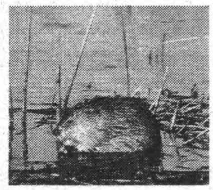
Canada Alberta Northwest Territories

Northern River Basins Study







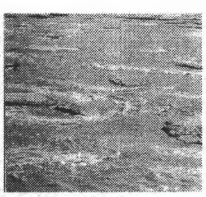


NORTHERN RIVER BASINS STUDY PROJECT REPORT NO. 129

ENVIRONMENTAL CONTAMINANTS IN FISH:

SPATIAL AND TEMPORAL TRENDS OF POLYCHLORINATED DIBENZO-*p*-DIOXINS AND DIBENZOFURANS,

PEACE, ATHABASCA AND SLAVE RIVER BASINS, 1992 TO 1994






Prepared for the
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by

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PREFACE:

The Northern River Basins Study was initiated through the "Canada-Alberta-Northwest Territories Agreement Respecting the Peace-Athabasca-Slave River Basin Study, Phase II - Technical Studies" which was signed September 27, 1991. The purpose of the Study is to understand and characterize the cumulative effects of development on the water and aquatic environment of the Study Area by coordinating with existing programs and undertaking appropriate new technical studies.

This publication reports the method and findings of particular work conducted as part of the Northern River Basins Study. As such, the work was governed by a specific terms of reference and is expected to contribute information about the Study Area within the context of the overall study as described by the Study Final Report. This report has been reviewed by the Study Science Advisory Committee in regards to scientific content and has been approved by the Study Board of Directors for public release.

It is explicit in the objectives of the Study to report the results of technical work regularly to the public. This objective is served by distributing project reports to an extensive network of libraries, agencies, organizations and interested individuals and by granting universal permission to reproduce the material.

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Whereas the above publication is the result of a project conducted under the Northern River Basins Study and the terms of reference for that project are deemed to be fulfilled,
IT IS THEREFORE REQUESTED BY THE STUDY OFFICE THAT;
this publication be subjected to proper and responsible review and be considered for release to the public.

F. J. Wrona — 14 May 96

(Dr. Fred J. Wrona, Science Director) (Date)

Whereas it is an explicit term of reference of the Science Advisory Committee "to review, for scientific content, material for publication by the Board",
IT IS HERE ADVISED BY THE SCIENCE ADVISORY COMMITTEE THAT;
this publication has been reviewed for scientific content and that the scientific practices represented in the report are acceptable given the specific purposes of the project and subject to the field conditions encountered.
SUPPLEMENTAL COMMENTARY HAS BEEN ADDED TO THIS PUBLICATION: [ ] Yes [ ] No

P. A. Larkin — 24 May /96

(Dr. P. A. Larkin, Ph.D., Chair) (Date)

Whereas the Study Board is satisfied that this publication has been reviewed for scientific content and for immediate health implications,
IT IS HERE APPROVED BY THE BOARD OF DIRECTORS THAT;
this publication be released to the public, and that this publication be designated for: **[ ] STANDARD AVAILABILITY [ ] EXPANDED AVAILABILITY**

Lucille Partington — May 29/96

(Lucille Partington, Co-chair) (Date)

Robert McLeod — May 21/96

(Robert McLeod, Co-chair) (Date)

ENVIRONMENTAL CONTAMINANTS IN FISH: SPATIAL AND TEMPORAL TRENDS OF POLYCHLORINATED DIBENZO-*P*-DIOXINS AND DIBENZOFURANS, PEACE, ATHABASCA AND SLAVE RIVER BASINS, 1992 TO 1994

STUDY PERSPECTIVE

A major goal of the Northern River Basins Study is to determine the effects of contaminants from industrial and municipal sources on the aquatic ecosystem of the Peace, Athabasca and Slave rivers. Contaminant information for these basins was lacking and additional research needed to be done to describe the nature and distribution of chemical contaminants entering the rivers. Such information would allow scientists to assess contaminant fate and toxicity for aquatic life and humans. People were particularly interested in the dioxin / furan group of chlorinated hydrocarbons because of their toxicity and ability to bioaccumulate in animal / fish tissue. Three Alberta pulp mills used chlorine in their pulping processes and were known contributors of dioxin and furan. The presence, abundance and affects of these compounds in the basin were of major interest.

Related Study Questions

4a) Describe the contents and nature of the contaminants entering the system and describe their distribution and toxicity in the aquatic ecosystem with particular reference to water, sediment and biota.

8) Recognizing that people drink water and eat fish from these rivers systems, what is the current concentration of contaminants in water and edible fish tissue and how are these levels changing through time and by location?

13a) What predictive tools are required to determine the cumulative effects of man-made discharges on the water and aquatic environment?

b) What are the cumulative effects of man-made discharges on the water and aquatic environment?

This report succeeds an earlier report that described the levels of polychlorinated dibenzo-p-dioxins and dibenzofurans in water, sediment, suspended sediment, invertebrates and mountain whitefish and northern pike samples collected during the spring of 1992. A significant finding of the earlier work was the high concentration of these contaminants in fish flesh near the pulp mill at Hinton and the role that suspended sediment transport may have in the availability and movements of contaminants in the food chain. Follow-up collection and analysis of fish (mountain whitefish, burbot) and sediment samples throughout the Study area was undertaken to describe possible spatial and temporal trends.

Examination of data arising from NRBS, industry and other regulatory initiatives, indicates that there has been a definite decline in the 2,3,7,8 - trichlorodibenzodioxin and furans found in fish tissues below Hinton but that most of this decrease took place between 1988 and 1992. Some fish tissues, e.g., burbot liver, tend to have higher concentrations of dioxins and furans. Generally, there has been a 3 to 5 fold decline in the previously reported levels of contaminants, depending on location and fish species. Except for some individual fish tissue measurements, e.g., burbot liver, the mean concentration of contaminants found in all fish sampled were below the level set by Health Canada for the commercial sale and export of fish (20 parts per trillion). Examination of composite fish muscle tissue samples collected from the Peace-Athabasca delta subsistence fishery revealed concentrations at or near the level of analytical detection. These latter values compared favourably with values obtained at other control or far field sample-sites.

The decline of the dioxins and furans is attributed in part to the pulp mills instituting a change in pulping processes from elemental chlorine to chlorine dioxide substitution. Further work is recommended to determine whether the diminishment of the contaminants in fish tissue, water and sediment will continue since dioxins and furans present themselves as more of a human health concern than PCBs or organochlorine pesticides. Levels of dioxins and furans in the Hinton to Whitecourt reach of the Athabasca River exceed draft Canadian Environmental Quality Guidelines for protection of wildlife (1.1 part per trillion) and warrants further examination to see if the observed declines continue to a level below draft EQG.

REPORT SUMMARY

As part of the work to examine the impact of development on ecosystem health and integrity on the Peace and Athabasca river basins in Alberta, the Northern River Basin Study (NRBS) was required to determine "the contents and nature of the contaminants entering the system ... particular reference to water, sediments and biota" and to determine "... the current concentration of contaminants in water and edible fish tissue and how are these levels changing through time and by location". The Reach Specific Study (RSS) was designed to measure spatial and temporal trends of contaminants including polychlorinated dibenzo-*p*-dioxins and -dibenzofurans (PCDD/Fs) in sediment, water and and biota (fish and invertebrate) samples collected at six locations on the upper Athabasca River downstream of Hinton (AB) in spring 1992, fall 1992 and spring 1993. The General Fish Collection (spring 1992), the Long nose sucker and Northern pike liver study (fall 1994) and the Special Burbot Collection (fall 1992 and 1994), and the Ft. Chipewyan winter fishery study (1994/95) were also conducted to examine levels in fish tissues within the Athabasca, Peace and Slave River basins. The purpose of this report is to summarize the levels of PCDDs and PCDFs in fish from these various studies and to assess temporal trends of 2,3,7,8-TCDD and 2,3,7,8-TCDF by comparison with previously published data. A second objective was to reexamine pathways of accumulation of 2,3,7,8-TCDD and 2,3,7,8-TCDF from water and suspended sediment to fish, first measured in the upper Athabasca River in 1992 (Pastershank and Muir 1995).

The major PCDD/F congeners in muscle (skinless fillet) of mountain whitefish and northern pike samples collected in the upper Athabasca River downstream of Hinton in fall 1992 and spring 1993 were 2,3,7,8-TCDD and -TCDF. Mean concentrations of 2,3,7,8-TCDD in mountain whitefish ranged 0.6 to 7.7 $pg \cdot g^{-1}$ wet wt and from 1.7 to 9.8 $pg \cdot g^{-1}$ for 2,3,7,8-TCDF. Concentrations of other 2,3,7,8-substituted penta- to octachloro- PCDD/F congeners were generally much lower or non-detectable in both species. Two lower chlorinated congeners, 2,7/2,8-dichlorodibenzodioxin and 2,3,8-trichlorodibenzofuran were detected in most samples of mountain whitefish from fall 1992 at low $pg \cdot g^{-1}$ concentrations. TCDF was the most frequently detected PCDD/F congener in longnose sucker and northern pike livers collected from the Wapiti/Smoky and Peace Rivers in fall 1994. TCDF concentrations in liver were in the low $pg \cdot g^{-1}$ range similar to levels in muscle of these species. Highest concentrations of TCDF in livers of longnose sucker (9.2 ± 17.8 $pg \cdot g^{-1}$) were found at a site on the Smoky River (SR1) downstream of the pulp mill effluent near Grande Prairie.

Temporal trends in 2,3,7,8-TCDD and -TCDF in mountain whitefish were examined over a four year period by combining the three sampling times in the upper Athabasca River with data from previous studies (DFO National Dioxin Program 1989). There was a definite decline in 2,3,7,8-TCDD and -TCDF concentrations in mountain whitefish downstream of the Hinton but most of the decrease took place in the period 1989 to 1992. The extent of the decline depends to a large extent on which results for spring 1993 are used. If samples from the near-field sites of Weldwood and Obed (mean concentrations of 1.1 and 2.6 $pg \cdot g^{-1}$ wet, for TCDD and TCDF respectively) are used the decline is about five-fold for both TCDD and TCDF over four years. But if the fish from Emerson Lake (48 km downstream) are included (mean concentrations are 3.6 and 7.1 $pg \cdot g^{-1}$ wet, for TCDD and TCDF, respectively) the decline is about 3-fold.

In general, concentrations of PCDD/Fs were higher in burbot liver than in muscle or liver of mountain whitefish or northern pike and a greater number of congeners were detected. TCDF was detected

(mean concentrations, 0.30 to 65 pg·g^{-1}) in 86% of all 203 burbot liver samples analysed, while 2,3,7,8-TCDD was detected in 35% of samples (mean concentrations, <0.3 to 8.5 pg·g^{-1}). Two other 2,3,7,8-substituted- PCDD/F congeners, 1,2,3,6,7,8-HxCDD and the heptachlorodioxin, 1,2,3,4,6,7,8-HpCDD were detected in 37% of burbot liver samples. OCDD was also detected relatively frequently (17%) while OCDF was found in only 3 of 203 samples. Di and trichloro-CDDs and CDFs were detected infrequently in burbot liver and at low levels relative to tetra- to octachloro congeners. Significantly higher levels (ANCOVA; Tukey's or least squares means test) of TCDD and TCDF were found in burbot liver downstream of the Hinton BKM than at all other sites.

Levels of 2,3,7,8-TCDD and -TCDF in burbot liver were lower in the fall 1994 collection than in fall 1992 at four sites; downstream of the Grande Prairie pulp mill outlet, PR2 on the Peace River near the mouth of the Notikewin River (674 km from confluence of the Peace/Slave), and PR3 upstream of Fort Vermillion (396 km). Comparison of concentrations in burbot liver near the BKM at Grande Prairie was problematic because sampling sites were not in the same locations each year. Nevertheless, the results show a decline of 4 to 17-times in the case of 2,3,7,8-TCDF at three sites. No significant decline of TCDD or TCDF concentrations was found in burbot livers from PR2. The burbot liver results, expressed as TCDD TEQ's, also agreed well with those of Swanson et al. (1995) who found a 5-fold decline in TEQs downstream of the Grande Prairie BKM between summer 1991 and spring 1994.

Concentrations of all 2,3,7,8-substituted PCDD/F congeners in composite samples of fish muscle from the Ft. Chipewyan domestic winter fishery in the Peace-Athabasca delta were at or near detection limits (<0.1 to <0.8 pg·g^{-1}). Only 2,3,7,8-TCDF was detectable in most samples (<0.1 to 0.5 pg·g^{-1}). Burbot liver samples from the three sites in the Peace-Athabasca delta had higher levels of 2,3,7,8-TCDF than burbot muscle (1.7 to 2.9 pg·g^{-1}). These levels were similar to those at other far-field and reference sites located far from BKMs.

The bioavailability of TCDD and TCDF to mountain whitefish and northern pike was assessed using biota-sediment (or suspended sediment) accumulation factors (BSAF/BSSAFs). BSAFs for 2,3,7,8-TCDD ranged from 1.1 to 2.0 and for TCDF from 0.19 to 1.63 in mountain whitefish in spring 1992. A similar range of BSAFs was found in 1993. BSSAFs for both 2,3,7,8-TCDD and TCDF were generally lower and showed greater consistency than BSAFs with distance from the BKM. The results suggest that TCDD/TCDF levels in fish can be estimated with an average, site specific, BSAF or BSSAF using concentrations of TCDD/F in bed sediment or suspended sediments. Application of the Thomann and Connolly food chain model (steady-state version) to predict levels of TCDF in the food web downstream of Hinton showed that good agreement between predicted and observed results could be obtained for benthic feeding organisms (and longnose suckers and pike) which were close to equilibrium with sediments or biofilm. The model overpredicted concentrations in filter-feeding invertebrates and mountain whitefish; these organisms are not in equilibrium with TCDF in the water and suspended solids in the river due to the dynamic nature of the system.

All mean concentrations of TCDD TEQs in fish muscle or liver were below the limit of 20 pg·g^{-1} (wet wt) set by Health Canada for commercial sale and export of fish. A few individual samples, mainly burbot liver from the Athabasca River downstream of Hinton, exceeded the 20 pg·g^{-1} guideline. Assuming TCDD TEQs of 8.3 pg·g^{-1} in mountain whitefish downstream of Hinton a 60 kg individual would have to consume 72 g of mountain whitefish muscle per day to exceed the Health Canada

Tolerable Daily Intake (10 pg·kg-body wt^{-1}·day^{-1}) for TCDD. More typical levels of TCDD TEQs in fish muscle are those found in lake whitefish, goldeye, burbot muscle and walleye sampled in the Peace-Athabasca delta. TCDD TEQs in these samples are about 0.5 pg·g^{-1} or less. A 60 kg individual would have to consume 1.2 kg per day to exceed the TDI for these samples.

TCDD TEQ levels in mountain whitefish muscle from the upper Athabasca River exceeded draft Canadian environmental quality guidelines (EQGs) for protection of wildlife (1.1 pg·g^{-1} wet wt) in spring 1993. The concentrations of PCDD/Fs observed in river water and sediments also exceeded EQGs for raw water (for protection of aquatic life) of 0.02 pg·L^{-1} and sediment (0.091 pg·g^{-1}) downstream of Hinton in spring 1992 and 1993.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1.0 INTRODUCTION

The Northern River Basin Study (NRBS) was designed to examine the impact of development on ecosystem health and integrity on three large river basins in Alberta and the Northwest Territories: Athabasca, Peace, and Slave. There are over 100 projects in eight study areas: contaminants, nutrients, hydrology/hydraulics, drinking water, food chain, synthesis/modelling, traditional knowledge, and other uses. This report summarizes results for polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) in fishes collected from the Athabasca River during fall of 1992, spring 1993, from the Peace- Athabasca delta in 1994-95, and in burbot livers collected on both the Athabasca, Peace and Slave Rivers and their tributaries during the fall of 1994.

The NRBS study board has prepared 16 guiding questions to ensure project leaders address a common mandate. The two questions most relevant to this report are:

4-a) "What are the contents and nature of the contaminants entering the system and what is their distribution and toxicity in the aquatic ecosystem with particular reference to water, sediments and biota?"

8) "... what is the current concentration of contaminants in water and edible fish tissue and how are these levels changing through time and by location?"

The Reach Specific Study (RSS) initiated in the spring of 1992 was designed to address these questions by determining spatial and temporal trends of a large suite of contaminants (metals, polyaromatic hydrocarbons, organochlorine pesticides, PCDD/Fs) in abiotic and biotic samples collected at six locations on the upper Athabasca River downstream of Hinton, Alberta. The General Fish Collection and the Special Burbot Collection (1992 and 1994), and the Fort Chipewyan winter domestic fishery study were also conducted to examine levels on a larger scales within the Peace, Athabasca and Slave River basins. Liver samples from longnose suckers collected from the upper Athabasca River in 1992 were also analysed for PCDD/Fs. Results for PCDD/Fs in montain whitefish, longnose suckers and northern pike muscle samples from the upper Athabasca River in spring 1992 have been reported by Pastershank and Muir (1995). Results for PCBs, chlorinated phenolics and organochlorine pesticides in fish from the upper Athabasca River study, the General Fish collection, Ft. Chipewyan winter domestic fishery, and Special Burbot Collections are reported by Pastershank and Muir (1996).

The presence of polychlorinated dibenzo-*p*-dioxins and -dibenzofurans (PCDD/Fs) in fishes and sediments downstream of pulp mills using chlorine bleaching (BKMs) has been well documented in Canada (Whittle et al. 1993; Trudel 1991), the US (Keuhl et al. 1989) and Europe (Swanson et al. 1988) since first observed in 1987. The pulp and paper industry in Canada, the USA and Scandinavia has reduced the emissions of PCDD/Fs by reductions in use of Cl_2, substitution of ClO_2, and other process changes over the past five years (Strömberg et al. 1995).

Initial surveys of fish and bottom sediments downstream of two BKMs in Alberta in 1988-89 showed detectable levels of the two most common PCDD/F congeners, 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD) and 2,3,7,8-tetrachlorodibenzofuran (2,3,7,8-TCDF) (Trudel 1991; Whittle et al. 1993; Owens et al. 1994). Since that time the pulp and paper industry in the Peace-Athabasca basin has reduced the use of molecular chlorine. Weyerhauser Canada Ltd. at Grande Prairie (Wapiti River) had implemented a 25% substitution of molecular chlorine with chlorine dioxide in 1989, which rose to 70% in early 1991, and 100% during the summer of 1992 (Owens et al. 1994). In June 1993, the Weldwood of Canada Ltd. at Hinton (Athabasca River) shifted from 45% to 100% substitution of molecular chlorine with chlorine dioxide. As of October 1995, three of the four BKMs on the Peace-Athabasca system were at 100% ClO_2 substitution with only the Diashowa mill still using molecular chlorine. Emissions of 2,3,7,8-TCDD by each of the three mills at full ClO_2 substitution were <1 pg·L^{-1} (the approximate detection limit) while emissions of 2,3,7,8-TCDF continued at low levels (<1.6 - 6.3 1 pg·L^{-1})(Weldwood 1995). These changes in the pulp bleaching technology have been shown to reduce the loadings of PCDD/Fs to the Wapiti/Smoky Rivers and to reduce the concentrations in riverine biota (Owens et al. 1994). A similar trend was anticipated downstream of Hinton although past emissions deposited in sediments along the river bed could be remobilized during high flows thereby complicating interpretion of the bioaccumulation pathway. Initial work by NRBS on PCDD/Fs in the aquatic food web in spring 1992 (Pastershank and Muir 1995) did not address temporal trends because it represented a single "snapshot" of the prevailing concentrations.

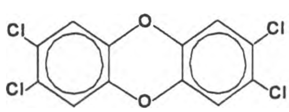
The purpose of this report is to summarize the levels of PCDDs and PCDFs in fish from fall 1992 and spring 1993 in the upper Athabasca River and to assess temporal trends of 2,3,7,8-TCDD and 2,3,7,8-TCDF in fish from this reach using previously published data. A second objective was to examine the spatial trends of PCDD/Fs in burbot livers collected in 1994 and to compare them with results from 1992 and with other reports on PCDD/Fs in burbot liver from studies on the Slave River, Great Slave Lake and other subarctic lakes.

2.0 BACKGROUND INFORMATION ON CHLORINATED DIOXINS AND FURANS

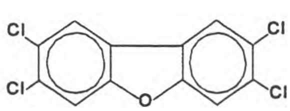
In our previous report (Pastershank and Muir 1995) we reviewed the published information on physiochemical properties, persistence, bioaccumulation and toxicity of PCDDs and PCDFs. This information is briefly summarized in the following section with references to the appropriate scientific literature.

2.1. STRUCTURE, PERSISTENCE AND TOXICITY

PCDDs and PCDFs are large families of chlorinated hydrocarbons consisting of 75 PCDD and 135



2,3,7,8-TCDD



2,3,7,8-TCDF

PCDF congeners (each congener having a different Cl substitution pattern). The core molecules are tricyclic aromatic structures: two benzene rings connected by a third ring containing a single oxygen atom for the furans and two oxygen atoms for the dioxins (see structures 2,3,7,8-TCDD/F above). PCDD/Fs all display relatively similar molecular, physical, and chemical properties. An increase in chlorine substitution of PCDD/Fs is positively correlated to greater hydrophobicity (insolubility in water), lipophilicity (strong affinity for lipids), and environmental persistence (Mackay et al. 1992).

PCDD/Fs are characterized as environmentally stable and persistent compounds. Recent reviews by Fletcher and McKay (1993) and Hites (1990) provide good overviews of current information on the environmental behavior of PCDD/Fs. The two major pathways of degradation of PCDD/Fs in the aquatic environment are photolysis and biodegradation.

The toxicity of 2,3,7,8-TCDD to aquatic life was thoroughly reviewed in a recent report by the US Environmental Protection Agency (USEPA 1993). Most studies support the hypothesis that fish are more sensitive to 2,3,7,8-TCDD than mammals or aquatic macroinvertebrates (USEPA 1993). Toxic effects caused by 2,3,7,8-TCDD/F in fish are species-specific and include effects on mixed function oxidase (MFO) enzyme induction, reproduction (e.g., hormone dysfunction and fetotoxicity), behaviour, immune systems, and development (e.g., wasting syndrome), as well as hepatoxicity (e.g., liver lesions) and teratogenicity (birth defects)(Cooper 1989, USEPA 1993). Increases in mortality occurred in lake trout fry when body burdens exceeded 0.055 ng g^{-1} (Walker et al. 1991). The levels of 2,3,7,8-TCDD required to generate a 50% lethality (LD_{50}) in carp and rainbow trout ranged from one to two ng g^{-1} (Cook et al. 1991). MFO enzyme activity responses to 2,3,7,8-TCDD have been observed in rainbow trout liver at 0.02 ng g^{-1} (Parrott et al. 1995).

2.2 SOURCES OF PCDDs AND PCDFs

PCDDs/Fs were first detected during the late 1980's in the pulp, effluent, and sludge from BKMs using chlorine (Keuhl et al. 1987, Swanson et al. 1988, Amendola et al. 1989, Clement et al. 1989, Safe 1990) and in many pulp products such as paper, coffee filters, and diapers (Safe 1990). The predominant PCDD/Fs identified in the effluent of BKMs were 2,3,7,8-TCDD, 2,3,7,8-TCDF, and 1,2,7,8-TCDF (Muller and Halliburton 1990).

