near Elsa, Yukon, for United Keno Hill Mines Limited

## August 1994 - September 1995

White Mountain Environmental Consulting

# FISH AND FISH HABITAT ASSESSMENT CONDUCTED NEAR ELSA, YUKON FOR UNITED KENO HILL MINES AUGUST 1994 - SEPTEMBER 1995

Prepared by White Mountain Environmetntal Consulting
P. Sparling and M. Connor

December 16,1995

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## 1.0 INTRODUCTION

White Mountain Environmental Consulting (WMEC) began fisheries investigations into aquatic environments surrounding United Keno Hill Mines property near the community of Elsa, Yukon during August of 1994 and continued until August of 1995.

The goals of these preliminary investigations were to obtain and compile baseline fisheries data from waters influenced or affected by mining activities. And in doing so gain an understanding of the current situation with regards to habitat availability and the level of utilization of that habitat by fish.

Prior to this investigation, fisheries data for this area were scattered and did not provide a comprehensive understanding of the fish resources or the extent the area was being utilized.

Fish habitat and utilization assessments were conducted at three different periods during the open water season to provide a representation of spring, summer and fall utilization's

### 1.1 STUDY AREA

The principal areas of study for this investigation were the drainages influenced by historic and current mining activities. These include Christal and Flat Creeks, both tributaries of the South McQuesten River which was also investigated. Lightning Creek in the Mayo River drainage was also investigated (Figure 1).

Christal Creek was investigated from Christal Lake to its mouth at the South McQuesten River . Flat Creek was investigated from the point immediately below UKHM's tailing ponds to its mouth at the South McQuesten River. The South McQuesten River was investigated from McQuesten Lake to Seattle Creek. Investigations into Lightning Creek were restricted to a reach that extended from 350 m upstream of the outlet of Thunder Gulch down to Duncan Creek( Figure 2).

Part of the Yukon River drainage, the McQuesten River has had a total of 14 species of fish recorded in its waters. The list of species includes Arctic grayling, slimy sculpin, round whitefish, burbot, northern pike, longnose sucker, chinook salmon, chum salmon, lake trout, lake chubb, least cisco, lake whitefish, Arctic lamprey and inconnu (see appendix A for scientific names ).

Most of the species recorded can be considered resident and a few as seasonal migrants. Two definite migrants are chinook and chum salmon, both of which spawn in the river and utilize the McQuesten as a rearing area. Chum salmon have been recorded only a short distance upstream of the mouth of the McQuesten near the Stewart River. Chinook have been documented throughout the drainage, however the extent of their utilization of the South McQuesten upstream of the mouth of Haggart Creek remains uncertain. Arctic lamprey have two documented forms, one a dwarf form residing in freshwater rivers and the other an anadromous, parasitic migrant (Scott and Crossman, 1973). Inconnu most likely migrate in and out of the system although little has been documented on this species life history in the Yukon River drainage, in other areas the inconnu life history involves river migrations to and from spawning, wintering and summer feeding areas (Scott and Crossman 1973). Lake trout, least cisco and lake chubb would likely be associated with lake habitats in the headwaters..

### 1.2 BACKGROUND

Concerns with mine effluent in the Elsa-Keno Hill area effecting fish date back to 1961 when UKHM's tailing pond at the head of Flat Creek washed out during spring freshet. The ensuing contaminated slug of water entered the South McQuesten River via Flat Creek and caused a large die-off of resident fish species (DFO unpublished correspondence 1961-64).

An assessment of the water quality and biological conditions in watersheds surrounding the UKHM property was conducted during the summers of 1974 and 1975 by the Environmental Protection

Service (EPS) , Yukon branch. The parameters studied in this report included ; water chemistry, trace metals, benthic species diversity, fish concentrations, and toxicity testing . The report indicated that elevated metal concentrations were found in association with the tailings pond decant and runoff from the Husky mine . Zinc was the main metal contaminant with elevated levels found in Flat Creek as well as in the South McQuesten River immediately downstream of the mouth of Flat Creek . Elevated levels of cadmium and copper were found at the water decant but these did not persist downstream . Christal Creek did not show comparibly high zinc levels . The study found relatively low benthic species diversity in Flat Creek and immediately downstream of Flat in the south McQuesten River. Test fishing was done in Flat and Christal Creeks as well as the South McQuesten River with an electro-fisher and barrier nets, samples of fish tissue and liver were obtained and tested for concentrations of copper, zinc, and lead. The report states that few fish were caught in Flat Creek and speculates this could be related to high zinc and copper levels in the water or due to low benthic food invertebrates that resulted from these metal levels . The study also noted low fish numbers at their sample stations in Christal Creek but attributed this to the fact it was a small creek with relatively steep gradient (these same locations on Christal Creek did not produce any fish during the 1994,'95 study).

During August 1980 the Environmental Protection Service conducted a monitoring study of the effluent discharge from UKHM to determine the state of compliance with the Federal Metal Liquid Effluent Guidelines . This report states that receiving waters of both Flat Creek and the South McQuesten River , downstream of the confluence with Flat Creek , exhibited zinc concentrations above levels recommended to maintain aquatic life . In Situ bioassays were conducted to demonstrate the effect of treated mine effluent on Arctic grayling , after exposing the fish to the effluent and receiving streams for 96 hours and finding no fatalities , the report concluded the streams and effluent exhibited no acute toxicity at the time of the study.

During the summer of 1985, a receiving environment monitoring study was undertaken by EPS in Flat Creek, Christal Creek, and the South McQuesten River as streams with potential influence from UKHM operations . The report mentions a tailings pond release from a dam break that occurred in 1978, and states that water hardness exceeded levels recommended for drinking water at all stations . The report contains historical comparisons of metal levels in the water at sample stations dating from 1974 to 1985. These comparisons showed, among other things, copper levels dropping in Flat and Christal Creeks. Zinc levels were found to be dropping in Flat Creek (0.73 mg/l in 1974 to 0.215 in 1985) but increasing in Christal Creek (<0.17 in 1974 to 0.825 in 1985 ). Alkalinity and hardness levels were shown to be rising in both Flat and Christal Creeks and the report suggests that sustained mining activity in the area may be associated with these increases. The study found that seepage, and to a lesser degree Galena Creek, contribute to elevated zinc levels in Flat Creek. Mine drainage from the Galkeeno 900 adit was identified as the main source of metal contaminants in Christal Creek. Benthic invertebrate populations showed good abundance and diversity of species, although the station on the South McQuesten River downstream of Flat Creek showed a major dominance by one group (Simulium sp.).

Data from water, sediment, and benthic surveys from 1990 (EPS, 1992) showed that Christal Creek had a significant impact on the South McQuesten River in the form of an increase in metals in the water and sediments downstream of the confluence of Christal Creek . This study found that benthic abundance and diversity decrease in the South McQuesten downstream of its confluence with Christal Creek but start to recover downstream of the mouth of Flat Creek. Elevated levels of metals in sediments in Flat Creek might be responsible for reducing overall benthic habitat quality as diversity and abundance were found to be very low.

## 2.0 METHODS

### 2.1 TIMING

Fisheries investigations began during August of 1994. Fall habitat and utilization investigations were conducted between September 13 and 16, 1994. The emphasis of the fall and preliminary study period was to determine the extent of fish distribution and conduct the ground work for mapping and assessing available fish habitat.

Spring Investigations included two separate periods of investigation. The first period ran from May 19 to 23, 1995 when emphasis was placed on determining spring movements of all species and locating any areas used by Arctic grayling for spawning. The second period of investigation, June 1 to 4, 1995, was used to confirm the findings of the first period, and to record the emergence of grayling and chinook salmon fry in the South McQuesten River, and in the lower mainstem of the McQuesten River.

Summer investigations were conducted between July 14 and 21,1995. Intensive utilization assessments were conducted at this time throughout the study area. A minnow trapping program to determine chinook salmon distribution and utilization was also conducted.

### 2.2 HABITAT ASSESSMENTS

Fish habitat in both Christal and Flat Creeks was assessed by walking and mapping the length of each creek. Distances were paced and confirmed with topographic maps.

General characteristics, including an assessment of; depth, flow, velocity, bottom substrates, terrestrial and aquatic vegetation, bank stability and structure, channel configuration, anomalies and any obstructions were recorded over the entire length of the creek. All information was mapped and recorded into a field book at the time of the field assessment.

Results recorded during assessments were reviewed and maps were created showing the major habitat areas and unique areas and features.

A canoe was used to assess fish habitat between sites on the South McQuesten River. The reach between SM1 and SM4 was floated twice, once on September 16,1994, and then again during summer investigations on July 16,1995. Notes were made on the general and representative fish habitats.

The reach of the South McQuesten between site SM4 and the bridge at Haggart Creek was floated by canoe on August 5 and 6,1995. Detailed investigations were conducted around Shanghai Creek and the log jam 1 km upstream of Haggart Creek.

### 2.3 FISHERIES UTILIZATION ASSESSMENT

Sampling for utilization was conducted at selected locations on each drainage. The mouths of both Flat and Christal were intensively investigated as were 2 other sites on Flat Creek and 4 other sites on Christal Creek. Christal Lake was also investigated. A total of 14 sites on the South McQuesten were sampled intensively. These included assessments above the influence of Christal Creek , between Christal and Flat Creeks and at three sites below the mouth of Flat Creek.

Utilization assessment sampling was repeated 4 to 7 days after the original sampling whenever possible, during all three sample periods. This was done in order to address the fact that many of the species utilizing these waters are gregarious or school, a concern expressed by DFO.

A variety of techniques were used during the investigations to determine the presence and abundance of fishes, these were; seine nets, electro-shocker, gillnets, angling, surber sampling, visual observations, and two different types of minnow trap baiting.

Seining was accomplished with the use of 5 meter long 1/8" mesh rochel netting, nets had both floats and weight lines, both poled and non poled seines were used. Seining was restricted to depths of less than 1.5 meters.

Minnow traps (Gee type) were set along banks, typically near over hanging vegetation. Traps were baited with an even mix of gains burger dog food and canned salmon which was suspended in the trap inside a perforated "Alligator" sandwich bag and attached to the trap with a twist tie. Traps were checked on a 24-48 hour basis and catches were recorded. This type of baiting technique was used during the fall and spring investigations.

Minnow traps (Gee type) for assessing the distribution of chinook salmon fry were baited with fresh frozen salmon roe from Yukon River salmon. The roe was suspended inside the traps in perforated "Alligator" sandwich bags. These traps were set in all types of habitat as per DFO specifications for capturing juvenile salmon fry in the Yukon River drainage (1994). This type of minnow trap set was used during summer investigations.

Angling was done with light gear, #0 or #1, Panther Martin and Meps spinners were used, with primary lure colors being yellow, red and black.

Electro-fishing was conducted using a Smith-Route type 12 POW backpack, generator powered, electro-fisher. Fishing was typically done moving in an upstream direction, the operator of the electro-fisher was accompanied by a netter and an observer/recorder. Field crews wore peaked ball caps and polarizing sunglasses to aid visibility during electro-fishing.

Gillnetting was not a major method for fish capture due to high mortalities associated with this technique. Small mesh gill nets (1" and 2") were successfully used on Christal Lake and a single 2" mesh (stretch measure) by 10m gillnet was set in a back eddy on the South McQuesten River.

A surber sampler was used in attempts to locate grayling eggs to determine spawning locations. Samples were taken in gravel areas with flows between .2 to 1.5 m/second. Gravel under the 1 foot square sample frame was raked with a small hand rake for a period of one minute. Notes were made on the catches from these samples, including the presence of invertebrates.

Fry traps were installed in moderate flow areas after the grayling eggs were determined to have hatched. The fry trap used consisted of a 20 x 30 cm mouth and a fine meshed funnel sock. The trap was set for 15 minutes at a time and the contents were examined, then released after being recorded.

Temperatures were recorded at all sample stations during each sample period using a digital electronic thermometer ( ± 0.1°C ). Temperatures were recorded into a field note book with all other pertinent information and observations from each sample site.

All fish captured were handled delicately so as to avoid mortality and allow for release after measuring or counting. Most fish captured were returned to the water of capture unharmed immediately after counting or sampling. All fish captured or observed were counted and recorded. A sub-sample of those captured were live sampled for length ( ± 1mm) and weighed with spring loaded Chantillion scales or electronic balance, ± 1 g for fish less than 30 grams, ± 5 g for fish between 30 and 100 g, and ± 25 g for fish over 100 g. A smaller sub-sample were sacrificed for dead samples, these were weighed in grams, measured for fork length in mm, and assessed for sex and maturity. A scale sample was taken from all Arctic grayling dead samples, and stored for potential age determination.

## 2.4 HEAVY METAL ANALYSIS

Fish captured during fall assessments were sacrificed to be analyzed for the presence of heavy metals in the flesh and liver. Samples were taken from the South McQuesten River upstream of the mouth of Christal Creek, Flat Creek and Christal Creek.

Most samples taken from Flat Creek were composite samples of several individual fish. Five samples of slimy sculpin adults and a single sample of Arctic grayling were taken for analysis. The grayling sample consisted of 4 fry, one of the sculpin samples was a single large adult, another consisted of 7 individuals and the other 3 sculpin samples consisted of 4 individuals each. The samples from Flat Creek were taken in the area described as F1 and F2.

Three different sets of samples were taken from the Christal Creek Drainage. The first of these was from Christal Lake and consisted of 4 individual, whole, slimy sculpins. The second sample was comprised of 5 individual adult Arctic grayling captured at site C4. The third sample set from Christal were collected both in the lower and upper reaches of the creek, 2 sculpins samples came from site C5, a single grayling fry from site C3 and a single sculpin from site C2 provided a set of 4 individual samples.

Specimens from the South McQuesten River were taken from site SM1. These samples were all Arctic grayling, 2 were sub adults and 3 were adults.

Livers were extracted from the adult grayling. Two composite liver samples were made, the first from the five samples from C4, the other from the three adults taken at SM1. Flesh samples were taken from each of these fish and sent as individual samples. Flesh samples from large grayling were consistently taken from the right side of the body, below the dorsal fin but above the lateral line. Care was taken to ensure samples did not become contaminated, each sample was collected and stored in new and previously unopened whirl bag. All samples collected were frozen within one hour of capture.

All samples collected were held and shipped frozen to Quanta Trace Labs in Burnaby ,BC. At Quanta both liver and fish flesh samples were blended and dried at 55° C and the moisture content was determined. The dried tissue was then ground in a stainless steel mill. Approximately 0.5 grams of the liver or flesh was digested in a sealed Teflon vessel using microwave heating (EPA Method 3051). The level of 33 different metals were determined on the resulting solution by ICP-AES with ultrasonic nebulization. Mercury content was determined by cold -vapour atomic absorption. Metal content was expressed in parts per million.

### 2.5 DATA ANALYSIS

All data collected was collated and the raw data has been presented in the appropriate Appendix. Total numbers of fish captured at each location were tabulated to provide descriptions of species composition at each site. Catch data from seining, electro-fishing, gillnetting and minnow traps has been expressed as catch per unit of effort (CPUE) to account for differences in sample effort. Electro-fishing is expressed in fish per minute of shock time, seining in number of fish per square meter of seine area, gillnetting in number of fish per 100 meters of net per 24 hours, minnow trapping is expressed in number of fish per 24 hours. Seining and electro-fishing CPUE results were calculated for each site and season by combining all data for the relevant period and site.

## 3.0 RESULTS AND DISCUSSION

### 3.1 GENERAL FINDINGS

The South McQuesten River and its tributaries Christal and Flat Creeks contain a wide variety of fish habitats and fish species typical of those found in the Yukon River drainage. In total 5,316 fish were recorded during the course of this study representing 11 different fish species, these where; Arctic grayling, slimy sculpin, round whitefish, northern pike, Arctic lamprey, chinnok salmon, burbot, longnose sucker; least cisco and lake chubb. A summary of all fish recorded, by method has been presented in appendix B.

Seining was the most effective method used to record fish (Table 1), followed by electro-fishing ( Table 2), minnow trapping (Appendixes C and D)), visual observations (Table 3), angling (Table 4) and gillnetting (Table 5). Catch per unit of effort results (Tables 6 and 7) showed that Christal Creek was utilized more extensively than Flat Creek, and the South McQuesten River downstream of Haggart Creek was the most extensively utilized reach in the study area.

Slimy sculpins were the most widely dispersed species in the study area, and Arctic grayling were the most abundant. Length at weight regressions for grayling and sculpins are presented in figures 3 and 4 respectively. Both Grayling and longnose sucker fry were most typically encountered in groups or schools. Chinook salmon were found in the South McQuesten River, but not above the mouth of Haggart Creek. Most of the other species noted were found in small numbers, usually as individuals and in specific habitats.

Fish habitat in Lightning Creek has been dramatically altered by placer mining. Fish habitat that remains exists in small patches and is typically of poor quality. grayling were the only species found to be utilizing Lightning Creek.

A summary of all fish sampled has been presented in appendix E.

## 3.2 HABITAT ASSESSMENT

### 3.2.1 Flat Creek

Flat Creek was divided into five distinct reaches for habitat assessment, four of these were investigated for fish and fish habitat during this study. The uppermost reach that drains the steep hillside above the tailings pond was not investigated (Figure 2).

The first reach investigated was the mouth (reach #1) which extends upstream from the confluence with the South McQuesten River for 40 meters and corresponds to sample site F1. This reach has cobble gravel substrates in pool riffle sequences punctuated with partial log and stick jams that have built up in many of the riffle areas. Two small pools near the mouth have water up to 1 meter deep and steep cut banks on the outside corners. Both of these pools have submerged trees and provide excellent cover for small fish and some of the best habitat available on Flat Creek.

Reach #2 extends for 700 meters up stream of reach #1, sample site F2 is located in the lower end of this reach. This reach has fast flowing water in a narrow channel. Substrates consist primarily of gravel and sand, with layers of organic silts and debri in low flow areas. Thick willow and alder growth along the creek banks forms a canopy over the creek in most places. Fish habitat in this reach occurs occasionaly in pockets of small deep pools, below stick jams. The upper most 200 meters of this reach has an intense number of tight stick jams that may impede fish passage. Below these stick jams areas of potential habitat occur in cobble/gravel bottomed pool glide sequences, this type of habitat occurs infrequently.

Reach #3 extends for 4,200 meters starting above reach #2, this reach flows through mature forest that varies from stands of strictly white spruce in the lower section of the reach to mixed poplar, aspen and white spruce in the upper section. Alders and willows intersperse the larger trees throughout the reach. Substrates consist primarily of coppery hued and organic silts. Several areas of riffle pool sequences have cobble, gravel and some boulders although this type of habitat is limited and discontinuous. Log jams occur frequently but do not block the creek to fish passage.

Beaver activity in the upper stretch of this reach has created several deep pools. These beaver pools and several gravel bottomed pool/riffle areas have the potential to support limited numbers of fish and does resemble stretches of Christal Creek where Arctic grayling were observed.

Reach #4, the uppermost reach studied, begins immediately below UKHM's settling ponds (Fig. 2) and flows through an open meadow of sedges and shrubs to Reach #3,and contains sample site F3. This reach flows as a deep, narrow channel (1 m depth, 0.5 m width) with a consistent substrate of coppery hued silt/mud that may be old tailings. Through this reach the stream channel has cut into the floor of a wide valley wetland, this reach extends for a distance of 5 kms. Vegetation along this reach consists primarily of sedges, willows become more common and closer to the creek in the lower stretches of the reach. The substrates and channel configuration in this reach do not provide good fish habitat. Laminar flows and an even bottom provide little to no available cover. Littoral zones occur infrequently and because of the narrow deep channel the availability of surface water is minimized.

Water temperatures from Flat Creek during summer and fall remained a consistent 3 to 5°C colder than the South McQuesten at the mouth of Flat. The water from Flat Creek was 4.1° C at the creeks mouth by late May and 6.5°C in the receiving environment of the South McQuesten. By June 3 the South McQuesten had warmed to 11.4° and Flat had warmed to 6.2° (Table 8).

### 3.2.2 Christal Creek

Christal Creek has a variety of habitats throughout the 14 kms between the headwaters at Christal Lake and the confluence with the South McQuesten River (Figure 2). The creek was divided into six reaches for habitat descriptions.

From Christal Lake to the South McQuesten River a mat of fine black materials has been deposited on the creek bottom. This mat ranges in thickness from 1cm to 6cm, and does not cover the entire creek bed. The mat has been broken up, presumably by ice action, along much of the creek and exists as a remnant throughout the creek. This material likely came from tailings dumped into Christal Lake between 1956 and 1958. In areas where the mat remains the substrates have consolidated and all interstitial spaces have filled. Fish habitat will improve in the creek as more of this material becomes broken up.

Reach #1 is the actual mouth of the creek and extends upstream for 30 meters from the confluence with the South McQuesten River. Two pools joined by a shallow riffle have formed at the outlet of the creek. These pools have fine gravel and sand substrates that have been overlaid in low flow areas with organic silts. Submerged root wads and willows within these pools provide excellent cover for young fish from the South McQuesten River. This reach is sample site C 1.

Reach #2 flows through a wide flat area that is part of the South McQuesten Rivers flood plain to the mouth. The channel here although not constricted generally flows in well defined banks through a wide wetland area. Beaver dams both old and current occur regularly throughout this reach and play an important role in the formation of the channel. In many places the channel flows between deeply cut banks that rise sharply over a meter above the water level. Substrates vary through the reach and consist primarily of silt bottomed areas interspersed with fine pea gravel's, coarse gravel's, cobbles and sand. Organic debris and sticks form small jams against spruce sweepers but log jams are not common. This reach has many pools particularly behind active beaver dams that provide excellent habitat on a seasonal basis. The beaver dams creating the pools may create barriers to fish passage during the fall months when water levels typically become lower, effecting grayling that try to move out of the creek to over winter. Sample site C 2 is located near a set of these beaver ponds near the middle of the reach.

Reach #3 extends from just below the Hanson Lake Road crossing of Christal Creek to the bottom of the canyon. Through this reach the creek meanders around small knolls. The forest cover is thick with mature spruce and black poplar. Evidence of beaver activities , either current or old appear in most areas where the flood plain widens. Substrates consist predominantly of gravel with the occasional run of cobbles or boulders. The channel ranges in width from 3 to 5 meters, with an average depth of 0.4 meters and has many small log jams and associated pools. Fish habitat through this reach is limited by cover, and is therefore likely enhanced by the presence of beaver dams.

Reach #4 flows through a steep sided canyon for approximately 700 meters. Through the canyon the creek flows straight in a north west direction as an almost continuous rapid over angular boulders and cobbles. The channel flows very straight with no meanders or pools, likely as a result of placer mining in the canyon.

Extensive mining activities in the canyon included the construction of a road through the canyon with bridges crossing the creek at either end. Both of these bridges have partially collapsed or shifted and now pose barriers to fish passage. This reach does not provide much fish habitat in its present form, however a pool adjacent to the lowest bridge does provide habitat with available cover inside the old culvert, this is site C4.

Reach #5 of Christal Creek begins at the Keno road crossing and extends for approximately 5 kms down to the canyon. The creek grows substantially from an average width of 1m near the road to well over 3m before entering the canyon. The creek flows through a confined valley with a narrow flood plain. Substrates through this reach consist primarily of gravel mixed with boulders, cobbles and sand occur regularly and organic silts occur in backwater areas. Sparse willows and occasional black spruce in the upper reaches give way to denser stands that include white spruce and black poplar. This reach has many pools and riffle areas that could provide excellent fish habitat for grayling and sculpins. The pool areas become more common in the lower part of the reach. Sample site C5 is located at the Keno Road crossing at the upper end of this reach.

Reach #6 starts at the outlet of Christal Lake and flows 400m through a series of beaver ponds and slow deep channel before flowing through culverts under the Keno City Road. Outflow from the Galkeeno 900 adit enters Christal Creek at the start of this reach. The vegetation is typical of high altitudes and consists of sedges, Labrador tea, willows and black spruce. The substrates are entirely organic silts. Water depths vary between 0.5 and 2 meters. This reach has the potential to provide habitat to grayling and sculpins, the limiting factor to fish in this situation is most likely levels of heavy metals in the water.

### 3.2.3 Christal Lake

Christal Lake, a small sub-alpine lake has an organic silt bottom overlaying a heavy tailings sludge. The tailings likely were deposited in the lake between 1956 and 1958 when a Grizzley mill operated on the east shore of Christal Lake. Christal Lake recharges primarily through seepage and runoff from the surrounding hills. A small spring fed creek enters at the southern most end of the lake. Vegetation adjacent to the lake consists primarily of willows and alders. Some stunted black spruce grow along the shores.

Christal Lake has well developed aquatic vegetation that occurs as thick mats over much of the lake with depths less than 1 meter. The lake has consistent shallow depths with the deepest water being less than 3 meters. Beaver dams at the outlet of the lake control water levels in the lake.

The quality of fish habitat available in Christal Lake likely relates to the levels of heavy metals in solution.

### 3.2.4 South McQuesten River

The South McQuesten River, within the study area flows as a meandering mountain river with several different flow regimes. The most predominant regimes being gravel/cobble bottomed riffles interspersed with glide areas and occasional deep, often silted pools. Old meander scrolls have created sloughs along much of the river and provide slack water habitats.

The reach between Flat and Haggart Creek has a variety of habitat types. The river valley opens and large wetland areas become associated with the river. Silted areas and grassy silt banks become more common, gravel and cobble substrates become less common, and in several areas, especially immediately upstream of Haggart, the river widens and flows slowly through deep glide areas.

Although most of the tributary water comes from creeks a large amount of ground water seeps into the river below the north face ofMount Haldane. This seepage enters the river for a significant distance and introduces a large volume of cool water.

The South McQuesten River provides many important habitats for Arctic grayling, including spawning and rearing.

Suitable habitat for Chinook spawning does exist in the South McQuesten River. DFO (1995 internal document) states that the river has strong winter flows necessary for over-wintering. Suitable habitat for fry rearing occurs in many places above Haggart Creek.

### 3.2.5 Lightning Creek

The reach of Lightning Creek surveyed extends from a point just below the town site of Keno City, then upstream to a point approximately 200 meters above the influence of the placer mined Thunder Gulch. Placer mining activities have greatly influenced all of Lightning Creek investigated in this survey. The placer mining operation at Thunder Gulch operated during 1994 investigations but was idle during the spring of 1995.

The reach between Keno City and the confluence of Lightning Creek with Duncan Creek was investigated during summer investigations. This reach of creek has been extensively placer mined during recent history. For the most part the creek through this reach has been straightened and ditched. No habitat reclamation was evident and the present condition of the creek does not offer much suitable fish habitat. The lower most 200 meters of the creek has been allowed to flow around old gravel piles creating meanders and pools and a margin of fish habitat.

## 3.3 HABITAT UTILIZATION

### 3.3.1 Flat Creek

During fall and summer investigations young of the year grayling, sculpins, burbot and pike were found in the lowest reaches of the creek, the presence of these species declined quickly away from the mouth of the creek.. As with Christal Creek a deep pool near the mouth was utilized by grayling fry, however this utilization did not extend upstream more than 20 meters and was not as extensive as at the mouth of Christal Creek. No fish were observed or encountered in the mid or upper reaches of this creek. Slimy sculpins comprised 63% of the fish present in Reach #1, and grayling fry 36% (Figure 5). Sculpins comprised 97% of the fish found in Reach #2 (Figure 6), and 73 % of the fish recorded in the entire of Flat Creek (Figure 7).

Habitat does exist in Reach # 3 that could potentially support summer resident Arctic grayling, this habitat lies between the beaver dams at the end of the open wetland areas and in small pools along the creeks course were it passes through mature spruce forests. This habitat did not appear to be utilized during our investigations.

Spring utilization of Flat Creek was not extensive, however grayling fry and sculpins had moved into the mouth area by early June. No fish were found in Flat Creek during late May, suggesting that winter use of this habitat does not occur or is limited.

### 3.3.2 Christal Creek

Juvenile Arctic grayling, burbot, slimy sculpins and a single adult grayling were recorded in Reach #1 of Christal Creek during summer and fall investigations and no fish were recorded in this reach during spring investigations. The pool areas in Reach #1 were the most heavily utilized areas of Christal Creek. Grayling fry comprised 96% of the fish recorded in this reach ( Figure 8).

Adult Arctic grayling were found utilizing larger pool areas in Reach #2, and in the pool below the obstruction located at the bottom of the canyon area. Adult Arctic grayling were observed utilizing this pool in August of 1994 by Environmental Protection personnel (Davidge per com, 1995). The pool below the obstruction bridge likely provides good habitat because of the cover offered by the collapsed wooden culverts. Adult grayling comprised 53% of the fish recorded in Christal Creek excluding the mouth area (Figure 9).

Slimy sculpins were the only fish found above the obstruction in Reach #4. These were not found in abundance, sculpins comprised only 9% of all fish recorded in Christal Creek ( Figure 10).

Christal Creek showed a major thermal difference to the adjacent South McQuesten River during the spring of 1995. Severe ice daming on the creek during the winter caused ice build-ups that persisted until early July, water temperatures at the mouth of Christal Creek remained near 1° while temperatures in the South McQuesten had risen to over 10° (Table 10). This may in part explain a lack of any grayling being found in the creek during spring investigations. Although Christal Creek has potential spawning habitat for Arctic grayling the cold water temperatures make it unlikely that grayling would have used that habitat during the 1995 season.

### 3.3.3 Christal Lake

Several large adult slimy sculpin (max. 17 gr) were captured from the lake during the fall investigations.. A specimen that appeared to be considerably larger than any we captured was observed when a Belted King Fisher attempted to eat the specimen, the bird was unsuccessful in its attempt to swallow the fish due to the fishes large size. No other species of fish were found utilizing the lake.

### 3.3.4 South McQuesten River

All fish species recorded in this study were encountered in the South McQuesten River.

The section of river adjacent to the mine site provides a full range of habitats necessary for most life stages of the species listed in this report other than the salmon.

Arctic grayling were the most common species recorded near the outlet of McQuesten Lake (Figure 11). Species composition between sites above Christal Creek and those below Christal to just below Flat Creek had very little difference (Figures 12 and 13). Sculpins comprised over 50% of fish recorded in both of these areas. Sculpins remained the dominant species below Flat Creek (Figure 14), until the confluence with Haggart Creek where grayling fry became the dominant species (Figure 15). The species composition of Haggart Creek (Figure 16) closely resembled that of the South McQuesten below the mouth of Haggert Creek. The majority of the samples for this analysis came from within the area of influence of Haggart Creek.

Grayling of all life stages were found, however the various life stages did use different habitats. Grayling spawning was observed to occur during mid-May. Adult grayling became more dispersed and less common after spawning had occurred. Grayling fry utilize most habitats found in this reach of river but were found predominantly associated with shallow riffle areas and at the mouths of clear water tributaries. Sub-adults utilized habitats with heavy cover or near deep water and were not common during spring investigations except near the mouth of Haggart Creek after the grayling had spawned (See section 3.4.2 for more information on Arctic grayling).

Seining yielded large numbers of sculpin at most locations. All life stages were present, a fact to be expected as slimy sculpins tend to be mostly stationary in their habits.

Arctic lamprey were encountered in the South McQuesten at several locations. The majority of the lamprey encountered were found in areas with silty or muddy bottoms. Three distinct length classes were observed, amocoetes between 40 and 60 mm, between 90 and 105 mm, and a third class between 150 and 200 mm. None of the specimens observed were of the eyed life stage.

Longnose sucker fry were present upstream of Christal Creek, at the mouth of Haggart Creek and at several slack water areas between. Longnose sucker likely use the South McQuesten River for spawning during early spring.

Juvenile burbot were the only burbot captured in the South McQuesten River. Adults of this species may utilize larger pools or may move downstream to larger waters.

Northern pike were found dispersed through the reach of river studied, juveniles were more commonly observed than adults, however this may be due to selectivity of gear rather than occurrence.

Round whitefish were encountered in the South McQuesten River as an occasional species, most of the individuals recorded were young of the year and came from clean gravel riffle areas. Adults and sub-adults were encountered near cut bank areas but were not common.

A single lake chub was captured in a side pool upstream of Christal Creek at site SM1. A single least cisco fry was captured in the river just below McQuesten Lake.

Chinook salmon fry were observed in the South McQueston River, however none were found at any point above the mouth of Haggart Creek. The mouth of Haggart Creek was extensively used by chinook fry as was were the areas of the South McQuesten downstream of Haggart and site SM11.

The area immediately below Haggart Creek was determined to be an important rearing area for chinook salmon, Arctic grayling and longnose suckers.

### 3.3.5 Lightning Creek

During both fall and summer investigations the reach of Creek above the influence of Thunder Gulch was utilized exclusively by adult Arctic grayling during our sampling. Sub-adult grayling were found below the influence of Thunder Gulch in the fall when the water was more turbid, a situation also reported by Gormican (1992), and likely relates to the less aggressive sub-adults seeking cover in the turbidity. These sub adults were found in the areas were the creek channel was allowed to meander. Areas with straight channels left from placer operations had no resident fish. Sub-adult grayling were observed in the fall near old bridge works near the town of Keno. No fish were not found in the reach below the town site of Keno until the last 200 meters before Lightning Creek joins Duncan Creek. This site had sub-adult and juvenile Arctic grayling.

Placer mining was discontinued after the 1994 season on Thunder Gulch. A small pond below a recently mined area was utilized by adult and sub-adult Arctic grayling during the summer of 1995 as witnessed by good angling results. Efforts to capture fish from this pond during fall investigations were unsuccessful.

Slimy sculpins were conspicuously absent from Lightning Creek during all investigations.

## 3.4 FISH SPECIES DISTRIBUTION AND SYSTEMATICS

### 3.4.1 Chinook Salmon

Although the McQuesten River has been called an important chinook salmon river by DFO, documentation of chinook utilization of the South McQuesten River remains scant and all reports of salmon upstream of Haggart Creek remain unsubstantiated. DFO does agree that potential spawning habitat exists upstream of Haggart Creek and suggests that what appears to be old spawning dunes exist at the outlet of McQuesten Lake, these dunes do not seem to have been used recently.( DFO 1995 internal document)

Milligan et al (1984) describe the Yukon River chinook salmon as having a life cycle that includes a freshwater rearing period of one to two years. The McQuesten does not appear much utilized by juveniles beyond the first year of growth. Underyearling chinook over-winter in the McQuesten and subsequently (at age 1) emigrate from this large tributary downstream either to sea or to other freshwater rearing and over-wintering habitat (Gormican et al, 1992).

Chinook salmon generally enter the McQuesten River some time towards the end of July each season, with spawning usually occurring sometime during the middle of August. A helicopter supported survey (Gormican et al, 1992) of the McQuesten River from its mouth to Oliver Creek (approximately 60 kms) was conducted on August 7,1990. A total of 294 adult chinook, 26 carcasses and 62 redds were observed on this survey. Spawning was far advanced at the time of the survey and females had left some of the redds. The count of fish and redds has been described as being a conservative estimate of actual numbers. The redds occurred in 13 "clumps" evenly distributed between the river mouth and Bear Creek. This survey did not include the South McQuesten River.

Attempts at capturing juvenile chinook salmon in the South McQuesten River near Elsa in this study, and in 1991 and '92 by DFO staff proved unsuccessful. The absence of chinook juveniles in this area may be due to a log jam located 1 km upstream of the Haggart Creek and McQuesten River confluence. A debate exists as to whether the log jam has created an effective barrier to all life stages of chinook salmon.

This log jam may prevent the passage of adult spawning salmon to spawning areas upstream of this site. Alternatively adult salmon may be showing an avoidance behavior to metal concentrations in the South McQuesten River and not going past Haggart Creek. Suitable spawning and rearing habitat for chinook salmon was observed during 1995 investigations on the South McQuesten River upstream of the mouth of Haggart Creek, but at this point in time it does not appear to be utilized.

A single site on the mainstem of the McQuesten River was sampled during early June, 1995. The site sampled was approximately 500 meters upstream of the Klondike Highway crossing. This site has been recorded as a known chinook salmon spawning location. The purpose of investigating the lower McQuesten was to determine when chinook salmon fry had emerged. Seining and electro-shocking were conducted on June 1. Newly emerged chinook salmon fry were present and common, especially around submerged willow clumps. Yolk sacs had dropped and most fry captured were fully "zipped", indicating the emergence had occurred at least several days previous, dating the emergence near May 20.

Chinook salmon fry were determined to have emerged from the gravel in the lower McQuesten River during late May of 1995. Chinook have been documented emerging in the McQuesten River as early as May 10 in 1990 (Gormican et al, 1992).

Chinnok salmon fry were found present in good number at the outlet of Haggart Creek and at sites downstream of the confluence with Haggart Creek. Salmon fry were not encountered upstream of Haggart Creek on the South McQuesten River even though extensive effort was exerted to capture them in those waters.

### 3.4.2 Arctic Grayling

Large numbers of adult grayling were present in the South McQuesten River during early spring (mid May). Grayling spawning has been reported as occurring at a temperature of 7 to 10°C (Scott and Crossman 1973). The South McQuesten warmed early during the 1995 season and temperatures of >8° was reached during late May.

Large numbers of grayling were reported at the Haggart Creek mouth during early May. Employees of UKHM reported catching large numbers of fish at this site. Catch and release fishermen reported catches in excess of 150 adult grayling in a single days fishing. Similar large numbers of grayling were reported at the outlet of McQuesten Lake by area residents. Both of these areas had large numbers of fry during subsequent sampling and it is very likely that both of these sites are important spawning grounds for Arctic grayling. We suspect that grayling spawning, although concentrated at certain sites as described above, also occurred to a lesser degree at many sites throughout the river.

Several adult grayling were captured on May 21 and sacrificed, both females and males had spawned, spawning appeared to have occurred approximately 7-10 days previous. Stomach analysis from these grayling showed the adults to be actively eating their own eggs, a common occurrence. Several of these eggs had reached the eyed stage.

Grayling fry were found distributed throughout the study area during summer and fall investigations. The river provides large areas of suitable rearing habitat for young grayling. The most common areas to find large numbers of rearing fry was near clear water tributaries such as Flat and Christal Creeks and in association with riffle areas.

Adult grayling disperse throughout the system after spawning, with only a few remaining behind for the summer and fall seasons, some of these utilize Christal Creek. We assume that most of the adults move downstream to bigger waters. Sub adult grayling were dispersed throughout the river at all times during investigations, however were more common during summer and fall.

### 3.4.3 Rainbow trout

Attempts by the Calumet Fishing Society (defunct) were made to establish populations of rainbow trout in the Elsa area during the early 1960's, these attempts met with little to no success. The introductions were aimed at providing recreational opportunities for what was a large community of mine workers and their families ( Walker et al 1973). Christal and Hanson Lakes (near the head waters of the South McQuesten River) were the lakes chosen for stocking.

The only record of the stocking program comes from DFO stream files. A review of correspondence from the late 1950's and early 1960's shows that stocking of Christal Lake with rainbow trout eggs was as follows; on June 1, 1961 with 35,000, on June 15,1961 with 13,000 and on July 7,1962 with 13,000 eggs. Test netting during 1962 and '63 caught no rainbow trout and the introduction was not considered a success.

Hanson Lakes, the second choice for stocking were treated with "poison" as it was determined to be "absolutely necessary that the two major species inhabiting the lake, northern pike and lake whitefish, be eradicated if rainbow trout were to be established". Lower Hanson Lakes was determined to be more suitable for the introduction of rainbow trout, however both lakes were poisoned with toxaphene at a concentration of 0.006 ppm in July of 1963. Rotenone was used to poison the outlet and two inlet streams prior to introducing rainbow trout.

Hanson Lakes were planted with rainbow trout eggs as follows; in 1965 (100,000 eggs), 1966 (100,000 eggs), and 1968 (150,000 eyed eggs). Survival at the time of planting was observed, however any continued survival has not been reported.

The most lasting result of the attempts to establish rainbow trout in Hanson Lakes was the extirpation of the rare species of whitefish known as the Squanga whitefish, a sub-species of the lake whitefish that did reside in 5 water bodies within the Yukon Territory, including Hanson Lakes. The Hanson Lakes population was extirpated during the poisoning of the lake prior to the rainbow trout introductions (Bodaly et al, 1987). The remaining four populations have been assigned "rare" status by international convention.

### 3.5 HEAVY METAL ANALYSIS

Analysis of fish tissue, fish livers and whole fish samples (Tables 9 and 10) showed that fish from Christal Creek and Lake had the highest levels of most metals sampled for. Flat creek had elevated levels but those levels were lower than fish from Christal Creek. The samples taken from the South McQuesten River above the mouth of Christal Creek had the lowest levels of the fish sampled during this study. All fish sampled in this study had high levels of zinc compared to samples taken from other waters of the Yukon (Table 11).

Sculpins from Christal Creek and Christal Lake have extremely high levels of zinc present in their flesh. A single specimen captured near the Keno City road crossing of Christal Creek had dramatically high levels of most metals, zinc was present at a level of 853 ppm. This specimen was not a healthy looking individual and its weight was light in proportion to its length. Specimens from Christal Lake had zinc levels ranging from 314 to 365 ppm. The levels recorded from the head waters of Christal Creek represent the highest zinc levels found in this investigation. The threshold values established by the Canadian Government for edible meat for zinc is 100 ppm (CCREM 1987).

Sculpins from Flat Creek had zinc levels ranging from 187 to 287 ppm, approximately 30% lower than levels from Christal. However, levels of copper and lead were considerably higher in Flat than those in Christal.

Levels of copper are approximately 100% higher in the liver samples as opposed to flesh samples. According to the federal guidelines for freshwater aquatic life (CCREM 1987) zinc bioaccumulates, but no evidence of biomagnification has been found. This report also states zinc concentrations are greater in benthic insects than in fish, and greater in omnivorous fish than in piscivorous species.

Results from the analysis of fish flesh taken from several other Yukon lakes showed levels of zinc in the flesh to be much lower than levels found in the livers, with livers being up to 4 times as high in concentrations. Grayling taken from site C4, presumably resident in that environment for most of the summer, had flesh concentrations of zinc that were as much as 2 times higher than those from the livers. The stomachs of these grayling showed that 90% of the diet of these fish was terrestrial insects..

Arctic grayling have been found to be one of the most sensitive fish species when exposed to various concentrations of zinc (Spear 1981). Fish have been found to avoid areas of even very low concentrations of zinc above background levels. Studies on the effects of zinc on fish have shown avoidance reactions to zinc at levels of 0.01 mg/l in rainbow trout and to copper at 0.004 mg/l in Atlantic salmon (Sprauge 1964 , 1968). Although Christal Creek waters have significantly higher zinc levels than those which fish have been shown to exhibit avoidance behavior to, grayling were found to be utilizing much of the creek and did not appear to be exhibiting avoidance behavior. Pre-exposure to zinc has been shown to result in large increases in zinc tolerance (3 to 5 fold) (Anadu et al, 1989).

Various studies have shown that some fish can acclimatize to increased zinc levels. Fish that developed from eggs that were exposed to zinc had a higher tolerance to zinc than eggs not exposed to zinc . Adult fish that had been exposed to high total hardness prior to zinc exposure , were more tolerant than those at low total hardness (Moore et al 1984). Chapman (1978) observed significant acclimation to zinc in the one month alevin stage. Even though fish may acclimatize to lethal levels of zinc, chronic or sublethal effects can occur such as reduced growth and reproduction (Sprague 1971) Chronic effects of zinc toxicity include stress, poorly developed organs, inhibition of normal growth and severe hormonal disorders.

Water hardness has been shown to exhibit a significant effect on the toxicity of zinc to freshwater fish (Holcombe et al 1978, Sinley et al 1974, Lloyd 1962 and Mount 1966 ). In particular zinc has been shown to be more toxic in soft water than in hard water. It is thought that calcium may act competitively with zinc thereby reducing zinc uptake (Spear, 1981). Falfs et al (1973) found that increased calcium content due to increased hardness, decreased the sensitivity of the fish to zinc. It should be noted that water in Christal creek is hard to very hard.

Toxicity of zinc increases in the presence of other metals often producing an additive or synergistic effect, especially with copper (Taylor and Demayo 1980, Nriagu 1980 ) Toxicity of zinc also increases with a reduction in dissolved oxygen or a decrease in hardness, pH, alkalinity, salinity, or suspended solids (Alabaster et al 1980 , Nriagu 1980)

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**TABLE1** **Summary of fish caught by seining UKHM study 1994-95**

SS= slimy sculpin, AG= Arctic grayling, AG(f)=Arctic grayling fry, CH= chinook salmon, NP= northern pike

LNS= longnose sucker, BB= burbot, AL= Arctic lamprey, RWF= round whitefish

| | | | | | | | | #fish caught | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LOCATION | DATE | # SIENES | AREA (m2) | AG(f) | AG | SS | BB | NP | RWF | LNS | CH | AL |
| C1 | fall /94 | 1 | 18 | 147 | | | | | | | | |
| C3 | fall /94 | 3 | 40 | | | | | | | | | |
| C5 | spring /95 | 1 | 12 | | | 2 | | | | | | |
| F1 | fall /94 | 3 | 136 | 16 | | 36 | | 1 | | | | |
| F1 | summer /95 | 2 | 69 | 11 | | 8 | | | | | | |
| Hg | spring /95 | 5 | 198 | | 8 | 11 | | | 4 | | | |
| Hg | summer /95 | 5 | 251 | 221 | | 23 | | | | 10 | 15 | |
| LC | fall /94 | 5 | 415 | | 9 | | | | | | | |
| LC | spring /95 | 6 | 333 | | 1 | | | | | | | |
| LC | summer /95 | 13 | 905 | | 11 | | | | | | | |
| MQ | spring /95 | 5 | 106 | | 1 | 9 | | | | | 17 | |
| Shg | summer /95 | 1 | 30 | 3 | | 4 | | | | | | |
| SM1 | fall /94 | 5 | 274 | 12 | | 27 | | | | 1 | | |
| SM1 | spring /95 | 7 | 339 | | | 14 | | | 1 | | | |
| SM1 | summer /95 | 7 | 356 | 131 | | 14 | | | | 49 | | 5 |
| SM2 | fall /94 | 7 | 189 | 31 | | 100 | | | | 15 | | |
| SM2 | spring /95 | 2 | 92 | | | 3 | | | | | | |
| SM2 | summer /95 | 6 | 314 | 32 | | 36 | | | | 15 | | |
| SM3 | fall /94 | 4 | 213 | 29 | | 64 | | | 1 | 9 | | |
| SM3 | spring /95 | 1 | 45 | | 1 | | | | | | | 1 |
| SM3 | summer /95 | 9 | 409 | 182 | 3 | 106 | | | 1 | 14 | | 1 |
| SM4 | fall /94 | 4 | 90 | 2 | | 73 | | 1 | 1 | | | |
| SM4 | summer /95 | 8 | 292 | 32 | | 75 | | 1 | | 1 | | |
| SM6 | fall /94 | 4 | 110 | 5 | | 44 | | 1 | | 1 | | |
| SM6 | spring /95 | 2 | 118.5 | | | 4 | | | | | | |
| SM6 | summer /95 | 5 | 141 | 6 | | 22 | | 1 | | | | |
| SM7 | fall /94 | 3 | 176 | 9 | | 30 | | | | | | |
| SM7 | summer /95 | 5 | 201 | 139 | | 44 | | | 1 | | | |
| SM8 | summer /95 | 5 | 154 | 7 | | 38 | | 1 | | 34 | | |
| SM9 | spring /95 | 5 | 239 | 5 | 9 | 15 | | | | 2 | | |
| SM9 | summer /95 | 3 | 207 | | | 2 | | | | | | |
| SM10 | spring /95 | 10 | 424 | | 14 | 63 | | | 1 | 4 | | |
| SM10 | summer /95 | 9 | 451 | 419 | 1 | 32 | | | 38 | 17 | 26 | |
| SM11 | summer /95 | 7 | 360 | 49 | | 72 | | | 5 | | 28 | |
| SM12 | summer /95 | 7 | 287 | 91 | | 66 | 1 | 1 | 3 | | | |
| SM13 | summer /95 | 4 | 167 | 150 | | 71 | | | 2 | 40 | | |
| SML | spring /95 | 8 | 543 | | | 6 | | | | | | |
| SML | summer /95 | 11 | 522 | 89 | 10 | 5 | | 2 | 7 | | | |
| **TOTALS** | | 198 | 9226.5 | 1818 | 34 | 1119 | 1 | 9 | 65 | 115 | 32 | 7 |

**TABLE 2 Summary of Fish Caught by Electrofishing UKHM 1994-95**

SS= slimy sculpin, AG= Arctic grayling, AG(f)=Arctic grayling fry, CH= chinnok salmon, NP= northern pike
LNS= longnose sucker, BB= burbot, AL= Arctic lamprey, RWF= round whitefish

| SITE | DATE | EFFORT (MIN) | SS | AG | AG(f) | CH | NP | LNS | BB | AL | RWF |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C1 | summer/95 | 8.3 | 6 | | 60 | | | | | | |
| C1 | fall/94 | 17.2 | 4 | | 8 | | | | 1 | | |
| C2 | summer/95 | 6.9 | | | | | | | | | |
| C2 | fall/94 | 13.9 | 1 | | | | | | | | |
| C3 | summer/95 | 7.6 | | | | | | | | | |
| C3 | fall/94 | 17.1 | | | 1 | | | | | | |
| C4 | summer/95 | 3.6 | | 9 | | | | | | | |
| C4 | fall/94 | 21.9 | | | | | | | | | |
| C5 | summer/95 | 5.9 | 10 | | | | | | | | |
| C5 | fall/94 | 10.2 | 13 | | | | | | | | |
| F1 | summer/95 | 3.4 | 35 | | 11 | | | | | | |
| F2 | fall/94 | 51.7 | 71 | | 1 | | | | | | |
| F1 | fall/94 | 11.5 | 29 | | 3 | | | | | | |
| F2 | summer/95 | 3.9 | 2 | | | | | | | | |
| F1 | spring/95 | 6.4 | 16 | | | | | | 1 | | |
| F3 | fall/94 | 19.4 | | | | | | | | | |
| MQ | spring/95 | 10.4 | 8 | | | 58 | | | | | |
| SM1 | summer/95 | 9.7 | 45 | | 5 | | | | | 1 | |
| SM1 | fall/94 | 11.8 | 64 | | 5 | | | | 1 | | |
| SM2 | fall/94 | 17.5 | 127 | | 8 | | | 21 | | | |
| SM3 | fall/94 | 18.5 | 91 | | 1 | | 2 | 11 | 1 | 1 | |
| SM4 | summer/95 | 20.3 | 50 | | 2 | | 6 | | | 1 | |
| SM4 | fall/94 | 15.2 | 9 | | | | | 1 | 1 | 1 | |
| SM6 | summer/95 | 3.1 | 2 | | | | 2 | | | | |
| SM6 | spring/95 | 3.5 | 16 | | | | | | | | |
| SM9 | spring/95 | 2.1 | 8 | | | | | | | | |
| SM6 | fall/94 | 18.0 | 75 | | 1 | | 1 | | 1 | | |
| SM7 | summer/95 | 4.8 | 4 | | | | 2 | | | | |
| SM7 | spring/95 | 3.8 | 8 | | | | | | | | |
| SM7 | fall/94 | 14.1 | 85 | | 3 | | 1 | | 1 | | |
| SM8 | spring/95 | 5.0 | 136 | | | | | | 1 | | |
| SM9 | spring/95 | 2.1 | 8 | | | | | | | | |
| SM10 | spring/95 | 7.4 | 15 | | 3 | | 1 | 7 | | | |
| SM12 | spring/95 | 8.7 | 58 | | | | 1 | | 1 | 17 | |
| TOTALS | | 384.5 | 996 | 9 | 112 | 58 | 16 | 40 | 9 | 21 | 0 |

Table 3.
Summary of visual observations made during fisheries investigations conducted near United Keno Hill Mines property at Elsa, Yukon, 1994, '95.

| DATE | SITE | OBSERVATION |
|---|---|---|
| Sept. 9/94 | C4 | 12 adult Grayling |
| Sept. 10/94 | CL | Sculpins - no number recorded several observers saw several specimens |
| Sept 10/94 | CL | 1 Sculpin ( with King Fisher) |
| Sept 12/94 | C2 | 15 adult, 17 sub-adult, 22 juvenile Grayling (600 m reach) |
| July 15/95 | C4 | 5 adult Grayling |
| July 16/95 | SM2 | 15 fry LN Sucker |
| July 16/95 | C1 | 100+ fry Grayling |
| July 16/95 | SM4 | 12 sub-adult Grayling |
| July 17/95 | SM7 | 3 juvenile N Pike |
| July 18/95 | SM10 | 5 adult Grayling; 1 adult N Pike |
| July 18/95 | SM9 | 3 adult Grayling; 1 juvenile N Pike |
| July 18/95 | SM8 | 6 juvenile N Pike |
| July 19/95 | C1 | 1 adult Grayling |

Table 4. Results obtained by angling during the habitat assessment and utilization surveys conducted near Elsa, Yukon during 1994 and 1995.

| Date | Location | Hrs. fished | Catch | Comments |
|---|---|---|---|---|
| Sept. 5/94 | SM1 | 0.68 | | |
| Sept. 5/94 | SM5 | 0.50 | 3 grayling | adult |
| Sept. 6/94 | SM4 | 1.50 | 1 grayling | sub adult |
| Sept. 6/94 | SM6 | 0.50 | 2 grayling | adults |
| Sept. 7/94 | C1 | 0.50 | 2 grayling | adults |
| Sept. 7/94 | SM4 | 0.55 | 2 grayling | adults |
| Sept. 8/94 | SM5 | 0.50 | 1 grayling | adult |
| Sept. 9/94 | C4 | 0.10 | 1 grayling | sub adult |
| Sept.16/94 | C2 | 0.50 | 3 grayling | sub adult |
| | | | | |
| May 19/95 | SM4 | 0.67 | | |
| May 20/95 | SM6 | 0.40 | | |
| May 20/95 | SM10 | 0.75 | | |
| May 20/95 | SM8 | 1.50 | 3 grayling | 1 adult, 2 sub adult |
| May 22/95 | SML | 1.00 | 5 grayling | adults (in river) |
| May 22/95 | SML | 0.30 | 3 n.pike | sub adults (at lake adge) |
| May 22/95 | C2 | 0.70 | | |
| May 22/95 | SM6 | 0.20 | | |
| May 22/95 | SM7 | 0.20 | | |
| May 22/95 | SM1 | 0.33 | | |
| May 23/95 | SM10 | 0.33 | | |
| May 23/95 | SM5 | 0.33 | | |
| | | | | |
| July 16/95 | SM4 | 0.67 | 4 grayling, 1 pike | gray - ui, pike adult (400mm) (pool area) |
| July 16/95 | SM4 | 0.50 | | riffle areas |
| July 18/95 | SM10 | 0.20 | 2 grayling | adults |
| July 18/95 | SM9 | 0.20 | 1 pike | adult |
| July 29/95 | LC | 0.33 | 6 grayling | adults (settling pond ) |

Table 5. Gillnetting results from gillnets set near Elsa, Yukon during fisheries investigations conducted in 1994 and 1995.

| DATE SET | LOCATION | MESH SIZE | HRS. SET | DEPTH SET | LENGTH SET | TOTAL CATCH | CPUE fish/100m/24hrs |
|---|---|---|---|---|---|---|---|
| Sept. 6/94 | Christal L. | 1″ | 59.25 | 3m | 20m | 4SS | 8.1 (sculpin) |
| Sept. 6/94 | Christal L. | 2.5″ | 59.25 | 2m | 24m | 0 | 0 |
| Sept. 8/94 | Christal L. | 1″ | 44.0 | 3m | 20m | 1SS | 2.7 |
| Sept. 8/94 | Christal L. | 2.5″ | 44.0 | 2m | 24m | 0 | 0 |
| May 21/95 | SM4 | 2″ | 3 | 2m | 12m | 0 | 0 |

**TABLE 6: Combined catch per unit of effort for electrofishing results UKHM study 1994-95**

SS= slimy sculpin, AG= Arctic grayling, AG(f)=Arctic grayling fry, CH= chinnok salmon, NP= northern pike
LNS= longnose sucker, BB= burbot, AL= Arctic lamprey, RWF= round whitefish

| | | | | | | CPUE | ( # fish / minutes ) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SITE | DATE | EFFORT (MIN) | SS | AG | AG(f) | CH | NP | LNS | BB | AL | RWF |
| C1 | summer/95 | 8.32 | 0.721 | 0 | 7.214 | 0 | 0 | 0 | 0 | 0 | 0 |
| C1 | fall/94 | 17.20 | 0.233 | 0 | 0.465 | 0 | 0 | 0 | 0.058 | 0 | 0 |
| C2 | summer/95 | 6.85 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C2 | fall/94 | 13.92 | 0.072 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C3 | summer/95 | 7.55 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C3 | fall/94 | 17.12 | 0 | 0 | 0.058 | 0 | 0 | 0 | 0 | 0 | 0 |
| C4 | summer/95 | 3.55 | 0 | 2.535 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C4 | fall/94 | 21.87 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C5 | summer/95 | 5.88 | 1.700 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C5 | fall/94 | 10.18 | 1.277 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| F1 | summer/95 | 3.41 | 10.264 | 0 | 3.226 | 0 | 0 | 0 | 0 | 0 | 0 |
| F2 | fall/94 | 51.65 | 1.375 | 0 | 0.019 | 0 | 0 | 0 | 0 | 0 | 0 |
| F1 | fall/94 | 11.53 | 2.514 | 0 | 0.260 | 0 | 0 | 0 | 0 | 0 | 0 |
| F2 | summer/95 | 3.85 | 0.519 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| F1 | spring/95 | 6.37 | 2.512 | 0 | 0 | 0 | 0 | 0 | 0.157 | 0 | 0 |
| F3 | fall/94 | 19.38 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MQ | spring/95 | 10.42 | 0.768 | 0 | 0 | 5.568 | 0 | 0 | 0 | 0 | 0 |
| SM1 | summer/95 | 9.65 | 4.663 | 0 | 0.518 | 0 | 0 | 0 | 0 | 0.104 | 0 |
| SM1 | fall/94 | 11.80 | 5.424 | 0 | 0.424 | 0 | 0 | 0 | 0.085 | 0 | 0 |
| SM2 | fall/94 | 17.53 | 7.243 | 0 | 0.456 | 0 | 0 | 1.198 | 0 | 0 | 0 |
| SM3 | fall/94 | 18.47 | 4.928 | 0 | 0.054 | 0 | 0.108 | 0.596 | 0.054 | 0.054 | 0 |
| SM4 | summer/95 | 20.32 | 2.461 | 0 | 0.098 | 0 | 0.295 | 0 | 0 | 0.049 | 0 |
| SM4 | fall/94 | 15.23 | 0.591 | 0 | 0 | 0 | 0 | 0.066 | 0.066 | 0.066 | 0 |
| SM6 | summer/95 | 3.10 | 0.645 | 0 | 0 | 0 | 0.645 | 0 | 0 | 0 | 0 |
| SM6 | spring/95 | 3.47 | 4.615 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SM9 | spring/95 | 2.13 | 3.756 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SM6 | fall/94 | 17.98 | 4.171 | 0 | 0.056 | 0 | 0.056 | 0 | 0.056 | 0 | 0 |
| SM7 | summer/95 | 4.77 | 0.839 | 0 | 0 | 0 | 0.420 | 0 | 0 | 0 | 0 |
| SM7 | spring/95 | 3.75 | 2.133 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SM7 | fall/94 | 14.12 | 6.021 | 0 | 0.213 | 0 | 0.071 | 0 | 0.071 | 0 | 0 |
| SM8 | spring/95 | 4.98 | 27.309 | 0 | 0 | 0 | 0 | 0 | 0.201 | 0 | 0 |
| SM9 | spring/95 | 2.13 | 3.756 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SM10 | spring/95 | 7.38 | 2.032 | 0 | 0.406 | 0 | 0.135 | 0.948 | 0 | 0 | 0 |
| SM12 | spring/95 | 8.65 | 6.705 | 0 | 0 | 0 | 0.116 | 0 | 0.116 | 1.965 | 0 |