The production of PCDD/F is the result of aqueous chlorination of the precursor molecules such as unsubstituted dibenzo-*p*-dioxin and dibenzofuran, chlorophenols, and chlorinated hydroxydiphenyl ethers. These precursors are formed during either the chlorination or extraction stages of pulp production as a result of a complex series of reactions including chlorination, oxidation, and demethylation (Alasdair et al. 1990, Fiedler et al. 1990, USEPA 1990). It was found that the substitution of the strong chlorination agent, molecular chlorine, with other oxidants such as ClO_2 and hydrogen peroxide could substantially reduce emissions of many chlorinated byproducts including PCDD/Fs (Swanson et al. 1988, Craig et al. 1990).

Other possible sources of PCDD/Fs in pulp mill effluent are the tetra- and pentachlorophenol fungicides. PCDD/Fs were found to be contaminants in these fungicides which were used to treat wood chips, especially in coastal BC (Yunker and Cretney 1995; USEPA 1990). Penta- and tetrachlorophenols are no longer registered for use for wood preservation in Canada, however, they are persistent compounds which may still be found at some locations. This source is characterized by non-detectable levels of 2,3,7,8-TCDD, and higher proportions of hexa-, hepta- and octachloro-dioxin and -furan congeners (Hagenmaier and Brunner, 1987).

The major source of PCDD/Fs to the global environment is combustion, especially emissions of waste incinerators (Fiedler et al. 1990,USEPA 1993). Other combustion-related sources include exhaust from automobile combustion of diesel and leaded fuels and cigarette smoke (Buchert and Ballschmiter 1986, Marklund et al. 1990). Forest fires may represent a major "natural" source of some PCDD/Fs although evidence for this is largely indirect. Measurements of PCDD/Fs in soils and vegetation from the past century shows low concentrations of octachlorodioxin (Kjeller et al.1991) which, assuming that they are not from lab contamination, are indicative of combustion sources prior to the introduction of chlorinated organic chemicals during this century. Analysis of dated sediment cores, as well as archived soils and plants, clearly shows an increased in combustion related PCDD/Fs since the 1930's (Hites 1990). The pattern of PCDD/F congeners in combustion sources is dominated by non-2,3,7,8-substituted congeners with OCDD predominating, and can be readily distinguished from pulp mill sources.

2.3 INTERNATIONAL TOXICITY EQUIVALENT FACTORS (I-TEFS)

International Toxicity Equivalent Factors (I-TEFs) have been assigned to 17 of the most hazardous PCDD/Fs (Safe 1990) as well as to non-ortho and mono-ortho-substituted PCBs (Ahlborg et al. 1994). I-TEFs allow the total toxicity to be expressed as a single Toxic Equivalent (TEQ) value (Equation 1). The most toxic congener, 2,3,7,8-TCDD, has been appointed a value of 1. The remaining 16 PCDD/F congeners were given I-TEF values in proportions to their relative toxicity to 2,3,7,8-TCDD. For example the I-TEF for 2,3,7,8-TCDF is 0.1. The I-TEFs for lower chlorinated PCDD/Fs, such as dichlorodibenzodioxin (DCDD), have not been assigned but are assumed to be zero. TEQs are calculated by multiplying the I-TEF by congener concentration:

$$TEQ = \Sigma_{n=1 \text{ to } 17} (\text{I-TEF}_i \times [\text{contaminant}]_i) \qquad \text{(Equation 1)}$$

where $[\text{contaminant}]_i$ = the concentration of a PCDD, PCDF or PCB congener.

3.0 METHODOLOGY

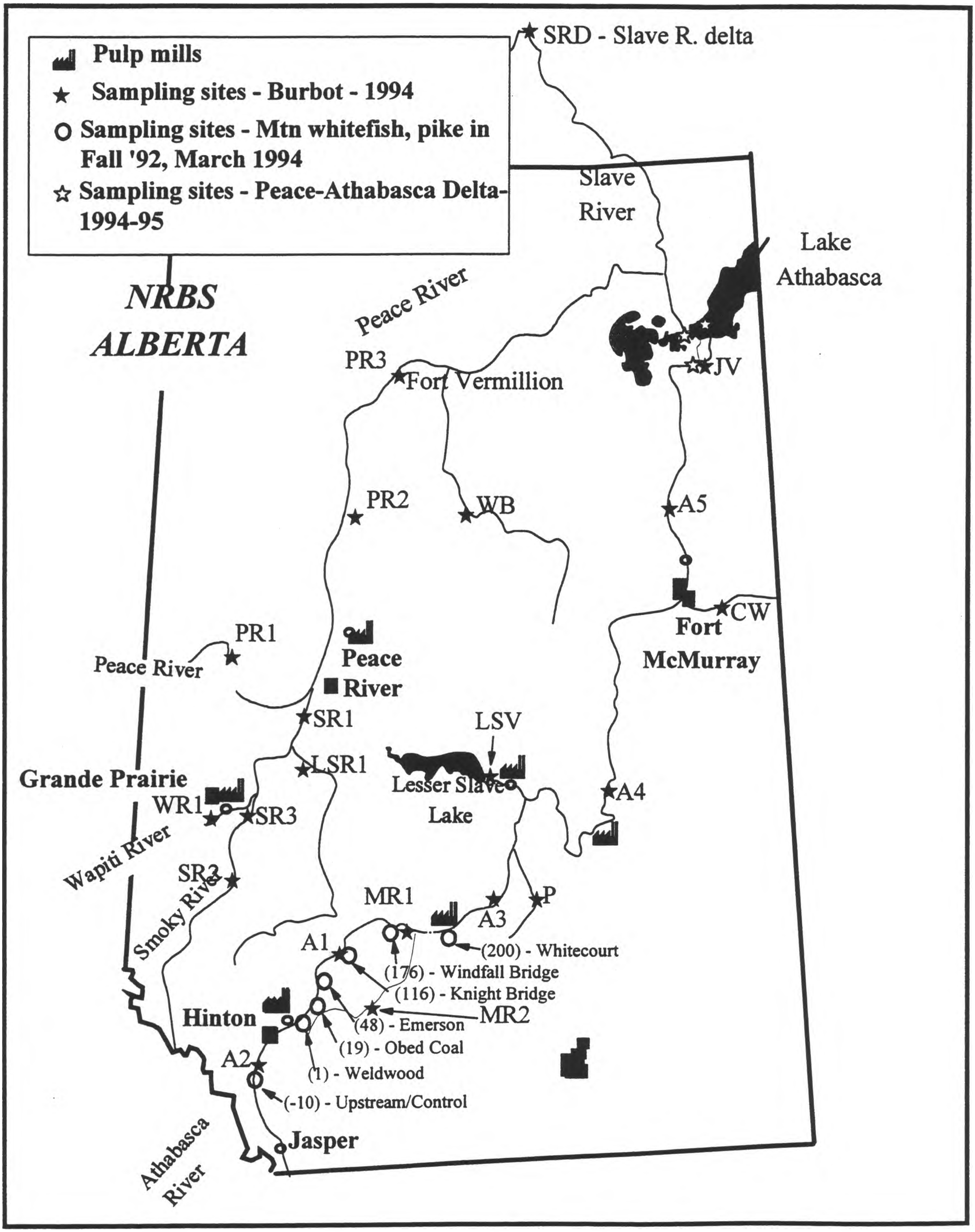
3.1 SITE LOCATIONS AND SAMPLE DESCRIPTIONS

3.1.1 Reach Specific Study (upper Athabasca River) Survey (May 1992 - April 1993)

Mountain whitefish (Family Salmonidae, *Prosopium willamsoni* (Girard)), and northern pike (Family Esocidae, *Esox lucius* (Linnaeus)) samples were collected from the Athabasca River in September and October of 1992, of 1992 at five sampling sites downstream from the Weldwood of Canada Ltd. BKM and one site upstream (Figure 1). The same sites had been sampled previously for these species in May/June 1992 (Pastershank and Muir 1995). In May 1993, mountain whitefish were collected from the upstream site and three sites immediately downstream.

Muscle (fillet) samples of mountain whitefish and northern pike samples were analyzed for for PCDDs and PCDFs. Sampling sites for the upper Athabasca River Survey are summarized in Table 1.

Figure 1. Locations of Sampling Sites for fish in the RSS near Hinton, basin wide burbot collections in 1994 and Ft. Chipewyan winter domestic fishery study (1994-95)



PCDD/F concentrations were also determined in mill effluent and river water (centrifuged with a continuous flow centrifuge), as well as suspended sediments (centrifuged solids) were collected in early February 1993. Depositional sediment were collected in early May 1993. Sampling locations were the same as those described in Pastershank and Muir (1995). Further details on the sampling and analysis of water, effluent, sediments and suspended sediments are given by Crosley (1996a,b,c).

3.1.2 Longnose sucker and northern pike liver analysis (1994)

A set of 22 liver samples from longnose suckers and 11 samples from northern pike collected in fall 1994 on the Wapiti/Smoky and Peace Riverswere analysed for di- to octachloro-PCDD/Fs. Sampling of suckers and pike was carried out a one site above Grand Prairie (WR1), at one site on the Smoky River downstream of Grand Prairie (SR1) and at two sites on the Peace River (PR1 and PR2).

3.1.3 Basin wide Burbot Collection (Sept to Dec 1994)

Burbot (Family Gadidae, *Lota lota* (Linnaeus)) were caught between September and December 1994 at 26 sites along 12 major rivers and deltas in northern Alberta as well as in the Slave River delta (Figure 1). Sampling site descriptions are summarized in Table 2. A total of 236 burbot were collected. Ages were available on 213 and length and weight on 215 of the samples. For analysis of PCDD/Fs samples from some sites were combined (e.g. A1a and A1b, WR1 and WR2) resulting in 20 sites comprising a total of 203 burbot liver samples.

3.1.4. Fort Chipewyan Winter Domestic Fishery study (1994-1995)

A survey of contaminants in the Fort Chipewyan Winter Domestic Fishery was conducted in the winter of 1994-1995. Burbot, northern pike, lake whitefish (*Coregonus clupeaformis*), Goldeye (Family Hiodontidae, *Hiodon alosoides* (Rafinesque)), walleye (Family Percidae, *Stizostedion vitreum* (Mitchill)) were collected from three sites in the Peace-Athabasca delta region: Quatre Fourches, Jackfish Lake Fishing Village, and Potato Island (Lake Athabasca) in the Fall of 1994 and winter of 1995. Jackfish Lake Fishing Village is located 1208 km downstream from the Weldwood Pulp and Paper Mill (35 km from Lake Athabasca) while Potato Island is in Lake Athabasca south of Fort Chipewin. Composite muscle samples from eight to ten individual fish of each species from each of the three sites (plus burbot liver composites) were analyzed for PCDD/Fs.

3.2 FIELD AND LABORATORY METHODOLOGIES

Fish sampling procedures are outlined in NRBS reports by EnviResource Consulting Ltd (1995). Concentrations of PCDD/Fs in biological tissues were determined by ETL using procedures identical to those for previous studies (ETL 1995). Samples of fish muscle and macroinvertebrate tissues (≈ 10 g) were mixed with Na_2SO_4 and Soxhlet-extracted following addition of $^{13}C_{12}$-surrogates. A portion of this extract was analyzed for lipid content. The remainder of the extract was initially subjected to sulfuric acid charring, followed by multisilica, Florisil, basic alumina and carbon column chromatography. The extracts were dried prior to adding a solvent containing internal standards. Analysis for specific PCDD/F congeners was performed by GC-high resolution mass spectrometry.

Table 1. Sampling sites for the upper Athabasca River, September/October 1992 and February/March 1993[1]

Site	Code	Description of Sampling Sites:	
A	REF	Upstream	10 km upstream of Hinton, AB
B	HB	Weldwood Haul Road Bridge	1 km downstream of Hinton, AB
C	OB	Obed Mountain Coal Bridge	19 km downstream of Hinton, AB
D	EL	Emerson Lakes Road Bridge	48 km downstream of Hinton, AB
E	KB	Knight Bridge	116 km downstream of Hinton, AB
F	WB	Windfall Bridge	176 km downstream of Hinton, AB

[1] Sites A, B, C and D were sampled for mountain whitefish only in 1993

Table 2. Collection Sites for Burbot in the Northern River Basins Study Area, September to December 1994.

River/Delta	Field[1]	Site	Description
Peace	Far	PR1	Upstream from Dunvegan (near Many Islands)
	Near	PR2	Downstream from Daishowa (near Notikewin River)
	Far	PR3	Near Fort Vermillion
Smoky	Near	SR1	Downstream from confluence of Wapiti R. (Near Highway 49
	Ref	SR2	Upstream from confluence of Wapiti R. (Near Grande Cache)
	Ref	SR3	Upstream from confluence of Wapiti R. (Near Canfor bridge)
Wapiti	Ref	WR1	Upstream from Grande Prairie (near Pipestone Creek Provincial
	Ref	WR2	Upstream from Grande Prairie (near O'Brian Provincial Park)
Little Smoky	Ref	LSR1	Near Highway 744 crossing
	Ref	LSR2	Downstream from Highway 744 crossing
Wabasca	Ref	WAB	Near Highway 67 crossing
Athabasca	Near	A1a	Downstream from Hinton (near Highway 947 crossing)
	Near	A1b	Downstream from Hinton (near Berland River)
	Ref	A2	Upstream from Hinton
	Near	A3	Downstream from Whitecourt (near Fort Assiniboine)
	Near	A4	Downstream from ALPAC (near Calling River)
	Far	A5	Near Fort MacKay
McLeod	Ref	MR1	Near Eagle Campground
	Ref	MR2	At Big Eddy upstream from Edson
Pembina	Ref	P	Near Jarvie
Lesser Slave	Near	LSV	Downstream from Slave Lake Pulp
Clearwater	Ref	CW	Upstream from Fort McMurray
Peace-Athabasca	Far	JV1	Near Jackfish Village
	Far	JV2	Near Big Eddy
Slave River Delta	Far	SRD1	Upstream from Nagle Channel
	Far	SRD2	At mouth of Nagle Channel

[1] Sites were designated as "Near-field", "Far-field" and reference (Ref) depending upon their proximity to pulp mills and municipal effluents.

3.3 QUALITY ASSURANCE

Quality assurance protocols are described in the analytical data reports by ETL. In brief, the laboratories followed quality assurance requirements set out by Environment Canada (1992) which include the use of ^{13}C-PCDD/F surrogates, blank analyses to demonstrate laboratory cleanliness, multi-level instrument calibration to demonstrate linearity of mass spectrometer response, and analyses of duplicate samples once every 10 samples. Sample extraction and analyses were repeated if surrogate recoveries were less than 40% or greater than 120%. Detection limits were calculated for each congener in each sample, based on a method detection limit (MDL) of three times the standard deviation of the analyte peak in the sample blank.

3.4 STATISTICAL ANALYSIS

Mean concentrations of PCDD/Fs were calculated assuming non-detect concentrations were at detection limits as was done by Pastershank and Muir (1995). This decision was based on the fact that 2,3,7,8-TCDD and -TCDF were detected in most samples and could reasonably be assumed to be present in all other fish tissues at or near detection limits.

The Student's t-tests ($p = 0.05$) or non-parametric tests were used to compare levels of 2,3,7,8-TCDD/F in mountain whitefish and northern pike (fall 1992) at each site and to examine differences between spring 1992 and fall 1992 concentrations. The Univariate Procedure was used to test the normality of all data. If the assumptions of normality or homogeneity of variances were not met, the data were analyzed with the nonparametric Wilcoxon Rank Sum test or Mann-Whitney U test (at $p = 0.05$). Proc Corr (SAS 1991) was used to determine if the levels of 2,3,7,8-TCDD/F correlated with the length, wet weight, and age of the fish for each site. To test the effect of location (upstream vs. downstream BKM sits) on the bioaccumulation of TCDD/F in mountain whitefish and northern pike the "post hoc" Wilcoxon Rank Sum test (PROC NPAR1WAY, $p = 0.05$) was used.

Data for 2,3,7,8-TCDD and -TCDF in burbot liver were compared using Analysis of Covariance (ANCOVA) following the approach of Hebert and Keenleyside (1995). A subset of the larger database consisting of 186 samples for which weight, length and lipid as well as TCDD/F concentrations were available for each fish was used. To avoid spurious correlations from substituting detection limit values, random numbers between the detection limit (0.3 $pg \cdot g^{-1}$) and 0.05 $pg \cdot g^{-1}$ were used. For ANCOVA TCDD and TCDF concentrations were log transformed and % lipid was arcsine transformed to reduce skewness. Results of the ANCOVA showed that lipid was a significant covariate for TCDF ($P=0.022$) but not for TCDD ($P>0.1$). There was no significant lipid-site interaction for TCDF. Therefore comparisons for TCDF among locations were made with least-square mean concentrations adjusted by the common slope of lipid vs TCDF derived from the ANCOVA (Hebert and Keenleyside 1995). Comparisons of mean TCDD concentrations between sites were made using Tukey's multiple means test using the mean square error from the ANCOVA (SAS 1991).

4.0 RESULTS AND DISCUSSION:

4.1 THE UPPER ATHABASCA RIVER SURVEY (FALL 1992/MAY 1993)

4.1.1. Spatial trends of PCDD/Fs in fish

The major PCDD/F congeners in muscle (skinless fillet) of mountain whitefish and northern pike samples collected downstream of Hinton in the upper Athabasca River were 2,3,7,8-TCDD and -TCDF (Table 3 and 4). Concentrations of other 2,3,7,8-substituted penta- to octachloro- PCDD/F congeners were generally much lower or non-detectable (Appendix Table A1). Two lower chlorinated congeners, 2,7/2,8-dichlorodibenzodioxin (diCDD) and 2,3,8-trichlorodibenzofuran (TrCDF) were detected in most samples of mountain whitefish from fall 1992 at low $pg \cdot g^{-1}$ concentrations (Appendix Table A2). Concentrations of 2,3,8-TrCDF in whitefish ranged from <0.1 $pg \cdot g^{-1}$ at the upstream site to 1.9 $pg \cdot g^{-1}$ immediately downstream of the Hinton Combined Effluent (HCE) at Weldwood Haul bridge. Non-2,3,7,8-substituted PCDD/Fs (with four or more chlorines) were also detected in mountain whitefish and pike muscle but at much lower concentrations than 2,3,7,8-TCDD or -TCDF. Concentrations of non-2,3,7,8-substituted TCDFs in whitefish ranged from 1.1 $pg \cdot g^{-1}$ at the Weldwood site, 0.2 $pg \cdot g^{-1}$ at Emerson Lakes and <0.1 $pg \cdot g^{-1}$ at Obed (Appendix Table A2). The overall ranking of congeners in

Table 3. Comparison of 2,3,7,8-TCDD and 2,3,7,8-TCDF ($pg \cdot g^{-1} \pm SD$) in Northern Pike and Mountain Whitefish Muscle from the Athabasca River, Sept/Oct 1992.

Location	Northern pike $pg \cdot g^{-1}$ (wet wt)	Northern pike N	Mountain whitefish $pg \cdot g^{-1}$ (wet wt)	Mountain whitefish N	NPAR1WAY[a] (p = 0.05)
2,3,7,8-TCDD					
U/S Hinton (-10 km)	ND[c]	ND	0.58±0.63	4	N/A
Weldwood Haul Bridge (1 km)	0.1	1	5.3±6.5	4	N/A
Obed Coal Bridge (19 km)	ND	ND	5.1±2.7[d]	5	N/A
Emerson Lake (48 km)	0.25±0.071	2	7.7±9.3	4	*[b]
Knight Bridge (116 km)	1.0±1.7	7	0.80±0.63	4	NS
Windfall Bridge (176 km)	0.94±1.0	7	ND	ND	N/A
2,3,7,8-TCDF					
U/S Hinton (-10 km)	ND	ND	1.7 ± 1.9	4	N/A
Weldwood Haul Bridge (1 km)	0.2	1	7.2±5.7	4	N/A
Obed Coal Bridge (19 km)	ND[c]	ND	7.3±6.6	5	N/A
Emerson Lake (48 km)	0.55±0.21	2	9.8±13	4	*[b]
Knight Bridge (116 km)	3.2±5.8	7	1.8±0.43	4	NS
Windfall Bridge (176 km)	3.0±3.5	7	ND	ND	N/A

[a] This column tests significant differences between the levels of TCDD or TCDF in mountain whitefish and northern pike. Symbols: NS = Not Significant; ND = No Data; N/A = Not Applicable.
[b] Significantly higher in fall 1992 samples (NPAR1WAY, $p < 0.05$).

mountain whitefish in terms of concentrations and frequency of detection was 2,3,7,8-TCDF> 2,3,7,8-TCDD>2,3,8-TrCDF>other TCDFs>2,7/2,8-DiCDD≥Total HpCDD> other PCDD/F homolog groups. Concentrations of 2,3,7,8-TCDD and -TCDF were generally higher in mountain whitefish than in northern pike muscle (at two of three sites) although limited sample numbers precluded a thorough comparison (Table 3). At Knight Bridge (116 km downstream of the HCE) mean concentrations of 2,3,7,8-TCDD/F were higher in pike than whitefish although concentrations did not differ significantly ($p > 0.05$) because of high variance of the levels in pike.

Concentrations of 2,3,7,8-TCDD and -TCDF in mountain whitefish collected in September/October 1992 were significantly lower at Knight Bridge than at Weldwood and Obed, sites closer to the mill effluent (Table 3; Figure 2 and 3). TCDD/F concentrations were also significantly lower ($p > 0.05$) in whitefish sampled at the upstream site compared to Weldwood or Obed. A similar spatial trend was found in mountain whitefish muscle samples from May 1993 but the number of samples analysed was limited. These spatial trends in TCDD and TCDF were also observed in the spring 1992 samples (Pastershank and Muir 1995).

Table 4. Comparison of 2,3,7,8-TCDD and -TCDF ($pg \cdot g^{-1} \pm SD$) in mountain whitefish muscle from the Athabasca River, Spring and fall samples, 1992-1993.

	Spring 1992		Fall 1992		Spring 1993		
Location	$pg \cdot g^{-1}$ (wet wt)	N	$pg \cdot g^{-1}$ (wet wt)	N	$pg \cdot g^{-1}$ (wet wt)	N	Significant[a] ($p \leq 0.05$)
2,3,7,8-TCDD							
U/S Hinton	0.40±0.43	10	0.58±0.63	4	0.25±0.21	2	NS[b]
Weldwood Haul Br. (1 km)	7.7±5.6	12	5.3±6.5	4	0.60±0.14	2	*[c]
Obed Coal Br. (19 km)	8.0±5.5	10	5.1±2.7	5	1.6±0.21	2	*[c]
Emerson Lake (48 km)	8.5±8.4	10	7.7±9.3	4	7.0±5.0	3	NS
Knight Br. (116 km)	3.0±3.2	10	0.80±0.63	4	ND	-	*[c]
Windfall Br. (176 km)	3.8±4.0	10	ND	ND	ND	-	N/A
2,3,7,8-TCDF							
U/S Hinton (-10 km)	0.86±1.2	10	1.7±1.9	4	0.20±0.14	2	NS
Weldwood Haul Br. (1 km)	13±12	12	7.2±5.7	4	1.4±0.28	2	*[c]
Obed Coal Br. (19 km)	12±8.5	10	7.3±6.6	5	3.8±0.14	2	*[c]
Emerson Lake (48 km)	14±11	10	9.8±3.0	4	13±7.8	3	NS
Knight Br. (116 km)	3.7±4.2	10	1.8±0.43	4	ND	-	NS
Windfall Br. (176 km)	8.6±11	10	ND	ND	ND	-	N/A

[a] This column tests significant differences between the levels of TCDD or TCDF in mountain whitefish between the three sampling times. Symbols: NS = Not Significant; ND = No Data; N/A = Not Applicable; * = significant at the $p < 0.05$ level.

[b] Significant difference between spring 1992 and May 1993.

[c] Significant difference between spring and fall 1992.

Lower 2,3,7,8-TCDD and -TCDF concentrations were observed in the spring 1993 whitefish samples from Weldwood and Obed compared to the spring and fall 1992 samples (Table 4). However only two

Figure 2. Temporal and spatial trends of 2,3,7,8-TCDD levels (pg g^{-1} wet wt) in mountain whitefish (1992-93)

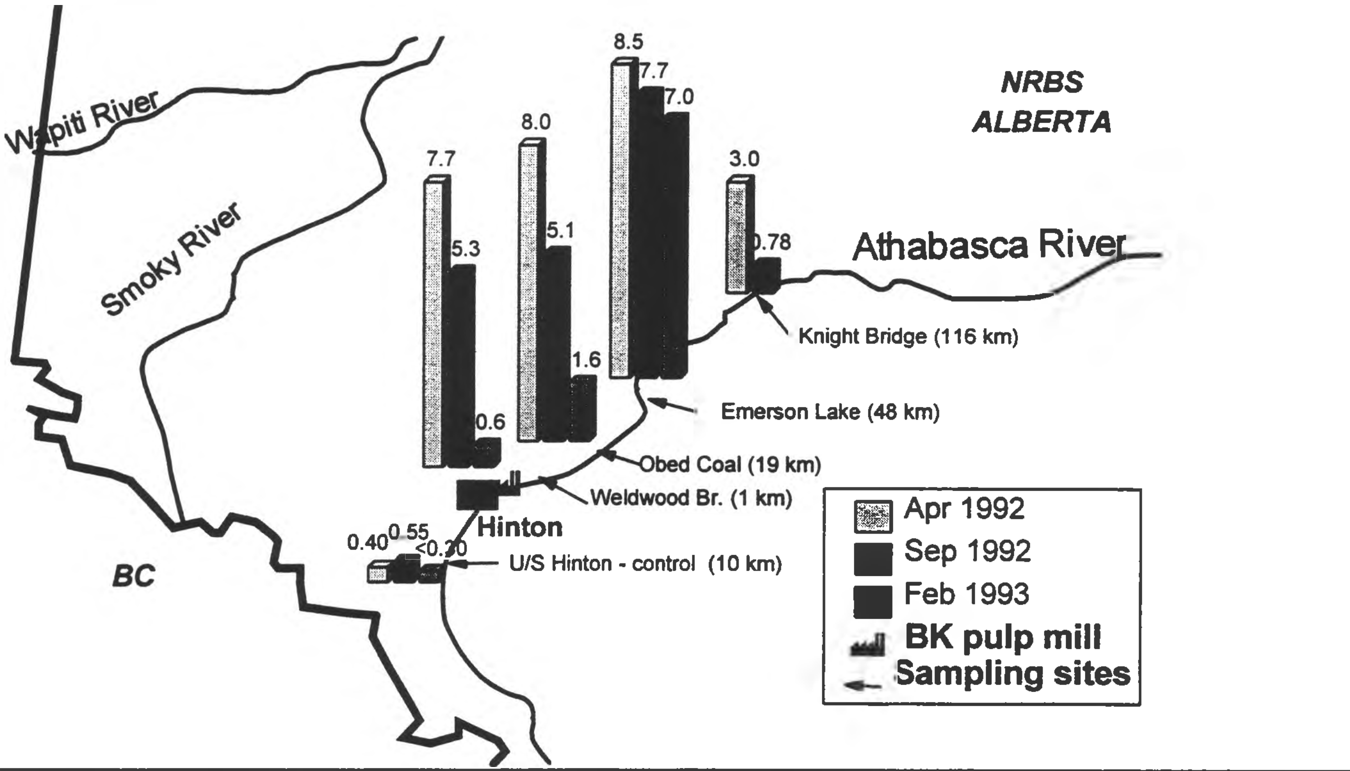


Figure 3 Temporal and spatial trends of 2,3,7,8-TCDF levels (pg g^{-1} wet wt) in mountain whitefish (1992-93)

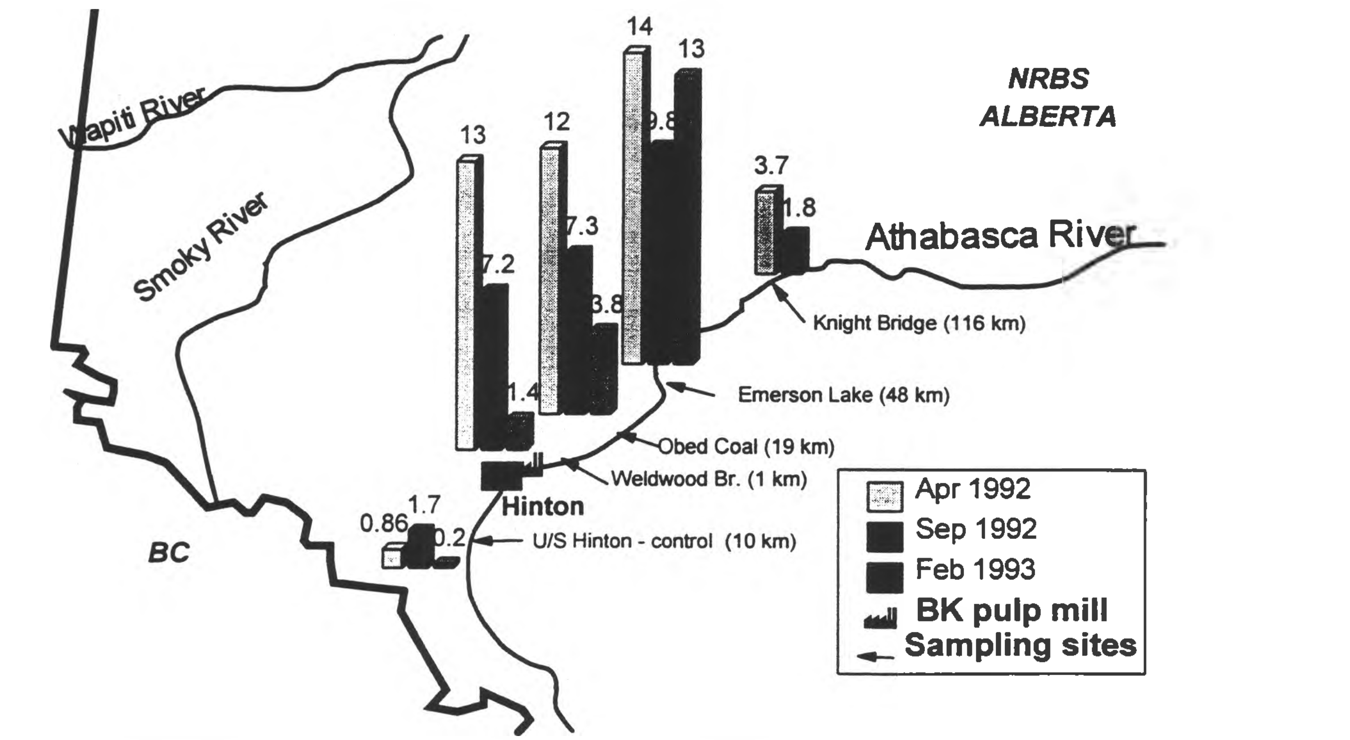
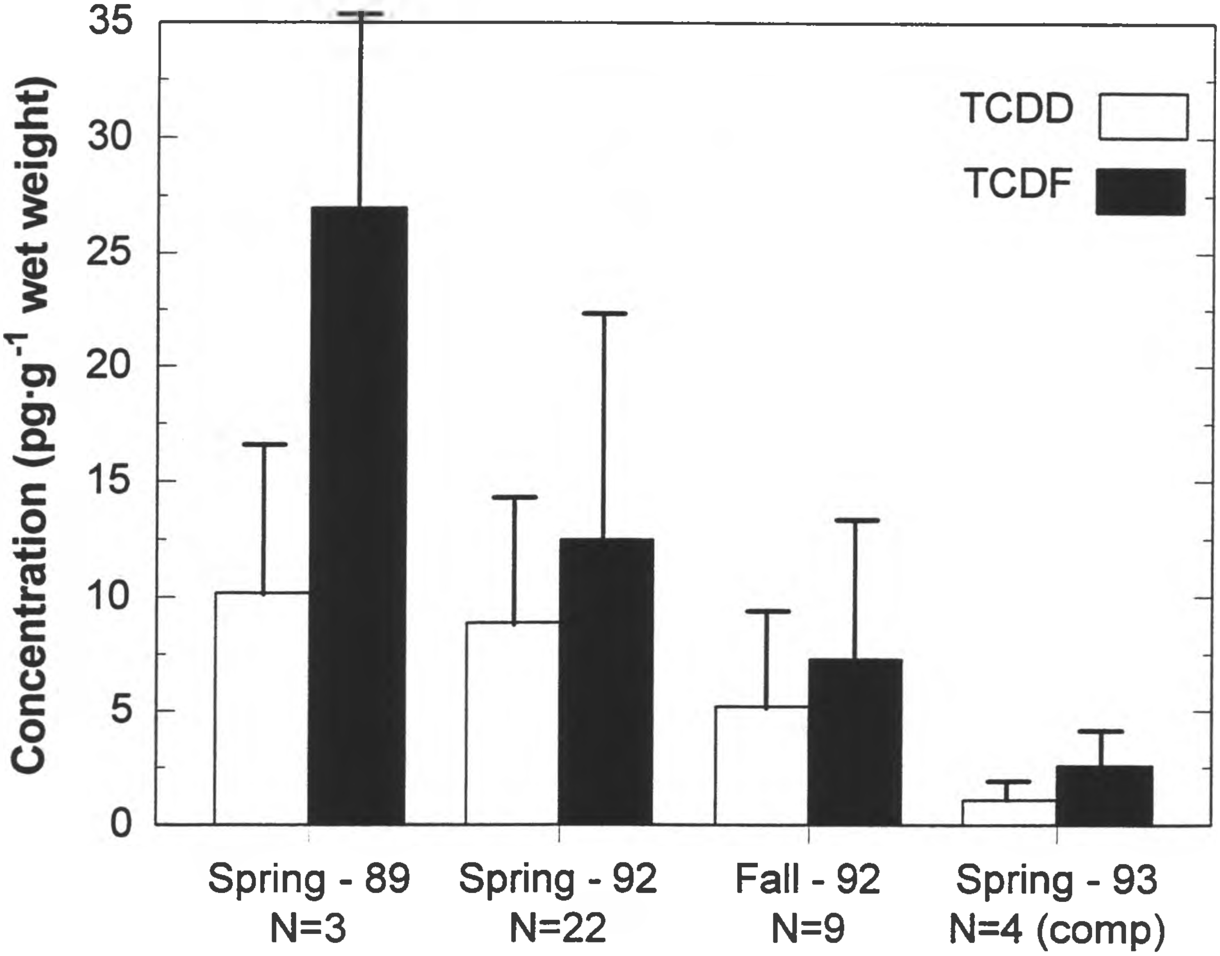


Figure 4. Decline in concentrations of 2,3,7,8-TCDD and - TCDF in mountain whitefish fillets from the Athabasca River downstream of Hinton AB - 1989-93. Vertical bars represent one standard deviation.



samples from each of these sites were analysed in 1993. There was no significant difference between mean fall 1992 and spring 1993 levels of TCDD or TCDF in whitefish at Emerson Lake ($p < 0.05$). Other (tetra to octachloro-) PCDD/F congeners were also near or below detection limits in the 1993 whitefish samples (Appendix Table A2). Di and trichloro-PCDD/Fs were not determined in the 1993 samples.

4.1.2. Temporal Trends of PCDD/Fs in fish

The Dept of Fisheries and Oceans national dioxin survey included a sampling site for whitefish at Weldwood in spring 1989 (Whittle et al. 1993). Thus it was possible to examine temporal trends in 2,3,7,8-TCDD and TCDF over a four year period. There has been a definite decline in 2,3,7,8-TCDD and -TCDF concentrations in mountain whitefish downstream of the Hinton but most of the decrease took place in the period 1989 to 1992 (Figure 4). The extent of the decline depends to a large extent on which results for spring 1993 are used. Figure 4 includes the samples from the near-field sites of Weldwood and Obed (mean concentrations of 1.1 and 2.6 $pg \cdot g^{-1}$ wet, for TCDD and TCDF respectively). But if the fish from Emerson Lake (48 km downstream) are included mean concentrations are 3.6 and 7.1 $pg \cdot g^{-1}$ wet, for TCDD and TCDF, respectively. These latter concentrations are not significantly lower ($p > 0.05$) than spring or fall 1992 results. Swanson et al. (1995) found a steep decline in TCDD and TCDF in mountain whitefish following process changes at the BKM at Grande Prairie, especially after the shift to 100% ClO_2 substitution. The BKM at Hinton did not implement full ClO_2 substitution until mid-1993, and 2,3,7,8-TCDD and -TCDF were present in the effluent at concentrations ranging from <1 to 6.5 $pg \cdot L^{-1}$ and from 2 to 41 $pg \cdot L^{-1}$, respectively, during the period spring 1992 to May 1993 (Alberta Environment 1995).

Possible temporal trends of 2,3,7,8-TCDD and -TCDF in spring and fall-collected northern pike were examined using the Wilcoxon Rank Sum test. TCDD/F results for northern pike in spring 1992 were reporte by Pastershank and Muir (1995). Statistical comparisons were possible at Knight Bridge and Windfall Bridge sampling sites. No significant differences ($p < 0.05$) in mean concentrations were observed between the spring and fall collections for either congener (results not shown).

4.2 PCDD/FS IN LONGNOSE SUCKER AND NORTHERN PIKE LIVERS (1994)

Twenty-two samples of longnose sucker livers and 11 samples of northern pike livers from four locations on the Wapiti/Smoky and Peace Rivers were analysed for di- to octachloro-PCDD/Fs. Results for 2,3,7,8-TCDD and -TCDF are presented in Table 5 and results for all congeners are given in Appendices Tables A4 and A5. TCDF was the most frequently detected congener in liver samples of both species (Appendix Table A4). Highest concentrations of 2,3,7,8-TCDF in longnose sucker livers were found at SR1. TCDF was also detected in all samples from WR1 (upstream of the Weyerhaeuser Canada Ltd BKM at Grand Prairie) but was at or near detection limits at the two sites on the Peace River (Table 5). TCDD was not detected in northern pike liver and was present above detection limits in only one of 22 samples of longnose sucker livers. Di- and trichloro- PCDD/Fs were not detected in either longnose sucker or northern pike livers (Appendix Table A5). Detection limits for the di- and trichloro- congeners were higher than for 2,3,7,8-TCDD/F. No other PCDD/F congeners were present above detection limits in longnose sucker liver samples. However, northern pike liver from WR1 contained low levels of hexachlorodioxins and - furans in one of four samples (Appendix Table A4).

Table 5. Concentrations of 2,3,7,8-TCDD and -TCDF ($pg \cdot g^{-1}$ ± SD wet wt) in Longnose sucker and Northern Pike liver from the Wapiti/Smoky and Peace Rivers, fall 1994

River/Location/species			DL pg g^{-1}	Min - Max	Frequency	Mean ± SD[a] pg g^{-1}
Longnose sucker						
Wapiti	WR1	TCDD	0.3	<0.2 - 0.8	(1/6)	0.1
		TCDF	0.3	0.6 - 5.4	(6/6)	2.2 ± 1.9
Smoky	SR1	TCDD	0.4	<0.2 - <0.8	(0/5)	<0.4
		TCDF	0.4	0.6 - 41.0	(5/5)	9.2 ± 17.8
Peace	PR1	TCDD	0.3	<0.2 - <0.3	(0/5)	<0.3
		TCDF	0.3	<0.2 - <0.3	(5/5)	<0.3
	PR2	TCDD	0.3	<0.1 - <0.4	(0/6)	<0.3
		TCDF	0.3	<0.1 - 0.5	(3/6)	0.1 ± 0.20
Northern pike						
Wapiti	WR1	TCDD	0.4	<0.2 - <0.4	(0/4)	<0.4
		TCDF	0.4	1 - 4	(4/4)	2.3 ± 1.5
Smoky	SR1	TCDD	0.3	<0.2 - <0.3	(0/2)	<0.3
		TCDF	0.4	1.8 - 3.6	(2/2)	2.7
Peace	PR1	TCDD	0.4	<0.2 - <0.5	(0/2)	<0.4
		TCDF	0.3	<0.2 - <0.4	(0/2)	<0.3
	PR2	TCDD	0.1	-	(0/1)	
		TCDF	0.2	-	(1/1)	0.2

[a] Means ± SD are calculated where concentrations are above detection limits in three or more samples.

4.3. BASIN WIDE SURVEY OF PCDDs AND PCDFs IN BURBOT LIVER (1994)

4.3.1. Spatial trends of PCDD/F

Of the 203 burbot liver samples analysed, results from 186 samples from 16 sites were also available with age, % lipid, length or weight data. Concentrations of 2,3,7,8-TCDD and -TCDF, the major PCDD/F congeners in these samples, along with weight, length, age and % lipid for the same animals are presented in Table 6. Mean concentrations and detection frequency of homolog groups and major congeners for the complete set of 203 samples from 20 sites are given in Appendix Table A6.

In general, concentrations of PCDD/Fs were higher in burbot liver than in mountain whitefish or northern pike muscle and a greater number of congeners were detected (Appendix Table A6). TCDF was detected (> ~0.30 $pg \cdot g^{-1}$) in 86% of all burbot liver samples analysed, while 2,3,7,8-TCDD was detected in 35% of samples (Table 7). Two other 2,3,7,8-substituted- PCDD/F congeners, 1,2,3,6,7,8-HxCDD and the heptachlorodioxin, 1,2,3,4,6,7,8-HpCDD were detected in 37% of burbot liver samples. OCDD was also detected relatively frequently (17%) while OCDF was found in only three of 203 samples (Table 7). Di and trichloro-CDDs and CDFs were detected infrequently in burbot liver

Table 6 . Geometric mean (± SE) concentrations ($pg\ g^{-1}$ wet wt) of 2,3,7,8-TCDD and -TCDF in burbot liver (fall 1994), geometric mean[a], weight, length and age, and % lipid, for samples at each site[b]

	A1	CW	A2	A3	A4	A5	SR	SR1
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
N	7	5	8	21	14	18	18	19
2,3,7,8-TCDD	8.53 ± 2.24	<0.3	0.55 ± 0.46	0.63 ± 0.19	0.45 ± 0.19	0.23 ± 0.06	0.25 ± 0.04	0.59 ± 0.18
2,3,7,8-TCDF	65 ± 7.4	0.37 0.21	5.6 ± 2.1	14.9 ± 1.8	8.6 ± 1.3	1.2 ± 0.50	5.6 ± 0.46	17.7 ± 2.0
Weight (g)	526 ± 52	467 69	1223 ± 386	616 ± 70	690 ± 145	780 ± 66	845 ± 83	465 ± 38
length (cm)	478 ± 14	440 25	614 ± 55	496 ± 17	515 ± 31	510 ± 15	505 ± 14	446 ± 13
age (yrs)	6.7 ± 0.4	5.6 0.9	7.7 ± 2.0	6.9 ± 0.6	6.6 ± 0.6	6.2 ± 0.4	8.4 ± 0.4	7.3 ± 0.5
lipid (%)	62 ± 4	25 2	55 ± 4	55 ± 3	46 ± 4	32 ± 4	48 ± 2	60 ± 2

	LSV	MCR	P	PR2	PR1	PR3	WAB1	WR
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
N	18	6	6	8	10	6	5	17
2,3,7,8-TCDD	0.24 ± 0.06	<0.3	0.36 ± 0.24	0.14 ± 0.05	<0.3	<0.3	<0.3	0.54 ± 0.19
2,3,7,8-TCDF	3.5 ± 1.4	1.3 1.0	2.0 ± 1.9	3.0 ± 1.5	1.4 ± 0.81	0.17 ± 0.09	0.18 ± 0.15	18.4 ± 3.2
Weight (g)	717 ± 53	537 45	605 ± 118	1082 ± 262	737 ± 103	658 ± 173	353 ± 26	689 ± 78
length (cm)	520 ± 17	471 12	502 ± 27	598 ± 35	530 ± 22	519 ± 37	402 ± 10	500 ± 19
age (yrs)	9.1 ± 0.5	7.2 0.6	7.5 ± 1.5	9.6 ± 0.9	9.1 ± 0.9	7.5 ± 0.7	5.3 ± 0.5	7.7 ± 0.8
lipid (%)	48 ± 3	14 2	32 ± 8	nd	27 ± 5	14 ± 3	34 ± 9	51 ± 2

[a] Results for 186 fish from 16 locations for which >2 samples were available along with either weight, length,age or lipid. Geometric means were calculated by assigning non-detects random number values between 0.05 and 0.3 $pg\ g^{-1}$. Where all non-detects were observed the approximate detection limit has been substituted.

[b] Site abbreviations: A1 = Athabasca R. downstream of Hinton, A2=Athabasca R. upstream of Hinton, A3 = Athabasca R. at Ft. Assiniboine, A4 = Athabasca R. at Calling R., A5 = Athabasca R. at Ft. MacKay, CW = Clearwater River, LSV = Lesser Slave River, SR = Slave River delta, SR1 = Wapiti River upstream of Grande Prairie, P = Pembina River, MCR = McLeod R., WAB = Wabasca R., WR = Wapiti R at Grande Prairie, PR1 = Peace R. at Many Is., PR2 = Peace R. at Notikekwin R., PR3 = Peace R. at Ft. Vermilion

Table 7. Frequency of detection[a] of major PCDD and PCDF congeners in burbot liver at NRBS "near field", "far field" and "reference" sites

N	203	61	90	52
	Overall detection frequency %	Far field %	Near Field %	Reference %
Di- to-octachloro dioxins				
27/28 -DiCDD	5.4	0	10.0	3.8
23 -DiCDD	0	0	0	0
237 -TrCDD	0	0	0	0
2378-TCDD	35.0	19.7	48.9	28.8
12378-PeCDD	1.0	0	2.2	0
123478-HxCDD	0.5	0	1.1	0
123678-HxCDD	36.9	18.0	53.3	30.8
123789-HxCDD	4.9	0	11.1	0
1234678-HpCDD	37.4	14.8	53.3	36.5
OCDD	17.2	9.8	25.6	11.5
Total -DiCDD	0	0	0	0
Total -TrCDD	0	0	0	0
Total TCDD	23.6	32.8	25.6	9.6
Total PeCDD	0	0	0	0
Total HxCDD	3.4	4.9	3.3	1.9
Total HpCDD	2.5	1.6	4.4	0
Di- to-octachloro furans				
28 -DiCDF	0	0	0	0
238 -TrCDF	2.0	1.6	1.1	3.8
2378-TCDF	86.2	75.4	96.7	80.8
12378-PeCDF	12.8	19.7	15.6	0
23478-PeCDF	4.4	3.3	7.8	0
123478-HxCDF	1.5	0.0	3.3	0
123678-HxCDF	1.0	1.6	1.1	0
123789-HxCDF	0	0	0	0
234678-HxCDF	0	0	0	0
1234678-HpCDF	4.9	1.6	10.0	0
1234789-HpCDF	0	0	0	0
OCDF	1.5	0	3.3	0
Total -DiCDF	0	0	0	0
Total -TrCDF	5.9	3.3	8.9	3.8
Total TeCDF	8.9	19.7	3.3	5.8
Total PeCDF	5.9	3.3	7.8	5.8
Total HxCDF	12.8	6.6	22.2	3.8
Total HpCDF	1.5	0	3.3	0

[a] Number of samples with concentrations greater than or equal to detection limit divided by total analysed

Figure 5. Concentrations of 2,3,7,8-TCDD in burbot liver at 20 sampling sites in the Peace-Athabasca-Slave river basin (fall 1994). Bars are geometric means ± SE (hats) for sites with N >=2 samples and at least one detectable level of TCDD. Stars indicate approximate position of sampling sites.