**TABLE 7** **Combined catch per unit of effort data for seine results UKHM study 1994 -95**

SS= slimy sculpin, AG= Arctic grayling, AG(f)=Arctic grayling fry, CH= chinnok salmon, NP= northern pike
LNS= longnose sucker, BB= burbot, AL= Arctic lamprey, RWF= round whitefish

| | | | | | | | | cpue (#fish/m2) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LOCATION | DATE | #SEINES | AREA (m2) | AG(f) | AG | SS | BB | NP | RWF | LNS | CH | AL |
| C1 | fall /94 | 1 | 18 | 8.167 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C3 | fall /94 | 3 | 40 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C5 | spring /95 | 1 | 12 | 0 | 0 | 0.167 | 0 | 0 | 0 | 0 | 0 | 0 |
| F1 | fall /94 | 3 | 136 | 0.118 | 0 | 0.265 | 0 | 0.007 | 0 | 0 | 0 | 0 |
| F1 | summer /95 | 2 | 69 | 0.159 | 0 | 0.116 | 0 | 0 | 0 | 0 | 0 | 0 |
| Hg | spring /95 | 5 | 198 | 0 | 0.040 | 0.056 | 0 | 0 | 0.020 | 0 | 0 | 0 |
| Hg | summer /95 | 5 | 251 | 0.880 | 0 | 0.092 | 0 | 0 | 0 | 0.040 | 0.060 | 0 |
| LC | fall /94 | 5 | 415 | 0 | 0.022 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| LC | spring /95 | 6 | 333 | 0 | 0.003 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| LC | summer /95 | 13 | 905 | 0 | 0.012 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MQ | spring /95 | 5 | 106 | 0 | 0.009 | 0.085 | 0 | 0 | 0 | 0 | 0.160 | 0 |
| Shg | summer /95 | 1 | 30 | 0.1 | 0 | 0.133 | 0 | 0 | 0 | 0 | 0 | 0 |
| SM1 | fall /94 | 5 | 274 | 0.044 | 0 | 0.099 | 0 | 0 | 0 | 0.004 | 0 | 0 |
| SM1 | spring /95 | 7 | 339 | 0 | 0 | 0.041 | 0 | 0 | 0.003 | 0 | 0 | 0 |
| SM1 | summer /95 | 7 | 356 | 0.368 | 0 | 0.039 | 0 | 0 | 0 | 0.138 | 0 | 0.014 |
| SM2 | fall /94 | 7 | 189 | 0.164 | 0 | 0.529 | 0 | 0 | 0 | 0.079 | 0 | 0 |
| SM2 | spring /95 | 2 | 92 | 0.000 | 0 | 0.033 | 0 | 0 | 0 | 0 | 0 | 0 |
| SM2 | summer /95 | 6 | 314 | 0.102 | 0 | 0.115 | 0 | 0 | 0 | 0.048 | 0 | 0 |
| SM3 | fall /94 | 4 | 213 | 0.136 | 0 | 0.300 | 0 | 0 | 0.005 | 0.042 | 0 | 0 |
| SM3 | spring /95 | 1 | 45 | 0 | 0.022 | 0 | 0 | 0 | 0 | 0 | 0 | 0.022 |
| SM3 | summer /95 | 9 | 409 | 0.445 | 0.007 | 0.259 | 0 | 0 | 0.002 | 0.034 | 0 | 0.002 |
| SM4 | fall /94 | 4 | 90 | 0.022 | 0 | 0.811 | 0 | 0.011 | 0.011 | 0 | 0 | 0 |
| SM4 | summer /95 | 8 | 292 | 0.110 | 0 | 0.257 | 0 | 0.003 | 0 | 0.003 | 0 | 0 |
| SM6 | fall /94 | 4 | 110 | 0.045 | 0 | 0.400 | 0 | 0.009 | 0 | 0.009 | 0 | 0 |
| SM6 | spring /95 | 2 | 118.5 | 0 | 0 | 0.034 | 0 | 0 | 0 | 0 | 0 | 0 |
| SM6 | summer /95 | 5 | 141 | 0.043 | 0 | 0.156 | 0 | 0.007 | 0 | 0 | 0 | 0 |
| SM7 | fall /94 | 3 | 176 | 0.051 | 0 | 0.170 | 0 | 0 | 0 | 0 | 0 | 0 |
| SM7 | summer /95 | 5 | 201 | 0.692 | 0 | 0.219 | 0 | 0 | 0.005 | 0 | 0 | 0 |
| SM8 | summer /95 | 5 | 154 | 0.045 | 0 | 0.247 | 0 | 0.006 | 0 | 0.221 | 0 | 0 |
| SM9 | spring /95 | 5 | 239 | 0.021 | 0.038 | 0.063 | 0 | 0 | 0 | 0.008 | 0 | 0 |
| SM9 | summer /95 | 3 | 207 | 0 | 0 | 0.010 | 0 | 0 | 0 | 0 | 0 | 0 |
| SM10 | spring /95 | 10 | 424 | 0 | 0.033 | 0.149 | 0 | 0 | 0.002 | 0.009 | 0 | 0 |
| SM10 | summer /95 | 9 | 451 | 0.929 | 0.002 | 0.071 | 0 | 0 | 0.084 | 0.038 | 0.058 | 0 |
| SM11 | summer /95 | 7 | 360 | 0.136 | 0 | 0.200 | 0 | 0 | 0.014 | 0 | 0.078 | 0 |
| SM12 | summer /95 | 7 | 287 | 0.317 | 0 | 0.230 | 0.003 | 0.003 | 0.010 | 0 | 0 | 0 |
| SM13 | summer /95 | 4 | 167 | 0.898 | 0 | 0.425 | 0 | 0 | 0.012 | 0.240 | 0 | 0 |
| SML | spring /95 | 8 | 543 | 0 | 0 | 0.011 | 0 | 0 | 0 | 0 | 0 | 0 |
| SML | summer /95 | 11 | 522 | 0.170 | 0.019 | 0.010 | 0 | 0.004 | 0.013 | 0 | 0 | 0 |

Table 8.
Temperatures recorded at main sample sites during field investigations (1994-'95) in the area surrounding United Keno Hill Mines property near Elsa, Yukon. Temperatures have been reported in ° Celsius.

| Date | SML | SM1 | SM2 | SM3 | SM4 | SM6 | SM7 | SM8 | SM10 | H | F 1 | F2 | F3 | C1 | C2 | C3 | C4 | C5 | CL | LC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sept. 5 |  | 10.3 |  |  |  | 8.0 | 5.6 |  |  |  |  | 5.4 |  |  |  | 5.3 |  |  | 8.4 |  |
| 6 |  |  |  |  | 7.7 | 8.2 | 6.7 |  |  |  | 5.8 |  |  |  |  |  |  |  |  |  |
| 7 |  |  | 8.0 | 7.8 |  |  |  |  |  |  |  |  |  | 2.0 |  |  |  |  |  |  |
| 9 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 3.4 | 3.3 | 4.1 | 3.5 |  |  |
| 10 |  | 6.2 |  |  |  |  |  |  |  |  |  |  | 0.0 | 5.6 |  |  |  |  | 6.6 |  |
| 11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 6.7 |  |
| 15 |  | 5.9 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 7.3 |  |  |  |
| 16 |  |  | 9.7 | 7.5 |  | 9.4 | 8.7 |  |  |  | 8.5 |  |  | 7.4 |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| May.19 |  | 6.2 |  |  | 6.5 |  |  |  |  |  |  |  |  |  |  | 3.5 | 4.5 | 7.9 |  |  |
| 20 |  |  |  |  |  | 6.5 | 5.5 |  | 6.2 |  | 4.1 | 4.7 |  |  |  |  |  |  |  |  |
| 21 | 7.4 |  |  |  | 6.0 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 22 |  |  | 6.4 |  |  |  |  |  |  |  |  |  |  | 1.0 | 0.6 | 3.6 | 4.9 | 8.0 |  |  |
| June 1 |  |  |  |  |  |  |  |  | 10.0 |  |  |  |  |  |  |  |  |  |  |  |
| 2 |  |  |  |  |  |  |  |  | 10.3 | 6.4 |  |  |  |  |  |  |  |  |  |  |
| 3 | 9.2 |  |  |  |  | 11.4 | 10.8 | 10.3 | 9.4 |  | 6.6 |  |  |  |  | 3.4 | 4.3 |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| July 14 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 15 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 9.4 | 8.7 | 9.2 | 16.0 |  | 7.0 |
| 16 |  | 18.1 | 17.5 | 17.1 | 16.4 |  |  |  |  |  |  |  |  | 9.4 |  |  |  |  |  |  |
| 18 |  |  |  |  | 14.1 | 15.0 | 14.8 | 15.9 | 15.2 | 12.3 | 10.2 |  |  |  |  |  |  |  |  |  |
| 19 |  |  | 17.2 | 17.0 | 17.1 | 14.8 |  |  |  |  | 9.2 |  |  | 9.3 |  | 10.2 | 10.7 |  |  |  |
| 20 |  |  |  |  |  | 14.6 | 13.5 | 13.9 | 13.2 |  | 9.8 |  |  |  |  |  |  |  |  |  |

Table 9. Metal levels recorded from muscle, whole fish and liver composites taken from Arctic grayling and slimy sculpins captured in Flat Creek, Christal Creek, Christal Lake and the South McQuesten River during field investigations in September of 1994. See table 10 for complete physical descriptions of each sample recorded in this table.

| Location | Samp | Descrip | Zn | Cu | Pb | As | Cd | Cr | Co | Hg | Ni |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Christal Ck | CDS 1 | muscle | 133 | 1.6 | 1.0 | <2. | 0.07 | 1. | 0.4 | <0.1 | 0.4 |
| | CDS 2 | muscle | 126 | 1.8 | 1.0 | <2. | <0.06 | 1. | <0.1 | <0.1 | 2.4 |
| | CDS3 | muscle | 138 | 1.6 | 1.0 | <2. | <0.16 | 1. | 0.3 | <0.1 | 0.6 |
| | CDS 4 | muscle | 231 | 1.0 | 2.0 | <2. | 0.20 | 1.8 | 0.4 | 0.1 | 0.8 |
| | CDS 4 | muscle | 219 | 1.0 | 2.0 | <2. | 0.17 | 1.4 | 0.3 | 0.1 | 0.9 |
| | CDS 5 | muscle | 116 | 1.4 | < 1 | <2. | <0.06 | 0.9 | 0.2 | <0.1 | 0.6 |
| | CC1 | whole fish | 289 | 2.9 | 4.0 | 4.0 | 1.28 | 0.9 | <0.1 | <0.1 | 1. |
| | CC2 | whole fish | 163 | 3.8 | 2.0 | 2.0 | 0.52 | 0.7 | 0.2 | <0.1 | 0.4 |
| | CC3 | whole fish | 853 | 6.1 | 68 | 18.0 | 4.71 | 3.1 | 0.8 | <0.1 | 5.0 |
| | CC4 | whole fish | 325 | 2.3 | 9. | 6.0 | 0.94 | 1.3 | 0.6 | <0.1 | 2.5 |
| Christal Lk | CLk1 | whole fish | 324 | 1.8 | <1. | 4. | 0.18 | 0.9 | 0.4 | <0.1 | 1. |
| | CLk2 | whole fish | 314 | 2.2 | <1. | 4. | 0.19 | 0.9 | 0.3 | <0.1 | 1.4 |
| | CLk3 | whole fish | 362 | 2.4 | <1. | 4. | 0.32 | 0.9 | 0.4 | <0.1 | 1.6 |
| replicate | CLk3 | whole fish | 365 | 2.4 | <1. | 3. | 0.29 | 1.0 | 0.5 | <0.1 | 1.5 |
| | CLk4 | whole fish | 340 | 2.7 | 2. | 5. | 0.30 | 0.9 | 0.4 | <0.1 | 1. |
| S.McQuest | SMR1 | muscle | 81.7 | 1.9 | <1. | <2. | 0.07 | 0.8 | <0.1 | 0.2 | 0.4 |
| | SMR2 | muscle | 84.7 | 2.2 | <1. | <2. | 0.10 | 0.9 | 0.2 | 0.1 | 0.6 |
| | SMR3 | muscle | 121 | 2.4 | <1. | <2. | 0.27 | 1.0 | 0.3 | 0.2 | 0.6 |
| | SMR4 | muscle | 122 | 2.7 | 2. | <2. | 0.25 | 1.0 | 0.2 | <0.1 | 0.5 |
| | SMR5 | muscle | 94.3 | 2.5 | <1. | <2. | 0.07 | 0.9 | 0.4 | 0.1 | 4.5 |
| Flat creek | FCk1 | whole fish | 194 | 4.6 | 23 | 3.0 | 1.0 | 1. | 0.1 | <0.1 | 0.6 |
| | FCk2 | whole fish | 264 | 4.9 | 39 | 3.0 | 1.48 | 1. | 0.1 | <0.1 | 1. |
| | FCk3 | whole fish | 260 | 6.9 | 54 | 7.0 | 1.79 | 1.2 | 0.2 | <0.1 | 0.9 |
| | FCk4 | whole fish | 287 | 13.0 | 110 | 13.0 | 2.21 | 1.2 | 0.2 | <0.1 | 0.8 |
| | FCk5 | whole fish | 187 | 4.6 | 25 | 5.0 | 1.0 | 1. | 0.1 | <0.1 | 0.6 |
| | FCk6 | whole fish | 171 | 4.8 | 14. | 3.0 | 0.82 | 0.9 | 0.2 | <0.1 | 0.8 |
| Christal Ck | CDS 1-5 | liver composite | 127. | 17.6 | 1. | <2. | 9.42 | 0.4 | 1.3 | 0.1 | 0.5 |
| | CDS 1-5 | liver replicate | 135. | 18.3 | <1.0 | <2. | 9.79 | 0.4 | 1.3 | <0.1 | 0.5 |
| S.McQuest | SMR 1,2,5 | liver composite | 101 | 14. | 4.0 | <3. | 2.62 | 0.5 | 2.0 | 0.1 | 1.7 |

Table 10. Physical descriptions of contaminant samples and fish taken to comprise those samples for analysis of metal content. Samples collected during September of 1994 from Christal Creek, Flat Creek and the South McQuesten River.

| Sample # | Sample Location | Species | Fork Length | Round Weight | Sex and Maturity | Sample Description |
|---|---|---|---|---|---|---|
| CDS1 | C4 | Grayling | 283mm | 200g | | 25g flesh |
| CDS2 | C4 | Grayling | 316mm | 300g | mat. male | 30g flesh |
| CDS3 | C4 | Grayling | 280mm | 175g | mat. female | 17g flesh |
| CDS4 | C4 | Grayling | 321mm | 325g | mat. female | 24g flesh |
| CDS5 | C4 | Grayling | 265mm | 200g | mat. male | 17g flesh |
| CC1 | C2 | Sculpin | 107mm | 17g | | whole fish |
| CC2 | C3 | Grayling | 95mm | 7g | fry | whole fish |
| CC3 | C5 | Sculpin | 112mm | 10g | | whole fish |
| CC4 | C5 | Sculpin | 106mm | 13g | | whole fish |
| CLk1 | CL | Sculpin | 103mm | 13g | mat. female | whole fish |
| CLk2 | CL | Sculpin | 99mm | 11g | mat. female | whole fish |
| CLk3 | CL | Sculpin | 103mm | 12g | mat. female | whole fish |
| CLk4 | CL | Sculpin | 108mm | 14g | mat. female | whole fish |
| SMR1 | SM1 | Grayling | 195mm | 76g | imm. female | 14g flesh |
| SMR2 | SM1 | Grayling | 198mm | 97g | imm. female | 21g flesh |
| SMR3 | SM1 | Grayling | 156mm | 39g | imm. female | whole fish |
| SMR4 | SM1 | Grayling | 142mm | 27g | imm. female | whole fish |
| SMR5 | SM1 | Grayling | 227mm | 114g | mat. male | 19g flesh |
| FCk1 | F2 | Sculpin | 54mm | | | 4 whole fish |
| | | | 69mm | | | |
| | | | 67mm | | | |
| | | | 68mm | | | |
| FCk2 | F2 | Sculpin | 70mm | | | 4 whole fish |
| | | | 69mm | | | |
| | | | 92mm | | | |
| | | | 65mm | | | |
| FCk3 | F2 | Sculpin | 63mm | | | 4 whole fish |
| | | | 62mm | | | |
| | | | 60mm | | | |
| | | | 67mm | | | |
| FCk4 | F2 | Sculpin | 101mm | 14g | mat. female | whole fish |
| FCk5 | F2 | Sculpin | 55mm | 2g | | 7 whole fish |
| | | | 59mm | 2g | | |
| | | | 57mm | | | |
| | | | 66mm | | | |
| | | | 71mm | | | |
| | | | 52mm | | | |
| | | | 67mm | | | |
| FCk6 | F2 | Grayling | 66mm | 2.5g | | 4 whole fish |
| | | | 69mm | 2g | | |
| | | | 71mm | | | |
| | | | 71mm | | | |
| CDS1-5 | C4 | Grayling | | | | liver composite |
| SMR1,2,5 | SM1 | Grayling | | | | liver composite |
| | | | | | | |

Table 11. Heavy Metal Levels found in fish from selected Yukon locations. Concentrations of metals expressed as parts per million (ppm).

| Location | Date | Species | Sample Descr. | Cu | As | Zn | Pb | Cd | Cr | Co | Hg | Ni |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aishihik lake | 1990, '91 | lake trout | liver | 10.15 | 0.88 | 4.5 | 0.42 | 0.13 | 10.1 | .07 | 0.11 | 0.06 |
| | | | muscle | 1.05 | 0.93 | 11.7 | nd | nd | 1.05 | nd | 0.09 | nd |
| | | Northern pike | liver | 6.93 | 0.88 | 66.6 | 0.74 | 0.07 | 0.24 | 0.05 | 0.11 | 0.09 |
| | | | muscle | 0.59 | nd | 10.8 | 0.09 | nd | 0.13 | nd | 0.13 | nd |
| | | lake whitefish | liver | 15.16 | 1.10 | 35.4 | 0.59 | 0.19 | 0.19 | 0.07 | 0.08 | 0.06 |
| | | | muscle | 0.61 | 0.67 | 7.3 | nd | 0.01 | 0.08 | nd | 0.04 | nd |
| Mayo lake | 1990,'91 | lake trout | liver | 23.36 | 1.21 | 41.0 | nd | 0.12 | nd | 2.67 | 0.15 | nd |
| | | | muscle | 0.20 | nd | 11.7 | nd | 0.03 | nd | 0.08 | 0.11 | nd |
| | | Northern pike | liver | 10.50 | 0.80 | 42.5 | nd | 0.10 | 0.045 | 0.85 | 0.05 | nd |
| | | | muscle | 0.25 | 0.74 | 6.1 | nd | 0.07 | 0.069 | 0.07 | 0.11 | nd |
| | | lake whitefish | liver | 10.23 | 0.71 | 27.7 | nd | 0.19 | 0.07 | 0.98 | 0.12 | nd |
| | | | muscle | 0.14 | 1.59 | 16.0 | nd | 0.03 | nd | 0.091 | 0.06 | nd |
| | | burbot | liver | 5.75 | nd | 17.3 | nd | 0.05 | nd | 0.50 | 0.03 | nd |
| | | | muscle | 0.205 | 0.75 | 4.3 | 0.75 | .0007 | 0.10 | 0.14 | 0.11 | nd |

| Minnow trapping catch per unit effort for fall and spring, UKHM 1994-95 | | | | | | | |
|---|---|---|---|---|---|---|---|
| SS= slimy sculpin, AG= Arctic grayling, BB= burbot | | | | | CPUE | #fish/24 hrs | |
| TRAP # | SITE | TIME SET | TIME LIFTED | HRS | SS | AG | BB |
| 28 | F2 | 9/06/94/1800hr | 9/08/94/1100hr | 41 | 0 | 0 | 0 |
| 35 | F2 | 9/08/94/1800hr | 9/14/94/1830hr | 140 | 0 | 0.17 | 0 |
| 89 | MQ | 6/03/95/2130hr | 6/04/95/1630hr | 19 | 0 | 0 | 0 |
| 90 | MQ | 6/03/95/2130hr | 6/04/95/1630hr | 19 | 0 | 0 | 0 |
| 58 | SM1 | 5/19/95/1530hr | 5/22/95/1330hr | 70 | 0 | 0 | 0 |
| 59 | SM1 | 5/19/95/1530hr | 5/22/94/1330hr | 70 | 0.34 | 0 | 0 |
| 12 | SM1 | 9/05/94/1515hr | 9/07/94/1400hr | 23.5 | 0 | 0 | 0 |
| 13 | SM1 | 9/05/94/1515hr | 9/07/94/1400hr | 23.5 | 0 | 0 | 0 |
| 76 | SM10 | 5/20/95/1600hr | 5/23/95/1100hr | 67 | 0 | 0 | 0 |
| 81 | SM10 | 6/02/95/1530hr | 6/03/95/1400hr | 22.5 | 0 | 0 | 0 |
| 87 | SM12 | 6/02/95/1730hr | 6/03/95/1500hr | 21.5 | 0 | 0 | 0 |
| 88 | SM12 | 6/02/95/1730hr | 6/03/95/1500hr | 21.5 | 0 | 0 | 0 |
| 67 | SM4 | 5/19/95/2100hr | 5/21/95/1130hr | 38.5 | 0 | 0 | 0 |
| 68 | SM4 | 5/19/95/2100hr | 5/21/95/1130hr | 38.5 | 0 | 0 | 0 |
| 77 | SM4 | 5/21/95/1130hr | 5/23/95/2030hr | 33 | 0 | 0 | 0 |
| 78 | SM4 | 5/21/95/1130hr | 5/23/95/2030hr | 33 | 0 | 0 | 0 |
| 19 | SM4 | 9/06/94/1250hr | 9/07/94/1800hr | 31 | 0 | 0 | 0 |
| 20 | SM4 | 9/06/94/1330hr | 9/07/94/1800hr | 28 | 0 | 0 | 0 |
| 33 | SM4 | 9/07/94/1800hr | 9/11/94/1700hr | 93 | 0 | 0 | 0 |
| 34 | SM4 | 9/07/94/1800hr | 9/11/94/1700hr | 93 | 0 | 0 | 0 |
| 69 | SM5 | 5/20/95/0830hr | 5/23/95/1300hr | 76.5 | 0 | 0 | 0 |
| 70 | SM5 | 5/20/95/0830hr | 5/23/95/1300hr | 76.5 | 0 | 0 | 0 |
| 10 | SM5 | 9/05/94/1130hr | 9/06/94/1700hr | 31.5 | 0 | 0 | 0 |
| 11 | SM5 | 9/05/94/1130hr | 9/06/94/1700hr | 31.5 | 0 | 0 | 0 |
| 29 | SM5 | 9/06/94/1700hr | 9/08/94/1100hr | 41 | 0 | 0 | 0 |
| 30 | SM5 | 9/06/94/1700hr | 9/08/94/1100hr | 41 | 0 | 0 | 0 |
| 56 | SM5 | 9/15/94/1700hr | 9/16/94/1700hr | 24 | 0 | 0 | 0 |
| 57 | SM5 | 9/15/94/1700hr | 9/16/94/1700hr | 24 | 1 | 0 | 0 |
| 72 | SM6 | 5/20/95/0830hr | 5/23/95/1400hr | 77.5 | 0 | 0 | 0 |
| 7 | SM6 | 9/05/94/1010hr | 9/06/94/1535hr | 30 | 0 | 0 | 0 |
| 6 | SM6 | 9/05/94/1015hr | 9/06/941545hr | 30 | 0 | 0 | 0 |
| 24 | SM6 | 9/06/94/1545hr | 9/08/94/0845hr | 40 | 0 | 0 | 0 |
| 26 | SM6 | 9/06/94/1545hr | 9/08/94/0845hr | 40 | 0 | 0 | 0 |
| 71 | SM7 | 5/20/95/0830hr | 5/23/95/1400hr | 77.5 | 0 | 0 | 0 |
| 8 | SM7 | 9/05/94/1010hr | 9/06/94/1535hr | 30 | 0 | 0 | 0 |
| 9 | SM7 | 9/05/94/1020hr | 9/06/94/1545hr | 30 | 0 | 0 | 0 |
| 25 | SM7 | 9/06/94/1545hr | 9/08/94/0845hr | 40 | 0 | 0 | 0 |
| 85 | SM8 | 6/02/95/1700hr | 6/03/95/1430hr | 21.5 | 0 | 0 | 0 |
| 86 | SM8 | 6/02/95/1700hr | 6/03/95/1430hr | 21.5 | 0 | 0 | 0 |
| 75 | SM9 | 5/20/95/1600hr | 5/23/95/1100hr | 67 | 0 | 0 | 0.36 |
| 82 | SM9 | 6/02/95/1530hr | 6/03/95/1400hr | 22.5 | 0 | 0 | 0 |
| 83 | SM9 | 6/02/95/1530hr | 6/03/95/1400hr | 22.5 | 0 | 0 | 0 |
| 84 | SM9 | 6/02/95/1530hr | 6/03/95/1400hr | 22.5 | 0 | 0 | 0 |