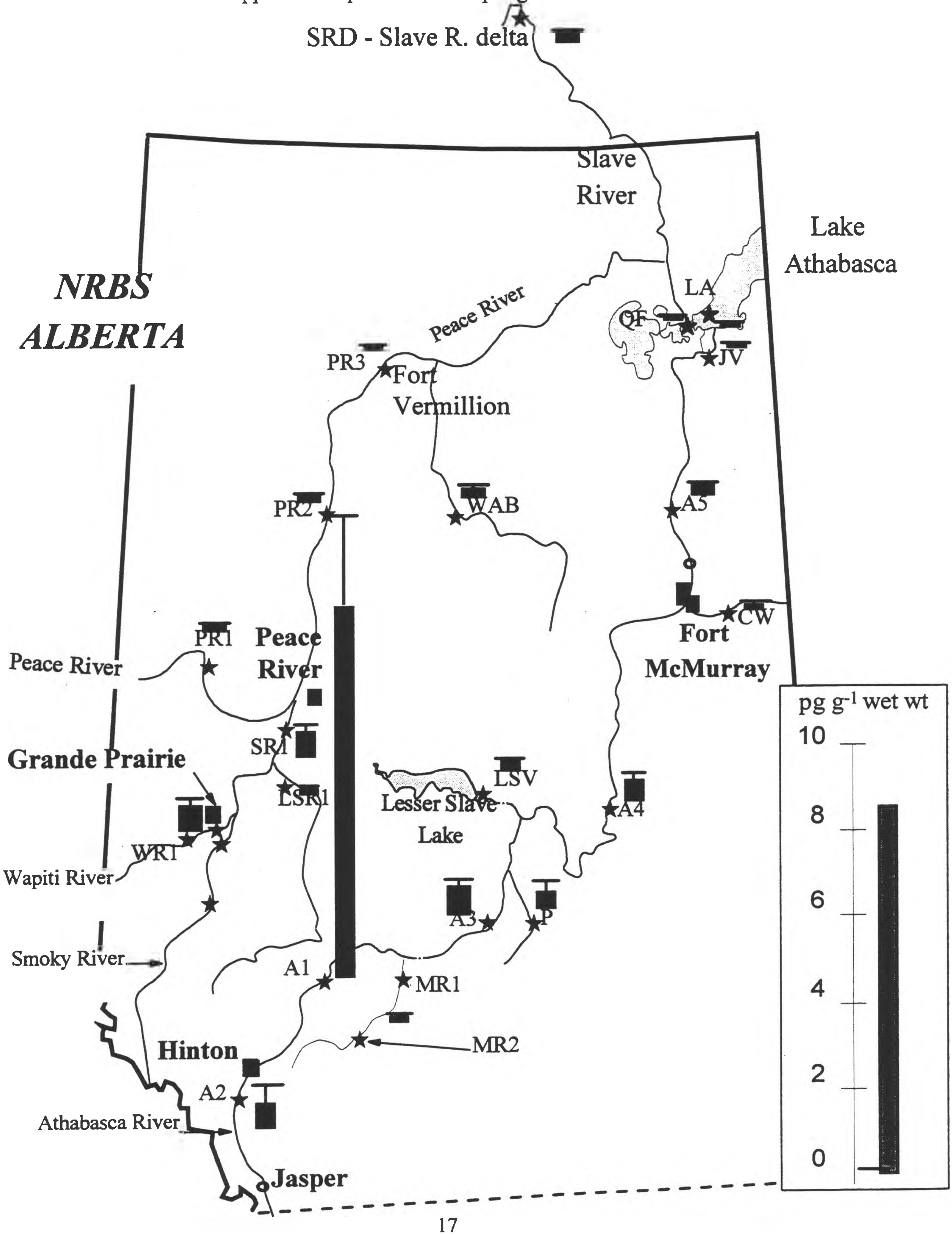
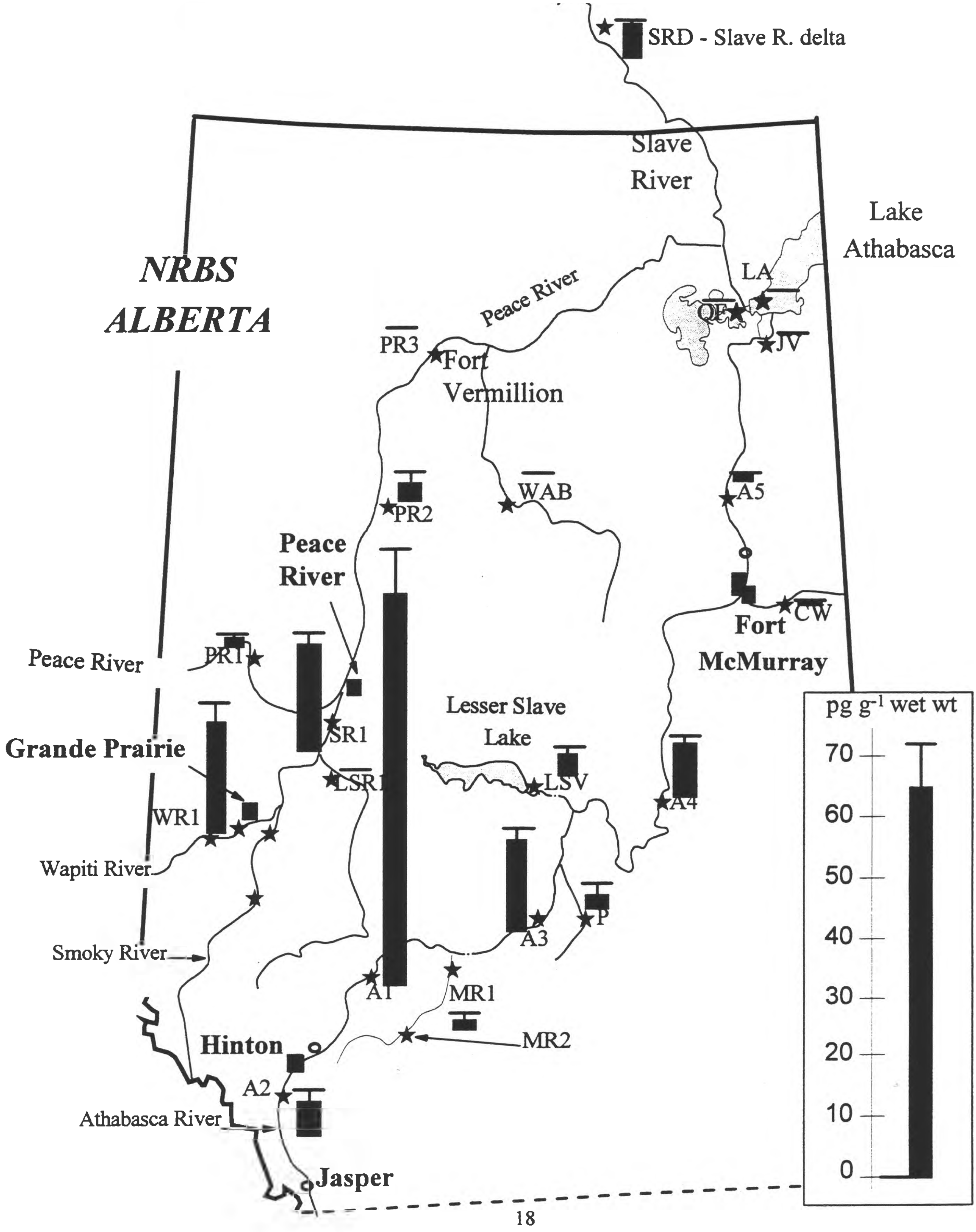


Figure 6. Concentrations of 2,3,7,8-TCDF in burbot liver at 20 sampling sites in the Peace-Athabasca-Slave river basin (fall 1994). Bars are geometric means ± SE (hats) for sites with N >=2 samples and at least one detectable level of TCDF. Stars indicate approximate position of sampling sites.



and at low levels relative to tetra- to octachloro congeners, unlike the pattern observed in mountain whitefish muscle.

Highest detection frequencies for all 2,3,7,8-substituted congeners were observed at near field sites, i.e. those immediately downstream of BKMs (EnviResource Consulting 1995). TCDF was above detection limits in 97% of near field samples compared to 75% of far field samples. An exception was 1,2,3,7,8-PeCDF which was found slightly more frequently at far field sites (20%) compared to near field (16%). The hexa- and heptachlorodioxins were much more frequently found at near field sites than far field or reference locations (Table 7). For e.g. 1,2,3,6,7,8-HxCDD and 1,2,3,4,6,7,8-HpCDD were found in six of nine fish at PR2 (Peace River at Notikewin River downstream of the Daishowa BKM) but were undetectable at PR3 (Ft. Vermilion). On the Athabasca River, TCDD, 1,2,3,6,7,8-HxCDD, 1,2,3,4,6,7,8-HpCDD, TCDF as well as 1,2,3,7,8-PeCDF were detected in nearly all burbot livers downstream of Hinton (A1 and A3) but infrequently at far-field sites (A5) or reference sites (A2). Some extremely high OCDD values were found in two of 23 samples from site A3. Relatively high levels of 1,2,3,4,6,7,8-HpCDD, 1,2,3,6,7,8-HxCDD and 1,2,3,4,6,7,8-HpCDF were also observed in the same fish. The pattern of PCDD/F was similar to that found in pentachlorophenol wood preservative formulations (Hagenmaier and Brunner 1987) The PCDD/F pattern at other near-field sites was dominated by 2,3,7,8-TCDF and TCDD indicating a chlorine-bleach process source. Statistical analysis of the PCDD/F data was confined to 2,3,7,8-TCDD and TCDF because of their relatively high frequency of detection and toxicological importance. Concentrations of 2,3,7,8-TCDD and -TCDF were significantly ($p<0.01$) correlated with each other, with total PCB congeners and with % lipid, but not with length or weight ($p\geq0.38$). Log transformation generally reduced the skewness, which is a measure of deviation from a normal distribution, and was therefore used for ANCOVA. Log transformed TCDD and TCDF concentrations were significantly correlated with PCBs and with lipid (which was arcsine transformed) but were also not significantly correlated with age, length or weight of burbot. Therefore ANCOVA was conducted to examine effects of lipid and sampling location, and lipid-location interactions on TCDD and TCDF concentrations in burbot liver.

Results of the ANCOVA showed that lipid was a significant covariate for TCDF ($p=0.022$) but not for TCDD ($p>0.1$). There was no significant lipid-site interaction for TCDF therefore lipid-adjusted means were compared using the least-squares means test (SAS 1991). Lipid was not a significant covariate for TCDD and there was no significant lipid-site interaction, therefore, geometric means were compared with Tukey's multiple means test using the mean square error from the ANCOVA (SAS 1991). Geometric means concentrations for 2,3,7,8-TCDD and -TCDF are presented in Table 6 for 16 sampling locations and are compared graphically in Figure 5 and 6. The figures include results from four other locations (Quatre Fourches, Jackfish Village, Lake Athabasca and Little Smoky River) in which TCDD and/or TCDF was non-detectable and for which there were $\leq$ 2 samples.

Mean concentrations of 2,3,7,8-TCDD in burbot liver (8.5 $pg \cdot g^{-1}$) were significantly higher at Site A1 (downstream of Hinton) than at all other locations. TCDD concentrations at Site A3 were also significantly higher than at one other site (PR3). All other sites could not be distinguished statistically using Tukey's test ($p>0.05$). Because of the high frequency of non-detect TCDD levels in reference and far-field sites, the statistical comparison was influenced by the value substituted for the detection limit. Use of the detection limit for non-detect value increased mean concentrations substantially (compare means in Table A4 with Table 6) but would also have led to falsely elevated results at some locations. For e.g., the arithmetic mean concentration of TCDD at Site A3 was 3.0±2.7 pg·g^{-1} assuming non-detects=DL while the geometric mean was 0.63±0.19 pg·g^{-1} because eight of 23 results were non-detects and were given a random value between 0.05 and 0.3 pg·g^{-1}.

Table 8. Pearson correlation coefficients[a] for 2,3,7,8-TCDD and -TCDF in burbot liver with age, % lipid, length, and weight as well as PCB concentrations

Congener		TCDF	ΣPCB	Age (yrs)	Lipid %	Length (cm)	Weight (g)
Untransformed data							
TCDD	R	0.832	0.243	-0.0001	0.282	0.002	0.011
	Prob	<0.001	0.004	0.999	<0.001	0.984	0.879
	N	186	139	184	174	186	186
TCDF	R	-	0.568	-0.019	0.433	-0.064	-0.065
	Prob	-	<0.001	0.797	<0.001	0.388	0.379
	N	-	139	184	174	186	186
Log transformed[b]		LTCDF	LΣPCB	Log age	AS-lipid	Log length	Log weight
LTCDD	P	0.535	0.363	0.109	0.335	0.097	0.084
	Prob	<0.001	<0.001	0.141	<0.001	0.187	0.253
	N	186	139	184	174	186	186
LTCDF	P	-	0.708	0.111	0.572	0.092	0.087
	Prob	-	<0.001	0.133	<0.001	0.212	0.239
	N	-	139	184	174	186	186

[a] Correlation coefficients; probability > R value under null hypothesis R=0.

[b] Log 10 transformed except for lipid (arcsine transformed).

The geometric mean (lipid adjusted) concentrations of 2,3,7,8-TCDF in burbot liver at Site A1 were also significantly higher than all other sites (p<0.01). But, unlike results for TCDD, additional spatial trends were evident from the least squares means test. TCDF concentrations at site A3 (geometric mean 14.9±1.8 pg·g^{-1}) were higher than all other locations except SR1 (Smoky River) and WR (Wapiti River). At Site A2 (upstream of Hinton), TCDF were significantly higher (p<0.05) than most other reference sites except LSV (Lesser Slave river downstream of Slave Lake pulp), Pembina River, Slave River delta. Similarly burbot from WR1 and WR2 sites upstream of the BKM at Grande Prairie had significantly higher TCDF than the downstream sites on the Wapitii/Smoky system (SR1), and the Athabasca River, A1 and A3. The full least squares comparison is given in Appendix Table A7.

4.3.2. Temporal Trends of PCDD/Fs

Comparison of concentrations of PCDD/Fs in burbot liver was possible at four locations on the

Wapiti/Smoky/Peace rivers where samples were collected in both 1992 and 1994. Collections were made at PR2 on the Peace River near the mouth of the Notikewin River (674 km from confluence of the Peace/Slave), and PR3 upstream of Fort Vermillion (396 km) in both years. No 1994 samples were available from the site immediately downstream of the mill at Grande Prairie (D2) or the next downstream site (B3; Hwy 34 bridge crossing). Therefore the closest sites on the Wapiti River, WR1 and WR2 (immediately upstream of Grande Prairie), and the next downstream site on the Smoky River (SR1) were used for a partial comparison. In all cases, comparisons were made with geometric means calculated with random numbers between the detection limit for 2,3,7,8-TCDD (0.3 $pg \cdot g^{-1}$) and 0.05 $pg \cdot g^{-1}$. Results were not adjusted for percent lipid, however, lipid content of burbot liver at three of the sites were similar in both years and was not available for samples from PR2 in 1994.

At three of four sites, levels of 2,3,7,8-TCDD and -TCDF were significantly lower (Students t-test with geometric means, $p<0.05$) in 1994 than 1992 (Figure 7). There were no significant differences ($p>0.05$) between sampling years in concentrations of TCDD or TCDF at PR2. For 2,3,7,8-TCDD, differences between years ranged from about 20-times at the two Wapiti/Smoky sites (WR and SR1) to about 10-times at PR3. For TCDF, the decline was 4x at WR, 8x at SR1 and 17x at PR3. The lack of a significant change in TCDD levels at PR2 reflects the fact that most results were non-detect in both years. The apparent declines of both TCDD and TCDF at the two Wapiti/Smoky sites (WR and SR1) may be due in part to the lack of corresponding sample sites in 1994. Burbot at WR1 and 2 were captured upstream of the BKM effluent while the collection site SR1 was about 90 km further downstream on the Smoky River than B3. Burbot liver samples from C1 (1992), which corresponded to SR1, were collected but not analysed for PCDD/Fs.

Higher concentrations of 1,2,3,4,6,7,8-HpCDD and OCDD were found in burbot at PR2 in 1994 than in 1992 (Appendix Table A6). The high frequency of detection HpCDD and OCDD in burbot from this site was not observed in 1992 (Pastershank and Muir 1995). These congeners were present in low $pg \cdot g^{-1}$ concentrations in 1992 at PR3 but were undetectable in 1994 samples.

Temporal trends in TCDD TEQ's downstream of the Grande Prairie BKM were also be assessed by combining the 1992 and 1994 results with those of Swanson et al. (1995). These authors found an overall decline of TCDD TEQs (based on 2,3,7,8-TCDD + 0.1 x 2,3,7,8-TCDF) in burbot liver between summer 1991 and spring 1994 from 41 $pg \cdot g^{-1}$ TEQs to 8.1 $pg \cdot g^{-1}$. The fall 1992 results fit well into this trend (Figure 8). The fall 1994 results from WR/SR1 are lower than predicted from the slope of the means for the seven previous sampling times. This may be due to sampling fish living further both downstream (SR1) and upstream (WR1 and 2) than were sampled in 1992 by NRBS or by Swanson et al. (1995). There is clearly some variation in concentrations found in burbot probably because of migration past the BKM effluent on the Wapiti or into tributaries of the Smoky.

4.3.3. Regional variation in PCDD/Fs in burbot liver

Results for 2,3,7,8-TCDD and -TCDF in burbot liver from 1992 collections on the Wapiti/Smoky Peace River are compared in Figure 9 with results from other studies in NWT and the Yukon. The Slave River Environmental Quality Monitoring Program conducted between 1990 and 1995 characterized the baseline aquatic ecosystem conditions in the Slave River at Fort Smith, NWT (Peddle et al. 1995). Water, suspended sediment and fish samples (burbot liver and walleye muscle) were

Figure 7 . Temporal trend in 2,3,7,8-TCDD and - TCDF concentrations in burbot liver at four sites on the Wapiti/Smoky and Peace Rivers where collections were made in fall 1992 and in fall 1994.. Bars are geometric means +/1 SE. Sites WR/ and SR1 in 1994 were not at the locations of D2 and B3 however they may nevertheless be representative of PCDD/F levels downstram of Grande Paririe.

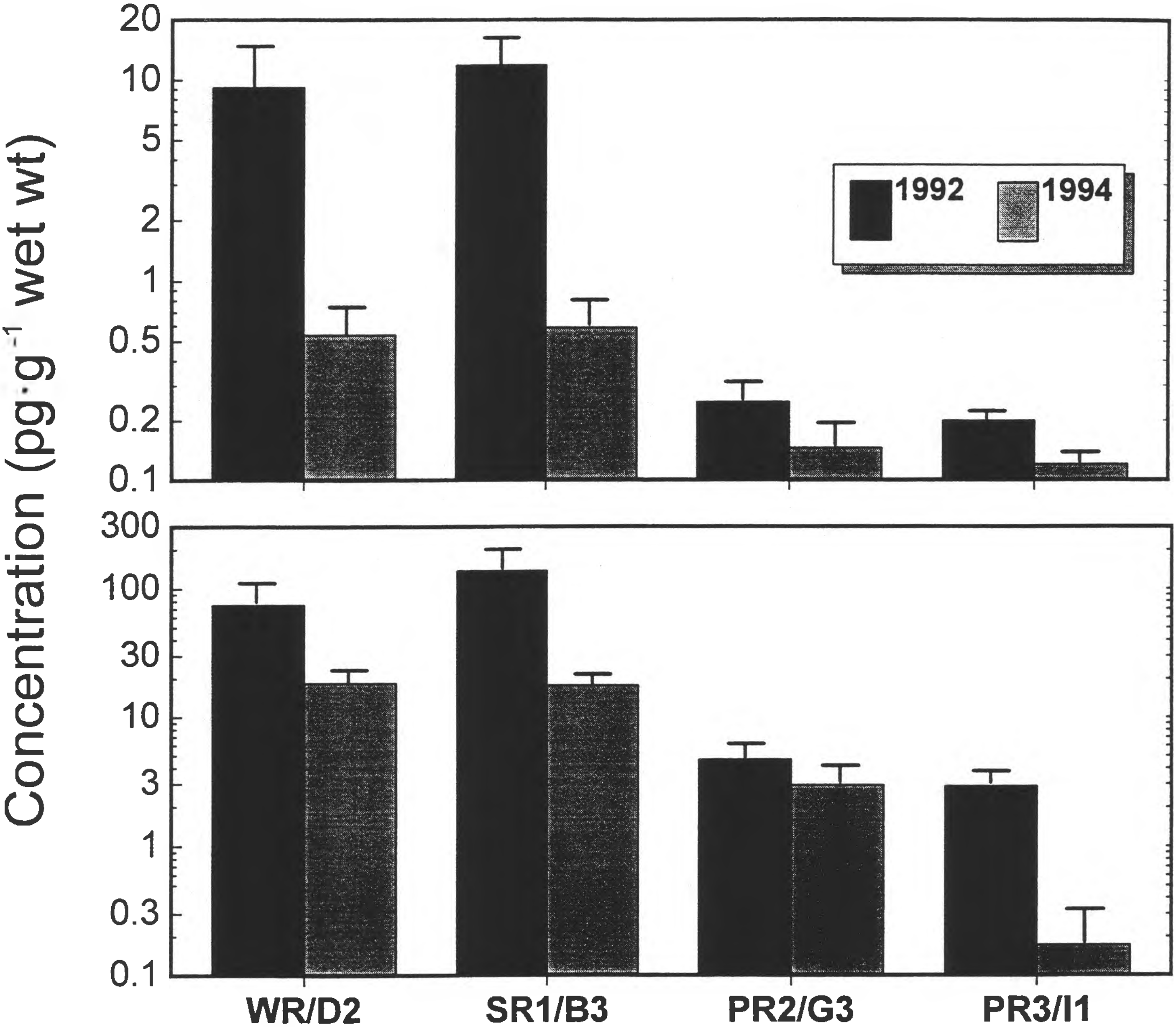


Figure 8. Mean (+/- SE) concentrations of TCDD TEQs (based on 2,3,7,8-TCDD and -TCDF) in burbot liver downstream of the BKM at Grande Prairie, 1991-1994. NRBS data from burbot collections of 1992 and 1994 are combined with results from Swanson et al. (1995).