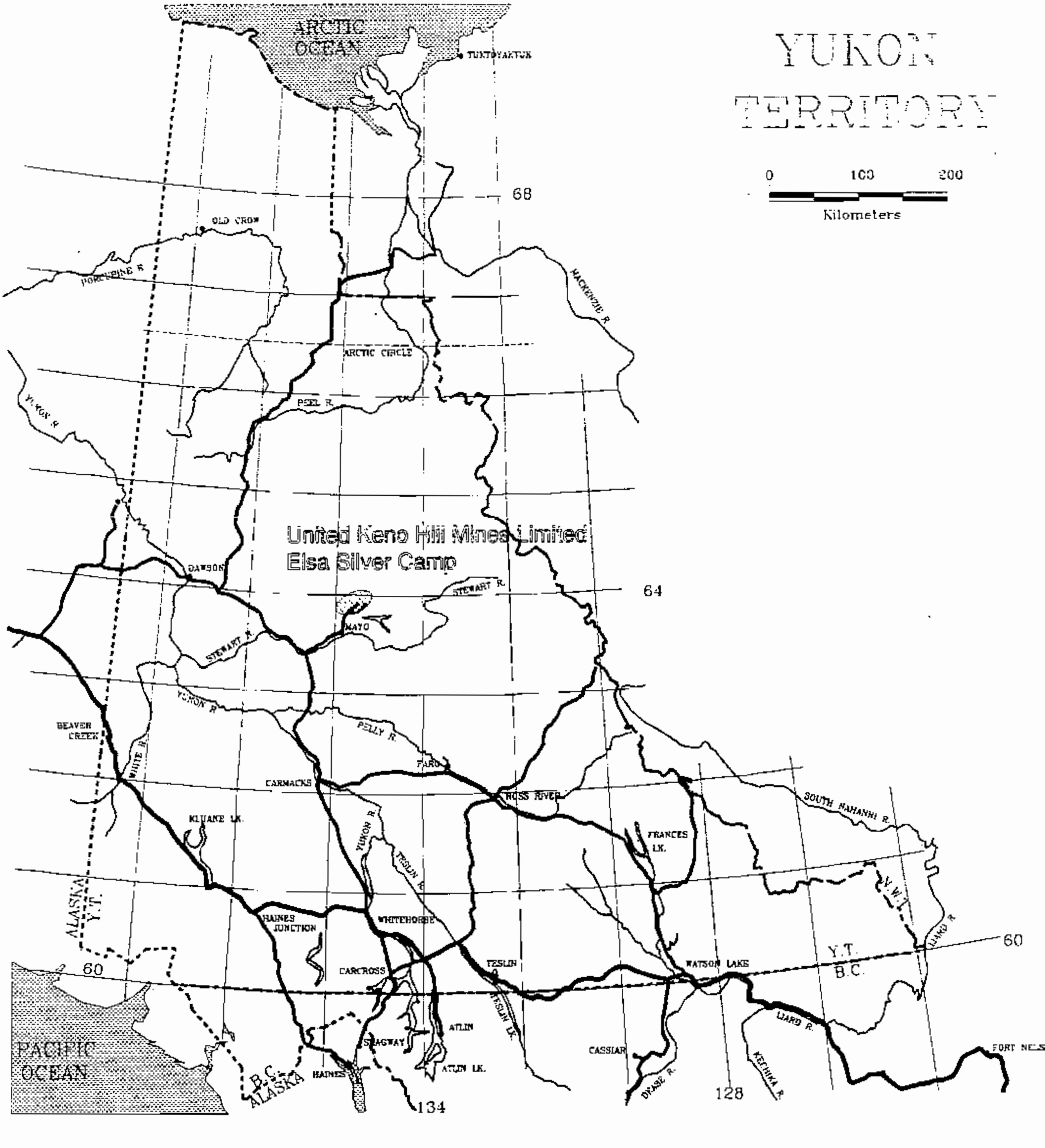
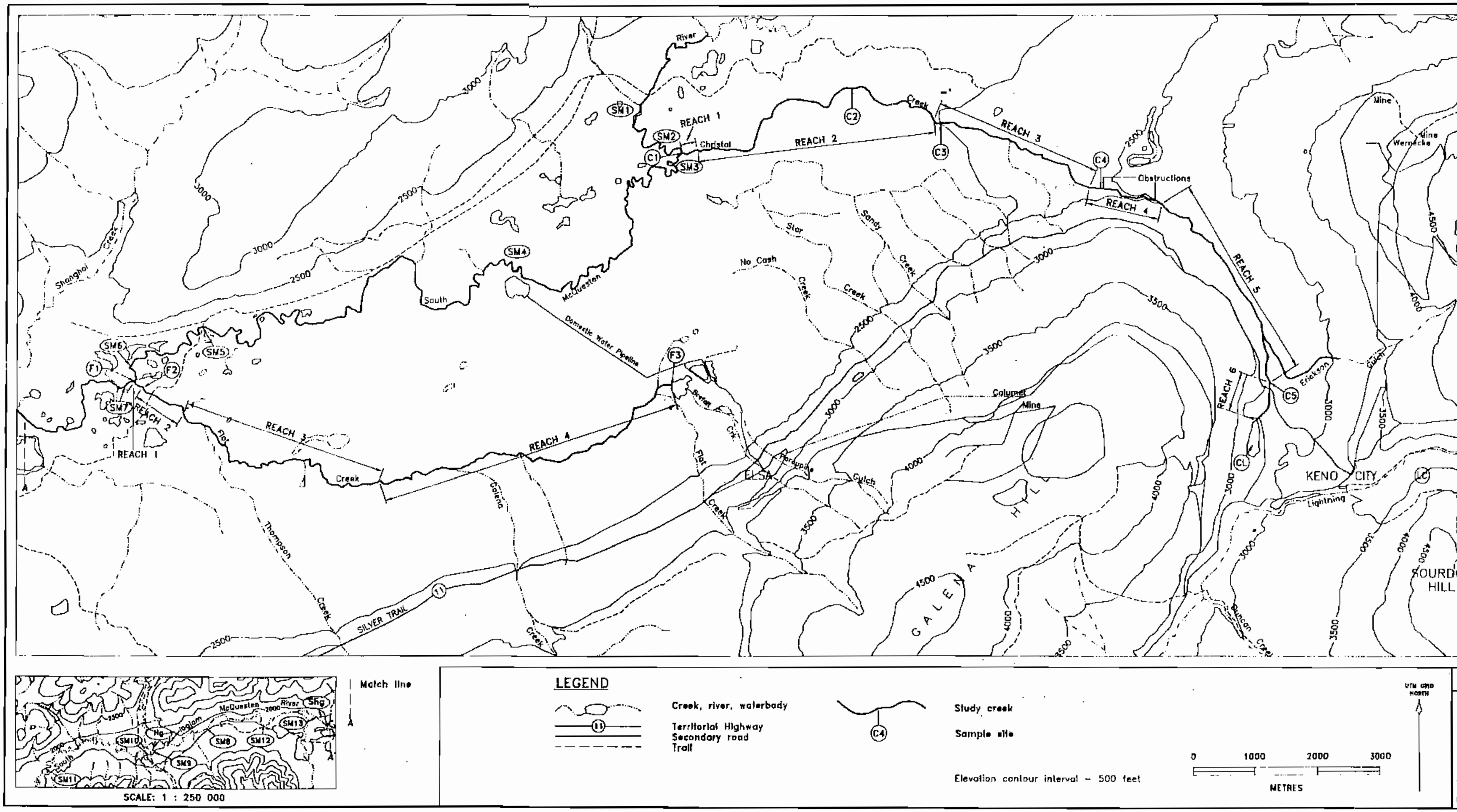


Figure 1 General location map, Elsa Silver Camp, Yukon.



**UNITED KENO HILL MINES LIMITED**

**1994-95 UKHM FISHERIES INVESTIGATIONS**
**WHITE MOUNTAIN ENVIRONMENTAL SERVICES**

*ACCESS MINING CONSULTANTS LTD.*

| | | |
|---|---|---|
| SCALE: 1 : 50 000 | FILE: 224_2.DWG | DATE: 30/05/96 |
| DRAWN: | DWG: 95UK25 | FIGURE: 2 |

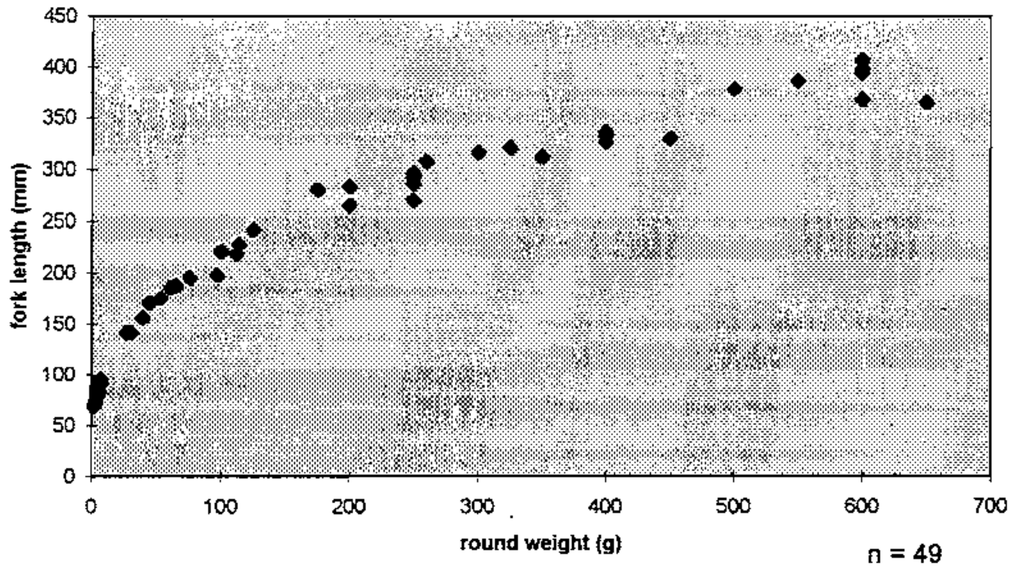


**Figure 3** Length and weight correlation for Arctic grayling caught during 1994,'95, UKHM.

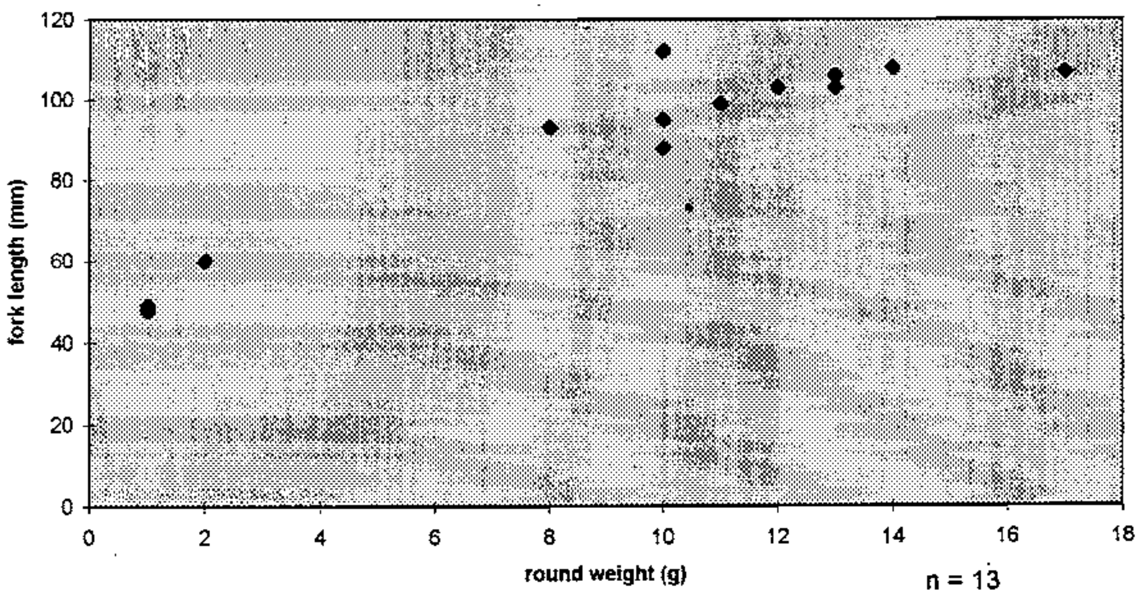


**Figure 4** Length and weight correlation for slimy sculpin caught during 1994,'95, UKHM.

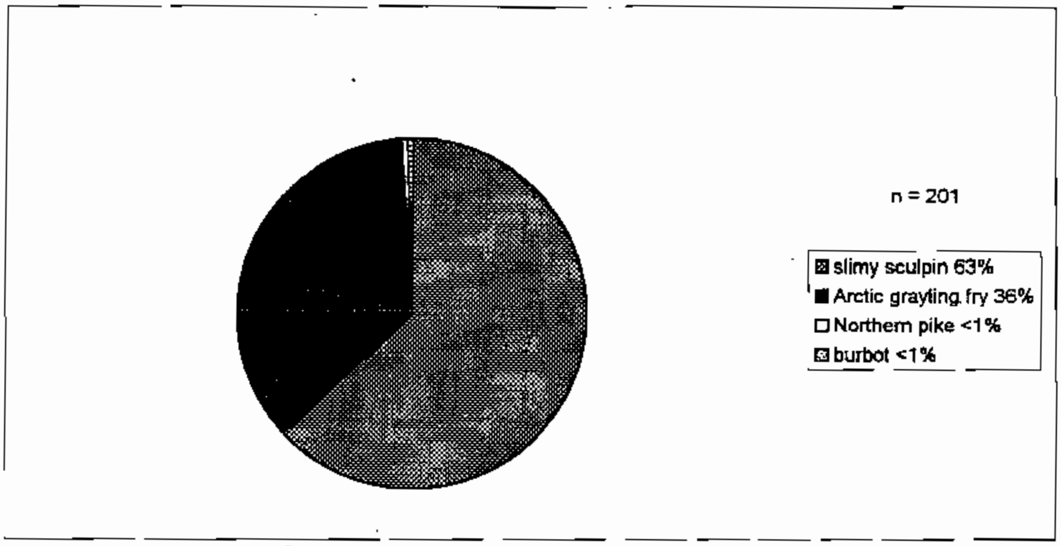


Figure 5 Species composition site F1

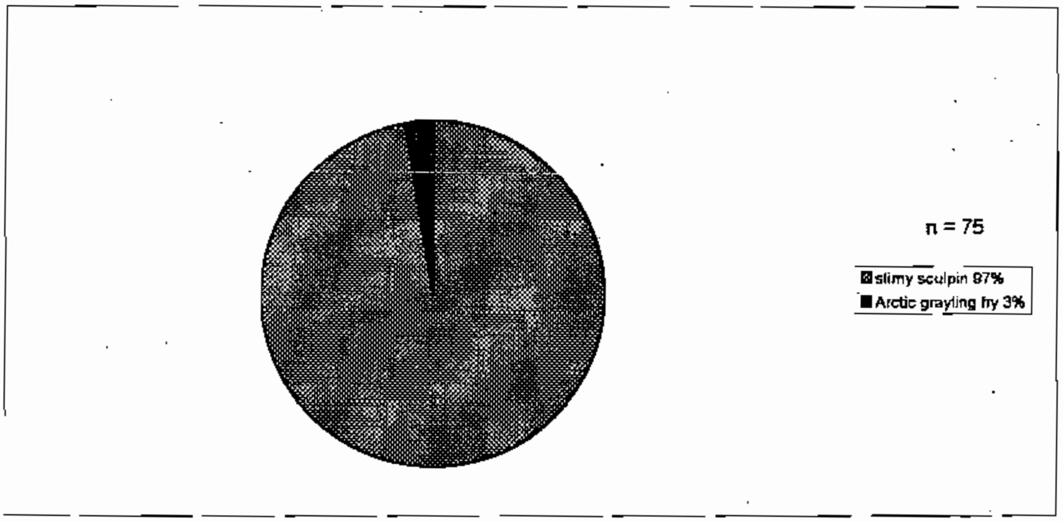


Figure 6 Species composition sites F2, F3 combined

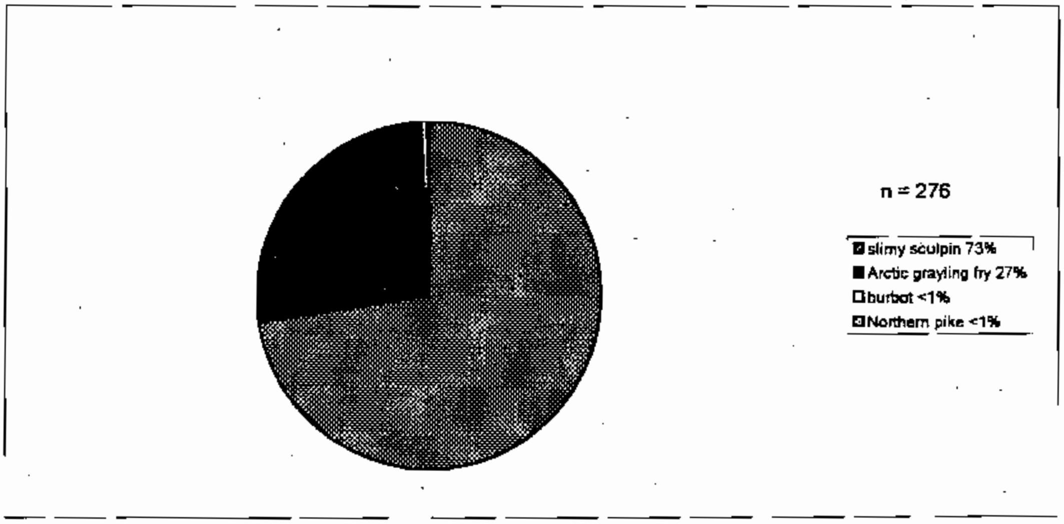


Figure 7 Species composition Flat Creek combined

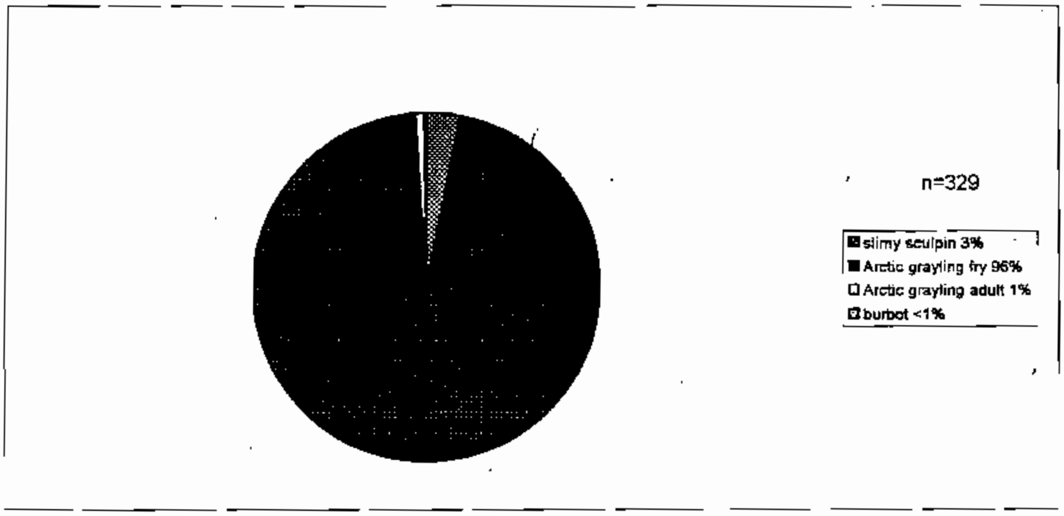


Figure 8 Species composition site C1

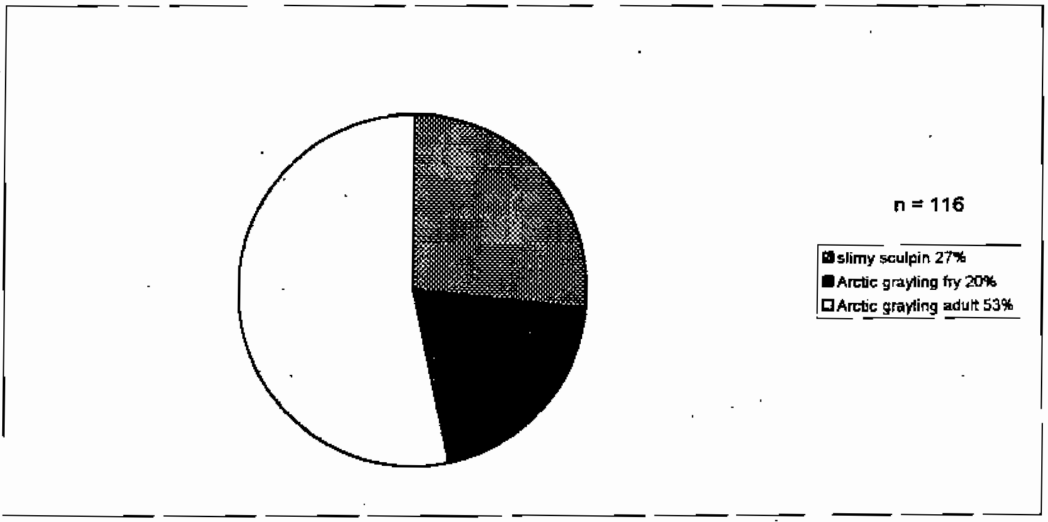


Figure 9 Species composition sites C2, C3, C4, C5 combined

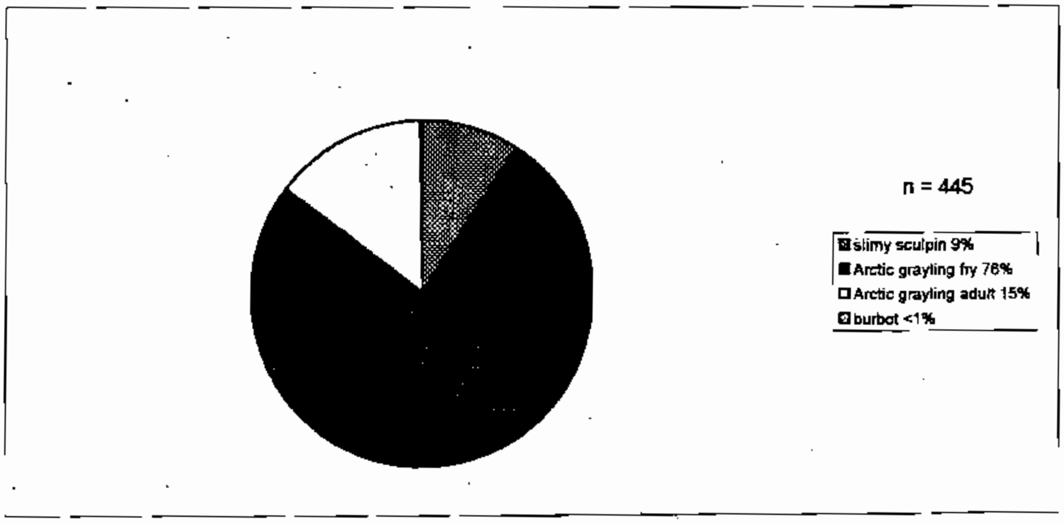


Figure 10 Species composition for Christal Creek combined

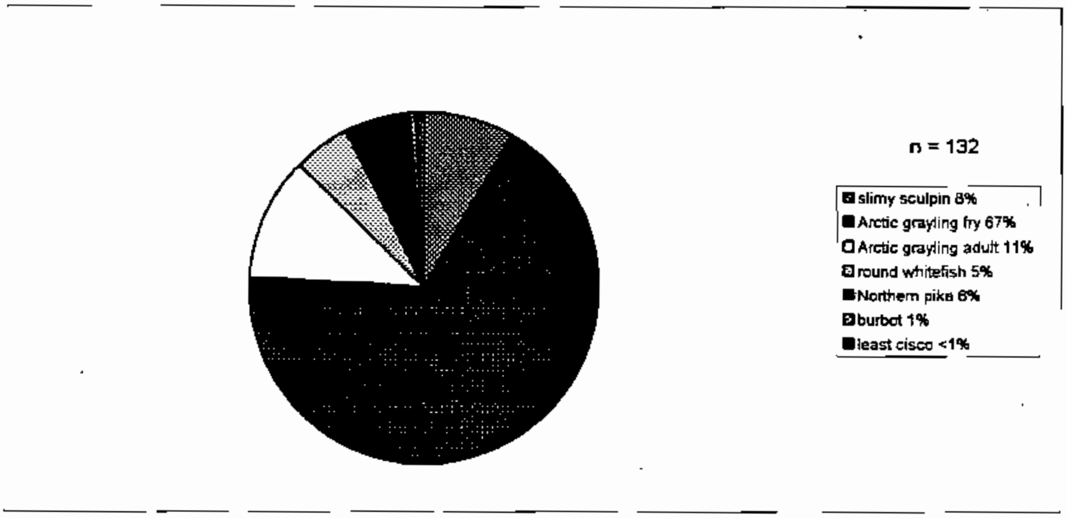


Figure 11 Species composition site SML

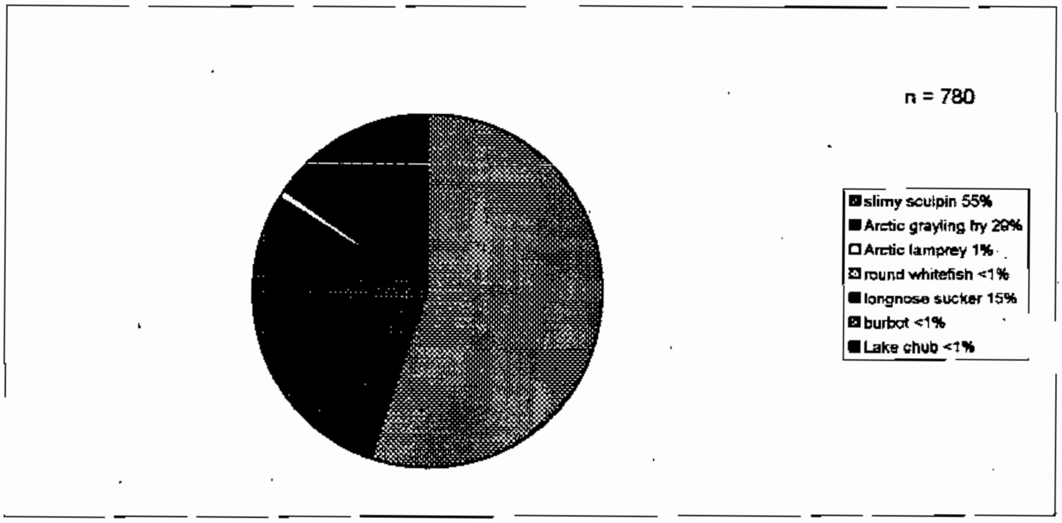


Figure 12 Species composition sites SM1, SM2

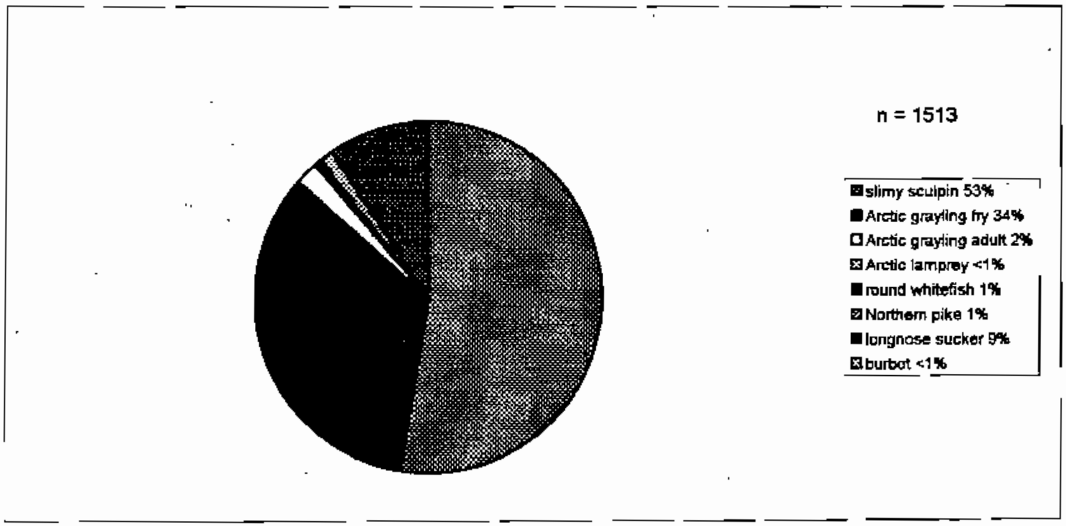


Figure 13 Species composition sites SM3, SM4, SM5, SM6, SM7.

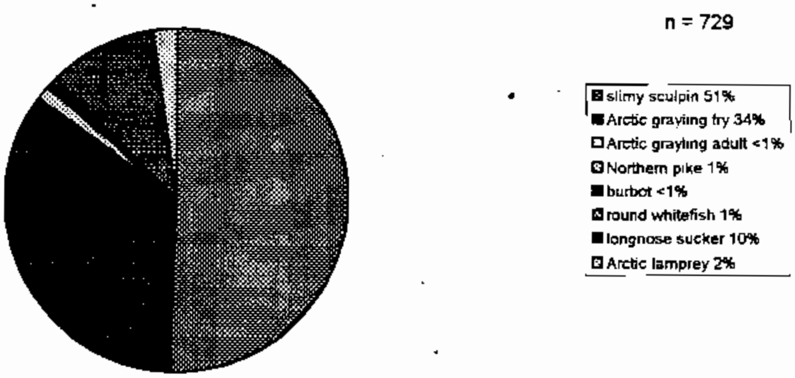


Figure 14: Species composition sites SM8, SM12, SM13

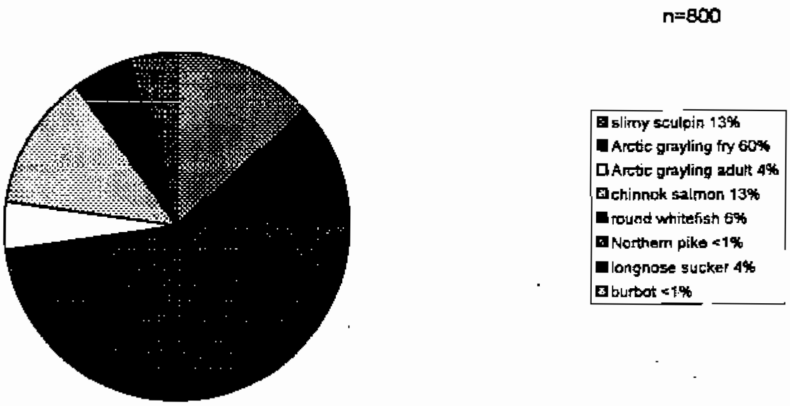


Figure 15: Species composition sites SM9, SM10, SM11

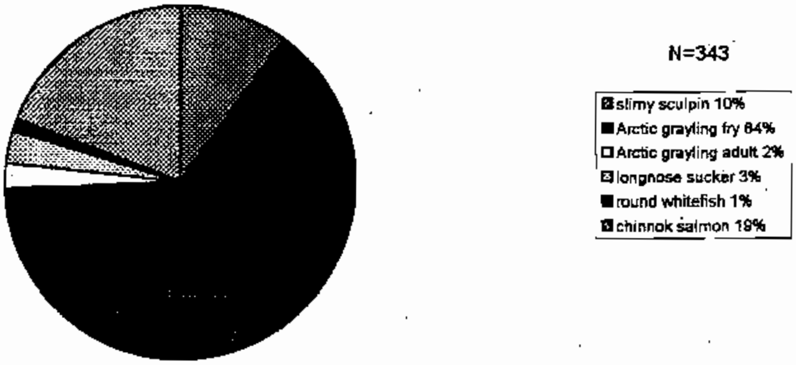


Figure 16: Species composition site Hg

Appendix A: Scientific names for fish species discussed in the habitat utilization and assessment studies conducted for UKHM.

| COMMON NAME | SCIENTIFIC NAME |
|---|---|
| Chinook salmon | *Oncorhynchus tshawytscha* (Walbaum) |
| Slimy sculpin | *Cottus cognatus* (Richardson) |
| Arctic grayling | *Thymallus arcticus* (Pallas) |
| Burbot | *Lota lota* (Linnaeus) |
| Round whitefish | *Prosopium cylindraceum* (Pallus) |
| Arctic lamprey | *Lampetra japonica* (Martens) |
| Longnose sucker | *Catastomus catastomus* (Forster) |
| Northern pike | *Esox lucius* (Linnaeus) |
| Innconnu | *Stenodus leucichthys* (Guldenstadt) |
| Lake chub | *Couesius plumbeus* (Agassiz) |
| Least cisco | *Coregonus sardinella* (Valenciennes) |
| Chum salmon | *Oncorhynchus keta* (Walbaum) |
| Lake trout | *Salvelinus namayscush* (Walbaum) |
| Rainbow trout | *Oncoryhynchus mikiss* (formerly *Salmo gairdneri*) |
| Lake whitefish | *Coregonius clupeaformis* (Mitchill) |

**Appendix B** **Summary of fish recorded by method UKHM study 1994-95**

AG(f)= Arctic grayling fry, AG= Arctic grayling, SS= slimy sculpin, BB= burbot, NP= Northern pike
RWF= round whitefish, LNS= longnose sucker, CH= chinnok salmon, AL= Arctic lamprey
lco=least cisco, lch= lake chub.

| | | | | | # FISH CAUGHT | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SITE | METHOD | AG(f) | AG | SS | BB | NP | RWF | LNS | CH | AL | OTHER |
| C1 | seine | 147 | | | | | | | | | |
| | els | 68 | | 10 | 1 | | | | | | |
| | mnt | | | | | | | | | | |
| | visual | 100 | 1 | | | | | | | | |
| | angle | | 2 | | | | | | | | |
| | gillnet | | | | | | | | | | |
| total | | 315 | 3 | 10 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| C2 | seine | | | | | | | | | | |
| | els | | | 1 | | | | | | | |
| | mnt | | | | | | | | | | |
| | visual | 22 | 32 | | | | | | | | |
| | angle | | 3 | | | | | | | | |
| | gillnet | | | | | | | | | | |
| total | | 22 | 35 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | | | | | | |
| C3 | seine | | | | | | | | | | |
| | els | 1 | | | | | | | | | |
| | mnt | | | | | | | | | | |
| | visual | | | | | | | | | | |
| | angle | | | | | | | | | | |
| | gillnet | | | | | | | | | | |
| totals | | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C4 | seine | | | | | | | | | | |
| | els | | 9 | | | | | | | | |
| | mnt | | | | | | | | | | |
| | visual | | 17 | | | | | | | | |
| | angle | | 1 | | | | | | | | |
| | gillnet | | | | | | | | | | |
| total | | 0 | 27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Appendix B** **Summary of fish recorded by method UKHM study 1994-95**

AG(f)= Arctic grayling fry, AG= Arctic grayling, SS= slimy sculpin, BB= burbot, NP= Northern pike
RWF= round whitefish, LNS= longnose sucker, CH= chinnok salmon, AL= Arctic lamprey
lco=least cisco, lch= lake chub.

| | | | | | # FISH CAUGHT | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SITE | METHOD | AG(f) | AG | SS | BB | NP | RWF | LNS | CH | AL | OTHER |
| | | | | | | | | | | | |
| C5 | seine | | | 2 | | | | | | | |
| | els | | | 23 | | | | | | | |
| | mnt | | | 5 | | | | | | | |
| | visual | | | | | | | | | | |
| | angle | | | | | | | | | | |
| | gillnet | | | | | | | | | | |
| total | | 0 | 0 | 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CL | seine | | | | | | | | | | |
| | els | | | | | | | | | | |
| | mnt | | | 5 | | | | | | | |
| | visual | | | 1 | | | | | | | |
| | angle | | | | | | | | | | |
| | gillnet | | | 4 | | | | | | | |
| total | | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | | | | | | |
| F1 | seine | 27 | | 44 | | 1 | | | | | |
| | els | 14 | | 80 | 1 | | | | | | |
| | mnt | 1 | | 3 | | | | | | | |
| | visual | 30 | | | | | | | | | |
| | angle | | | | | | | | | | |
| | gillnet | | | | | | | | | | |
| total | | 72 | 0 | 127 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| F2 | seine | | | | | | | | | | |
| | els | 2 | | 73 | | | | | | | |
| | mnt | | | | | | | | | | |
| | visual | | | | | | | | | | |
| | angle | | | | | | | | | | |
| | gillnet | | | | | | | | | | |
| total | | 2 | 0 | 73 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | | | | | | |

**Appendix B** **Summary of fish recorded by method UKHM study 1994-95**

AG(f)= Arctic grayling fry, AG= Arctic grayling, SS= slimy sculpin, BB= burbot, NP= Northern pike
RWF= round whitefish, LNS= longnose sucker, CH= chinnok salmon, AL= Arctic lamprey
lco=least cisco, lch= lake chub.

| | | | | | # FISH CAUGHT | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SITE | METHOD | AG(f) | AG | SS | BB | NP | RWF | LNS | CH | AL | OTHER |
| | | | | | | | | | | | |
| Hg | seine | 221 | 8 | 34 | | | 4 | 10 | 15 | | |
| | els | | | | | | | | | | |
| | mnt | | | | | | | | 51 | | |
| | visual | | | | | | | | | | |
| | angle | | | | | | | | | | |
| | gillnet | | | | | | | | | | |
| total | | 221 | 8 | 34 | 0 | 0 | 4 | 10 | 66 | 0 | 0 |
| LC | seine | | 21 | | | | | | | | |
| | els | | | | | | | | | | |
| | mnt | | | | | | | | | | |
| | visual | | | | | | | | | | |
| | angle | | 6 | | | | | | | | |
| | gillnet | | | | | | | | | | |
| total | | 0 | 27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MQ | seine | | 1 | 9 | | | | | 17 | | |
| | els | | | | | | | | | | |
| | mnt | | | | | | | | | | |
| | visual | | | | | | | | | | |
| | angle | | | | | | | | | | |
| | gillnet | | | | | | | | | | |
| total | | 0 | 1 | 9 | 0 | 0 | 0 | 0 | 17 | 0 | 0 |
| SML | seine | 89 | 10 | 11 | | 2 | 7 | | | | 1lco |
| | els | | | | | | | | | | |
| | mnt | | | | | 3 | | | | | |
| | visual | | | | | | | | | | |
| | angle | | 5 | | | 3 | | | | | |
| | gillnet | | | | | | | | | | |
| total | | 89 | 15 | 11 | 0 | 8 | 7 | 0 | 0 | 0 | 1 |

**Appendix B** **Summary of fish recorded by method UKHM study 1994-95**

AG(f)= Arctic grayling fry, AG= Arctic grayling, SS= slimy sculpin, BB= burbot, NP= Northern pike

RWF= round whitefish, LNS= longnose sucker, CH= chinnok salmon, AL= Arctic lamprey

lco=least cisco, lch= lake chub.

| | | | | | # FISH CAUGHT | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SITE | METHOD | AG(f) | AG | SS | BB | NP | RWF | LNS | CH | AL | OTHER |
| | | | | | | | | | | | |
| SM1 | seine | 143 | | 55 | | | 1 | 50 | | 5 | 1lch |
| | els | 10 | | 109 | 1 | | | | | 1 | |
| | mnt | | | 1 | | | | | | | |
| | visual | | | | | | | | | | |
| | angle | | | | | | | | | | |
| | gillnet | | | | | | | | | | |
| total | | 153 | 0 | 165 | 1 | 0 | 1 | 50 | 0 | 6 | 1 |
| SM2 | seine | 63 | | 139 | | | | 30 | | | |
| | els | 8 | | 127 | | | | 21 | | | |
| | mnt | | | | | | | | | | |
| | visual | | | | | | | 15 | | | |
| | angle | | | | | | | | | | |
| | gillnet | | | | | | | | | | |
| total | | 71 | 0 | 266 | 0 | 0 | 0 | 66 | 0 | 0 | 0 |
| SM3 | seine | 211 | 4 | 170 | | | 2 | 23 | | 2 | |
| | els | 91 | | 83 | 1 | 2 | | 11 | | 1 | |
| | mnt | | | | | | | | | | |
| | visual | 100 | 5 | | | | | 100 | | | |
| | angle | | | | | | | | | | |
| | gillnet | | | | | | | | | | |
| total | | 402 | 9 | 253 | 1 | 2 | 2 | 134 | 0 | 3 | 0 |
| SM4 | seine | 34 | | 148 | | 2 | 1 | 1 | | | |
| | els | 2 | | 59 | 1 | 6 | | 1 | | 2 | |
| | mnt | | | | | | | | | | |
| | visual | | 12 | | | | | | | | |
| | angle | | 7 | | | 1 | | | | | |
| | gillnet | | | | | | | | | | |
| total | | 36 | 19 | 207 | 1 | 9 | 1 | 2 | 0 | 2 | 0 |

**Appendix B** **Summary of fish recorded by method UKHM study 1994-95**

AG(f)= Arctic grayling fry, AG= Arctic grayling, SS= slimy sculpin, BB= burbot, NP= Northern pike

RWF= round whitefish, LNS= longnose sucker, CH= chinnok salmon, AL= Arctic lamprey

lco=least cisco, lch= lake chub.

| | | | | | # FISH CAUGHT | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SITE | METHOD | AG(f) | AG | SS | BB | NP | RWF | LNS | CH | AL | OTHER |
| | | | | | | | | | | | |
| SM5 | seine | | | | | | | | | | |
| | els | | | | | | | | | | |
| | mnt | | | 1 | | | | | | | |
| | visual | | | | | | | | | | |
| | angle | | 4 | | | | | | | | |
| | gillnet | | | | | | | | | | |
| total | | 0 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SM6 | seine | 11 | | 70 | | 2 | | 1 | | | |
| | els | 1 | | 93 | 1 | 3 | | | | | |
| | mnt | | | | | | | | | | |
| | visual | | | | | | | | | | |
| | angle | | 2 | | | | | | | | |
| | gillnet | | | | | | | | | | |
| total | | 12 | 2 | 163 | 1 | 5 | 0 | 1 | 0 | 0 | 0 |
| SM7 | seine | 148 | | 74 | | | 1 | | | | |
| | els | 3 | | 97 | 1 | 3 | | | | | |
| | mnt | | | | | 1 | | | | | |
| | visual | | | | | 3 | | | | | |
| | angle | | | | | | | | | | |
| | gillnet | | | | | | | | | | |
| total | | 151 | 0 | 171 | 1 | 7 | 1 | 0 | 0 | 0 | 0 |
| SM8 | seine | 7 | | 38 | | 1 | | 34 | | | |
| | els | | | 136 | 1 | | | | | | |
| | mnt | | | | | 1 | | | | | |
| | visual | | | | | 6 | | | | | |
| | angle | | 3 | | | | | | | | |
| | gillnet | | | | | | | | | | |
| total | | 7 | 3 | 174 | 1 | 8 | 0 | 34 | 0 | 0 | 0 |

**Appendix B** **Summary of fish recorded by method UKHM study 1994-95**

AG(f)= Arctic grayling fry, AG= Arctic grayling, SS= slimy sculpin, BB= burbot, NP= Northern pike
RWF= round whitefish, LNS= longnose sucker, CH= chinnok salmon, AL= Arctic lamprey
lco=least cisco, lch= lake chub.

| | | | | | # FISH CAUGHT | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SITE | METHOD | AG(f) | AG | SS | BB | NP | RWF | LNS | CH | AL | OTHER |
| | | | | | | | | | | | |
| SM9 | seine | 5 | 9 | 17 | | | | 2 | | | |
| | els | | | 8 | | | | | | | |
| | mnt | | | | 1 | | | | 1 | | |
| | visual | | 3 | | | 1 | | | | | |
| | angle | | | | | 1 | | | | | |
| | gillnet | | | | | | | | | | |
| total | | 5 | 12 | 25 | 1 | 2 | 0 | 2 | 1 | 0 | 0 |
| SM10 | seine | 419 | 15 | 95 | | | 39 | 21 | 26 | | |
| | els | 3 | | 15 | | 1 | | 7 | | | |
| | mnt | | | | | | | | 49 | | |
| | visual | | 5 | | | 1 | | | | | |
| | angle | | 2 | | | | | | | | |
| | gillnet | | | | | | | | | | |
| total | | 422 | 22 | 110 | 0 | 2 | 39 | 28 | 75 | 0 | 0 |
| SM11 | seine | 49 | | 72 | | | 5 | | 28 | | |
| | els | | | | | | | | | | |
| | mnt | | | | | | | | | | |
| | visual | | | | | | | | | | |
| | angle | | | | | | | | | | |
| | gillnet | | | | | | | | | | |
| total | | 49 | 0 | 72 | 0 | 0 | 5 | 0 | 28 | 0 | 0 |
| SM12 | seine | 91 | | 66 | 1 | 1 | 3 | | | | |
| | els | | | 58 | 1 | 1 | | | | 17 | |
| | mnt | | | | | | | | | | |
| | visual | | | | | | | | | | |
| | angle | | | | | | | | | | |
| | gillnet | | | | | | | | | | |
| total | | 91 | 0 | 124 | 2 | 2 | 3 | 0 | 0 | 17 | 0 |

**Appendix B** **Summary of fish recorded by method UKHM study 1994-95**

AG(f)= Arctic grayling fry, AG= Arctic grayling, SS= slimy sculpin, BB= burbot, NP= Northern pike

RWF= round whitefish, LNS= longnose sucker, CH= chinnok salmon, AL= Arctic lamprey

lco=least cisco, lch= lake chub.

| | | | | | # FISH CAUGHT | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SITE | METHOD | AG(f) | AG | SS | BB | NP | RWF | LNS | CH | AL | OTHER |
| | | | | | | | | | | | |
| SM13 | seine | 150 | | 71 | | | 2 | 40 | | | |
| | els | | | | | | | | | | |
| | mnt | | | | | | | | | | |
| | visual | | | | | | | | | | |
| | angle | | | | | | | | | | |
| | gillnet | | | | | | | | | | |
| total | | 150 | 0 | 71 | 0 | 0 | 2 | 40 | 0 | 0 | 0 |
| Shg | seine | 3 | | 4 | | | | | | | |
| | els | | | | | | | | | | |
| | mnt | | | | | | | | | | |
| | visual | 40 | | | | | | | | | |
| | angle | | | | | | | | | | |
| | gillnet | | | | | | | | | | |
| total | | 43 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## APPENDIX C

### Minnow trapping catch per unit effort for fall and spring, UKHM 1994-95

| SS= slimy sculpin, AG= Arctic grayling, BB= burbot | | | | | CPUE | #fish/24 hrs | |
|---|---|---|---|---|---|---|---|
| TRAP # | SITE | TIME SET | TIME LIFTED | HRS | SS | AG | BB |
| 31 | C1 | 9/07/94/1400hr | 9/10/94/1500hr | 72 | 0 | 0 | 0 |
| 32 | C1 | 9/07/94/1400hr | 9/10/94/1500hr | 72 | 0 | 0 | 0 |
| 60 | C3 | 5/19/95/1700hr | 5/22/95/1600hr | 71 | 0 | 0 | 0 |
| 61 | C3 | 5/19/95/1700hr | 5/22/95/1600hr | 71 | 0 | 0 | 0 |
| 62 | C3 | 5/19/95/1700hr | 5/22/95/1600hr | 71 | 0 | 0 | 0 |
| 63 | C3 | 5/19/95/1700hr | 5/22/95/1600hr | 71 | 0 | 0 | 0 |
| 14 | C3 | 9/05/94/1700hr | 9/06/94/1120hr | 18.5 | 0 | 0 | 0 |
| 15 | C3 | 9/05/94/1711hr | 9/06/94/1120hr | 18.5 | 0 | 0 | 0 |
| 16 | C3 | 9/05/94/1715hr | 9/06/94/1600hr | 23 | 0 | 0 | 0 |
| 17 | C3 | 9/05/94/1720hr | 9/06/94/1600hr | 23 | 0 | 0 | 0 |
| 18 | C3 | 9/05/94/1720hr | 9/06/94/1600hr | 23 | 0 | 0 | 0 |
| 36 | C3 | 9/09/94/1600hr | 9/11/94/1530hr | 47.5 | 0 | 0 | 0 |
| 37 | C3 | 9/09/94/1600hr | 9/11/94/1530hr | 47.5 | 0 | 0 | 0 |
| 38 | C3 | 9/09/94/1600hr | 9/11/94/1530hr | 47.5 | 0 | 0 | 0 |
| 64 | C4 | 5/19/95/1700hr | 5/22/95/1600hr | 71 | 0 | 0 | 0 |
| 65 | C4 | 5/19/95/1700hr | 5/22/95/1600hr | 71 | 0 | 0 | 0 |
| 47 | C4 | 9/11/94/1600hr | 9/12/94/1500hr | 23 | 0 | 0 | 0 |
| 48 | C4 | 9/11/94/1600hr | 9/12/94/1500hr | 23 | 0 | 0 | 0 |
| 49 | C4 | 9/11/94/1600hr | 9/12/94/1500hr | 23 | 0 | 0 | 0 |
| 66 | C5 | 5/19/95/1800hr | 5/21/95/1700hr | 47 | 1.02 | 0 | 0 |
| 39 | CL | 9/10/94/1700hr | 9/11/94/1500hr | 22 | 0 | 0 | 0 |
| 40 | CL | 9/10/94/1700hr | 9/11/94/1500hr | 22 | 0 | 0 | 0 |
| 41 | CL | 9/10/94/1700hr | 9/11/94/1500hr | 22 | 0 | 0 | 0 |
| 42 | CL | 9/10/94/1700hr | 9/09/94/1500hr | 22 | 0 | 0 | 0 |
| 43 | CL | 9/11/94/1500hr | 9/15/94/1600hr | 97 | 0.49 | 0 | 0 |
| 44 | CL | 9/11/94/1500hr | 9/15/94/1600hr | 97 | 0 | 0 | 0 |
| 45 | CL | 9/11/94/1500hr | 9/15/94/1600hr | 97 | 0.25 | 0 | 0 |
| 46 | CL | 9/11/94/1500hr | 9/15/94/1600hr | 97 | 0.25 | 0 | 0 |
| 50 | CL | 9/12/94/1500hr | 9/13/94/1000hr | 19 | 0 | 0 | 0 |
| 51 | CL | 9/12/94/1500hr | 9/13/94/1000hr | 19 | 0 | 0 | 0 |
| 52 | CL | 9/12/94/1500hr | 9/13/94/1000hr | 19 | 0 | 0 | 0 |
| 53 | CL | 9/13/94/1000hr | 9/15/94/1400hr | 52 | 0 | 0 | 0 |
| 54 | CL | 9/13/94/1000hr | 9/15/94/1400hr | 52 | 0 | 0 | 0 |
| 55 | CL | 9/13/94/1000hr | 9/15/94/1400hr | 52 | 0 | 0 | 0 |
| 73 | F1 | 5/20/95/0830hr | 5/23/95/1400hr | 77.5 | 0 | 0 | 0 |
| 74 | F1 | 5/20/95/0830hr | 5/23/95/1400hr | 77.5 | 0 | 0 | 0 |
| 4 | F1 | 9/05/94/0955hr | 9/06/94/1535hr | 29 | 0 | 0 | 0 |
| 5 | F1 | 9/05/94/0955hrs | 9/06/94/1535hr | 29 | 0 | 0 | 0 |
| 22 | F1 | 9/06/94/1530hr | 9/08/94/0830hr | 40 | 0 | 0 | 0 |
| 23 | F1 | 9/06/94/1530hr | 9/08/94/0830hr | 40 | 0 | 0 | 0 |
| 79 | F2 | 5/20/95/0900hr | 5/23/95/1300hr | 76 | 0 | 0 | 0 |
| 80 | F2 | 5/20/95/0900hr | 5/23/95/1300hr | 76 | 0 | 0 | 0 |
| 1 | F2 | 9/05/94/0920hr | 9/06/94/1500hr | 29 | 0 | 0 | 0 |
| 2 | F2 | 9/05/94/0920hr | 9/06/94/1800hr | 32 | 0 | 0 | 0 |
| 3 | F2 | 9/05/94/0920hr | 9/06/94/1800hr | 32 | 0 | 0 | 0 |
| 21 | F2 | 9/06/94/1530hr | 9/08/94/0830hr | 40 | 0 | 0 | 0 |
| 27 | F2 | 9/06/94/1800hr | 9/08/94/1100hr | 41 | 1.17 | 0.59 | 0 |

## APPENDIX D

**Catch per unit effort for minnow trapping summer 1995, UKHM**

| | | | CPUE (#fish /24hrs) | | |
|---|---|---|---|---|---|
| SITE | TIME SET | HRS | SS | NP | CH |
| C1 | 0930/7/15/95 | 24 | 0 | 0 | 0 |
| C1 | 0930/7/15/95 | 24 | 0 | 0 | 0 |
| C1 | 0930/7/15/95 | 24 | 0 | 0 | 0 |
| C1 | 1000/7/15/95 | 23.5 | 0 | 0 | 0 |
| C1 | 1130/7/16/95 | 21.5 | 0 | 0 | 0 |
| C1/SM3 | 1130/7/16/95 | 21.5 | 0 | 0 | 0 |
| C2 | 1200/7/15/95 | 22.5 | 0 | 0 | 0 |
| C2 | 1200/7/15/95 | 22.5 | 0 | 0 | 0 |
| C2 | 1200/7/15/95 | 22.5 | 0 | 0 | 0 |
| C2 | 1030/7/16/95 | 23 | 0 | 0 | 0 |
| C2 | 1030/7/16/95 | 23 | 0 | 0 | 0 |
| C3 | 1300/7/15/95 | 22 | 0 | 0 | 0 |
| C3 | 1300/7/15/95 | 22 | 0 | 0 | 0 |
| C3 | 1300/7/15/95 | 19.5 | 0 | 0 | 0 |
| C3 | 1300/7/15/95 | 19.5 | 0 | 0 | 0 |
| C3 | 1300/7/15/95 | 22 | 0 | 0 | 0 |
| C3 | 1100/7/16/95 | 23 | 0 | 0 | 0 |
| C3 | 1100/7/16/95 | 23 | 0 | 0 | 0 |
| C3 | 1100/7/16/95 | 23 | 0 | 0 | 0 |
| C4 | 1400/7/15/95 | 20.5 | 0 | 0 | 0 |
| C4 | 1400/7/15/95 | 20.5 | 0 | 0 | 0 |
| C4 | 1400/7/15/95 | 20.5 | 0 | 0 | 0 |
| C4 | 1400/7/15/95 | 20.5 | 0 | 0 | 0 |
| C4 | 1400/7/15/95 | 20.5 | 0 | 0 | 0 |
| C4 | 1400/7/15/95 | 20.5 | 0 | 0 | 0 |
| C4 | 1115/7/16/95 | 23 | 0 | 0 | 0 |
| C4 | 1115/7/16/95 | 23 | 0 | 0 | 0 |
| C4 | 1115/7/16/95 | 23 | 0 | 0 | 0 |
| C4 | 1115/7/16/95 | 23 | 0 | 0 | 0 |
| C5 | 1600/7/15/95 | 24 | 0 | 0 | 0 |
| C5 | 1600/7/15/95 | 24 | 1.00 | 0 | 0 |
| C5 | 1600/7/15/95 | 24 | 2.00 | 0 | 0 |
| C5 | 1600/7/15/95 | 24 | 0 | 0 | 0 |
| C5 | 1600/7/16/95 | 19 | 2.53 | 0 | 0 |
| C5 | 1600/7/16/95 | 19 | 0 | 0 | 0 |
| C6 | 1600/7/16/95 | 19 | 0 | 0 | 0 |
| C6 | 1600/7/16/95 | 19 | 0 | 0 | 0 |
| CL | 1500/7/15/95 | 25.5 | 0 | 0 | 0 |
| CL | 1500/7/15/95 | 25.5 | 0.94 | 0 | 0 |
| CL | 1500/7/15/95 | 25.5 | 0 | 0 | 0 |
| CL | 1630/7/16/95 | 18.5 | 0 | 0 | 0 |
| CL | 1630/7/16/95 | 18.5 | 0 | 0 | 0 |
| CL | 1630/7/16/95 | 18.5 | 0 | 0 | 0 |
| F1 | 1400/7/17/95 | 27 | 0 | 0 | 0 |
| F1 | 1400/7/17/95 | 27 | 0 | 0 | 0 |
| F1 | 1400/7/17/95 | 27 | 0 | 0 | 0 |
| F1 | 1400/7/17/95 | 27 | 0 | 0 | 0 |

**Catch per unit effort for minnow trapping summer 1995, UKHM**

| | | | | CPUE ( #fish /24hrs) | |
|---|---|---|---|---|---|
| SITE | TIME SET | HRS | SS | NP | CH |
| F1 | 1700/7/18/95 | 15.5 | 0 | 0 | 0 |
| F1 | 1700/7/18/95 | 15.5 | 0 | 0 | 0 |
| F1 | 1700/7/18/95 | 15.5 | 0 | 0 | 0 |
| F1 | 1700/7/18/95 | 15.5 | 1.55 | 0 | 0 |
| F2 | 1330/7/17/95 | 27.5 | 0 | 0 | 0 |
| F2 | 1330/7/17/95 | 27.5 | 0 | 0 | 0 |
| F2 | 1700/7/18/95 | 15.5 | 0 | 0 | 0 |
| F3 | 1330/7/17/95 | 27.5 | 0 | 0 | 0 |
| F3 | 1700/7/18/95 | 15.5 | 0 | 0 | 0 |
| Hg | 1000/7/19/95 | 23 | 0 | 0 | 7.30 |
| Hg | 1000/7/19/95 | 23 | 0 | 0 | 22.96 |
| Hg | 0900/7/20/95 | 24 | 0 | 0 | 21.00 |
| Hg | 0900/7/20/95 | 24 | 0 | 0 | 1.00 |
| SM1 | 0930/7/16/95 | 23 | 0 | 0 | 0 |
| SM1 | 0930/7/16/95 | 23 | 0 | 0 | 0 |
| SM1 | 0930/7/16/95 | 23 | 0 | 0 | 0 |
| SM10 | 1000/7/19/95 | 23 | 0 | 0 | 26.09 |
| SM10 | 1000/7/19/95 | 23 | 0 | 0 | 16.70 |
| SM10 | 1000/7/19/95 | 23 | 0 | 0 | 0 |
| SM10 | 1000/7/19/95 | 23 | 0 | 0 | 0 |
| SM10 | 0900/7/20/95 | 24.5 | 0 | 0 | 6.86 |
| SM10 | 0900/7/20/95 | 24.5 | 0 | 0 | 0.98 |
| SM10 | 0900/7/20/95 | 24.5 | 0 | 0 | 0 |
| SM10 | 0900/7/20/95 | 24.5 | 0 | 0 | 0 |
| SM3 | 1130/7/16/95 | 21.5 | 0 | 0 | 0 |
| SM4 | 1200/7/16/95 | 24 | 0 | 0 | 0 |
| SM4 | 1200/7/16/95 | 24 | 0 | 0 | 0 |
| SM4 | 1200/7/16/95 | 24 | 0 | 0 | 0 |
| SM4 | 1200/7/17/95 | 20.5 | 0 | 0 | 0 |
| SM4 | 1200/7/17/95 | 20.5 | 0 | 0 | 0 |
| SM4 | 1200/7/17/95 | 20.5 | 0 | 0 | 0 |
| SM4 | 1200/7/17/95 | 20.5 | 0 | 0 | 0 |
| SM4 | 1200/7/17/95 | 20.5 | 0 | 0 | 0 |
| SM4 | 1200/7/17/95 | 20.5 | 0 | 0 | 0 |
| SM5 | 1330/7/17/95 | 27.5 | 0 | 0 | 0 |
| SM5 | 1330/7/17/95 | 27.5 | 0 | 0 | 0 |
| SM5 | 1330/7/17/95 | 27.5 | 0 | 0 | 0 |
| SM5 | 1400/7/17/95 | 27 | 0 | 0 | 0 |
| SM5 | 1400/7/17/95 | 27 | 0 | 0 | 0 |
| SM5 | 1700/7/18/95 | 15.5 | 0 | 0 | 0 |
| SM5 | 1700/7/18/95 | 15.5 | 0 | 0 | 0 |
| SM5 | 1700/7/18/95 | 15.5 | 0 | 0 | 0 |
| SM5 | 1700/7/18/95 | 15.5 | 0 | 0 | 0 |
| SM5 | 1700/7/18/95 | 15.5 | 0 | 0 | 0 |
| SM6 | 1400/7/17/95 | 27 | 0 | 0 | 0 |
| SM6 | 1400/7/17/95 | 27 | 0 | 0 | 0 |
| SM6 | 1700/7/18/95 | 15.5 | 0 | 0 | 0 |
| SM6 | 1700/7/18/95 | 15.5 | 0 | 0 | 0 |