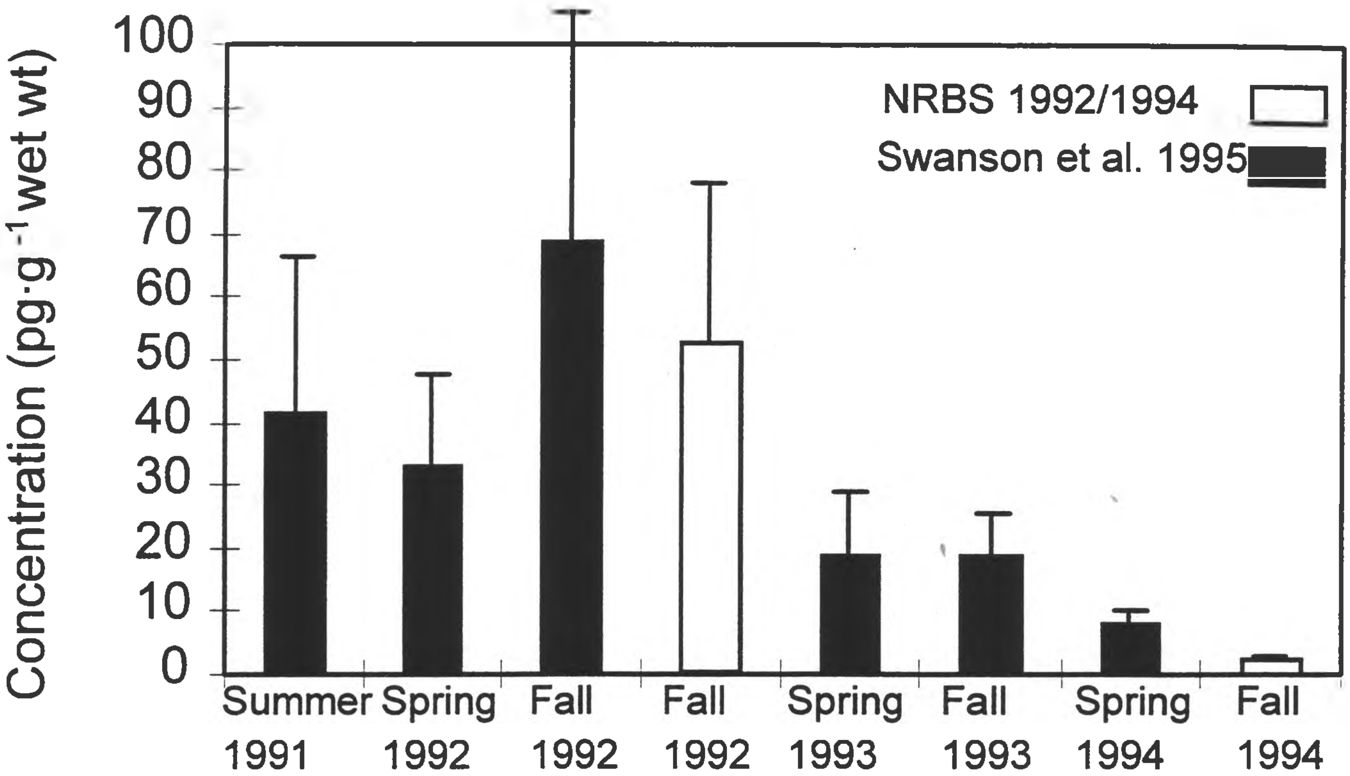
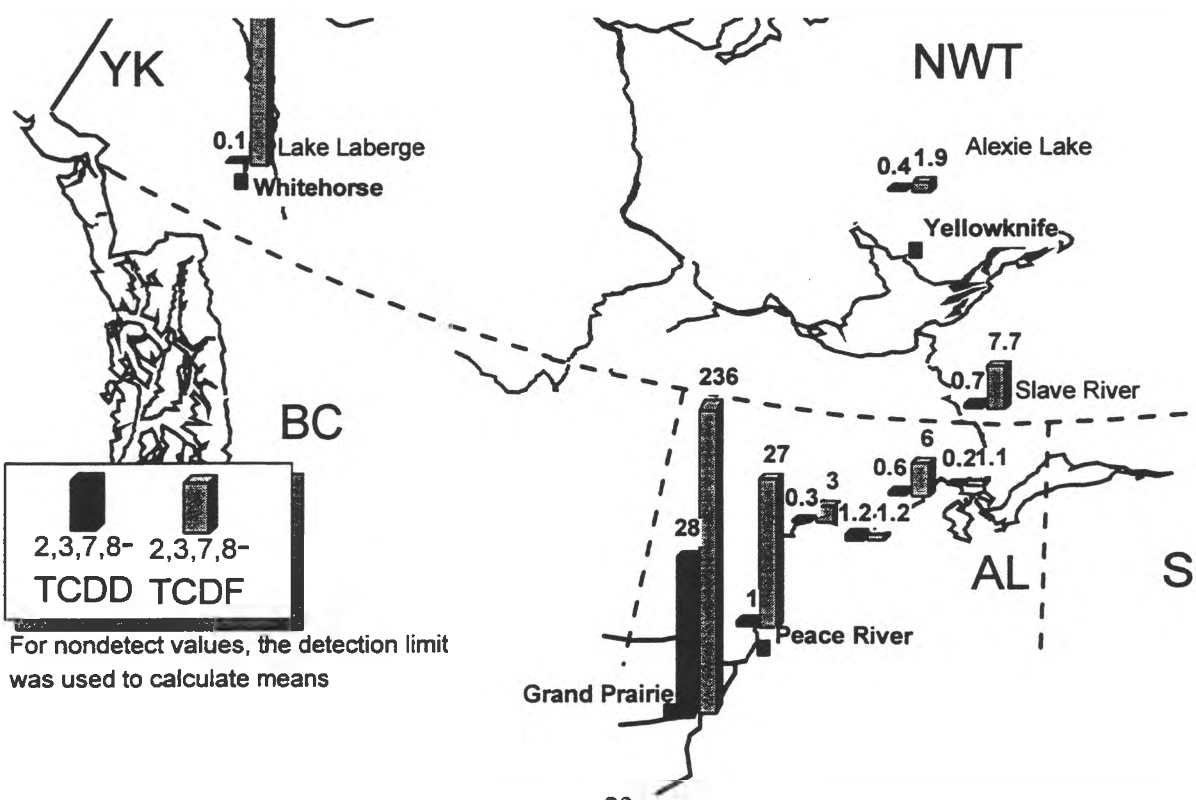


Figure 9. Regional variation of 2,3,7,8-TCDD and TCDF concentrations (pg·g) in burbot liver based on result s from the NRBS burbot collections (fall 1992) results from the Slave River study (Peddle et al. 1995) and from results of Muir and Lockhart (1993; 1994) in NWT and Yukon lakes.



analysed for PCDD/Fs. TCDD was detected in about 25% of burbot analysed at levels ranging from <0.06 to 16 $pg \cdot g^{-1}$ wet wt. TCDF was detected in 90% of burbot at levels ranging from <0.03 to 45 $pg \cdot g^{-1}$. Results for TCDD/F in burbot liver collected downstream of Ft. Smith (1990-93) were lower than results for burbot from the Slave River delta site near Ft. Resolution in 1994 (range of 0.3 to 1.8 for TCDD and 3.1 to 13 $pg \cdot g^{-1}$ for TCDF). The slightly lower levels in the NRBS study may reflect a decline in concentrations in the Slave River consistent with results from the Wapiti/Smoky/Peace rivers.

Walleye muscle from the Slave River had 2,3,7,8-TCDD concentrations ranging from <0.06 to 2.6 $pg \cdot g^{-1}$ wet wt and TCDF from <0.01 to 2.3 $pg \cdot g^{1}$ (Peddle et al. 1995). These levels were similar or slightly higher than found in composite samples of walleye muscle from the Peace-Athabasca delta (Table 9).

Burbot liver from Alexie Lake near Yellowknife, which was used as a control for the Slave River study, had low levels of 2,3,7,8-TCDD/F (Figure 9). Burbot in Lake Laberge, which have high PCBs in liver, had relatively low levels of 2,3,7,8-TCDD (Figure 9). Concentrations of TCDF were relatively high in Lake Laberge and similar to levels found in burbot from the Wapiti Smoky and upper Athabasca (near-field) sites. The source of TCDF in Laberge is thought to be from PCB contamination rather than atmospheric or pulp mill sources.

4.4 FORT CHIPEWYAN WINTER DOMESTIC FISHERY STUDY (1994-1995)

Concentrations of PCDD/Fs in composite samples of fish muscle from the Fort Chipewyan Winter Domestic Fishery study are given in Table 9. Concentrations of all 2,3,7,8-substituted PCDD/F congeners were at or near detection limits (<0.1 to <0.8 $pg \cdot g^{-1}$). Only 2,3,7,8-TCDF was detectable in most samples (<0.1 to 0.5 $pg \cdot g^{-1}$). Non-2,3,7,8-substituted TCDD congeners (see "total TCDD") were the major PCDD/F isomers. The identity and source of these congeners is unknown. The non-2,3,7,8-substituted congeners are readily metabolized by mammals (Esposito et al. 1980) and fish (Muir et al. 1986). They do not bioaccumulate to the same extent as 2,3,7,8-substituted congeners and are much less potent in terms of toxicological effects (such as induction of mixed function oxidase enzyme activity) (Safe 1990).

Burbot liver samples from the three sites had much higher levels of 2,3,7,8-TCDF than burbot muscle (Appendix Table A6). TCDF concentrations of 2.9 $pg \cdot g^{-1}$, 1.7 $pg \cdot g^{-1}$ and 2.5 $pg \cdot g^{-1}$ were observed in samples from Jackfish Village, Quatre Fourches and Lake Athabasca, respectively. These levels were similar to those at other far-field and reference sites located far from BKMs.

4.5. BIOAVAILABILITY OF PCDD/FS IN THE ATHABASCA RIVER

4.5.1. Collection and analysis of abiotic samples (1992/93)

Work by Crosley (1996b,c) on PCDD/Fs in BKM effluent, suspended solids and bottom sediments downstream of the Hinton Combined effluent (HCE) in spring 1992 and 1993 enables a more detailed examination of the fate and bioaccumulation of PCDD/Fs in this river reach. Pastershank and Muir

Table 9. Concentrations of PCDD/Fs (pg g^{-1} wet wt) in fish muscle from the Ft. Chipewyan domestic winter fishery survey, Peace-Athabasca delta,1994-1995. (N=1 composite of 8 to 10 individuals per species)

Species/Location[a] Congener	Lake whitefish JV	Burbot muscle JV	Goldeye LA	Lake whitefish LA	Burbot muscle LA	Northern Pike LA	Walleye LA	Goldeye QF	Lake whitefish QF	Burbot muscle QF	Northern Pike QF	Walleye QF
2378-TCDD	<0.3	<0.3	<0.3	<0.4	<0.3	<0.5	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
12378-PeCDD	<0.7	<0.7	<0.6	<0.5	<0.7	<0.7	<0.6	<0.5	<0.5	<0.7	<0.4	<0.4
123478-HxCDD	<0.2	<0.2	<0.7	<0.4	<0.2	<0.6	<0.5	<0.4	<0.3	<0.2	<0.4	<0.3
123678-HxCDD	<0.3	<0.3	<0.6	<0.4	<0.3	<0.6	<0.5	<0.4	<0.2	<0.3	<0.4	<0.3
123789-HxCDD	<0.2	<0.2	<0.7	<0.4	<0.2	<0.6	<0.5	<0.4	<0.2	<0.2	<0.4	<0.3
1234678-HpCDD	<0.6	<0.6	<0.7	<0.4	<0.6	<1.4	<0.6	<0.6	<0.4	<0.6	<0.7	<0.5
OCDD	<1.8	<1.8	<1.7	<1.1	<1.8	<1.8	<1.4	<1.2	2.4	<1.8	<1.5	<0.9
Total TCDD	1.3	<1.0	2.8	1.9	<1.0	3.2	1.6	2.5	0.9	<1.0	1.4	0.7
Total PeCDD	<0.7	<0.7	<0.6	<0.5	<0.7	<0.7	<0.6	<0.5	<0.5	<0.7	<0.4	<0.4
Total HxCDD	<0.2	<0.2	<0.7	<0.4	<0.2	<0.6	<0.5	<0.4	<0.2	<0.2	<0.4	<0.3
Total HpCDD	<0.6	<0.6	<0.7	<0.4	<0.6	<1.4	<0.6	<0.6	<0.4	<0.6	<0.7	<0.5
2378-TCDF	0.3	<0.3	0.4	<0.1	<0.3	<0.1	0.4	0.5	0.3	<0.3	0.4	<0.1
12378-PeCDF	<0.3	<0.3	<0.4	<0.4	<0.3	<0.4	<0.4	<0.3	<0.2	<0.3	<0.2	<0.3
23478-PeCDF	<0.3	<0.3	<0.3	<0.4	<0.3	<0.5	<0.5	<0.4	<0.3	<0.3	<0.3	<0.3
123478-HxCDF	<0.2	<0.2	<0.4	<0.3	<0.2	<0.5	<0.4	<0.4	<0.3	<0.2	<0.4	<0.3
123678-HxCDF	<0.2	<0.2	<0.4	<0.2	<0.2	<0.5	<0.3	<0.3	<0.2	<0.2	<0.4	<0.3
123789-HxCDF	<0.3	<0.3	<0.5	<0.4	<0.3	<0.6	<0.5	<0.5	<0.3	<0.3	<0.5	<0.4
234678-HxCDF	<0.2	<0.2	<0.5	<0.3	<0.2	<0.4	<0.4	<0.4	<0.3	<0.2	<0.4	<0.3
1234678-HpCDF	<0.5	<0.5	<0.5	<0.7	<0.5	<0.8	<0.7	<0.8	<0.4	<0.5	<0.4	<0.4
1234789-HpCDF	<0.5	<0.5	<0.6	<0.7	<0.5	<0.8	<0.8	<0.6	<0.4	<0.5	<0.5	<0.4
OCDF	<1.4	<1.4	<1.8	<1.4	<1.4	2.2	<1.3	<1.7	<1.4	<1.4	<1.7	<1.1
Total TCDF	<0.3	<0.3	<0.3	<0.3	<0.3	<0.4	<0.3	<0.2	<0.2	<0.3	<0.3	<0.2
Total PeCDF	<0.3	<0.3	<0.3	<0.4	<0.3	<0.5	<0.4	<0.4	<0.2	<0.3	<0.2	<0.3
Total HxCDF	<0.3	<0.3	<0.5	<0.3	<0.3	<0.5	<0.4	<0.4	<0.3	<0.3	<0.4	<0.3
Total HpCDF	<0.5	<0.5	<0.5	<0.7	<0.5	<0.8	<0.8	<0.7	<0.4	<0.5	<0.5	<0.4
% Lipid	2.68		5.18	2.45		0.44	1.58	6.13	2.08		0.67	1.73

[a] JV = Jackfish Village, LA = Lake Athabasca, QF = Quatre Fourches

(1995) examined the bioavailability of PCDD/F congeners to invertebrates and mountain whitefish in the HCE for the spring 1992 collection. In February 1993, additional samples of effluent, suspended solids and river water (centrifugate) were collected and analysed for PCDD/Fs. Bottom sediments were collected in May 1993 at five sites downstream of the HCE and at the upstream locations. PCDD/F analysis was conducted by two laboratories, AXYS Analytical Services, Sidney, BC (analysis of water, effluent and sediments), and EnviroTest Laboratories Ltd (ETL), Edmonton, AB (sediments). Analytical methodology and quality assurance procedures were identical to those for the 1992 study (Pastershank and Muir 1995). Forty-one monochloro- to octachloro dioxins and -furan congeners were determined. The organic carbon content of suspended and depositional sediments were also determined (Crosley 1996c). PCDD/F concentrations in effluent, suspended solids, river water, and bottom sediments are present in Appendix Tables B1 to B8.

4.5.2. PCDD/F concentrations in suspended solids in effluent and river water

The concentration profiles of PCDD/F congeners in the HCE and in suspended solids from the Athabasca River downstream of the effluent in February 1992 and 1993 are shown in Figure 10. Thirty-eight PCDD/Fs were detected in suspended solids. The lower chlorinated mono-, di-, and trichloro -furans predominated ($\leq$1400 pg·g^{-1}). Concentrations of tetra-, penta-, hexachloro- furans were also higher than their dioxin analogs, however, levels of HpCDDs ($\leq$38 pg·g^{-1}) and OCDD (140 pg·g^{-1}) exceeded those obtained for HpCDFs ($\leq$7.3 pg·g $^{-1}$) and OCDF (9.1 pg·g $^{-1}$). 2,3,7,8-TCDD (11 pg·g^{-1}) was found in a ratio of 1:4 with 2,3,7,8-TCDF (40 pg·g^{1}) in effluent and suspended solids in both years. Concentrations of 2,3,7,8-TCDF in suspended solids in February 1993 (7.6 pg·g^{-1}), at Obed Coal Bridge, 19 km downstream of the BKM, were similar levels to those found one year earlier (Figure 10; Appendix Table B5). The reproducibility of three suspended solids samples collected at Obed was excellent for most congeners. The BKM was at 45% Cl_2 substitution with ClO_2 throughout this period.

4.5.3. PCDD/Fs in centrifugate and "dissolved phase"

In February 1992, most PCDD congeners (including 2,3,7,8-TCDD) were undetectable (<0.1 pg·L^{-1}) in the centrifugate (particles greater than approximately 1.0 µm were removed by continuous centrifugation) but 2,3,7,8-TCDF was above the detection limits at the 1 km site (Weldwood; 0.10 pg·L^{-1}) and at 48 km (Emerson Lake; 0.09 pg·L^{-1}). In February 1993, TCDF was undetectable in the dissolved phase (<0.1 pg L^{-1}) at Obed (10 km) and Knight Bridge (116 km downstream) (Appendix Table B3). However other non-2,3,7,8-TCDFs were detected at both locations in February 1993 (0.24 and 0.14 pg·L^{-1}). Lower chlorinated PCDD/Fs, especially dichloro- furans predominated in the centrifugate (Appendix Table B4).

The dissolved fraction (f_{DIS}) of 2,3,7,8-TCDD and -TCDF (which would be readily bioavailable via uptake across respiratory surfaces) was estimated from the equation:

$$f_{DIS} = 1/(1 - DOC*K_{DOC})$$

where DOC = mass fraction of dissolved organic carbon and K_{DOC} = partition coefficent for PCDFs on DOC. K_{DOC} was assumed to be equal to K_{POC} which was calculated from the suspended solids and

Figure 10. PCDD/F congener pattern in suspended sediment (1992 vs 1993) in Hinton Combined effluent and at the Weldwood Haul Bridge sampling site 1km downstream of the effluent.

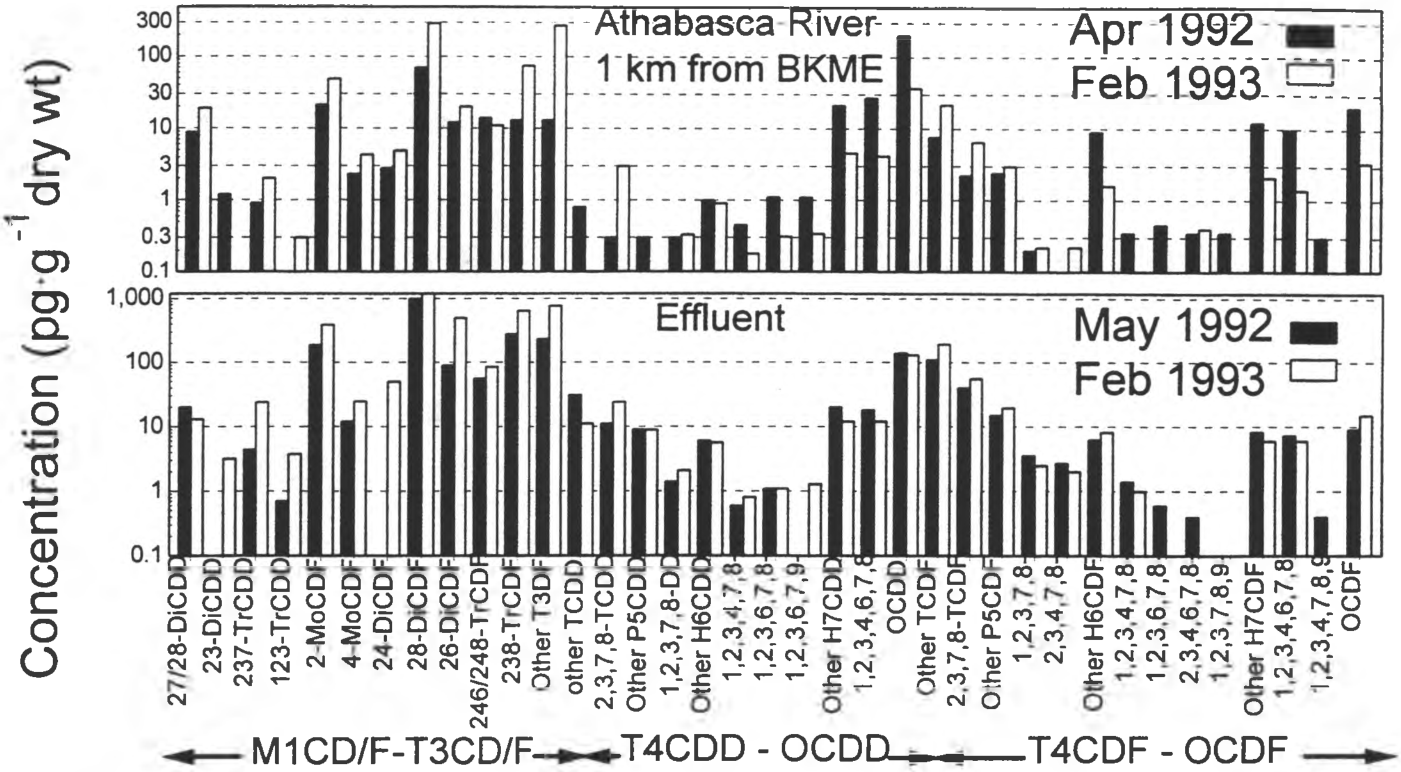
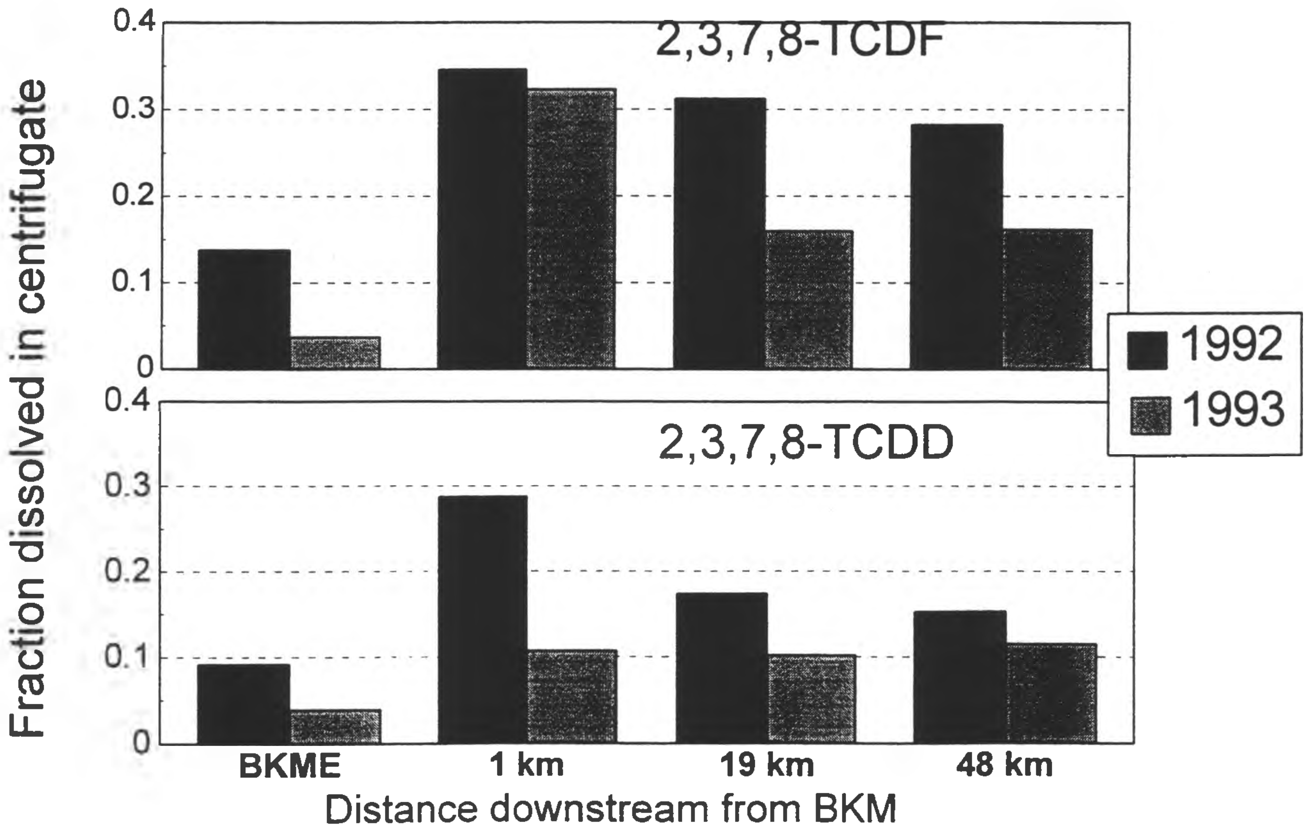


Figure 11. Estimated fraction of TCDF and TCDD in the dissolved phase in centrifuged river water and BKM effluent - 1992-93 Results for TCDD estimated using 0.25x detection limit in centrifugate



centrifugate data assuming detection limit values for non-detectable concentrations. The use of detection limit values for TCDF for the 1993 results was judged a reasonable approximation of actual values because other non-2,3,7,8-substituted TCDF congeners were detectable and levels in suspended solids were similar to those in 1992. However use of the detection limit to estimate dissolved TCDD concentrations would undoubtedly be an overestimate assuming a similar K_{POC} for TCDD and TCDF. Therefore a concentration of 0.25-times the detection limit was used for TCDD.

The estimated dissolved fractions of TCDF declined from 35% at 1 km to 15 % at 116 km (Figure 11) indicating that "dissolved", DOC-bound, and particle-bound fractions undergo major shifts from effluent to receiving waters (Appendix Table B9). A lower dissolved fraction was estimated for TCDD in the 1993 samples compared to 1992 because of the use of 0.25x DL. The range of K_{POC} values estimated for TCDF (7.9×10^6 to 1.2×10^7) exceeded the reported K_{OW} (3.2×10^6) for this congener. K_{POC} values for TCDD ranged from 2.1 to 2.7×10^7 similar to the reported K_{OW} (6.3×10^6) but were low estimates because of the use of 0.25x DL for the dissolved concentration. The results indicate that both TCDD and TCDF are predominately associated with particles in both effluent and river water.

4.5.4. Bioavailability of 2,3,7,8-TCDD and -TCDF to mountain whitefish

Biota-sediment accumulation factors (BSAF) were calculated (BSAF = lipid-based concentration in fish ÷ concentration in sediment OC; BSSAF for suspended solids) for mountain whitefish using results for 2,3,7,8-TCDF in depositional sediments and suspended solids (Figure 12). BSAFs normalize results for varying lipid content in biota and sediment organic carbon. At steady-state BSAFs should equal the K_{OW} divided by the K_{OC} value assuming octanol is a surrogate for lipids:

$$\text{BSAF (or BSSAF)} \approx K_{OW}/K_{POC} \approx C_{oct}/C_{fd} \div C_{POC}/C_{fd} \approx C_{lipid}/C_{POC}$$

Because K_{OW} is of similar magnitude to K_{POC} the BSAF should approach one. The limited information available for PCDD/Fs has shown BSAF values for 2,3,7,8-TCDD and -TCDF ranging from 0.03 to 0.3 for fish from different lake ecosystems and river ecosystems (Muir et al. 1992a). However, in BC and Alberta rivers BSAFs were found in earlier work to be generally >1 for mountain whitefish (Muir et al. 1992b). Pastershank and Muir (1995) reported BSAFs for 2,3,7,8-TCDD in mountain whitefish ranging from 12-19 and those for northern pike from 12-15 downstream of the HCE. But further analysis indicated that these BSAFs were too high by about 5x because incorrect fraction organic carbon was used for the bottom sediments. Recalculated BSAFs for TCDD and TCDF in mountain whitefish in spring 1992 are presented in Appendix Table B10 and in Figure 12 for six locations downstream of the HCE and compared with results for the same species calculated using spring 1993 data. BSAFs for 2,3,7,8-TCDD ranged from 1.1 to 2.0 and for TCDF from 0.19 to 1.63 in mountain whitefish in spring 1992. A similar range of BSAFs was found in 1993 but the limited sample number at Weldwood and Obed increases the uncertainity of the BSAF. There was great uncertainity in the BSAFs for TCDD because of low or non-detect levels in depositional sediments. BSAFs calculated for the upstream location are very high because of nondetect values for TCDD and TCDF in suspended sediments.

BSSAFs for both 2,3,7,8-TCDD and TCDF were generally lower and showed greater consistency than

Figure 12. Variation of BSAFs for 2,3,7,8-TCDD and -TCDF in mountain whitefish at two sampling times (Apr 1992 and May 1993)

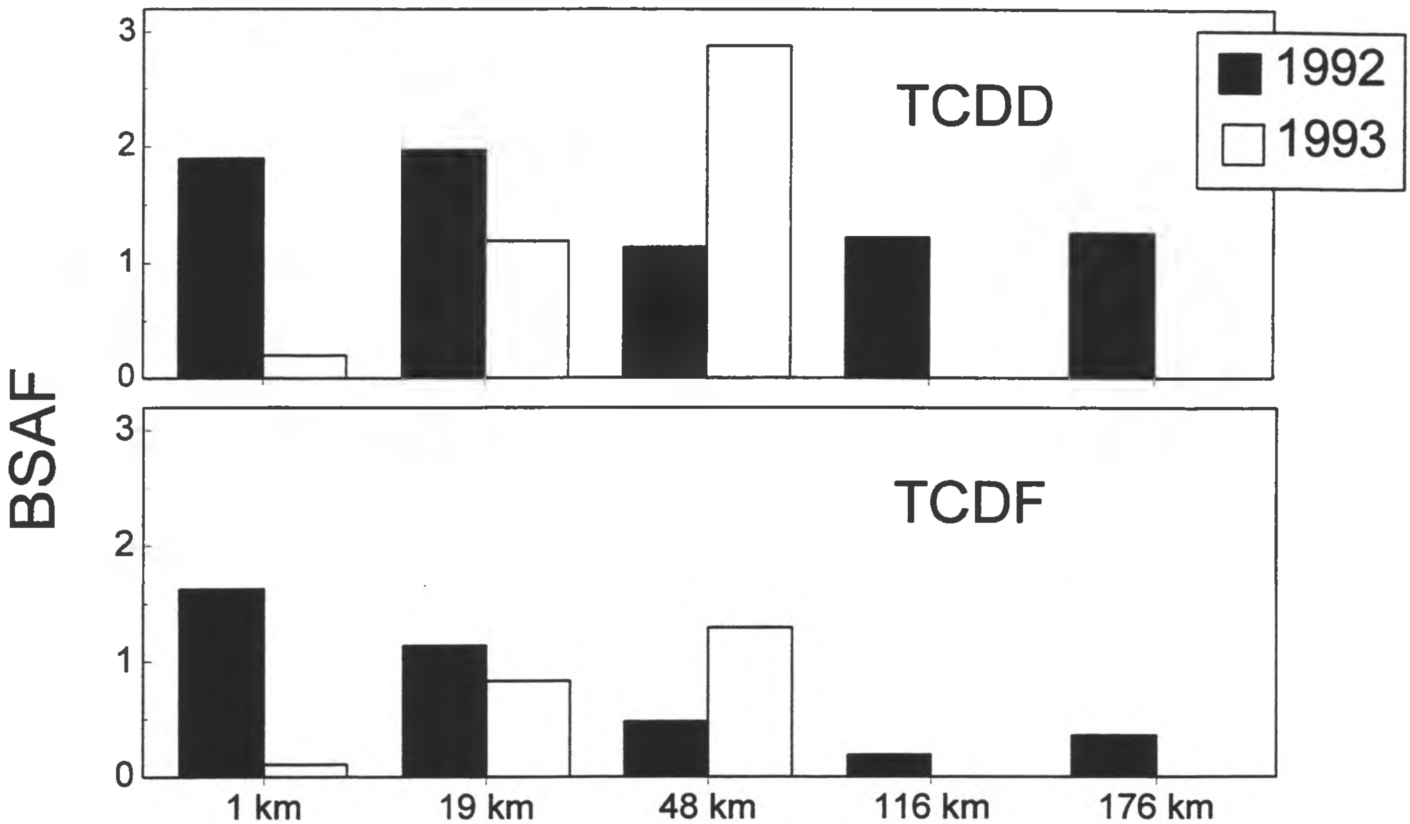
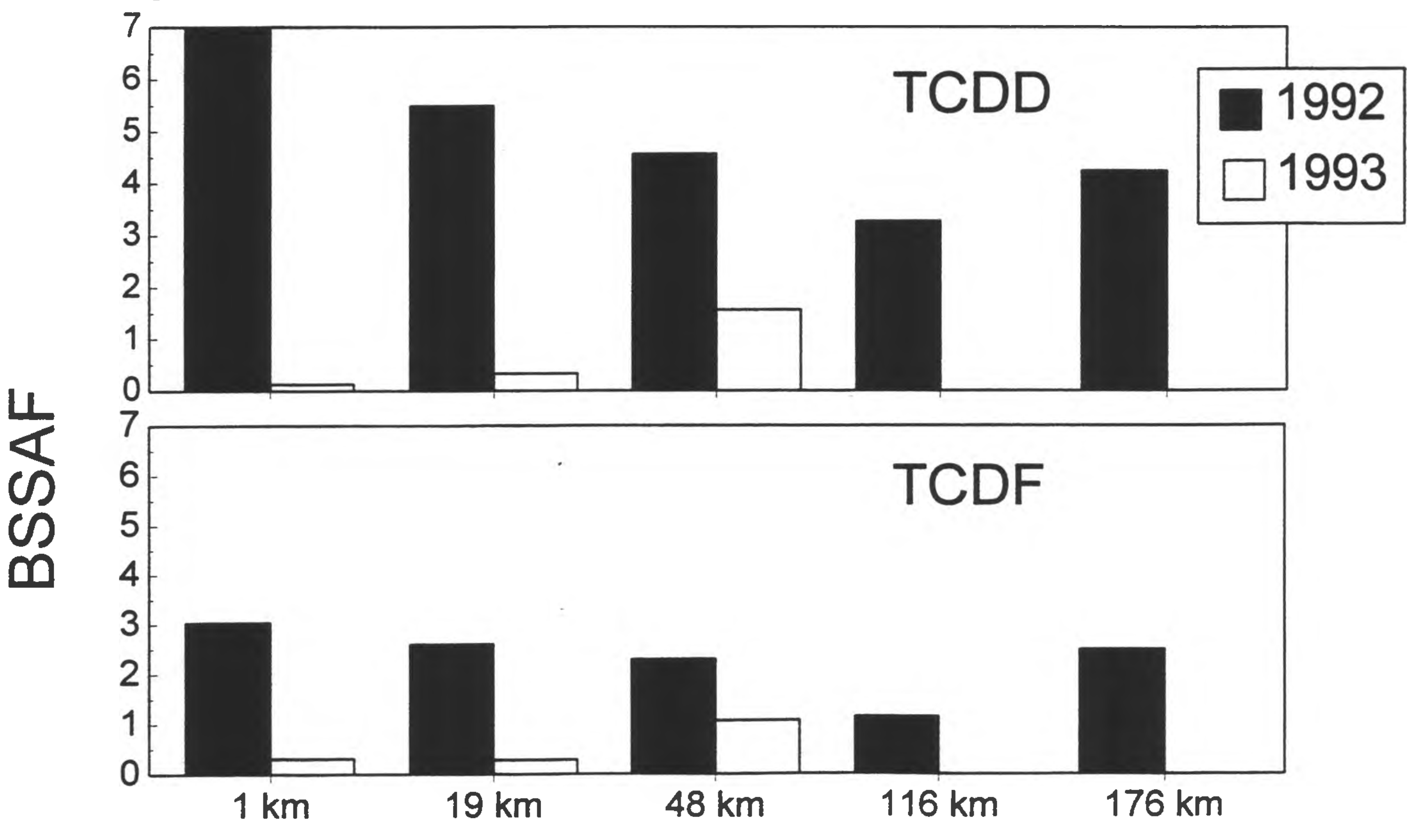


Figure 13.Variation of BSSAFs for 2,3,7,8-TCDD and -TCDF in mountain whitefish at two sampling times (Apr 1992 and May 1993)



BSAFs with distance from the BKM especially in 1992 (Figure 13). This is due to the presence of detectable levels of both TCDD and TCDF in suspended solids at all sites. Results for 1992 are from Pastershank and Muir (1995). BSSAFs for TCDD and TCDF were much lower in 1993 at Weldwood and Obed reflecting lower concentrations in mountain whitefish. The decline was not due to fraction organic carbon or % lipid which were similar in both years.

The BSAF/BSSAFs for TCDD/F in mountain whitefish and northern pike are similar despite differences in feeding behavior. The piscivorous northern pike feed mainly on detritivorous fishes (e.g. cyprinids). Mountain whitefish consume a diet predominately of filter-feeding invertebrates. These invertebrates have higher TCDD/F concentrations (wet wt) than northern pike possibly because they are selectively feeding on fine organic-rich particles in the water column (Owens et al. 1994; Pastershank and Muir 1995). Thus both pike and whitefish achieve similar concentrations on a lipid-normalized basis due to biomagnification of 2,3,7,8-TCDD and -TCDF, but via different food chains. Wet weight concentrations of TCDD/F in pike muscle are lower than in whitefish muscle because of lower lipid content.

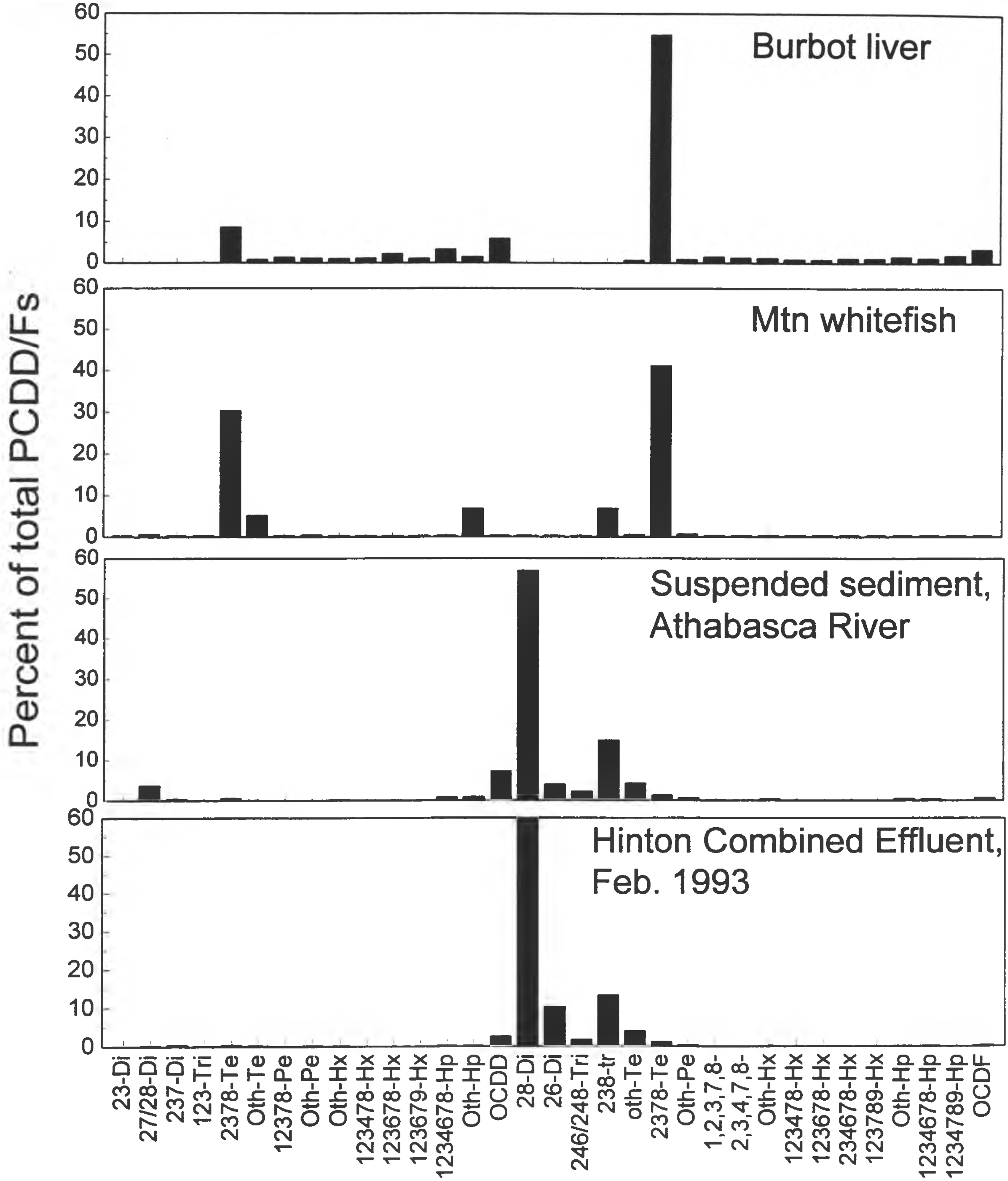
BSAFs could be calculated for burbot liver from the basin wide study using bottom sediment concentrations from Crosley (1996b,c). We have not done so because results for whole burbot or burbot muscle are not available. The composite samples of burbot muscle from the Peace-Athabasca delta study indicated non-detect levels in muscle but these sites also have very low concentrations of PCDD/Fs in liver relative to near-field locations. The reason for the high concentrations of PCDD/Fs in burbot liver may be the fact that the liver is very large, accounting for some 15% of the body weight versus some 4% in lake trout or walleye. Thus, proportionately more of the contaminant body burden is stored in burbot liver than in other fish. TCDD/F concentrations in burbot muscle can be estimated knowing the lipid content of muscle and assuming that concentrations in liver on a lipid basis are the same as concentrations in muscle lipid (i.e. multiply concentrations in liver by ratio of % lipid in muscle to that in liver). This would yield results for muscle of about 1/10 those in liver assuming 50% lipid content of liver and 5% lipid in muscle. Whole body levels of PCDD/Fs could also be estimated by assuming levels in muscle (if available) are representative of all tissues except the liver and that the liver accounts for 15% of the whole body weight.

4.5.5. Bioaccumulation modelling of TCDF

The bioaccumulation of 2,3,7,8-TCDD and -TCDF in the aquatic food web is illustrated in Figure 14. Of 33 di- to octachloro PCDD/F congeners readily detectable in effluent and suspended solids only three or four are detectable in mountain whitefish muscle or burbot liver. The pattern of congeners in fish is completely different from that in the effluent or suspended solids which is dominated by di and trichloro- furans. The major factor accounting for the observed differences is the ability of fish to metabolize and rapidly excrete non-2,3,7,8-substituted congeners (Muir et al. 1992a). Elimination rates of 2,8-DiCDF, 1,2,3,7-TCDF and 1,2,7,8-TCDF following dietary exposure of juvenile rainbow trout were 10-20 times more rapid than for 2,3,7,8-TCDF (Muir et al. 1992a).

Starodub (1995) applied the food chain model of Thomann and Connolly (1984) to simulate the bioaccumulation of TCDF by fish downstream of the Hinton BKM. This is a bioenergetics based model which includes uptake via the gills (based on respiration rate) and via food. Each level of the

Figure 14. Proportions of di-i to octa- PCDD and PCDF congeners (or homolog groups of non-2,3,7,8-substituted congeners) in mill effluents, river water suspended solids, mountain whitefish muslce and burbot liver. Suspended solids and biota are from the Weldwood Haul bridge site immediately downstream of the HCE



food chain leading from water, suspended sediment and bottom sediment, to fish is included. Loss of chemical occurs by elimination (metabolism, diffusive transfer across respiratory surfaces) and growth. Starodub (1995) applied the steady-state version of the model, i.e. no overall change in concentration in each trophic level over time. There was insufficient data available on changes in concentrations in water or the dietary items of fish with which to apply a dynamic version of the model. The feeding relationships and prey preferences for mountain whitefish and northern pike were derived from stomach content analyses of fish from the 1992 upper Athabasca River (R.L.L. Environmental Services 1993). For longnose suckers, prey preferences were based on gut analysis of fish from the Wapiti/Smoky river (Swanson et al. 1992). Two distinct exposure pathways, bottom-feeding invertebrates and filter-feeding invertebrates were distinguished for the model.

Sensitivity analysis of the food chain model showed that the elimination rate of TCDF was a key parameter. Model predictions of steady-state concentrations of TCDF in fish approached observed levels (spring 1992) using elimination rates of 0.0025 day^{-1} (equivalent to a half-life of 280 days) for mountain whitefish, 0.025 day^{-1} for suckers and 0.0075 day^{-1} for northern pike (Table 10). An elimination rate of 0.015 day^{-1} (equivalent to a half-life of 46 days) for invertebrates. In general, elimination rates of 2,3,7,8-TCDD and -TCDF are inversely related to size and lipid content of the organism (Geyer et al. 1995).