**Catch per unit effort for minnow trapping summer 1995, UKHM**

| | | | | CPUE ( #fish /24hrs) | |
|---|---|---|---|---|---|
| SITE | TIME SET | HRS | SS | NP | CH |
| SM7 | 1100/7/20/95 | 23.5 | 0 | 0 | 0 |
| SM7 | 1100/7/20/95 | 23.5 | 0 | 1.02 | 0 |
| SM7 | 1100/7/20/95 | 23.5 | 0 | 0 | 0 |
| SM7 | 1100/7/20/95 | 23.5 | 0 | 0 | 0 |
| SM7 | 1100/7/20/95 | 23.5 | 0 | 0 | 0 |
| SM7 | 1100/7/20/95 | 23.5 | 0 | 0 | 0 |
| SM7 | 1100/7/20/95 | 23.5 | 0 | 0 | 0 |
| SM7 | 1100/7/20/95 | 23.5 | 0 | 0 | 0 |
| SM7 | 1100/7/20/95 | 23.5 | 0 | 0 | 0 |
| SM7 | 1100/7/20/95 | 23.5 | 0 | 0 | 0 |
| SM7 | 1100/7/20/95 | 23.5 | 0 | 0 | 0 |
| SM7 | 1100/7/20/95 | 23.5 | 0 | 0 | 0 |
| SM8 | 1600/7/18/95 | 19 | 0 | 0 | 0 |
| SM8 | 1600/7/18/95 | 19 | 0 | 0 | 0 |
| SM8 | 1600/7/18/95 | 19 | 0 | 0 | 0 |
| SM8 | 1600/7/18/95 | 19 | 0 | 0 | 0 |
| SM8 | 1600/7/18/95 | 19 | 0 | 0 | 0 |
| SM8 | 1600/7/18/95 | 19 | 0 | 1.26 | 0 |
| SM8 | 1100/7/19/95 | 22.5 | 0 | 0 | 0 |
| SM8 | 1100/7/19/95 | 22.5 | 0 | 0 | 0 |
| SM8 | 1100/7/19/95 | 22.5 | 0 | 0 | 0 |
| SM8 | 1100/7/19/95 | 22.5 | 0 | 0 | 0 |
| SM8 | 1100/7/19/95 | 22.5 | 0 | 0 | 0 |
| SM8 | 1100/7/19/95 | 22.5 | 0 | 0 | 0 |
| SM9 | 1000/7/19/95 | 23 | 0 | 0 | 0 |
| SM9 | 1000/7/19/95 | 23 | 0 | 0 | 0 |
| SM9 | 1000/7/19/95 | 23 | 0 | 0 | 0 |
| SM9 | 1000/7/19/95 | 23 | 0 | 0 | 1.04 |
| SM9 | 0900/7/20/95 | 24 | 0 | 0 | 0 |
| SM9 | 0900/7/20/95 | 24 | 0 | 0 | 0 |
| SM9 | 0900/7/20/95 | 24 | 0 | 0 | 0 |
| SM9 | 0900/7/20/95 | 24 | 0 | 0 | 0 |
| SML | 1730/7/17/95 | 24.5 | 0 | 0 | 0 |
| SML | 1800/7/17/95 | 24 | 0 | 0 | 0 |
| SML | 1800/7/17/95 | 24 | 0 | 0 | 0 |
| SML | 1800/7/17/95 | 24 | 0 | 0 | 0 |
| SML | 1730/7/17/95 | 24.5 | 0 | 0.98 | 0 |
| SML | 1800/7/18/95 | 23 | 0 | 2.09 | 0 |
| SML | 1800/7/18/95 | 23 | 0 | 0 | 0 |
| SML | 1800/7/18/95 | 23 | 0 | 0 | 0 |
| SML | 1800/7/18/95 | 23 | 0 | 0 | 0 |
| SML | 1800/7/18/95 | 23 | 0 | 0 | 0 |
| SML(CC) | 1700/7/17/95 | 25 | 0 | 0 | 0 |
| SML(CC) | 1800/7/18/95 | 23 | 0 | 0 | 0 |

## APPENDIX E

### Summary of all fish sampled UKHM study 1994-95

ag= Arctic grayling, ss= slimy sculpin, al= Arctic lamprey, rwf= round whitefish

lns= longnose sucker, bb= burbot, ch= chinnok salmon, np= northern pike

sn= seine, els= electrofishing, mnt= minnow trapping

| Date | Location | species | fork length (mm) | round weight (g) | method |
|---|---|---|---|---|---|
| 9/7/94 | c1 | ag | 91 | | sn |
| 9/7/94 | c1 | ag | 104 | | sn |
| 9/7/94 | c1 | ag | 107 | | sn |
| 9/7/94 | c1 | ag | 51 | | sn |
| 9/7/94 | c1 | ag | 89 | | sn |
| 9/7/94 | c1 | ag | 89 | | sn |
| 9/7/94 | c1 | ag | 101 | | sn |
| 9/7/94 | c1 | ag | 91 | | sn |
| 9/7/94 | c1 | ag | 82 | | sn |
| 9/7/94 | c1 | ag | 101 | | sn |
| 9/7/94 | c1 | ag | 101 | | sn |
| 9/7/94 | c1 | ag | 83 | | sn |
| 9/7/94 | c1 | ag | 88 | | sn |
| 9/7/94 | c1 | ag | 64 | | sn |
| 9/7/94 | c1 | ag | 74 | | sn |
| 9/7/94 | c1 | ag | 102 | | sn |
| 9/7/94 | c1 | ag | 61 | | sn |
| 9/7/94 | c1 | ag | 105 | | sn |
| 9/7/94 | c1 | ag | 78 | | sn |
| 9/7/94 | c1 | ag | 66 | | sn |
| 9/7/94 | c1 | ag | 83 | | sn |
| 9/7/94 | c1 | ag | 76 | | sn |
| 9/7/94 | c1 | ag | 78 | | sn |
| 9/7/94 | c1 | ag | 71 | | sn |
| 9/7/94 | c1 | ag | 93 | | sn |
| 9/7/94 | c1 | ag | 78 | | sn |
| 9/7/94 | c1 | ag | 90 | | sn |
| 9/7/94 | c1 | ag | 99 | | sn |
| 9/7/94 | c1 | ag | 100 | | sn |
| 9/7/94 | c1 | ag | 92 | | sn |
| 9/7/94 | c1 | ag | 96 | | sn |
| 9/7/94 | c1 | ag | 89 | | sn |
| 9/7/94 | c1 | ag | 89 | | sn |
| 9/7/94 | c1 | ag | 91 | | sn |
| 9/7/94 | c1 | ag | 69 | | sn |
| 9/7/94 | c1 | ag | 87 | | sn |
| 9/7/94 | c1 | ag | 91 | | sn |
| 9/7/94 | c1 | ag | 104 | | sn |
| 9/7/94 | c1 | ag | 78 | | sn |
| 9/7/94 | c1 | ag | 59 | | sn |
| 9/7/94 | c1 | ag | 71 | | sn |
| 9/7/94 | c1 | ag | 83 | | sn |
| 9/7/94 | c1 | ag | 89 | | sn |
| 9/7/94 | c1 | ag | 88 | | sn |
| 9/7/94 | c1 | ag | 94 | | sn |

## APPENDIX E

**Summary of all fish sampled UKHM study 1994-95**

ag= Arctic grayling, ss= slimy sculpin, al= Arctic lamprey, rwf= round whitefish
lns= longnose sucker, bb= burbot, ch= chinnok salmon, np= northern pike
sn= seine, els= electrofishing, mnt= minnow trapping

| Date | Location | species | fork length (mm) | round weight (g) | method |
|---|---|---|---|---|---|
| 9/7/94 | c1 | ag | 104 | | sn |
| 9/7/94 | c1 | ag | 93 | | sn |
| 9/10/94 | c1 | ag | 78 | | els |
| 9/10/94 | c1 | ag | 65 | | els |
| 9/10/94 | c1 | ag | 81 | | els |
| 9/10/94 | c1 | ag | 83 | | els |
| 9/10/94 | c1 | ag | 56 | | els |
| 9/10/94 | c1 | ag | 84 | | els |
| 9/10/94 | c1 | ag | 69 | | els |
| 9/10/94 | c1 | ag | 64 | | els |
| 9/10/94 | c1 | bb | 294 | | els |
| 9/10/94 | c1 | ss | 43 | | els |
| 9/10/94 | c1 | ss | 39 | | els |
| 7/19/95 | c1 | al | 44 | | sn |
| 9/9/94 | c2 | ss | 107 | 17 | els |
| 9/9/94 | c2 | ss | 112 | 10 | els |
| 9/9/94 | c2 | ss | 106 | 13 | els |
| 9/10/94 | c3 | ag | 95 | 7 | els |
| 9/9/94 | c4 | ag | 95 | 7 | els |
| 9/9/94 | c4 | ag | 265 | 200 | els |
| 9/9/94 | c4 | ag | 321 | 325 | els |
| 9/9/94 | c4 | ag | 280 | 175 | els |
| 9/9/94 | c4 | ag | 316 | 300 | els |
| 9/9/94 | c4 | ag | 283 | 200 | els |
| 9/9/94 | c4 | ag | 171 | 44 | els |
| 9/9/94 | c4 | ag | 175 | 53 | els |
| 9/9/94 | c4 | ag | 142 | 30 | els |
| 9/9/94 | c4 | ag | 188 | 65 | els |
| 9/9/94 | c4 | ag | 186 | 61 | els |
| 9/9/94 | c4 | ag | 218 | 112 | els |
| 9/9/94 | c4 | ag | 241 | 125 | els |
| 7/19/95 | c4 | ag | 285 | | els |
| 7/19/95 | c4 | ag | 175 | | els |
| 7/19/95 | c4 | ag | 248 | | els |
| 5/19/95 | c5 | ss | 95 | 10 | mnt |
| 5/19/95 | c5 | ss | 88 | 10 | mnt |
| 5/19/95 | c5 | ss | 99 | | mnt |
| 5/19/95 | c5 | ss | 71 | | mnt |
| 9/6/94 | CL | ss | 103 | 13 | gn |
| 9/6/94 | CL | ss | 99 | 11 | gn |
| 9/6/94 | CL | ss | 103 | 12 | gn |
| 9/6/94 | CL | ss | 108 | 14 | gn |
| 9/10/94 | CL | ss | 107 | | gn |
| 9/11/94 | CL | ss | 48 | 1 | mnt |
| 9/11/94 | CL | ss | 49 | 1 | mnt |

## APPENDIX E

### Summary of all fish sampled UKHM study 1994-95

ag= Arctic grayling, ss= slimy sculpin, al= Arctic lamprey, rwf= round whitefish

lns= longnose sucker, bb= burbot, ch= chinnok salmon, np= northern pike

sn= seine, els= electrofishing, mnt= minnow trapping

| Date | Location | species | fork length (mm) | round weight (g) | method |
|---|---|---|---|---|---|
| 9/11/94 | CL | ss | 60 | 2 | mnt |
| 9/11/94 | CL | ss | 93 | 8 | mnt |
| 9/6/94 | f1 | ag | 64 | | sn |
| 9/6/94 | f1 | ag | 59 | | sn |
| 9/6/94 | f1 | ag | 63 | | sn |
| 9/6/94 | f1 | ag | 63 | | sn |
| 9/6/94 | f1 | ag | 53 | | sn |
| 9/6/94 | f1 | ag | 65 | | sn |
| 9/6/94 | f1 | ag | 62 | | sn |
| 9/6/94 | f1 | ag | 58 | | sn |
| 9/6/94 | f1 | np | 204 | | sn |
| 9/6/94 | f1 | ss | 73 | | sn |
| 9/6/94 | f1 | ss | 70 | | sn |
| 9/6/94 | f1 | ss | 67 | | sn |
| 9/6/94 | f1 | ss | 42 | | sn |
| 9/6/94 | f1 | ss | 40 | | sn |
| 9/6/94 | f1 | ss | 36 | | sn |
| 9/6/94 | f1 | ss | 49 | | sn |
| 9/6/94 | f1 | ss | 39 | | sn |
| 9/6/94 | f1 | ss | 43 | | sn |
| 9/8/94 | f1 | ag | 69 | 2 | els |
| 9/8/94 | f1 | ag | 66 | | els |
| 9/8/94 | f1 | ag | 71 | | els |
| 9/8/94 | f1 | ss | 57 | | els |
| 9/8/94 | f1 | ss | 66 | | els |
| 9/8/94 | f1 | ss | 71 | | els |
| 9/8/94 | f1 | ss | 52 | | els |
| 9/8/94 | f1 | ss | 67 | | els |
| 9/8/94 | f1 | ss | 54 | | els |
| 9/8/94 | f1 | ss | 69 | | els |
| 9/8/94 | f1 | ss | 67 | | els |
| 9/8/94 | f1 | ss | 68 | | els |
| 9/8/94 | f1 | ss | 70 | | els |
| 9/8/94 | f1 | ss | 69 | | els |
| 9/8/94 | f1 | ss | 92 | | els |
| 9/8/94 | f1 | ss | 63 | | els |
| 9/8/94 | f1 | ss | 62 | | els |
| 9/8/94 | f1 | ss | 60 | | els |
| 9/16/94 | f1 | ag | 73 | | sn |
| 9/16/94 | f1 | ag | 67 | | sn |
| 9/16/94 | f1 | ag | 63 | | sn |
| 9/16/94 | f1 | ag | 66 | | sn |
| 9/16/94 | f1 | ag | 64 | | sn |
| 9/16/94 | f1 | ag | 76 | | sn |
| 9/16/94 | f1 | ag | 58 | | sn |

## APPENDIX E

### Summary of all fish sampled UKHM study 1994-95

ag= Arctic grayling, ss= slimy sculpin, al= Arctic lamprey, rwf= round whitefish

lns= longnose sucker, bb= burbot, ch= chinnok salmon, np= northern pike

sn= seine, els= electrofishing, mnt= minnow trapping

| Date | Location | species | fork length (mm) | round weight (g) | method |
|---|---|---|---|---|---|
| 9/16/94 | f1 | ag | 58 | | sn |
| 9/16/94 | f1 | ss | 40 | | sn |
| 9/16/94 | f1 | ss | 61 | | sn |
| 9/16/94 | f1 | ss | 35 | | sn |
| 9/16/94 | f1 | ss | 36 | | sn |
| 9/16/94 | f1 | ss | 37 | | sn |
| 9/16/94 | f1 | ss | 47 | | sn |
| 9/16/94 | f1 | ss | 67 | | sn |
| 9/16/94 | f1 | ss | 47 | | sn |
| 9/16/94 | f1 | ss | 78 | | sn |
| 9/16/94 | f1 | ss | 49 | | sn |
| 9/16/94 | f1 | ss | 34 | | sn |
| 9/16/94 | f1 | ss | 52 | | sn |
| 9/16/94 | f1 | ss | 39 | | sn |
| 9/16/94 | f1 | ss | 39 | | sn |
| 9/16/94 | f1 | ss | 42 | | sn |
| 9/16/94 | f1 | ss | 38 | | sn |
| 7/17/95 | f1 | ag | 51 | | sn |
| 7/17/95 | f1 | ag | 56 | | sn |
| 7/17/95 | f1 | ag | 49 | | sn |
| 7/17/95 | f1 | ag | 54 | | sn |
| 7/17/95 | f1 | ag | 55 | | sn |
| 7/17/95 | f1 | ag | 50 | | sn |
| 7/17/95 | f1 | ag | 47 | | sn |
| 7/17/95 | f1 | ag | 58 | | sn |
| 7/17/95 | f1 | ag | 47 | | sn |
| 7/17/95 | f1 | ag | 54 | | sn |
| 7/20/95 | f1 | ag | 59 | | sn |
| 7/20/95 | f1 | ag | 54 | | sn |
| 7/20/95 | f1 | ag | 71 | | sn |
| 7/20/95 | f1 | ag | 42 | | sn |
| 7/20/95 | f1 | ag | 49 | | sn |
| 7/20/95 | f1 | ag | 59 | | sn |
| 7/20/95 | f1 | ag | 55 | | sn |
| 7/20/95 | f1 | ag | 43 | | sn |
| 7/20/95 | f1 | ag | 42 | | sn |
| 7/20/95 | f1 | ag | 51 | | sn |
| 7/20/95 | f1 | rwf | 56 | | sn |
| 9/8/94 | f2 | ag | 71 | | mnt |
| 9/8/94 | f2 | ss | 101 | | mnt |
| 9/8/94 | f2 | ss | 67 | | mnt |
| 6/2/95 | hg | ag | 66 | | sn |
| 6/2/95 | hg | ag | 74 | | sn |
| 6/2/95 | hg | ag | 79 | | sn |
| 6/2/95 | hg | rwf | 72 | | sn |

## APPENDIX E

### Summary of all fish sampled UKHM study 1994-95

ag= Arctic grayling, ss= slimy sculpin, al= Arctic lamprey, rwf= round whitefish
lns= longnose sucker, bb= burbot, ch= chinnok salmon, np= northern pike
sn= seine, els= electrofishing, mnt= minnow trapping

| Date | Location | species | fork length (mm) | round weight (g) | method |
|---|---|---|---|---|---|
| 6/2/95 | hg | rwf | 98 | | sn |
| 6/2/95 | hg | rwf | 73 | | sn |
| 6/2/95 | hg | rwf | 76 | | sn |
| 7/18/95 | hg | ag | 49 | | sn |
| 7/18/95 | hg | ag | 61 | | sn |
| 7/18/95 | hg | ag | 48 | | sn |
| 7/18/95 | hg | ag | 56 | | sn |
| 7/18/95 | hg | ag | 53 | | sn |
| 7/18/95 | hg | ag | 52 | | sn |
| 7/18/95 | hg | ag | 47 | | sn |
| 7/18/95 | hg | ag | 39 | | sn |
| 7/18/95 | hg | ag | 48 | | sn |
| 7/18/95 | hg | ag | 49 | | sn |
| 7/18/95 | hg | ag | 42 | | sn |
| 7/18/95 | hg | ag | 39 | | sn |
| 7/18/95 | hg | ch | 64 | | sn |
| 7/18/95 | hg | ch | 62 | | sn |
| 7/18/95 | hg | ch | 61 | | sn |
| 7/18/95 | hg | ch | 63 | | sn |
| 7/18/95 | hg | ch | 59 | | sn |
| 7/18/95 | hg | ch | 56 | | sn |
| 7/18/95 | hg | ch | 62 | | sn |
| 7/18/95 | hg | ch | 64 | | sn |
| 7/18/95 | hg | ch | 62 | | sn |
| 7/18/95 | hg | ch | 59 | | sn |
| 7/18/95 | hg | ch | 49 | | sn |
| 7/18/95 | hg | ch | 63 | | sn |
| 7/18/95 | hg | ch | 59 | | sn |
| 7/18/95 | hg | ch | 62 | | sn |
| 7/18/95 | hg | ch | 54 | | sn |
| 7/18/95 | hg | lns | 32 | | sn |
| 7/18/95 | hg | lns | 49 | | sn |
| 7/18/95 | hg | lns | 28 | | sn |
| 7/18/95 | hg | lns | 29 | | sn |
| 7/18/95 | hg | lns | 33 | | sn |
| 7/18/95 | hg | lns | 38 | | sn |
| 7/18/95 | hg | lns | 32 | | sn |
| 9/15/94 | LC | ag | 333 | 400 | bsn |
| 9/15/94 | LC | ag | 312 | 350 | bsn |
| 9/15/94 | LC | ag | 296 | 250 | bsn |
| 9/15/94 | LC | ag | 270 | 250 | bsn |
| 9/15/94 | LC | ag | 207 | | sn |
| 9/15/94 | LC | ag | 217 | | sn |
| 9/15/94 | LC | ag | 178 | | sn |
| 9/15/94 | LC | ag | 164 | | sn |

## APPENDIX E

### Summary of all fish sampled UKHM study 1994-95

ag= Arctic grayling, ss= slimy sculpin, al= Arctic lamprey, rwf= round whitefish

lns= longnose sucker, bb= burbot, ch= chinnok salmon, np= northern pike

sn= seine, els= electrofishing, mnt= minnow trapping

| Date | Location | species | fork length (mm) | round weight (g) | method |
|---|---|---|---|---|---|
| 5/20/95 | LC | ag | 243 | | sn |
| 7/14/95 | LC | ag | 185 | | sn |
| 7/14/95 | LC | ag | 225 | | sn |
| 7/14/95 | LC | ag | 165 | | bsn |
| 7/14/95 | LC | ag | 325 | | bsn |
| 7/16/95 | LC | ag | 115 | | sn |
| 7/16/95 | LC | ag | 122 | | sn |
| 7/16/95 | LC | ag | 122 | | sn |
| 7/16/95 | LC | ag | 130 | | sn |
| 7/20/95 | LC | ag | 250 | | bsn |
| 7/20/95 | LC | ag | 382 | | bsn |
| 7/20/95 | LC | ag | 315 | | angle |
| 7/20/95 | LC | ag | 292 | | angle |
| 7/20/95 | LC | ag | 305 | | angle |
| 7/20/95 | LC | ag | 349 | | angle |
| 7/20/95 | LC | ag | 234 | | sn |
| 6/1/95 | mq | ag | 100 | | sn |
| 6/1/95 | mq | ch | 39 | | sn |
| 6/1/95 | mq | ch | 41 | | sn |
| 6/1/95 | mq | ch | 43 | | sn |
| 6/1/95 | mq | ch | 39 | | sn |
| 6/1/95 | mq | ch | 37 | | sn |
| 6/1/95 | mq | ch | 44 | | sn |
| 6/1/95 | mq | ch | 39 | | sn |
| 6/1/95 | mq | ch | 41 | | sn |
| 6/1/95 | mq | ch | 38 | | sn |
| 6/1/95 | mq | ch | 39 | | sn |
| 8/4/95 | Shg | ag | 55 | | sn |
| 8/4/95 | Shg | ag | 52 | | sn |
| 8/4/95 | Shg | ag | 57 | | sn |
| 9/5/94 | sm1 | ag | 83 | 4 | sn |
| 9/5/94 | sm1 | ag | 72 | 3 | sn |
| 9/5/94 | sm1 | ag | 81 | 5 | sn |
| 9/5/94 | sm1 | ag | 74 | 3 | sn |
| 9/5/94 | sm1 | ag | 91 | 7 | sn |
| 9/5/94 | sm1 | ag | 78 | 4 | sn |
| 9/5/94 | sm1 | ag | 94 | 7 | sn |
| 9/5/94 | sm1 | lns | 33 | | sn |
| 9/5/94 | sm1 | ss | 21 | | sn |
| 9/5/94 | sm1 | ss | 39 | | sn |
| 9/5/94 | sm1 | ss | 56 | | sn |
| 9/5/94 | sm1 | ss | 26 | | sn |
| 9/5/94 | sm1 | ss | 45 | | sn |
| 9/5/94 | sm1 | ss | 39 | | sn |
| 9/5/94 | sm1 | ss | 41 | | sn |

## APPENDIX E

### Summary of all fish sampled UKHM study 1994-95

ag= Arctic grayling, ss= slimy sculpin, al= Arctic lamprey, rwf= round whitefish
lns= longnose sucker, bb= burbot, ch= chinnok salmon, np= northern pike
sn= seine, els= electrofishing, mnt= minnow trapping

| Date | Location | species | fork length (mm) | round weight (g) | method |
|---|---|---|---|---|---|
| 9/5/94 | sm1 | ss | 43 |  | sn |
| 9/5/94 | sm1 | ss | 21 |  | sn |
| 9/5/94 | sm1 | ss | 60 |  | sn |
| 9/5/94 | sm1 | ss | 64 |  | sn |
| 9/5/94 | sm1 | ss | 43 |  | sn |
| 9/5/94 | sm1 | ss | 41 |  | sn |
| 9/5/94 | sm1 | ss | 52 |  | sn |
| 9/5/94 | sm1 | ss | 22 |  | sn |
| 9/5/94 | sm1 | ss | 21 |  | sn |
| 9/5/94 | sm1 | ss | 48 |  | sn |
| 9/5/94 | sm1 | ss | 23 |  | sn |
| 9/5/94 | sm1 | ss | 44 |  | sn |
| 9/5/94 | sm1 | ss | 56 |  | sn |
| 9/5/94 | sm1 | ss | 42 |  | sn |
| 9/10/94 | sm1 | ag | 84 |  | els |
| 9/15/94 | sm1 | ag | 81 |  | sn |
| 9/15/94 | sm1 | ag | 83 |  | sn |
| 9/15/94 | sm1 | ag | 102 |  | sn |
| 9/15/94 | sm1 | ag | 99 |  | sn |
| 9/15/94 | sm1 | ag | 81 |  | sn |
| 9/15/94 | sm1 | ss | 41 |  | sn |
| 9/15/94 | sm1 | ss | 46 |  | sn |
| 9/15/94 | sm1 | ss | 46 |  | sn |
| 9/15/94 | sm1 | ss | 41 |  | sn |
| 9/16/94 | sm1 | ag | 227 | 114 | angle |
| 9/16/94 | sm1 | ag | 142 | 27 | angle |
| 9/16/94 | sm1 | ag | 156 | 39 | angle |
| 9/16/94 | sm1 | ag | 198 | 97 | angle |
| 9/16/94 | sm1 | ag | 195 | 76 | angle |
| 7/15/95 | sm1 | ag | 62 |  | sn |
| 7/15/95 | sm1 | ag | 57 |  | sn |
| 7/15/95 | sm1 | ag | 37 |  | sn |
| 7/15/95 | sm1 | ag | 44 |  | sn |
| 7/15/95 | sm1 | ag | 42 |  | sn |
| 7/15/95 | sm1 | ag | 44 |  | sn |
| 7/15/95 | sm1 | ag | 63 |  | sn |
| 7/15/95 | sm1 | ag | 57 |  | sn |
| 7/15/95 | sm1 | ag | 52 |  | sn |
| 7/15/95 | sm1 | ag | 39 |  | sn |
| 7/15/95 | sm1 | ag | 52 |  | sn |
| 7/15/95 | sm1 | ag | 41 |  | sn |
| 7/15/95 | sm1 | ag | 74 |  | sn |
| 7/15/95 | sm1 | ag | 62 |  | sn |
| 7/15/95 | sm1 | ag | 61 |  | sn |
| 7/15/95 | sm1 | ag | 53 |  | sn |

# APPENDIX E

## Summary of all fish sampled UKHM study 1994-95

ag= Arctic grayling, ss= slimy sculpin, al= Arctic lamprey, rwf= round whitefish
lns= longnose sucker, bb= burbot, ch= chinnok salmon, np= northern pike
sn= seine, els= electrofishing, mnt= minnow trapping

| Date | Location | species | fork length (mm) | round weight (g) | method |
|---|---|---|---|---|---|
| 7/15/95 | sm1 | ag | 55 | | sn |
| 7/15/95 | sm1 | ag | 47 | | sn |
| 7/15/95 | sm1 | ag | 49 | | sn |
| 7/15/95 | sm1 | ag | 51 | | sn |
| 7/15/95 | sm1 | ag | 44 | | sn |
| 7/15/95 | sm1 | ag | 42 | | sn |
| 7/15/95 | sm1 | ag | 46 | | sn |
| 7/15/95 | sm1 | ag | 43 | | sn |
| 7/15/95 | sm1 | ag | 53 | | sn |
| 7/15/95 | sm1 | ag | 68 | | sn |
| 7/15/95 | sm1 | ag | 63 | | sn |
| 7/15/95 | sm1 | al | 49 | | sn |
| 7/15/95 | sm1 | al | 42 | | sn |
| 7/15/95 | sm1 | al | 42 | | sn |
| 7/15/95 | sm1 | al | 59 | | sn |
| 7/15/95 | sm1 | al | 150 | | els |
| 7/19/95 | sm1 | ag | 62 | | sn |
| 7/19/95 | sm1 | ag | 93 | | sn |
| 7/19/95 | sm1 | ag | 51 | | sn |
| 7/19/95 | sm1 | ag | 44 | | sn |
| 7/19/95 | sm1 | ag | 57 | | sn |
| 6/2/95 | sm10 | ag | 63 | | sn |
| 6/2/95 | sm10 | ag | 62 | | sn |
| 6/2/95 | sm10 | rwf | 205 | | sn |
| 7/18/95 | sm10 | ag | 62 | | sn |
| 7/18/95 | sm10 | ag | 62 | | sn |
| 7/18/95 | sm10 | ag | 42 | | sn |
| 7/18/95 | sm10 | ag | 65 | | sn |
| 7/18/95 | sm10 | ag | 57 | | sn |
| 7/18/95 | sm10 | ag | 54 | | sn |
| 7/18/95 | sm10 | ag | 58 | | sn |
| 7/18/95 | sm10 | ag | 58 | | sn |
| 7/18/95 | sm10 | ag | 56 | | sn |
| 7/18/95 | sm10 | ag | 52 | | sn |
| 7/18/95 | sm10 | ag | 62 | | sn |
| 7/18/95 | sm10 | ag | 41 | | sn |
| 7/18/95 | sm10 | ag | 125 | | sn |
| 7/18/95 | sm10 | ag | 51 | | sn |
| 7/18/95 | sm10 | ag | 47 | | sn |
| 7/18/95 | sm10 | ag | 42 | | sn |
| 7/18/95 | sm10 | ag | 52 | | sn |
| 7/18/95 | sm10 | ag | 62 | | sn |
| 7/18/95 | sm10 | ag | 49 | | sn |
| 7/18/95 | sm10 | ag | 53 | | sn |
| 7/18/95 | sm10 | ag | 49 | | sn |

## APPENDIX E

### Summary of all fish sampled UKHM study 1994-95

ag= Arctic grayling, ss= slimy sculpin, al= Arctic lamprey, rwf= round whitefish

lns= longnose sucker, bb= burbot, ch= chinnok salmon, np= northern pike

sn= seine, els= electrofishing, mnt= minnow trapping

| Date | Location | species | fork length (mm) | round weight (g) | method |
|---|---|---|---|---|---|
| 7/18/95 | sm10 | ag | 45 | | sn |
| 7/18/95 | sm10 | ag | 51 | | sn |
| 7/18/95 | sm10 | ag | 62 | | sn |
| 7/18/95 | sm10 | ag | 54 | | sn |
| 7/18/95 | sm10 | ag | 48 | | sn |
| 7/18/95 | sm10 | ag | 62 | | sn |
| 7/18/95 | sm10 | ag | 60 | | sn |
| 7/18/95 | sm10 | ag | 62 | | sn |
| 7/18/95 | sm10 | ag | 48 | | sn |
| 7/18/95 | sm10 | ag | 71 | | sn |
| 7/18/95 | sm10 | ag | 48 | | sn |
| 7/18/95 | sm10 | ag | 58 | | sn |
| 7/18/95 | sm10 | ch | 59 | | sn |
| 7/18/95 | sm10 | ch | 58 | | sn |
| 7/18/95 | sm10 | ch | 57 | | sn |
| 7/18/95 | sm10 | ch | 66 | | sn |
| 7/18/95 | sm10 | ch | 70 | | sn |
| 7/18/95 | sm10 | ch | 72 | | sn |
| 7/18/95 | sm10 | ch | 58 | | sn |
| 7/18/95 | sm10 | ch | 61 | | sn |
| 7/18/95 | sm10 | ch | 67 | | sn |
| 7/18/95 | sm10 | ch | 66 | | sn |
| 7/18/95 | sm10 | ch | 61 | | sn |
| 7/18/95 | sm10 | ch | 58 | | sn |
| 7/18/95 | sm10 | ch | 55 | | sn |
| 7/18/95 | sm10 | ch | 62 | | sn |
| 7/18/95 | sm10 | ch | 59 | | sn |
| 7/18/95 | sm10 | ch | 59 | | sn |
| 7/18/95 | sm10 | lns | 27 | | sn |
| 7/18/95 | sm10 | lns | 28 | | sn |
| 7/18/95 | sm10 | lns | 24 | | sn |
| 7/18/95 | sm10 | lns | 22 | | sn |
| 7/18/95 | sm10 | rwf | 78 | | sn |
| 7/18/95 | sm10 | rwf | 61 | | sn |
| 7/18/95 | sm10 | rwf | 62 | | sn |
| 7/18/95 | sm10 | rwf | 56 | | sn |
| 7/18/95 | sm10 | rwf | 57 | | sn |
| 7/18/95 | sm10 | rwf | 68 | | sn |
| 7/18/95 | sm10 | rwf | 64 | | sn |
| 7/18/95 | sm10 | rwf | 61 | | sn |
| 7/18/95 | sm10 | rwf | 59 | | sn |
| 7/18/95 | sm10 | rwf | 61 | | sn |
| 7/18/95 | sm10 | rwf | 61 | | sn |
| 7/18/95 | sm10 | rwf | 63 | | sn |
| 7/18/95 | sm10 | rwf | 59 | | sn |

## APPENDIX E

### Summary of all fish sampled UKHM study 1994-95

ag= Arctic grayling, ss= slimy sculpin, al= Arctic lamprey, rwf= round whitefish

lns= longnose sucker, bb= burbot, ch= chinnok salmon, np= northern pike

sn= seine, els= electrofishing, mnt= minnow trapping

| Date | Location | species | fork length (mm) | round weight (g) | method |
|---|---|---|---|---|---|
| 7/20/95 | sm10 | ch | 68 | | mnt |
| 7/20/95 | sm10 | ch | 63 | | mnt |
| 7/20/95 | sm10 | ch | 68 | | mnt |
| 7/20/95 | sm10 | ch | 75 | | mnt |
| 7/20/95 | sm10 | ch | 68 | | mnt |
| 7/20/95 | sm10 | ch | 69 | | mnt |
| 7/20/95 | sm10 | ch | 64 | | mnt |
| 7/20/95 | sm10 | ch | 63 | | mnt |
| 7/20/95 | sm10 | ch | 70 | | mnt |
| 7/20/95 | sm10 | ch | 62 | | mnt |
| 7/20/95 | sm10 | ch | 72 | | mnt |
| 7/20/95 | sm10 | ch | 73 | | mnt |
| 7/20/95 | sm10 | ch | 75 | | mnt |
| 7/20/95 | sm10 | ch | 66 | | mnt |
| 7/20/95 | sm10 | ch | 65 | | mnt |
| 7/20/95 | sm10 | ch | 66 | | mnt |
| 7/20/95 | sm10 | ch | 63 | | mnt |
| 7/20/95 | sm10 | ch | 64 | | mnt |
| 7/20/95 | sm10 | ch | 73 | | mnt |
| 7/20/95 | sm10 | ch | 62 | | mnt |
| 7/20/95 | sm10 | ch | 66 | | mnt |
| 7/20/95 | sm10 | ch | 64 | | mnt |
| 7/20/95 | sm10 | ch | 76 | | mnt |
| 7/20/95 | sm10 | ch | 62 | | mnt |
| 7/20/95 | sm10 | ch | 75 | | mnt |
| 7/20/95 | sm10 | ch | 64 | | mnt |
| 7/20/95 | sm10 | ch | 63 | | mnt |
| 7/20/95 | sm10 | ch | 67 | | mnt |
| 7/20/95 | sm10 | ch | 65 | | mnt |
| 7/18/95 | sm11 | ag | 58 | | sn |
| 7/18/95 | sm11 | ag | 53 | | sn |
| 7/18/95 | sm11 | ag | 48 | | sn |
| 7/18/95 | sm11 | ag | 49 | | sn |
| 7/18/95 | sm11 | ag | 43 | | sn |
| 7/18/95 | sm11 | ag | 59 | | sn |
| 7/18/95 | sm11 | ag | 53 | | sn |
| 7/18/95 | sm11 | ag | 52 | | sn |
| 7/18/95 | sm11 | ag | 53 | | sn |
| 7/18/95 | sm11 | ag | 54 | | sn |
| 7/18/95 | sm11 | ag | 59 | | sn |
| 7/18/95 | sm11 | ag | 61 | | sn |
| 7/18/95 | sm11 | ag | 53 | | sn |
| 7/18/95 | sm11 | ag | 54 | | sn |
| 7/18/95 | sm11 | ag | 55 | | sn |
| 7/18/95 | sm11 | ag | 49 | | sn |

## APPENDIX E

### Summary of all fish sampled UKHM study 1994-95

ag= Arctic grayling, ss= slimy sculpin, al= Arctic lamprey, rwf= round whitefish

lns= longnose sucker, bb= burbot, ch= chinnok salmon, np= northern pike

sn= seine, els= electrofishing, mnt= minnow trapping

| Date | Location | species | fork length (mm) | round weight (g) | method |
|---|---|---|---|---|---|
| 7/18/95 | sm11 | ag | 54 | | sn |
| 7/18/95 | sm11 | ag | 59 | | sn |
| 7/18/95 | sm11 | ag | 58 | | sn |
| 7/18/95 | sm11 | ag | 59 | | sn |
| 7/18/95 | sm11 | ch | 49 | | sn |
| 7/18/95 | sm11 | ch | 52 | | sn |
| 7/18/95 | sm11 | ch | 55 | | sn |
| 7/18/95 | sm11 | ch | 59 | | sn |
| 7/18/95 | sm11 | ch | 57 | | sn |
| 7/18/95 | sm11 | ch | 51 | | sn |
| 7/18/95 | sm11 | ch | 58 | | sn |
| 7/18/95 | sm11 | ch | 64 | | sn |
| 7/18/95 | sm11 | ch | 68 | | sn |
| 7/18/95 | sm11 | ch | 57 | | sn |
| 7/18/95 | sm11 | ch | 53 | | sn |
| 7/18/95 | sm11 | ch | 52 | | sn |
| 7/18/95 | sm11 | ch | 58 | | sn |
| 7/18/95 | sm11 | ch | 49 | | sn |
| 7/18/95 | sm11 | ch | 53 | | sn |
| 7/18/95 | sm11 | ch | 53 | | sn |
| 7/18/95 | sm11 | ch | 56 | | sn |
| 7/18/95 | sm11 | ch | 68 | | sn |
| 7/18/95 | sm11 | ch | 55 | | sn |
| 7/18/95 | sm11 | ch | 52 | | sn |
| 7/18/95 | sm11 | ch | 61 | | sn |
| 7/18/95 | sm11 | ch | 63 | | sn |
| 7/18/95 | sm11 | ch | 49 | | sn |
| 7/18/95 | sm11 | rwf | 62 | | sn |
| 7/18/95 | sm11 | rwf | 64 | | sn |
| 7/18/95 | sm11 | rwf | 68 | | sn |
| 7/18/95 | sm11 | ss | 70 | | sn |
| 8/4/95 | sm13 | ag | 81 | | sn |
| 8/4/95 | sm13 | ag | 49 | | sn |
| 8/4/95 | sm13 | ag | 61 | | sn |
| 8/4/95 | sm13 | ag | 62 | | sn |
| 8/4/95 | sm13 | ag | 63 | | sn |
| 8/4/95 | sm13 | ag | 63 | | sn |
| 8/4/95 | sm13 | ag | 53 | | sn |
| 8/4/95 | sm13 | ag | 58 | | sn |
| 8/4/95 | sm13 | ag | 60 | | sn |
| 8/4/95 | sm13 | ag | 63 | | sn |
| 8/4/95 | sm13 | ag | 77 | | sn |
| 8/4/95 | sm13 | ag | 68 | | sn |
| 8/4/95 | sm13 | ag | 71 | | sn |
| 8/4/95 | sm13 | ag | 59 | | sn |

## APPENDIX E

### Summary of all fish sampled UKHM study 1994-95

ag= Arctic grayling, ss= slimy sculpin, al= Arctic lamprey, rwf= round whitefish
lns= longnose sucker, bb= burbot, ch= chinnok salmon, np= northern pike
sn= seine, els= electrofishing, mnt= minnow trapping

| Date | Location | species | fork length (mm) | round weight (g) | method |
|---|---|---|---|---|---|
| 8/4/95 | sm13 | ag | 53 | | sn |
| 8/4/95 | sm13 | ag | 57 | | sn |
| 8/4/95 | sm13 | ag | 52 | | sn |
| 8/4/95 | sm13 | ag | 54 | | sn |
| 8/4/95 | sm13 | ag | 52 | | sn |
| 8/4/95 | sm13 | ag | 52 | | sn |
| 8/4/95 | sm13 | ag | 68 | | sn |
| 8/4/95 | sm13 | ag | 67 | | sn |
| 8/4/95 | sm13 | ag | 65 | | sn |
| 8/4/95 | sm13 | ag | 75 | | sn |
| 8/4/95 | sm13 | ag | 62 | | sn |
| 8/4/95 | sm13 | ag | 64 | | sn |
| 8/4/95 | sm13 | ag | 67 | | sn |
| 8/4/95 | sm13 | ag | 53 | | sn |
| 8/4/95 | sm13 | ag | 48 | | sn |
| 8/4/95 | sm13 | ag | 68 | | sn |
| 8/4/95 | sm13 | lns | 62 | | sn |
| 8/4/95 | sm13 | lns | 70 | | sn |
| 8/4/95 | sm13 | rwf | 67 | | sn |
| 8/4/95 | sm13 | rwf | 82 | | sn |
| 9/7/94 | sm2 | ag | 112 | | sn |
| 9/7/94 | sm2 | ag | 77 | | sn |
| 9/7/94 | sm2 | ag | 98 | | sn |
| 9/7/94 | sm2 | ag | 83 | | sn |
| 9/7/94 | sm2 | ag | 63 | | sn |
| 9/7/94 | sm2 | ag | 72 | | sn |
| 9/7/94 | sm2 | ag | 89 | | sn |
| 9/7/94 | sm2 | ag | 78 | | sn |
| 9/7/94 | sm2 | ag | 72 | | sn |
| 9/7/94 | sm2 | ag | 68 | | sn |
| 9/7/94 | sm2 | ag | 93 | | sn |
| 9/7/94 | sm2 | ag | 73 | | sn |
| 9/7/94 | sm2 | ag | 72 | | sn |
| 9/7/94 | sm2 | ag | 76 | | sn |
| 9/7/94 | sm2 | ag | 61 | | sn |
| 9/7/94 | sm2 | ag | 69 | | sn |
| 9/7/94 | sm2 | ag | 71 | | sn |
| 9/7/94 | sm2 | ag | 73 | | sn |
| 9/7/94 | sm2 | ag | 70 | | sn |
| 9/7/94 | sm2 | ag | 88 | | sn |
| 9/7/94 | sm2 | lns | 31 | | sn |
| 9/7/94 | sm2 | lns | 38 | | sn |
| 9/7/94 | sm2 | lns | 40 | | sn |
| 9/7/94 | sm2 | lns | 45 | | sn |
| 9/7/94 | sm2 | lns | 40 | | sn |

## APPENDIX E

### Summary of all fish sampled UKHM study 1994-95

ag= Arctic grayling, ss= slimy sculpin, al= Arctic lamprey, rwf= round whitefish

lns= longnose sucker, bb= burbot, ch= chinnok salmon, np= northern pike

sn= seine, els= electrofishing, mnt= minnow trapping

| Date | Location | species | fork length (mm) | round weight (g) | method |
|---|---|---|---|---|---|
| 9/7/94 | sm2 | lns | 34 | | sn |
| 9/7/94 | sm2 | lns | 42 | | sn |
| 9/7/94 | sm2 | ss | 45 | | sn |
| 9/7/94 | sm2 | ss | 40 | | sn |
| 9/7/94 | sm2 | ss | 49 | | sn |
| 9/7/94 | sm2 | ss | 36 | | sn |
| 9/7/94 | sm2 | ss | 45 | | sn |
| 9/7/94 | sm2 | ss | 41 | | sn |
| 9/7/94 | sm2 | ss | 29 | | sn |
| 9/7/94 | sm2 | ss | 47 | | sn |
| 9/7/94 | sm2 | ss | 40 | | sn |
| 9/7/94 | sm2 | ss | 46 | | sn |
| 9/7/94 | sm2 | ss | 44 | | sn |
| 9/7/94 | sm2 | ss | 51 | | sn |
| 9/7/94 | sm2 | ss | 41 | | sn |
| 9/7/94 | sm2 | ss | 43 | | sn |
| 9/7/94 | sm2 | ss | 39 | | sn |
| 9/7/94 | sm2 | ss | 52 | | sn |
| 9/7/94 | sm2 | ss | 41 | | sn |
| 9/10/94 | sm2 | ag | 63 | | els |
| 9/10/94 | sm2 | ag | 66 | | els |
| 9/10/94 | sm2 | ag | 60 | | els |
| 9/10/94 | sm2 | ag | 66 | | els |
| 9/10/94 | sm2 | ag | 66 | | els |
| 9/10/94 | sm2 | lns | 42 | | els |
| 9/10/94 | sm2 | lns | 46 | | els |
| 9/10/94 | sm2 | lns | 38 | | els |
| 9/10/94 | sm2 | lns | 34 | | els |
| 9/10/94 | sm2 | lns | 34 | | els |
| 9/10/94 | sm2 | lns | 39 | | els |
| 9/10/94 | sm2 | lns | 32 | | els |
| 9/10/94 | sm2 | lns | 41 | | els |
| 9/10/94 | sm2 | lns | 44 | | els |
| 9/10/94 | sm2 | lns | 45 | | els |
| 9/16/94 | sm2 | ag | 74 | | sn |
| 9/16/94 | sm2 | ag | 75 | | sn |
| 9/16/94 | sm2 | ag | 75 | | sn |
| 9/16/94 | sm2 | ag | 73 | | sn |
| 9/16/94 | sm2 | ag | 68 | | sn |
| 9/16/94 | sm2 | ag | 68 | | sn |
| 9/16/94 | sm2 | ag | 60 | | sn |
| 9/16/94 | sm2 | ag | 72 | | sn |
| 9/16/94 | sm2 | ag | 63 | | sn |
| 9/16/94 | sm2 | ag | 65 | | sn |
| 9/16/94 | sm2 | ag | 64 | | sn |

## APPENDIX E

### Summary of all fish sampled UKHM study 1994-95

ag= Arctic grayling, ss= slimy sculpin, al= Arctic lamprey, rwf= round whitefish
lns= longnose sucker, bb= burbot, ch= chinnok salmon, np= northern pike
sn= seine, els= electrofishing, mnt= minnow trapping

| Date | Location | species | fork length (mm) | round weight (g) | method |
|---|---|---|---|---|---|
| 9/16/94 | sm2 | lns | 35 | | sn |
| 9/16/94 | sm2 | lns | 35 | | sn |
| 9/16/94 | sm2 | lns | 38 | | sn |
| 9/16/94 | sm2 | lns | 41 | | sn |
| 9/16/94 | sm2 | lns | 40 | | sn |
| 9/16/94 | sm2 | lns | 37 | | sn |
| 9/16/94 | sm2 | lns | 45 | | sn |
| 9/16/94 | sm2 | lns | 42 | | sn |
| 9/16/94 | sm2 | ss | 42 | | sn |
| 9/16/94 | sm2 | ss | 45 | | sn |
| 9/16/94 | sm2 | ss | 48 | | sn |
| 9/16/94 | sm2 | ss | 41 | | sn |
| 9/16/94 | sm2 | ss | 46 | | sn |
| 9/16/94 | sm2 | ss | 46 | | sn |
| 9/16/94 | sm2 | ss | 41 | | sn |
| 9/16/94 | sm2 | ss | 38 | | sn |
| 5/22/95 | sm2 | al | 90 | | sn |
| 7/19/95 | sm2 | ag | 48 | | sn |
| 7/19/95 | sm2 | ag | 65 | | sn |
| 7/19/95 | sm2 | ag | 64 | | sn |
| 9/7/94 | sm3 | ag | 292 | 250 | sn |
| 9/7/94 | sm3 | ag | 88 | | sn |
| 9/7/94 | sm3 | ag | 100 | | sn |
| 9/7/94 | sm3 | ag | 115 | | sn |
| 9/7/94 | sm3 | ag | 100 | | sn |
| 9/7/94 | sm3 | ag | 78 | | sn |
| 9/7/94 | sm3 | ag | 94 | | sn |
| 9/7/94 | sm3 | ag | 75 | | sn |
| 9/7/94 | sm3 | ag | 65 | | sn |
| 9/7/94 | sm3 | ag | 75 | | sn |
| 9/7/94 | sm3 | ag | 74 | | sn |
| 9/7/94 | sm3 | ag | 74 | | sn |
| 9/7/94 | sm3 | ag | 60 | | sn |
| 9/7/94 | sm3 | ag | 64 | | sn |
| 9/7/94 | sm3 | ag | 63 | | sn |
| 9/7/94 | sm3 | ag | 64 | | sn |
| 9/7/94 | sm3 | ag | 82 | | sn |
| 9/7/94 | sm3 | ag | 62 | | sn |
| 9/7/94 | sm3 | ag | 286 | 250 | ang |
| 9/7/94 | sm3 | ag | 220 | 100 | ang |
| 9/7/94 | sm3 | lns | 44 | | sn |
| 9/7/94 | sm3 | lns | 40 | | sn |
| 9/7/94 | sm3 | lns | 35 | | sn |
| 9/7/94 | sm3 | lns | 25 | | sn |
| 9/7/94 | sm3 | lns | 34 | | sn |

# APPENDIX E

## Summary of all fish sampled UKHM study 1994-95

ag= Arctic grayling, ss= slimy sculpin, al= Arctic lamprey, rwf= round whitefish

lns= longnose sucker, bb= burbot, ch= chinnok salmon, np= northern pike

sn= seine, els= electrofishing, mnt= minnow trapping

| Date | Location | species | fork length (mm) | round weight (g) | method |
|---|---|---|---|---|---|
| 9/7/94 | sm3 | lns | 35 | | sn |
| 9/7/94 | sm3 | lns | 41 | | sn |
| 9/7/94 | sm3 | rwf | 260 | 150 | sn |
| 9/7/94 | sm3 | ss | 43 | | sn |
| 9/7/94 | sm3 | ss | 45 | | sn |
| 9/7/94 | sm3 | ss | 38 | | sn |
| 9/7/94 | sm3 | ss | 48 | | sn |
| 9/7/94 | sm3 | ss | 43 | | sn |
| 9/7/94 | sm3 | ss | 39 | | sn |
| 9/7/94 | sm3 | ss | 61 | | sn |
| 9/7/94 | sm3 | ss | 40 | | sn |
| 9/7/94 | sm3 | ss | 41 | | sn |
| 9/7/94 | sm3 | ss | 43 | | sn |
| 9/7/94 | sm3 | ss | 42 | | sn |
| 9/7/94 | sm3 | ss | 48 | | sn |
| 9/7/94 | sm3 | ss | 27 | | sn |
| 9/7/94 | sm3 | ss | 51 | | sn |
| 9/10/94 | sm3 | ag | 76 | | els |
| 9/10/94 | sm3 | bb | 222 | | els |
| 9/10/94 | sm3 | lns | 42 | | els |
| 9/10/94 | sm3 | lns | 38 | | els |
| 9/10/94 | sm3 | lns | 37 | | els |
| 9/10/94 | sm3 | np | 218 | | els |
| 9/16/94 | sm3 | ag | 76 | | sn |
| 9/16/94 | sm3 | ag | 89 | | sn |
| 9/16/94 | sm3 | ag | 73 | | sn |
| 9/16/94 | sm3 | ag | 66 | | sn |
| 9/16/94 | sm3 | ag | 64 | | sn |
| 9/16/94 | sm3 | ag | 75 | | sn |
| 9/16/94 | sm3 | ag | 68 | | sn |
| 9/16/94 | sm3 | ag | 88 | | sn |
| 9/16/94 | sm3 | ag | 63 | | sn |
| 9/16/94 | sm3 | ag | 63 | | sn |
| 9/16/94 | sm3 | lns | 41 | | sn |
| 9/16/94 | sm3 | lns | 33 | | sn |
| 9/16/94 | sm3 | ss | 37 | | sn |
| 9/16/94 | sm3 | ss | 38 | | sn |
| 9/16/94 | sm3 | ss | 43 | | sn |
| 9/16/94 | sm3 | ss | 48 | | sn |
| 9/16/94 | sm3 | ss | 43 | | sn |
| 9/16/94 | sm3 | ss | 42 | | sn |
| 9/16/94 | sm3 | ss | 39 | | sn |
| 9/16/94 | sm3 | ss | 40 | | sn |
| 9/16/94 | sm3 | ss | 46 | | sn |
| 9/16/94 | sm3 | ss | 43 | | sn |

## APPENDIX E

### Summary of all fish sampled UKHM study 1994-95

ag= Arctic grayling, ss= slimy sculpin, al= Arctic lamprey, rwf= round whitefish
lns= longnose sucker, bb= burbot, ch= chinnok salmon, np= northern pike
sn= seine, els= electrofishing, mnt= minnow trapping

| Date | Location | species | fork length (mm) | round weight (g) | method |
|---|---|---|---|---|---|
| 9/16/94 | sm3 | ss | 48 | | sn |
| 5/22/95 | sm3 | ag | 125 | | sn |
| 7/19/95 | sm3 | ag | 49 | | sn |
| 7/19/95 | sm3 | ag | 51 | | sn |
| 7/19/95 | sm3 | ag | 48 | | sn |
| 7/19/95 | sm3 | ag | 47 | | sn |
| 7/19/95 | sm3 | ag | 52 | | sn |
| 7/19/95 | sm3 | ag | 46 | | sn |
| 7/19/95 | sm3 | ag | 47 | | sn |
| 7/19/95 | sm3 | ag | 45 | | sn |
| 7/19/95 | sm3 | ag | 48 | | sn |
| 7/19/95 | sm3 | ag | 46 | | sn |
| 7/19/95 | sm3 | ag | 62 | | sn |
| 7/19/95 | sm3 | ag | 65 | | sn |
| 7/19/95 | sm3 | ag | 62 | | sn |
| 7/19/95 | sm3 | ag | 66 | | sn |
| 7/19/95 | sm3 | ag | 59 | | sn |
| 7/19/95 | sm3 | ag | 54 | | sn |
| 7/19/95 | sm3 | ag | 72 | | sn |
| 7/19/95 | sm3 | ag | 61 | | sn |
| 7/19/95 | sm3 | ag | 61 | | sn |
| 7/19/95 | sm3 | ag | 57 | | sn |
| 7/19/95 | sm3 | ag | 68 | | sn |
| 7/19/95 | sm3 | ag | 51 | | sn |
| 7/19/95 | sm3 | ag | 49 | | sn |
| 7/19/95 | sm3 | ag | 45 | | sn |
| 7/19/95 | sm3 | ag | 39 | | sn |
| 7/19/95 | sm3 | ag | 45 | | sn |
| 7/19/95 | sm3 | ag | 61 | | sn |
| 7/19/95 | sm3 | ag | 47 | | sn |
| 7/19/95 | sm3 | ag | 42 | | sn |
| 7/19/95 | sm3 | ag | 35 | | sn |
| 9/6/94 | sm4 | ag | 71 | 2 | sn |
| 9/6/94 | sm4 | ag | 92 | 4 | sn |
| 9/6/94 | sm4 | ag | 368 | 600 | ang |
| 9/6/94 | sm4 | np | 107 | 8 | sn |
| 9/6/94 | sm4 | rwf | 84 | | sn |
| 9/6/94 | sm4 | ss | 37 | | sn |
| 9/6/94 | sm4 | ss | 53 | | sn |
| 9/6/94 | sm4 | ss | 47 | | sn |
| 9/6/94 | sm4 | ss | 35 | | sn |
| 9/6/94 | sm4 | ss | 76 | | sn |
| 9/6/94 | sm4 | ss | 32 | | sn |
| 9/6/94 | sm4 | ss | 36 | | sn |
| 9/6/94 | sm4 | ss | 54 | | sn |