Table 10. Comparison of predicted steady-state concentrations and observed TCDF levels in fish using the Thomann and Connolly food chain model (from Starodub 1995)

Location/species		Concentrations in various organisms ($pg \cdot g^{-1}$ wet wt)				
		Benthic[a] feeder	Filter[b] feeder	Mtn whitefish	Longnose suckers	northern pike
Weldwood	Predicted	7.5	28	21	7.5	7
	Observed	6.4	13	13	2.4	0.6
Knight Br.	Predicted	8	35	26	-	8
	Observed	5.6	9	3.7	-	6.2

[a] Assumed to be mainly plecoptera and ephemeroptera. Detection limits were used for non-detects.
[b] Tricoptera

Best agreement was obtained for the benthic feeding invertebrates (Diptera). These animals are in direct contact with sediment or biofilm and better represented by a steady state model than filter feeding invertebrates utilizing suspended solids for food. Agreement was also quite good for suckers and northern pike (which were assumed to feed on small foraging fish for 95% of their diet. Slightly better agreement between predicted and observed was obtained by assuming benthic invertebrates utilized 10% bottom sediments and 90% biofilm in their diet. TCDF levels in biofilm, a periphyton growth on the cobble substrate in the river bed, were at detection limits so the introduction of a detection limit value had the effect of lowering predicted concentrations. TCDF levels in mountain whitefish and filter feeding invertebrates (trichoptera) were underpredicted by up to 5-fold. These organisms are not in equilibrium with the suspended sediment or water due to the dynamic nature of the river and resulting fluctuations in availability of particle sorbed TCDF. The disequilibrium of TCDF downstream of the HCE is also apparent from the relatively high BSSAFs (Figure 13) and shifting dissolved fraction (Figure 11). When linked to an environmental fate model which predicts concentrations in water, suspended sediments and bed sediments (Golder Associates 1995) the food chain model may be able to predict future trends in TCDF concentrations in fish given lower inputs from the BKM at Hinton.

4.6. ASSESSING RISK OF EXPOSURE TO PCDD/Fs

4.6.1. Preliminary human health risk assessment

Concentrations of TCDD TEQs in mountain whitefish muscle and burbot liver are presented in Table 11. All mean concentrations of TCDD TEQs are below the limit set by Health Canada for commercial fish sale and export of 20 $pg \cdot g^{-1}$wet wt. A few individual samples, mainly burbot liver from the Athabasca River downstream of Hinton, exceeded the 20 $pg \cdot g^{-1}$ guideline. These results are calculated using all 2,3,7,8-substituted congeners and assuming detection limit values for non-detect concentrations.

The data have been submitted for evaluation by Health Canada of human health risk assessment for subsistence use of fishes taking into account the traditional heavy use of fish by First Nations peoples in the Peace-Athabasca Region. For illustrative purposes only it is possible to do a preliminary assessment of the concentrations of PCDD/Fs (as TCDD TEQ) observed in the upper Athabasca River 1992/1993 and basin wide burbot (1994) studies.

Table 11. TCDD TEQs ($pg \cdot g^{-1}$) in burbot livers (Fall 1994) and mountain whitefish muscle (May 1993)

Location	Code	Mean ± SD $pg \cdot g^{-1}$ wet wt	Location		Mean ± SD $pg \cdot g^{-1}$ wet wt
Burbot 1994			**Mountain Whitefish 1993**		
Athabasca R. at Calling R.	A4	3.6 ± 1.6	Upstream of Hinton		<0.25
Athabasca R. at Ft. Assiniboine	A3	7.8 ± 5.9	Weldwood Haul Br.		0.61
Athabasca R. at Ft. Mackay	A5	2.6 ± 1.1	Obed Coal Br.		1.9
Athabasca R. d/s Hinton	A1	17.8 ± 6.4	Emerson Lakes Br.		8.3 ± 5.8
Athabasca R. u/s Hinton	A2	3.4 ± 2.4			
Clearwater R.	CW	2.2 ± 1.0			
Jackfish Village	JV	0.2 ± 0.2	**Burbot 1994**		
Lake Athabasca	LA	0.2 ± 0.1	Pembina R.	P	4.2 ± 2.4
Lesser Slave R.	LSV	3.0 ± 1.0	Quatre Fourches	QF	0.1
Little Smoky R.	LSR2	0.3 ± 1.6	Slave R. Delta at Ft Resolution	SR	1.8 ± 0.7
Little Smoky R.	LSR3	1.2	Wapiti R. u/s Grand Prairie	SR3	8.3
McLeod R.	MCR2	2.7	Wapiti R. u/s Grand Prairie	SR1	4.7 ± 1.9
Peace R. at Many Islands	PR1	5.5 ± 1.3	Wabasca R.	WA	4.3 ± 1.6
Peace R. at Ft. Vermilion	PR3	2.6 ± 3.7	Wapiti R. u/s Grand Prairie	WR2	6.0 ± 3.0
Peace R. at Notikewin	PR2	3.4 ± 1.9	Wapiti R. u/s Grand Prairie	WR1	4.9 ± 3.1

Health Canada's Tolerable daily intakes (TDIs) for TCDD TEQs is 10 $pg \cdot kg\text{-body } wt^{-1} \cdot day^{-1}$. This TDIs is based on No Observable Adverse Effect Levels (NOAEL) established from laboratory mammalian toxicology studies with TCDD. The TDIs are derived for a 60 kg person and assuming life-time exposure, by dividing NOAELs with a safety factor which takes into account species differences, the range variation in sensitivity of individuals in the population and also uncertainities in the toxicological data. Assuming TCDD TEQs of 8.3 $pg \cdot g^{-1}$ in mountain whitefish downstream of Hinton (means of 0.61-8.3 $pg \cdot g^{-1}$ were observed in May 1993) a 60 kg individual would have to consume 72 g of mountain whitefish muscle per day to exceed the TDI for TCDD. By comparison, we have calculated that to exceed the TDI for PCBs in mountain whitefish a 60 kg individual would have to consume 2 kg of whitefish (Pastershank and Muir 1996). Thus PCDD/Fs, rather than PCBs or organochlorine pesticides, are the chemicals of concern from the point of view of human exposure. The example of mountain whitefish from the upper Athabasca River downstream of Hinton is a worst case. More typical levels of PCDD/Fs in fish muscle are those found in lake whitefish, goldeye, burbot muscle and walleye sampled in the Peace-Athabasca delta (Table 9). Only 2,3,7,8-TCDF and OCDD were detected in these samples. Assuming levels of 2,3,7,8-TCDD at detection limits, the TCDD TEQs in these samples are about 0.5 $pg \cdot g^{-1}$ or less. A 60 kg individual would have to consume 1.2 kg per day to exceed the TDI for these samples.

4.6.2. Assessing risks to fish and wildlife

The concentrations in fish muscle can also be evaluated for possible risks to fish-eating wildlife. The draft Canadian environmental quality guideline for protection of fish-eating wildlife is 1.1 $pg \cdot g^{-1}$ TCDD TEQs. Mountain whitefish muscle from the upper Athabasca River and also from the Wapiti/Smoky downstream of the BKM at Grande Prairie (Swanson et al. 1995) exceeded this guideline in spring 1993. Swanson et al (1995) found whitefish muscle (n=5) had 2.3±1.5 $pg \cdot g^{-1}$ TCDD TEQs in spring 1994, two years after the BKM at Grande Prairie had converted to 100% ClO_2 bleaching. Concentrations in whitefish muscle also exceed the level thought to represent a hazard to the fish and other aquatic life. The aquatic life guideline of 18.2 $pg \cdot g^{-1}$ (lipid wt) TCDD TEQ is based upon a lowest observable adverse effect for 2,3,7,8-TCDD of 40 $pg \cdot g^{-1}$ associated with significant mortality in lake trout eggs at hatching ("blue-sac" disease) (Spitzbergen et al. 1991) and also taking into account the threshold of mixed-function oxidase enzyme induction of TCDD of about 20 $pg \cdot g^{-1}$ wet wt (68 $pg \cdot g^{-1}$ lipid wt) in rainbow trout liver (Parrott et al. 1995). The actual effects of TCDD on

Table 12. Draft environmental quality guidelines for PCDD/Fs for freshwater aquatic ecosystems (Environment Canada 1995)

Medium	Use protected	PCDD/F - TEQs
Water[a]	Aquatic life	0.02 $pg \cdot L^{-1}$
Sediment	Aquatic life	0.091 $pg \cdot g^{-1}$ dry wt
	Wildlife	0.091 $pg \cdot g^{-1}$ dry wt
Tissue	Wildlife	1.1 $pg \cdot g^{-1}$ wet wt
	Aquatic life	18.2 $pg \cdot g^{-1}$ lipid wt

[a] Unfiltered water

mountain whitefish or burbot have not been studied.

The concentrations of PCDD/Fs observed in river water and sediments can also be assessed with the draft Canadian Environmental Quality guidelines for TCDD (Table 12). The guideline level for raw water (for protection of aquatic life) of 0.02 $pg \cdot L^{-1}$ TCDD TEQ was probably exceeded downstream of Hinton in spring 1992 and 1993. Combining May 1993 results for centrifugate (where 2,3,7,8-TCDD was <0.1 $pg \cdot L^{-1}$) with suspended solids (7.5 $mg \cdot L^{-1}$; TCDD = ~3 $pg \cdot g^{1}$) gives a raw water concentration of >0.02 $pg \cdot L^{-1}$. With the conversion of this BKM to 100% ClO_2 substitution in summer 1993 the levels of PCDD/Fs were expected to be lower in river water.

Levels of 2,3,7,8-TCDD in bottom sediments consistently exceeded the draft guideline of 0.091 $pg \cdot g^{-1}$ downstream of Hinton in spring 1992 and 1992 and at most other sites within the basin (Crosley 1996b,c). The sediment guideline assumes a BSAF of 2 for TCDD (based in part on observations of fish near Canadian pulp mills (Muir et al. 1992b), the tissue guideline of 18.2 $pg \cdot g^{-1}$ (lipid wt) and a sediment organic carbon of 1% (2 x 18.2 x 0.01). Crosley (1996b,c) noted that TCDD TEQ levels had declined between spring 1992 and 1993 downstream of the BKM at Hinton. Continued declines in levels can be expected following the conversion to 100% ClO_2 and removal by erosion, dilution, and burial of contaminated sediments.

5.0 CONCLUSIONS

The analysis of PCDD/Fs in mountain whitefish and pike from sites downstream of Hinton in fall 1992 and spring 1993, combined with the basin wide survey of burbot liver, has provided a substantial amount of new information on the spatial and temporal trends of these contaminants in the Peace-Athabasca-Slave River basins. Combined with the work by Swanson et al (1992;1995) and the Slave River study (Peddle et al. 1995) a very large dataset now exists of PCDD/F levels in mountain whitefish, burbot liver, longnose suckers and walleye.

In general, concentrations of PCDD/Fs were higher in burbot liver than in mountain whitefish or northern pike muscle and a greater number of congeners were detected. Significantly higher levels of TCDD and TCDF were found in burbot liver downstream of the Hinton BKM in the fall 1994 survey than at all other sites.High levels in burbot are related to the fact that they are the top predator of the aquatic food web in the both the Peace and Athabasca basins and the fatty liver was analysed. The burbot liver is very large, accounting for some 15% of the body weight versus some 4% in lake trout or walleye. Thus, proportionately more of the contaminant body burden is stored in burbot liver than in other fish. While liver is a good monitoring tool whole body concentrations of PCDD/Fs in burbot are probably not much higher than in mountain whitefish, longnose suckers or pike based on a limited number of muscle and liver samples from the Peace-Athabasca delta and from downstream of the BKM at Grande Prairie.

TCDF was detected in almost all burbot liver and mountain whitefish muscle samples analysed, while 2,3,7,8-TCDD was detected in about one third of the same samples. Two other 2,3,7,8-substituted-PCDD/F congeners, 1,2,3,6,7,8-HxCDD and the heptachlorodioxin, 1,2,3,4,6,7,8-HpCDD were detected in 37% of burbot liver samples. OCDD was also detected relatively frequently (17%) while OCDF was found in only three of 203 samples. Di and trichloro-CDDs and CDFs were consistently detected in whitefish muscle but infrequently in burbot liver. The di and trichloro-CDDs and CDFs predominated in effluent and suspended solids. The predominance of the 2,3,7,8-substituted congeners reflects their much slower rates of elimination by fish compared with Di- and tri-CDD/Fs and non-2,3,7,8 subsituted tetrachloro congeners. Food chain modelling indicates that elimination rate is a key parameter for predicting TCDF concentrations in various trophic levels downstream of the BKM at Hinton on the Athabasca River.

Levels of 2,3,7,8-TCDD and -TCDF declined by three to five fold between 1989 (when first sampled by DFO and Alberta Environment) and 1993, in mountain whitefish muscle. There has been a definite decline in 2,3,7,8-TCDD and -TCDF concentrations in mountain whitefish downstream of the Hinton but most of the decrease took place in the period 1989 to 1992. The extent of the decline depends to a large extent on which results for spring 1993 are used. If samples from the near-field sites of Weldwood and Obed (mean concentrations of 1.1 and 2.6 $pg \cdot g^{-1}$ wet, for TCDD and TCDF respectively) are used the decline is about 5-fold for both TCDD and TCDF over four years. But if the fish from Emerson Lake (48 km downstream) are included (mean concentrations are 3.6 and 7.1 $pg \cdot g^{-1}$ wet, for TCDD and TCDF, respectively) the decline is about 3-fold. The greater decline at Hinton may be related to sampling of relatively uncontaminated fishes residing upstream of the BKME.

Levels of 2,3,7,8-TCDD and -TCDF in burbot liver were lower in the fall 1994 collection than in fall 1992 at four sites; downstream of the Grande Prairie pulp mill outlet, PR2 on the Peace River near the mouth of the Notikewin River (674 km from confluence of the Peace/Slave), and PR3 upstream of Fort Vermillion (396 km). Comparison of concentrations in burbot liver near the BKM at Grande Prairie was problematic because sampling sites were not in the same locations each year. Nevertheless, the results show a decline of 4 to 17-times in the case of 2,3,7,8-TCDF at three sites. No significant decline of TCDD or TCDF concentrations was found in burbot livers from PR2. The burbot liver results, expressed as TCDD TEQ's, also agreed well with those of Swanson et al. (1995) who found a 5-fold decline in TEQs downstream of the Grande Prairie BKM between summer 1991 and spring 1994. Limited sample numbers and lack of collections from exactly the same area precluded a more thorough examination of temporal trends in burbot. Future studies of temporal trends should focus on a few areas, such as the Wapiti/Smoky, the Athabasca River downstream of Hinton, and the Slave River delta where multi-year sampling has been carried out.

Concentrations of all 2,3,7,8-substituted PCDD/F congeners in composite samples of fish muscle from the Ft. Chipewyan winter domestic fishery study were at or near detection limits (<0.1 to <0.8 $pg \cdot g^{-1}$). Only 2,3,7,8-TCDF was detectable in most samples (<0.1 to 0.5 $pg \cdot g^{-1}$). Burbot liver samples from the three sites in the Peace-Athabasca delta had higher levels of 2,3,7,8-TCDF than burbot muscle (1.7 to 2.9 $pg \cdot g^{-1}$). These levels were similar to those at other far-field and reference sites located far from BKMs. TCDD TEQs in these samples are about 0.5 $pg \cdot g^{-1}$ or less. A preliminary risk assessment showed that the TDI for TCDD TEQs would not normally be exceeded by consumption of fish muscle from this region because a 60 kg individual would have to consume 1.2 kg per day to exceed the TDI for these samples.

The bioavailability of TCDD and TCDF to mountain whitefish and northern pike was assessed using biota-sediment (or suspended sediment) accumulation factors (BSAF/BSSAFs). BSAFs for 2,3,7,8-TCDD ranged from 1.1 to 2.0 and for TCDF from 0.19 to 1.63 in mountain whitefish in spring 1992. A similar range of BSAFs was found in 1993. BSSAFs for both 2,3,7,8-TCDD and TCDF were generally lower and showed greater consistency than BSAFs with distance from the BKM. The results suggest that TCDD/TCDF levels in fish can be estimated with an average, site specific, BSAF or BSSAF using bed sediment or or suspended sediment results. Application of the Thomann and Connolly food chain model (steady-state version) to predict levels of TCDF in the food web downstream of Hinton showed that good agreement between predicted and observed results could be obtained for benthic feeding organisms (and longnose suckers and pike) which were close to equilibrium with sediments or biofilm. The model overpredicted concentrations in filter-feeding invertebrates and mountain whitefish; these organisms are not in equilibrium with TCDF in the water and suspended solids in the river due to the dynamic nature of the system. Better predictions would be possible if further work was done to determine elimination rates of PCDD/Fs in adult fishes and the relationship between fish size and/or lipid and elimination rate.

All mean concentrations of TCDD TEQs in fish muscle or liver were below the limit set by Health Canada for commercial fish sale and export of 20 $pg \cdot g^{-1}$ wet wt. A few individual samples, mainly burbot liver from the Athabasca River downstream of Hinton, exceeded the 20 $pg \cdot g^{-1}$ guideline. Assuming the highest mean concentrations observed in the May 1993 whitefish samples (8.3 $pg \cdot g^{-1}$ TCDD TEQs downstream of Hinton) a 60 kg individual would have to consume 72 g of mountain whitefish muscle per day to exceed the Health Canada Tolerable Daily Intake (10 $pg \cdot kg\text{-body } wt^{-1} \cdot day^{-1}$) for TCDD. By comparison, we have calculated that to exceed the TDI for PCBs in mountain whitefish a 60 kg individual would have to consume 2 kg of whitefish (Pastershank and Muir 1996). Thus PCDD/Fs, rather than PCBs or organochlorine pesticides, are the chemicals of concern from the point of view of human exposure. But levels of TCDD and TCDF, the major contributors to TEQs, are expected to have declined further in fish downstream of Hinton following the conversion to 100% ClO_2 bleaching in July 1993. Additional analyses should be carried out to confirm this.

TCDD TEQ levels in mountain whitefish muscle from the upper Athabasca River exceeded draft Canadian environmental quality guidelines (EQGs) for protection of wildlife (1.1 $pg \cdot g^{-1}$ wet wt) in spring 1993. The concentrations of PCDD/Fs observed in river water and sediments also exceeded EQGs for raw water (for protection of aquatic life) of 0.02 $pg \cdot L^{-1}$ and sediment (0.091 $pg \cdot g^{-1}$) downstream of Hinton in spring 1992 and 1993. Declining emissions may bring TCDD levels in water and sediment below EQGs. Further analyses are needed to confirm this has happened.

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APPENDIX A.

CONCENTRATIONS OF INDIVIDUAL PCDD/F CONGENERS IN FISH TISSUES FROM THE PEACE-ATHABASCA-SLAVE RIVER BASIN: FALL 1992, SPRING 1993 AND FALL 1994.

Table A1. Levels of PCDD/Fs (pg g^{-1} wet wt) in Mountain Whitefish and Northern Pike muscle, Fall 1992[1]

Location	Fish Species	Congener	Detection Limit pg g^{-1} wet wt	Low		High	# of Detects	Mean ± SD
Upstream (Control)	mountain whitefish	2,3,7,8- TeCDD	0.10	0	-	1.5	(3/4)	0.55 ± 0.66
		1,2,3,7,8- PeCDD	0.10	0	-	0.20	(1/4)	0.05 ± 0.10
		Total TeCDD		0	-	2.9	(3/4)	0.90 ± 1.3
		Total PeCDD		0	-	0.20	(1/4)	0.05 ± 0.10
		Total HxCDD			-		(0/4)	
		Total HpCDD			-		(0/4)	
		OCDD			-		(0/4)	
		2,3,7,8- TeCDF	0.10	0.50	-	4.5	(4/4)	1.7 ± 1.9
		Total TeCDF		0.50	-	4.5	(4/4)	1.7 ± 1.9
		Total PeCDF			-		(0/4)	
		Total HxCDF			-		(0/4)	
		Total HpCDF			-		(0/4)	
		OCDF			-		(0/4)	
Weldwood	mountain whitefish	2,3,7,8- TeCDD	0.20	1.1	-	15	(4/4)	5.3 ± 6.5
		Total TeCDD		1.1	-	15	(4/4)	6.2 ± 6.4
		Total PeCDD		0	-	0.30	(1/4)	0.08 ± 0.15
		Total HxCDD			-		(0/4)	
		Total HpCDD		0.8	-	1.6	(4/4)	1.2 ± 0.34
		OCDD		0	-	0	(0/4)	
		2,3,7,8- TeCDF	0.25	2.2	-	13	(4/4)	7.2 ± 5.7
		Total TeCDF		2.2	-	13	(4/4)	7.3 ± 5.7
		Total PeCDF		0	-	0.50	(1/4)	0.13 ± 0.25
		Total HxCDF			-		(0/4)	
		Total HpCDF			-		(0/4)	
		OCDF			-		(0/4)	
Obed Coal	mountain whitefish	2,3,7,8- TeCDD	0.10	2.4	-	8.4	(5/5)	5.1 ± 2.7
		Total TeCDD		2.4	-	8.6	(5/5)	5.1 ± 2.8
		Total PeCDD		0	-	1.2	(2/5)	0.36 ± 0.54
		Total HxCDD		0	-	1.1	(2/5)	0.38 ± 0.53
		Total HpCDD		0	-	2	(3/5)	0.72 ± 0.83
		OCDD			-		(0/5)	
		2,3,7,8- TeCDF	0.10	3.0	-	19	(5/5)	7.3 ± 6.6
		2,3,4,7,8- PeCDF	0.10	0	-	0.30	(2/5)	0.1 ± 0.14
		Total TeCDF		3.0	-	19	(5/5)	7.3 ± 6.6
		Total PeCDF		0	-	1.8	(2/5)	0.58 ± 0.83
		Total HxCDF			-		(0/5)	
		Total HpCDF			-		(0/5)	
		OCDF			-		(0/5)	
Emerson	mountain whitefish	2,3,7,8- TeCDD	0.25	0.3	-	20	(4/4)	7.7 ± 9.3
		1,2,3,7,8- PeCDD	0.10	0	-	0.60	(2/4)	0.20 ± 0.28
		Total TeCDD		0.50	-	20	(4/4)	7.8 ± 9.2
		Total PeCDD		0	-	0.60	(2/4)	0.30 ± 0.35
		Total HxCDD		0	-	0.90	(3/4)	0.58 ± 0.39
		Total HpCDD		0	-	3.1	(2/4)	1.1 ± 1.5
		OCDD			-		(0/4)	
		2,3,7,8- TeCDF	0.1	1.1	-	29	(4/4)	9.8 ± 13