## APPENDIX E

### Summary of all fish sampled UKHM study 1994-95

ag= Arctic grayling, ss= slimy sculpin, al= Arctic lamprey, rwf= round whitefish
lns= longnose sucker, bb= burbot, ch= chinnok salmon, np= northern pike
sn= seine, els= electrofishing, mnt= minnow trapping

| Date | Location | species | fork length (mm) | round weight (g) | method |
|---|---|---|---|---|---|
| 9/6/94 | sm4 | ss | 64 | | sn |
| 9/6/94 | sm4 | ss | 39 | | sn |
| 9/6/94 | sm4 | ss | 33 | | sn |
| 9/6/94 | sm4 | ss | 37 | | sn |
| 9/6/94 | sm4 | ss | 58 | | sn |
| 9/6/94 | sm4 | ss | 40 | | sn |
| 9/6/94 | sm4 | ss | 42 | | sn |
| 9/6/94 | sm4 | ss | 36 | | sn |
| 9/6/94 | sm4 | ss | 35 | | sn |
| 9/7/94 | sm4 | bb | 250 | 100 | els test |
| 7/16/95 | sm4 | ag | 49 | | sn |
| 7/16/95 | sm4 | ag | 51 | | sn |
| 7/16/95 | sm4 | np | 400 | | angle |
| 7/16/95 | sm4 | np | 116 | | els |
| 7/16/95 | sm4 | np | 64 | | els |
| 7/16/95 | sm4 | np | 64 | | els |
| 9/5/94 | sm5 | ag | 398 | 600 | ang |
| 9/5/94 | sm5 | ag | 407 | 600 | ang |
| 9/5/94 | sm5 | ag | 378 | 500 | ang |
| 9/6/94 | sm5 | ag | 330 | 450 | ang |
| 9/6/94 | sm5 | ag | 337 | 400 | ang |
| 9/8/94 | sm5 | ag | 365 | 650 | ang |
| 9/6/94 | sm6 | ag | 71 | | sn |
| 9/6/94 | sm6 | ag | 83 | | sn |
| 9/6/94 | sm6 | ag | 74 | | sn |
| 9/6/94 | sm6 | ag | 77 | | sn |
| 9/6/94 | sm6 | ag | 72 | | sn |
| 9/6/94 | sm6 | lns | 35 | | sn |
| 9/6/94 | sm6 | ss | 39 | | sn |
| 9/6/94 | sm6 | ss | 44 | | sn |
| 9/6/94 | sm6 | ss | 35 | | sn |
| 9/6/94 | sm6 | ss | 43 | | sn |
| 9/6/94 | sm6 | ss | 53 | | sn |
| 9/6/94 | sm6 | ss | 36 | | sn |
| 9/6/94 | sm6 | ss | 44 | | sn |
| 9/8/94 | sm6 | bb | 289 | 99 | els |
| 9/8/94 | sm6 | np | 251 | 111 | els |
| 9/16/94 | sm6 | np | 240 | | sn |
| 9/16/94 | sm6 | ss | 41 | | sn |
| 9/6/94 | sm7 | ag | 68 | | sn |
| 9/6/94 | sm7 | ag | 75 | | sn |
| 9/6/94 | sm7 | ag | 190 | | sn |
| 9/6/94 | sm7 | ss | 62 | | sn |
| 9/6/94 | sm7 | ss | 61 | | sn |
| 9/6/94 | sm7 | ss | 36 | | sn |

## APPENDIX E

### Summary of all fish sampled UKHM study 1994-95

ag= Arctic grayling, ss= slimy sculpin, al= Arctic lamprey, rwf= round whitefish

lns= longnose sucker, bb= burbot, ch= chinnok salmon, np= northern pike

sn= seine, els= electrofishing, mnt= minnow trapping

| Date | Location | species | fork length (mm) | round weight (g) | method |
|---|---|---|---|---|---|
| 9/6/94 | sm7 | ss | 46 | | sn |
| 9/6/94 | sm7 | ss | 38 | | sn |
| 9/6/94 | sm7 | ss | 34 | | sn |
| 9/6/94 | sm7 | ss | 41 | | sn |
| 9/8/94 | sm7 | ag | 83 | 6 | els |
| 9/8/94 | sm7 | ag | 69 | | els |
| 9/8/94 | sm7 | lns | 40 | | els |
| 9/8/94 | sm7 | np | 191 | 41 | els |
| 9/16/94 | sm7 | ag | 68 | | sn |
| 9/16/94 | sm7 | ag | 63 | | sn |
| 9/16/94 | sm7 | ag | 92 | | sn |
| 9/16/94 | sm7 | ss | 36 | | sn |
| 9/16/94 | sm7 | ss | 41 | | sn |
| 9/16/94 | sm7 | ss | 36 | | sn |
| 9/16/94 | sm7 | ss | 39 | | sn |
| 9/16/94 | sm7 | ss | 36 | | sn |
| 9/16/94 | sm7 | ss | 31 | | sn |
| 9/16/94 | sm7 | ss | 54 | | sn |
| 9/16/94 | sm7 | ss | 40 | | sn |
| 9/16/94 | sm7 | ss | 36 | | sn |
| 9/16/94 | sm7 | ss | 40 | | sn |
| 9/16/94 | sm7 | ss | 60 | | sn |
| 9/16/94 | sm7 | ss | 41 | | sn |
| 9/16/94 | sm7 | ss | 31 | | sn |
| 9/16/94 | sm7 | ss | 41 | | sn |
| 9/16/94 | sm7 | ss | 56 | | sn |
| 9/16/94 | sm7 | ss | 42 | | sn |
| 9/16/94 | sm7 | ss | 35 | | sn |
| 9/16/94 | sm7 | ss | 48 | | sn |
| 9/16/94 | sm7 | ss | 43 | | sn |
| 9/16/94 | sm7 | ss | 52 | | sn |
| 9/16/94 | sm7 | ss | 52 | | sn |
| 9/16/94 | sm7 | ss | 46 | | sn |
| 9/16/94 | sm7 | ss | 37 | | sn |
| 6/2/95 | sm7 | al | 140 | | els |
| 6/2/95 | sm7 | np | 250 | | els |
| 7/17/95 | sm7 | ag | 46 | | sn |
| 7/17/95 | sm7 | ag | 72 | | sn |
| 7/17/95 | sm7 | ag | 60 | | sn |
| 7/17/95 | sm7 | ag | 48 | | sn |
| 7/17/95 | sm7 | ag | 59 | | sn |
| 7/17/95 | sm7 | ag | 61 | | sn |
| 7/17/95 | sm7 | ag | 54 | | sn |
| 7/17/95 | sm7 | ag | 56 | | sn |
| 7/17/95 | sm7 | ag | 48 | | sn |

# APPENDIX E

## Summary of all fish sampled UKHM study 1994-95

ag= Arctic grayling, ss= slimy sculpin, al= Arctic lamprey, rwf= round whitefish

lns= longnose sucker, bb= burbot, ch= chinnok salmon, np= northern pike

sn= seine, els= electrofishing, mnt= minnow trapping

| Date | Location | species | fork length (mm) | round weight (g) | method |
|---|---|---|---|---|---|
| 7/17/95 | sm7 | ag | 51 | | sn |
| 7/17/95 | sm7 | ss | 105 | | sn |
| 7/20/95 | sm7 | ag | 56 | | sn |
| 7/20/95 | sm7 | ag | 52 | | sn |
| 7/20/95 | sm7 | ag | 56 | | sn |
| 7/20/95 | sm7 | ag | 46 | | sn |
| 7/20/95 | sm7 | ag | 61 | | sn |
| 7/20/95 | sm7 | ag | 50 | | sn |
| 7/20/95 | sm7 | ag | 53 | | sn |
| 7/20/95 | sm7 | ag | 52 | | sn |
| 7/20/95 | sm7 | ag | 51 | | sn |
| 7/20/95 | sm7 | ag | 58 | | sn |
| 7/20/95 | sm7 | np | 74 | | sn |
| 7/20/95 | sm7 | rwf | 67 | | sn |
| 7/20/95 | sm7 | rwf | 66 | | sn |
| 7/20/95 | sm7 | rwf | 78 | | sn |
| 7/18/95 | sm8 | ag | 355 | | found |
| 7/20/95 | sm8 | np | 137 | | sn |
| 5/19/95 | sm9 | ag | 205 | | sn |
| 5/19/95 | sm9 | ag | 75 | | sn |
| 5/19/95 | sm9 | ag | 115 | | sn |
| 5/19/95 | sm9 | ag | 64 | | sn |
| 5/19/95 | sm9 | ag | 88 | | sn |
| 5/19/95 | sm9 | ag | 65 | | sn |
| 5/19/95 | sm9 | ag | 56 | | sn |
| 5/19/95 | sm9 | ag | 69 | | sn |
| 5/19/95 | sm9 | ag | 57 | | sn |
| 5/19/95 | sm9 | ag | 68 | | sn |
| 5/19/95 | sm9 | ag | 73 | | sn |
| 5/19/95 | sm9 | ag | 55 | | sn |
| 5/19/95 | sm9 | ag | 149 | | sn |
| 5/19/95 | sm9 | ag | 200 | | angle |
| 5/19/95 | sm9 | ag | 115 | | sn |
| 5/19/95 | sm9 | ag | 327 | | angle |
| 6/2/95 | sm9 | ag | 25 | | sn |
| 6/2/95 | sm9 | ag | 25 | | sn |
| 6/2/95 | sm9 | ag | 25 | | sn |
| 6/2/95 | sm9 | ag | 26 | | sn |
| 6/2/95 | sm9 | ag | 250 | | sn |
| 6/2/95 | sm9 | ag | 170 | | sn |
| 6/2/95 | sm9 | ag | 255 | | sn |
| 6/2/95 | sm9 | ag | 145 | | sn |
| 6/2/95 | sm9 | ag | 160 | | sn |
| 6/2/95 | sm9 | ag | 170 | | sn |
| 6/2/95 | sm9 | ag | 23 | | sn |

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| Date | Location | species | fork length (mm) | round weight (g) | method |
|---|---|---|---|---|---|
| 6/2/95 | sm9 | ag | 66 | | sn |
| 7/20/95 | sm9 | ch | 63 | | mnt |
| 7/20/95 | sm9 | ch | 65 | | mnt |
| 7/20/95 | sm9 | ch | 65 | | mnt |
| 7/20/95 | sm9 | ch | 64 | | mnt |
| 7/20/95 | sm9 | ch | 63 | | mnt |
| 7/20/95 | sm9 | ch | 67 | | mnt |
| 7/20/95 | sm9 | ch | 66 | | mnt |
| 7/20/95 | sm9 | ch | 67 | | mnt |
| 7/20/95 | sm9 | ch | 58 | | mnt |
| 7/20/95 | sm9 | ch | 63 | | mnt |
| 7/20/95 | sm9 | ch | 55 | | mnt |
| 5/20/95 | SML | ag | 327 | 400 | angle |
| 5/21/95 | SML | ag | 386 | 550 | angle |
| 5/21/95 | SML | ag | 307 | 260 | angle |
| 5/21/95 | SML | ag | 394 | 600 | angle |
| 5/21/95 | SML | ag | 368 | 600 | angle |
| 5/23/95 | SML | bb | 185 | 38 | mnt |
| 7/17/95 | SML | cisco | | | sn |
| 7/17/95 | SML | ag | 71 | | sn |
| 7/17/95 | SML | ag | 62 | | sn |
| 7/17/95 | SML | ag | 76 | | sn |
| 7/17/95 | SML | ag | 76 | | sn |
| 7/17/95 | SML | ag | 84 | | sn |
| 7/17/95 | SML | ag | 78 | | sn |
| 7/17/95 | SML | ag | 80 | | sn |
| 7/17/95 | SML | ag | 82 | | sn |
| 7/17/95 | SML | ag | 56 | | sn |
| 7/17/95 | SML | ag | 83 | | sn |
| 7/17/95 | SML | ag | 74 | | sn |
| 7/17/95 | SML | ag | 85 | | sn |
| 7/17/95 | SML | ag | 73 | | sn |
| 7/17/95 | SML | ag | 180 | | sn |
| 7/17/95 | SML | ag | 181 | | sn |
| 7/17/95 | SML | ag | 168 | | sn |
| 7/17/95 | SML | ag | 172 | | sn |
| 7/17/95 | SML | ag | 184 | | sn |
| 7/17/95 | SML | ag | 185 | | sn |
| 7/17/95 | SML | ag | 182 | | sn |
| 7/17/95 | SML | ag | 142 | | sn |
| 7/17/95 | SML | ag | 182 | | sn |
| 7/17/95 | SML | ag | 82 | | sn |
| 7/17/95 | SML | ag | 85 | | sn |
| 7/17/95 | SML | ag | 185 | | sn |
| 7/17/95 | SML | ag | 76 | | sn |

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sn= seine, els= electrofishing, mnt= minnow trapping

| Date | Location | species | fork length (mm) | round weight (g) | method |
|---|---|---|---|---|---|
| 7/17/95 | SML | ag | 80 | | sn |
| 7/17/95 | SML | ag | 75 | | sn |
| 7/17/95 | SML | ag | 72 | | sn |
| 7/17/95 | SML | ag | 75 | | sn |
| 7/17/95 | SML | ag | 65 | | sn |
| 7/17/95 | SML | ag | 72 | | sn |
| 7/17/95 | SML | ag | 85 | | sn |
| 7/17/95 | SML | ag | 72 | | sn |
| 7/17/95 | SML | ag | 77 | | sn |
| 7/17/95 | SML | ag | 74 | | sn |
| 7/17/95 | SML | ag | 73 | | sn |
| 7/17/95 | SML | ag | 87 | | sn |
| 7/17/95 | SML | ag | 62 | | sn |
| 7/17/95 | SML | ag | 63 | | sn |
| 7/17/95 | SML | np | 57 | | sn |
| 7/17/95 | SML | np | 215 | | sn |
| 7/17/95 | SML | rwf | 58 | | sn |
| 7/17/95 | SML | rwf | 58 | | sn |
| 7/17/95 | SML | rwf | 76 | | sn |
| 7/17/95 | SML | rwf | 68 | | sn |
| 7/17/95 | SML | rwf | 81 | | sn |
| 7/17/95 | SML | rwf | 75 | | sn |
| 7/17/95 | SML | rwf | 48 | | sn |
| 6/3/95 | sm6 | bb | 100 | | els |
| 6/2/95 | sm7 | bb | 140 | | els |

# Appendix VI

# Elsa Tailings and Groundwater Monitoring Investigation Field Program

## November 6 - 10, 1995

# ELSA TAILINGS AND GROUNDWATER MONITORING INVESTIGATION FIELD PROGRAM

## November 6th to 10th, 1995

## 1. Purpose of Program:

In order to be able to take measurements of metal levels in shallow groundwater flowing through Galena Hill and Keno Hill in the vicinity of some if the historic mining sites, piezometers were installed at twenty six locations.

Soil samples representative of the strata in the pits were taken for laboratory analysis in order to provide an understanding the soil geochemistry.

The selection of sites was made in order to intersect groundwater that may have been affected by surface and underground mining activities from the bulk of the UKHM property. The sites were initially selected based on examination of the 1995 air photos, and final refinements made upon field observations.

## 2. Equipment and Methods:

A Caterpillar 225 wide pad excavator was used to excavate the test pits. The seasonal frost crust of 0.1 to 0.3 metres was sufficient to support the hoe on otherwise inaccessible ground, yet was not an impediment to penetration by the bucket. Although many of the sites could have been accessed in the summer months, which would have facilitated description of the pits and better controlled sampling, some of the key sites are in soft wet ground, which would not be accessible by heavy equipment in summer conditions.

The pit depths were measured and recorded, and thirty five samples of 1-2 kilograms were taken. The samples were collected in plastic bags, taped shut to prevent oxidation. The samples have been shipped to Cominco Engineering Services Laboratory in Vancouver. Due to the cold ambient air temperature and the retained heat in the ground from the summer weather, freshly exposed soil at depth gave off considerable ice fog, which condensed instantly as frost on the pit wall. This, combined with seeping groundwater and poor light provided complications to observations. Although photographs were taken, it is anticipated that in most cases they will be less than useful. Detailed observations and descriptions of the soil strata were uncertain, therefore samples were taken representing one at the upper layer of soil in the pit, and one at the bottom of the pit.

Standard 50 mm PVC plastic piezometers were installed against one wall of each pit, and carefully backfilled by the hoe (with augmentation by hand shoveling at the pipe to prevent breakage) with material that had been excavated from the pit.

The piezometer sets consisted of one 5 foot slotted section covered with a geotextile "sock", threaded to a 10 foot section with a threaded cap. The geotextile sock was folded and taped over at the bottom, without a plastic cap. Metal tags with stamped numbers corresponding to the attached spreadsheet of pit locations were wired to the cap. The top 0.2 to 1.0 m of pipe protruding above the ground was spray painted orange to facilitate relocation during sampling visits. In some cases, two metres or more of pipe was left protruding, which will be cut off during warmer weather to facilitate sample collection.

Water sampling proved to be an unachievable goal due to cold weather (-25° to -35°C) conditions. In most cases, the minimal flow of groundwater froze instantly upon contact with the air, forming a glaciated sheet on the pit wall. In the few situations where there was significant groundwater flow so that glaciation did not occur, the sample in the bottle froze in the few minutes it took to transport the sample to a warm location.

It is not known whether groundwater samples can be taken from the piezometers in winter, but it is expected that the insulating soil cover is sufficient at some sites so that unfrozen groundwater will continue to flow past the piezometers.

## 3. Additional Sampling

One twenty litre pail of waste rock was collected at the Galkeno 900 adit site for inclusion in the waste rock characterization program. A low overhead power line prevented access by the hoe to the old tailings at the site of the old Galkeno Mill, and due to the seasonal frost, hand sampling was not possible.

## 4. Valley Tailings Deposit Examination

The test pit work conducted by Access Mining Consultants Ltd. on the valley tailings deposits has cast doubt on the previously accepted depths of these deposits. It should be noted that this examination does not provide enough data to recalculate tailings volumes, rather it is sufficient to demonstrate that more work should be done before any conclusions are drawn about the depths or the volume of tailings present in the valley.

The first indication that there was a misunderstanding of the thickness of the valley tailings deposit arose upon an attempt to find a location wherein a piezometer could be installed to sample shallow groundwater flow. Initial test pit digging in the area expected to contain five to seven metres of tailings (based upon verbal indications from a variety of sources) showed less than one metre thickness, and no groundwater flow. After discussions with mine site personnel, and a review of the UKHM report on the 1988 tailings drilling program, it was decided to complete a one kilometre transect of the tailings consisting of pits dug by the 225 excavator at one hundred metre intervals.

The transect was conducted across the "old" tailings, from the edge of water at the downstream (#3) pond, on a bearing of 127 degrees Azimuth across the tailings access road and onto the "new" tailings. In the area adjacent to the number 1 pond that is noted in the above mentioned 1988 report to average four to five metres thickness, nowhere was the depth greater that 1.4 metres. In order to provided accurate observation and measurement of the depth of the contact between the bottom of the tailings and the original ground, one pit in this area was excavated to a depth of seven metres. The location of the pit corresponds with the area that Environment Canada wished to see samples collected of deep tailings. This pit has the following strata:

- 0-1.3 metres : tailings
- 1.3 metres (contact): black stained brush, roots, leaves, moose antler, minimal groundwater seepage
- 1.3 - 5.1 metres : dark brown to black peat, occasionally silty, with wispy infiltration of tailings in top 0.3 metres
- 5.1 - 7.0 metres : sand and gravel, some cobbles (till?), significant groundwater flow

Due to significant groundwater infiltration (once the gravel stratum was intersected), and the fact that there were no "deep" tailings, no sample was collected at this site.

A further five pits were excavated, measured and photographed along the transect previously described. One additional deep pit was excavated adjacent to Porcupine Creek (also an area selected by Environment Canada for "deep" tailings sample collection). This pit, excavated to five metres depth, demonstrated a tailings depth of 3.4 metres, overlying black peat. Intersection of the sand and gravel at five metres caused rapid infilling of the pit with groundwater. A twenty litre sample of tailings at 3.4 metres (representing the deepest tailings encountered in the entire program) was collected for analysis. The locations and depths of the pits are shown on the overlay on the attached 1"=400' plan from the 1988 UKHM Tailings Drilling Report.

Once the physical nature of the contact between tailings and original ground was established by examination of the deep pit, the hoe operator was instructed to stop digging at the remaining sites when the black organic layer was intersected. These shallow pits have not been backfilled.

## 4.1 Comparison with earlier work

A check of the previous work indicates that there may have been errors in determining the depth of the contact between original ground and tailings due to sample interval contamination. The rotary, duocone drilling method moves disturbed sample up the outside of the drill hole to the collar by forced air. Use of this system when drilling through dry, cohesionless, dense tailings is problematic for accurate depth determination.

However, a review of the information in the UKHM report pertaining to areal extent of the tailings deposit, historic mill discharge figures, and tailings density assumptions does support an average depth of 3 metres. In the imperial units used in the UKHM report, the rough calculations are as follows:

- areal extent of existing tailings: approx. 8,000,000 square feet
- historic mill discharge : approx. 4,000,000 tons
- in situ density of tailings : 20 cubic feet per ton (= 1.6 tonnes/cu.m)
- therefore, the volume of tailings expected using these figures is approximately 80,000,000 cubic feet, which corresponds to an average depth of ten feet over the above surface area.

An eyeball estimate of the drilling figures indicates an approximate average depth of ten feet.

The November 1995 heavy equipment excavation program indicates an approximate average depth of three feet (in the area of the "old" tailings). Visual observations from ground traverses over the entire tailings area supports an expected two to four foot average depth.

There is a problem rationalizing the apparent good correlation between the expected depth based on the rough calculations listed above and the 1988 drill indicated depth, with the fact that the 1995 excavator testing indicates such a difference. It is possible that the variance arises from a collection of subtle but compounding errors, including inaccurate observations from drilling, inaccurate computations of total volume of tailings deposited in this area, and some movement of tailings.

These observations also raise questions about a possible migration of some of the tailings down the valley prior to the construction of the first two dams (date of construction unknown to the writer, expected to be in the early 1970's). There is, however, no evidence known to the writer of this possibility.

Without additional excavation coupled with surface surveying, and more precise calculation of other pertinent factors such as density and mill discharge, it is not possible to arrive at an accurate indication of the volume and depth of tailings present.

## 4.2 Conclusions

a) The previously accepted data about the thickness, location and volumes of the valley tailings should be taken as questionable.

c) More test work is required before important decisions are made about the valley tailings deposit.

The implications of these conclusions from the perspectives of abandonment planning and of possible future tailings reprocessing are not the subject of this report.

Robert L. McIntyre, C.E.T.
Vice President, Access Mining Consultants Ltd.

November 23, 1995

## APPENDIX E

### Summary of all fish sampled UKHM study 1994-95

ag= Arctic grayling, ss= slimy sculpin, al= Arctic lamprey, rwf= round whitefish

lns= longnose sucker, bb= burbot, ch= chinnok salmon, np= northern pike

sn= seine, els= electrofishing, mnt= minnow trapping

| Date | Location | species | fork length (mm) | round weight (g) | method |
|---|---|---|---|---|---|
| 6/2/95 | sm9 | ag | 66 | | sn |
| 7/20/95 | sm9 | ch | 63 | | mnt |
| 7/20/95 | sm9 | ch | 65 | | mnt |
| 7/20/95 | sm9 | ch | 65 | | mnt |
| 7/20/95 | sm9 | ch | 64 | | mnt |
| 7/20/95 | sm9 | ch | 63 | | mnt |
| 7/20/95 | sm9 | ch | 67 | | mnt |
| 7/20/95 | sm9 | ch | 66 | | mnt |
| 7/20/95 | sm9 | ch | 67 | | mnt |
| 7/20/95 | sm9 | ch | 58 | | mnt |
| 7/20/95 | sm9 | ch | 63 | | mnt |
| 7/20/95 | sm9 | ch | 55 | | mnt |
| 5/20/95 | SML | ag | 327 | 400 | angle |
| 5/21/95 | SML | ag | 386 | 550 | angle |
| 5/21/95 | SML | ag | 307 | 260 | angle |
| 5/21/95 | SML | ag | 394 | 600 | angle |
| 5/21/95 | SML | ag | 368 | 600 | angle |
| 5/23/95 | SML | bb | 185 | 38 | mnt |
| 7/17/95 | SML | cisco | | | sn |
| 7/17/95 | SML | ag | 71 | | sn |
| 7/17/95 | SML | ag | 62 | | sn |
| 7/17/95 | SML | ag | 76 | | sn |
| 7/17/95 | SML | ag | 76 | | sn |
| 7/17/95 | SML | ag | 84 | | sn |
| 7/17/95 | SML | ag | 78 | | sn |
| 7/17/95 | SML | ag | 80 | | sn |
| 7/17/95 | SML | ag | 82 | | sn |
| 7/17/95 | SML | ag | 56 | | sn |
| 7/17/95 | SML | ag | 83 | | sn |
| 7/17/95 | SML | ag | 74 | | sn |
| 7/17/95 | SML | ag | 85 | | sn |
| 7/17/95 | SML | ag | 73 | | sn |
| 7/17/95 | SML | ag | 180 | | sn |
| 7/17/95 | SML | ag | 181 | | sn |
| 7/17/95 | SML | ag | 168 | | sn |
| 7/17/95 | SML | ag | 172 | | sn |
| 7/17/95 | SML | ag | 184 | | sn |
| 7/17/95 | SML | ag | 185 | | sn |
| 7/17/95 | SML | ag | 182 | | sn |
| 7/17/95 | SML | ag | 142 | | sn |
| 7/17/95 | SML | ag | 182 | | sn |
| 7/17/95 | SML | ag | 82 | | sn |
| 7/17/95 | SML | ag | 85 | | sn |
| 7/17/95 | SML | ag | 185 | | sn |
| 7/17/95 | SML | ag | 76 | | sn |

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| 7/17/95 | SML | ag | 75 | | sn |
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| 7/17/95 | SML | ag | 75 | | sn |
| 7/17/95 | SML | ag | 65 | | sn |
| 7/17/95 | SML | ag | 72 | | sn |
| 7/17/95 | SML | ag | 85 | | sn |
| 7/17/95 | SML | ag | 72 | | sn |
| 7/17/95 | SML | ag | 77 | | sn |
| 7/17/95 | SML | ag | 74 | | sn |
| 7/17/95 | SML | ag | 73 | | sn |
| 7/17/95 | SML | ag | 87 | | sn |
| 7/17/95 | SML | ag | 62 | | sn |
| 7/17/95 | SML | ag | 63 | | sn |
| 7/17/95 | SML | np | 57 | | sn |
| 7/17/95 | SML | np | 215 | | sn |
| 7/17/95 | SML | rwf | 58 | | sn |
| 7/17/95 | SML | rwf | 58 | | sn |
| 7/17/95 | SML | rwf | 76 | | sn |
| 7/17/95 | SML | rwf | 68 | | sn |
| 7/17/95 | SML | rwf | 81 | | sn |
| 7/17/95 | SML | rwf | 75 | | sn |
| 7/17/95 | SML | rwf | 48 | | sn |
| 6/3/95 | sm6 | bb | 100 | | els |
| 6/2/95 | sm7 | bb | 140 | | els |

# Appendix VI

# Elsa Tailings and Groundwater Monitoring Investigation Field Program

## November 6 - 10, 1995

# ELSA TAILINGS AND GROUNDWATER MONITORING INVESTIGATION FIELD PROGRAM

## November 6th to 10th, 1995

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- 5.1 - 7.0 metres : sand and gravel, some cobbles (till?), significant groundwater flow

Due to significant groundwater infiltration (once the gravel stratum was intersected), and the fact that there were no "deep" tailings, no sample was collected at this site.

A further five pits were excavated, measured and photographed along the transect previously described. One additional deep pit was excavated adjacent to Porcupine Creek (also an area selected by Environment Canada for "deep" tailings sample collection). This pit, excavated to five metres depth, demonstrated a tailings depth of 3.4 metres, overlying black peat. Intersection of the sand and gravel at five metres caused rapid infilling of the pit with groundwater. A twenty litre sample of tailings at 3.4 metres (representing the deepest tailings encountered in the entire program) was collected for analysis. The locations and depths of the pits are shown on the overlay on the attached 1"=400' plan from the 1988 UKHM Tailings Drilling Report.

Once the physical nature of the contact between tailings and original ground was established by examination of the deep pit, the hoe operator was instructed to stop digging at the remaining sites when the black organic layer was intersected. These shallow pits have not been backfilled.

## 4.1 Comparison with earlier work

A check of the previous work indicates that there may have been errors in determining the depth of the contact between original ground and tailings due to sample interval contamination. The rotary, duocone drilling method moves disturbed sample up the outside of the drill hole to the collar by forced air. Use of this system when drilling through dry, cohesionless, dense tailings is problematic for accurate depth determination.

However, a review of the information in the UKHM report pertaining to areal extent of the tailings deposit, historic mill discharge figures, and tailings density assumptions does support an average depth of 3 metres. In the imperial units used in the UKHM report, the rough calculations are as follows:

- areal extent of existing tailings: approx. 8,000,000 square feet
- historic mill discharge : approx. 4,000,000 tons
- in situ density of tailings : 20 cubic feet per ton (= 1.6 tonnes/cu.m)
- therefore, the volume of tailings expected using these figures is approximately 80,000,000 cubic feet, which corresponds to an average depth of ten feet over the above surface area.

An eyeball estimate of the drilling figures indicates an approximate average depth of ten feet.

The November 1995 heavy equipment excavation program indicates an approximate average depth of three feet (in the area of the "old" tailings). Visual observations from ground traverses over the entire tailings area supports an expected two to four foot average depth.

There is a problem rationalizing the apparent good correlation between the expected depth based on the rough calculations listed above and the 1988 drill indicated depth, with the fact that the 1995 excavator testing indicates such a difference. It is possible that the variance arises from a collection of subtle but compounding errors, including inaccurate observations from drilling, inaccurate computations of total volume of tailings deposited in this area, and some movement of tailings.

These observations also raise questions about a possible migration of some of the tailings down the valley prior to the construction of the first two dams (date of construction unknown to the writer, expected to be in the early 1970's). There is, however, no evidence known to the writer of this possibility.

Without additional excavation coupled with surface surveying, and more precise calculation of other pertinent factors such as density and mill discharge, it is not possible to arrive at an accurate indication of the volume and depth of tailings present.

## 4.2 Conclusions

a) The previously accepted data about the thickness, location and volumes of the valley tailings should be taken as questionable.

c) More test work is required before important decisions are made about the valley tailings deposit.

The implications of these conclusions from the perspectives of abandonment planning and of possible future tailings reprocessing are not the subject of this report.

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