Location	Fish Species	Congener	Detection Limit pg g^{-1} wet wt	Low		High	# of Detects	Mean ± SD
		1,2,3,7,8- PeCDF	0.15	0	-	0.10	(1/4)	0.03 ± 0.05
		2,3,4,7,8- PeCDF	0.15	0	-	0.60	(2/4)	0.20 ± 0.28
				0.40	-	1.4	(4/4)	0.93 ± 0.41
		Total TeCDF		1.6	-	29	(4/4)	10 ± 13
		Total PeCDF		0	-	1.4	(4/4)	0.48 ± 0.63
		Total HxCDF			-		(0/4)	
		Total HpCDF			-		(0/4)	
		OCDF			-		(0/4)	
Knight Bridge	mountain whitefish	2,3,7,8- TeCDD	0.10	0.30	-	1.7	(4/4)	0.78 ± 0.63
		Total TeCDD		0.30	-	1.7	(4/4)	0.85 ± 0.60
		Total PeCDD		0	-	0	(0/4)	
		Total HxCDD		0	-	1.9	(3/4)	0.75 ± 0.81
		Total HpCDD		0	-	2.9	(3/4)	1.25 ± 1.3
		OCDD		0	-	0	(0/4)	0 ± 0
		2,3,7,8- TeCDF	0.10	1.4	-	2.4	(4/4)	1.8 ± 0.43
		Total TeCDF		1.4	-	2.8	(4/4)	2.0 ± 0.63
		Total PeCDF			-		(0/4)	
		Total HxCDF			-		(0/4)	
		Total HpCDF			-		(0/4)	
		OCDF			-		(0/4)	
Weldwood	northern pike	Total TeCDD					(0/1)	
		Total PeCDD					(0/1)	
		Total HxCDD					(0/1)	
		Total HpCDD					(0/1)	
		OCDD					(0/1)	
		2,3,7,8- TeCDF	0.10				(1/1)	0.20
		Total TeCDF					(1/1)	0.20
		Total PeCDF					(0/1)	
		Total HxCDF					(0/1)	
		Total HpCDF					(0/1)	
		OCDF					(0/1)	
Emerson Lake	northern pike	2,3,7,8- TeCDD	0.10	0	-	0.30	(1/2)	0.15
		Total TeCDD		0	-	0.30	(1/2)	0.15
		Total PeCDD			-		(0/2)	
		Total HxCDD			-		(0/2)	
		Total HpCDD			-		(0/2)	
		Total OCDD			-		(0/2)	
		2,3,7,8- TeCDF	0.10	0.40	-	0.70	(2/2)	0.55
		Total TeCDF		0.40	-	0.70	(2/2)	0.55
		Total PeCDF		0	-	0	(0/2)	
		Total HxCDF		0	-	0	(0/2)	
		Total HpCDF		0	-	0	(0/2)	
		Total OCDF		0	-	0	(0/2)	
Knight Bridge	northern pike	2,3,7,8- TeCDD	0.13	0	-	4.7	(4/6)	0.96 ± 1.71
		1,2,3,7,8- PeCDD	0.14	0	-	0.20	(1/6)	0.03 ± 0.08
		Total TeCDD	0.029	0	-	4.7	(4/6)	0.96 ± 1.71
		Total PeCDD		0	-	0.20	(1/6)	0.03 ± 0.08
		Total HxCDD			-		(0/6)	

Location	Fish Species	Congener	Detection Limit pg g^{-1} wet wt	Low		High	# of Detects	Mean ± SD
		Total HpCDD			-		(0/6)	
		OCDD			-		(0/6)	
		2,3,7,8- TeCDF	0.1	0.3	-	16	(6/6)	3.2 ± 5.8
		1,2,3,7,8- PeCDF	0.1	0	-	0.10	(1/6)	0.01 ± 0.04
		2,3,4,7,8- PeCDF	0.10	0	-	0.30	(1/6)	0.04 ± 0.11
		Total TeCDF	0.057	0.3	-	16	(6/6)	3.2 ± 5.8
		Total PeCDF		0	-	0.40	(1/6)	0.06 ± 0.15
		Total HxCDF			-		(0/6)	
		Total HpCDF			-		(0/6)	
		OCDF			-		(0/6)	
Windfall Br.	northern pike	2,3,7,8- TeCDD	0.17	0	-	2.5	(7/7)	0.90 ± 1.1
		1,2,3,7,8- PeCDD	0.16	0	-	0.20	(1/7)	0.03 ± 0.08
		1,2,3,6,7,8- HxCDD	0.27	0	-	0.20	(1/7)	0.03 ± 0.08
		Total TeCDD		0	-	2.5	(5/7)	0.9 ± 1.1
		Total PeCDD		0	-	0.20	(1/7)	0.03 ± 0.08
		Total HxCDD		0	-	0.20	(1/7)	0.03 ± 0.08
		Total HpCDD			-		(0/7)	
		OCDD			-		(0/7)	
		2,3,7,8- TeCDF	0.13	0.40	-	10	(7/7)	3.0 ± 3.5
		1,2,3,7,8- PeCDF	0.13	0	-	0.10	(1/7)	0.014 ± 0.038
		2,3,4,7,8- PeCDF	0.13	0	-	0.10	(1/7)	0.014 ± 0.038
		Total TeCDF		0.40	-	10	(7/7)	3.0 ± 3.5
		Total PeCDF		0	-	0.20	(1/70	0.029 ± 0.076
		Total HxCDF			-		(0/7)	
		Total HpCDF			-		(0/7)	
		OCDF			-		(0/7)	

[1] Congeners not detected in any sample are not included

Table A2. Levels of lower chlorinated PCDD/Fs (pg g^{-1} wet wt) in Mountain Whitefish and Northern Pike muscle, Fall 1992[1]

Fish species	location	congener	DL[1] pg g^{-1} wet wt	Concentration range low - high	detects	Concentration mean ± SD
mountain whitefish	Upstream (control)	2,3- DiCDD	1.3	-	(0/4)	0.0
		2,7/2,8- DiCDD	1.0	<1 - 12	(2/4)	4.7 ± 5.8
		2,3,7- TrCDD	1.0	-	(0/4)	0.0
		2,8- DiCDF	8.5	-	(0/4)	0.0
		2,3,8- TrCDF	0.8	-	(0/4)	0.0
mountain whitefish	Weldwood	2,3- DiCDD	1.4	-	(0/12)	0.0
		2,7/2,8- DiCDD	1.6	<1.6 - 1.5	(1/12)	0.1 ± 0.4
		2,3,7- TrCDD	1.5	-	(0/12)	0.0
		2,8- DiCDF	6.4	-	(0/12)	0.0
		2,3,8- TrCDF	1.1	<1.1 - 2.5	(8/12)	1.2 ± 0.9
mountain whitefish	Obed Coal	All congeners were N/R for the Obed Coal Sampling site				
mountain whitefish	Emerson	2,3- DiCDD	0.89	-	(0/9)	0.0
		2,7/2,8- DiCDD	0.82	<0.82 - 1.1	(1/9)	0.1 ± 0.4
		2,3,7- TrCDD	0.99	-	(0/9)	0.0
		2,8- DiCDF	4.1	-	(0/9)	0.0
		2,3,8- TrCDF	0.68	<0.68 - 4.1	(8/9)	1.9 ± 1.4
mountain whitefish	Knight Br.	2,3- DiCDD	0.80	-	(0/9)	0.0
		2,7/2,8- DiCDD	0.89	<0.89 - 0.8	(1/9)	0.1 ± 0.3
		2,3,7- TrCDD	0.83	-	(0/9)	0.0
		2,8- DiCDF	4.7	-	(0/9)	0.0
		2,3,8- TrCDF	0.54	<0.54 - 1.5	(4/9)	0.4 ± 0.6
mountain whitefish	Windfall Br.	2,3- DiCDD	0.40	-	(0/3)	0.0
		2,7/2,8- DiCDD	0.47	-	(0/3)	0.0
		2,3,7- TrCDD	0.37	-	(0/3)	0.0
		2,8- DiCDF	2.6	-	(0/3)	0.0
		2,3,8- TrCDF	0.20	0.20 - 0.60	(3/3)	0.4 ± 0.2
northern pike	Upstream	All northern pike were N/R for all congeners for the U/S Sampling site				
northern pike	Weldwood	2,3- DiCDD	1.1	-	(0/2)	0.0
		2,7/2,8- DiCDD	1.1	-	(0/2)	0.0
		2,3,7- TrCDD	3	-	(0/2)	0.0
		2,8- DiCDF	5.4	-	(0/2)	0.0
		2,3,8- TrCDF	0.5	<0.5 - 0.5	(1/2)	0.3
northern pike	Emerson	2,3- DiCDD	1.1	-	(0/1)	0.0
		2,7/2,8- DiCDD	1.2	-	(0/1)	0.0
		2,3,7- TrCDD	0.8	-	(0/1)	0.0
		2,8- DiCDF	4.2	-	(0/1)	0.0
		2,3,8- TrCDF	0.5	-	(0/1)	0.0
northern pike	Knight Br.	2,3- DiCDD	1.2	-	(0/11)	0.0
		2,7/2,8- DiCDD	1.3	<1.3 - 13	(2/11)	1.7 ± 4.1
		2,3,7- TrCDD	1.2	-	(0/11)	0.0
		2,8- DiCDF	6.4	-	(0/11)	0.0
		2,3,8- TrCDF	0.65	-	(0/11)	0.0

[1] Sample detection limit

Table A3. Levels of Higher Chlorinated PCDD/Fs (pg g^{-1} wet wt) in Mountain Whitefish muscle samples from the Athabasca River, May 1993[1]

Location	Compound		DL pg g^{-1} wet wt	Low		High	Detects	Mean ± SD
Upstream	2,3,7,8-	TeCDD	0.3		-		(0/2)	<0.30
(Control)	1,2,3,7,8-	PeCDD	0.4		-		(0/2)	<0.35
	1,2,3,4,7,8-	HxCDD	0.6		-		(0/2)	<0.6
	1,2,3,6,7,8-	HxCDD	0.7		-		(0/2)	<0.7
	1,2,3,7,8,9-	HxCDD	0.6		-		(0/2)	<0.6
	1,2,3,4,6,7,8-	HpCDD	1.2		-		(0/2)	<1.2
	OCDD		2.0		-		(0/2)	<2.0
	Total	TeCDD			-		(0/2)	
	Total	PeCDD			-		(0/2)	
	Total	HxCDD			-		(0/2)	
	Total	HpCDD			-		(0/2)	
	2,3,7,8-	TeCDF	0.2		-		(0/2)	<0.2
	1,2,3,7,8-	PeCDF	0.2		-		(0/2)	<0.2
	2,3,4,7,8-	PeCDF	0.2		-		(0/2)	<0.2
	1,2,3,4,7,8-	HxCDF	0.5		-		(0/2)	<0.5
	1,2,3,6,7,8-	HxCDF	0.5		-		(0/2)	<0.5
	1,2,3,7,8,9-	HxCDF	1.1		-		(0/2)	<1.1
	2,3,4,6,7,8-	HxCDF	0.7		-		(0/2)	<0.7
	1,2,3,4,6,7,8-	HpCDF	0.7		-		(0/2)	<0.7
	1,2,3,4,7,8,9-	HpCDF	1.2		-		(0/2)	<1.2
	OCDF		3.1		-		(0/2)	<3.1
	Total	TeCDF			-		(0/2)	
	Total	PeCDF			-		(0/2)	
	Total	HxCDF			-		(0/2)	
	Total	HpCDF			-		(0/2)	
	Lipid	Content		0.03	-	0.05	(0/2)	0.04
	Moisture	Content		0.75	-	0.77	(0/2)	0.76
Weldwood	2,3,7,8-	TeCDD	0.3	0.5	-	0.7	(2/2)	0.6
	1,2,3,7,8-	PeCDD	0.6		-		(0/2)	<0.6
	1,2,3,4,7,8-	HxCDD	1.0		-		(0/2)	<1.0
	1,2,3,6,7,8-	HxCDD	1.0		-		(0/2)	<1.1
	1,2,3,7,8,9-	HxCDD	1.0		-		(0/2)	<1.2
	1,2,3,4,6,7,8-	HpCDD	2.2		-		(0/2)	<2.2
	OCDD		5.7		-		(0/2)	<5.7
	Total	TeCDD		0.5	-	0.7	(2/2)	0.6
	Total	PeCDD			-		(0/2)	
	Total	HxCDD			-		(0/2)	
	Total	HpCDD			-		(0/2)	
	2,3,7,8-	TeCDF	0.4	1.2	-	1.6	(2/2)	1.4
	1,2,3,7,8-	PeCDF	0.4		-		(0/2)	<0.4
	2,3,4,7,8-	PeCDF	0.4		-		(0/2)	<0.4
	1,2,3,4,7,8-	HxCDF	0.6		-		(0/2)	<0.6
	1,2,3,6,7,8-	HxCDF	0.6		-		(0/2)	<0.6
	1,2,3,7,8,9-	HxCDF	1.2		-		(0/2)	<1.2

Location	Compound		DL pg g^{-1} wet wt	Low		High	Detects	Mean ± SD
	2,3,4,6,7,8-	HxCDF	0.9		-		(0/2)	<0.9
	1,2,3,4,6,7,8-	HpCDF	1.3		-		(0/2)	<1.2
	1,2,3,4,7,8,9-	HpCDF	2.6		-		(0/2)	<2.6
	OCDF		5.0		-		(0/2)	<5.0
	Total	TeCDF		1.2	-	1.6	(2/2)	1.4
	Total	PeCDF			-		(0/2)	
	Total	HxCDF			-		(0/2)	
	Total	HpCDF			-		(0/2)	
	Lipid	Content		0.067	-	0.070	(2/2)	0.069
	Moisture	Content		0.749	-	0.763	(2/2)	0.756
Obed	2,3,7,8-	TeCDD	0.2	1.4	-	1.7	(2/2)	1.6
	1,2,3,7,8-	PeCDD	0.2		-		(0/2)	<0.2
	1,2,3,4,7,8-	HxCDD	0.3		-		(0/2)	<0.3
	1,2,3,6,7,8-	HxCDD	0.3		-		(0/2)	<0.4
	1,2,3,7,8,9-	HxCDD	0.3		-		(0/2)	<0.5
	1,2,3,4,6,7,8-	HpCDD	0.4		-		(0/2)	<0.4
	OCDD		1.8		-		(0/2)	1.8
	Total	TeCDD		1.4	-	1.7	(2/2)	1.6
	Total	PeCDD			-		(0/2)	
	Total	HxCDD			-		(0/2)	
	Total	HpCDD			-		(0/2)	
	2,3,7,8-	TeCDF	0.2	3.7	-	3.9	(2/2)	3.8
	1,2,3,7,8-	PeCDF	0.2		-	0.1	(0/2)	0.1
	2,3,4,7,8-	PeCDF	0.2		-		(0/2)	<0.2
	1,2,3,4,7,8-	HxCDF	0.3		-		(0/2)	<0.3
	1,2,3,6,7,8-	HxCDF	0.3		-		(0/2)	<0.4
	1,2,3,7,8,9-	HxCDF	0.4		-		(0/2)	<0.4
	2,3,4,6,7,8-	HxCDF	0.3		-		(0/2)	<0.3
	1,2,3,4,6,7,8-	HpCDF	0.3		-		(0/2)	<0.3
	1,2,3,4,7,8,9-	HpCDF	0.6		-		(0/2)	<0.6
	OCDF		1.9		-		(0/2)	<1.9
	Total	TeCDF		5.2	-	5.9	(2/2)	5.6
	Total	PeCDF			-	0.1	(0/2)	0.1
	Total	HxCDF			-		(0/2)	
	Total	HpCDF			-		(0/2)	
	Lipid	Content		0.060	-	0.110	(2/2)	0.085
	Moisture	Content		0.707	-	0.728	(2/2)	0.718
Emerson Lake Br.	2,3,7,8-	TeCDD	0.8	1.2	-	10	(3/3)	7.0 ± 5.0
	1,2,3,7,8-	PeCDD	0.2		-		(0/3)	<0.2
	1,2,3,4,7,8-	HxCDD	0.4		-		(0/3)	<0.4
	1,2,3,6,7,8-	HxCDD	0.4		-		(0/3)	<0.4
	1,2,3,7,8,9-	HxCDD	0.4		-		(0/3)	<0.4
	1,2,3,4,6,7,8-	HpCDD	0.9		-		(0/3)	<0.9
	OCDD		2.0		-	1.2	(1/3)	0.4 ± 0.7
	Total	TeCDD		1.2	-	10	(3/3)	7.0 ± 5.0

Location	Compound		DL pg g[-1] wet wt	Low		High	Detects	Mean ± SD
	Total	PeCDD			-		(0/3)	
	Total	HxCDD			-		(0/3)	
	Total	HpCDD			-		(0/3)	
	2,3,7,8-	TeCDF	0.17	4	-	18	(3/3)	13 ± 7.8
	1,2,3,7,8-	PeCDF	0.2		-		(0/3)	<0.2
	2,3,4,7,8-	PeCDF	0.2		-		(0/3)	<0.3
	1,2,3,4,7,8-	HxCDF	0.4		-		(0/3)	<0.4
	1,2,3,6,7,8-	HxCDF	0.3		-		(0/3)	<0.3
	1,2,3,7,8,9-	HxCDF	0.7		-		(0/3)	<0.7
	2,3,4,6,7,8-	HxCDF	0.5		-		(0/3)	<0.5
	1,2,3,4,6,7,8-	HpCDF	0.7		-		(0/3)	<0.7
	1,2,3,4,7,8,9-	HpCDF	1.1		-		(0/3)	<1.1
	OCDF		1.7		-		(0/3)	<1.7
	Total	TeCDF		5.5	-	21	(3/3)	15.3 ± 8.5
	Total	PeCDF			-		(0/3)	
	Total	HxCDF			-		(0/3)	
	Total	HpCDF			-		(0/3)	
	Lipid	Content		0.072	-	0.075	(3/3)	0.074 ± 0.002
	Moisture	Content		0.694	-	0.723	(3/3)	0.704 ± 0.017

[1] Sample detection limit

Table A4. Summary of PCDD/F concentrations (pg g^{-1} wt wt) in long-nose sucker and northern pike liver from the Peace, Smoky, and Athabasca River and major tributaries (1994)

Location	Species	Congener	DL pg g^{-1}	Min - Max	Frequency	Mean ± SD
WR1	long-nose sucker	2378 -TCDD	0.3	<0.2 - 0.8	(1/6)	0.1
		12378 -PeCDD	0.3	<0.2 - <0.6	(0/6)	<0.3
		123478 -HxCDD	0.5	<0.3 - <0.8	(0/6)	<0.5
		123678 -HxCDD	0.4	<0.3 - <0.7	(0/6)	<0.4
		123789 -HxCDD	0.4	<0.3 - <0.7	(0/6)	<0.4
		1234678 -HpCDD	0.4	<0.3 - <0.7	(0/6)	<0.4
		OCDD	0.7	<0.5 - <1.1	(0/6)	<0.7
		Total TCDD	0.3	<0.2 - <0.4	(1/8)	0.1
		Total PeCDD	0.3	<0.2 - <0.6	(0/6)	<0.3
		Total HxCDD	0.4	<0.3 - <0.7	(0/6)	<0.4
		Total HpCDD	0.4	<0.3 - <0.7	(0/6)	<0.4
		2378 -TCDF	0.3	0.6 - 5.4	(6/6)	2.2 ± 1.9
		12378 -PeCDF	0.3	<0.1 - <0.6	(0/6)	<0.3
		23478 -PeCDF	0.3	<0.1 - <0.5	(0/6)	<0.3
		123478 -HxCDF	0.4	<0.2 - <0.7	(0/6)	<0.4
		123678 -HxCDF	0.4	<0.2 - <0.6	(0/6)	<0.4
		123789 -HxCDF	0.5	<0.3 - <0.9	(0/6)	<0.5
		234678 -HxCDF	0.4	<0.2 - <0.6	(0/6)	<0.4
		1234678 -HpCDF	0.4	<0.2 - <0.5	(0/6)	<0.4
		1234789 -HpCDF	0.6	<0.3 - <0.7	(0/6)	<0.6
		Total TeCDF	0.3	<0.2 - 1	(1/6)	0.2
		Total PeCDF	0.2	<0.1 - <0.5	(0/6)	<0.2
		Total HxCDF	0.4	<0.2 - 5.8	(1/6)	1.0
		Total HpCDF	0.5	<0.3 - <0.6	(0/6)	<0.5
		OCDF	0.4	<0.3 - <0.6	(0/6)	<0.4
		Lipid		3.48 - 13.3	(6/6)	6.6 ± 4.1
WR1	northern pike	2378 -TCDD	0.4	<0.2 - <0.4	(0/4)	<0.4
		12378 -PeCDD	0.5	<0.4 - <0.5	(0/4)	<0.5
		123478 -HxCDD	0.5	<0.3 - 0.7	(1/4)	0.2
		123678 -HxCDD	0.5	<0.4 - 1.7	(1/4)	0.4
		123789 -HxCDD	0.5	<0.4 - <0.5	(0/4)	<0.5
		1234678 -HpCDD	0.4	<0.4 - <0.5	(0/4)	<0.4
		OCDD	1.1	<0.9 - <1.2	(0/4)	<1.1
		Total TCDD	0.4	<0.3 - <0.4	(1/4)	<0.4
		Total PeCDD	0.5	<0.4 - <0.5	(0/4)	<0.5
		Total HxCDD	0.5	<0.4 - <0.5	(0/4)	<0.5
		Total HpCDD	0.4	<0.4 - <0.5	(0/4)	<0.4
		2378 -TCDF	0.4	1 - 4	(4/4)	2.3 ± 1.5
		12378 -PeCDF	0.4	<0.3 - <0.5	(0/4)	<0.4
		23478 -PeCDF	0.4	<0.3 - 4.6	(1/4)	1.15
		123478 -HxCDF	0.4	<0.2 - 2.8	(1/4)	0.7
		123678 -HxCDF	0.4	<0.3 - 2.6	(1/4)	0.7
		123789 -HxCDF	0.5	<0.5 - <0.6	(0/4)	<0.5
		234678 -HxCDF	0.4	<0.4 - 4.4	(1/4)	1.1
		1234678 -HpCDF	0.5	<0.4 - <0.7	(0/4)	<0.5
		1234789 -HpCDF	0.8	<0.6 - <0.8	(0/4)	<0.8
		Total TeCDF	0.4	<0.3 - <0.4	(0/4)	<0.4
		Total PeCDF	0.4	<0.3 - <0.5	(0/4)	<0.4
		Total HxCDF	0.4	<0.4 - <0.4	(1/4)	<0.4
		Total HpCDF	0.6	<0.5 - <0.7	(0/4)	<0.6
		OCDF	0.8	<0.5 - <1.0	(0/4)	<0.8
		Lipid		3.2 - 9.7	(4/4)	7.2 ± 3.1
SR1	long-nose sucker	2378 -TCDD	0.4	<0.2 - <0.8	(0/5)	<0.4
		12378 -PeCDD	0.7	<0.3 - <2.1	(0/5)	<0.7
		123478 -HxCDD	0.4	<0.2 - <1.0	(0/5)	<0.4

Location	Species	Congener	DL pg g^{-1}	Min - Max	Frequency	Mean ± SD
		123678 -HxCDD	0.4	<0.2 - <0.9	(0/5)	<0.4
		123789 -HxCDD	0.4	<0.2 - <0.9	(0/5)	<0.4
		1234678 -HpCDD	0.5	<0.3 - <0.8	(0/5)	<0.5
		OCDD	1.3	<0.8 - <2.5	(0/5)	<1.3
		Total TCDD	0.4	<0.2 - 0.4	(1/5)	0.1
		Total PeCDD	0.7	<0.2 - <2.1	(0/5)	<0.7
		Total HxCDD	0.4	<0.2 - <0.9	(0/5)	<0.4
		Total HpCDD	0.5	<0.3 - <0.8	(0/5)	<0.5
		2378 -TCDF	0.4	0.6 - 41.0	(5/5)	9.2 ± 17.8
		12378 -PeCDF	0.3	<0.2 - <0.7	(0/5)	<0.3
		23478 -PeCDF	0.3	<0.2 - <0.6	(0/5)	<0.3
		123478 -HxCDF	0.6	<0.3 - <1.8	(0/5)	<0.6
		123678 -HxCDF	0.6	<0.3 - <1.8	(0/5)	<0.6
		123789 -HxCDF	0.7	<0.3 - <1.8	(0/5)	<0.7
		234678 -HxCDF	0.6	<0.3 - <1.7	(0/5)	<0.6
		1234678 -HpCDF	0.6	<0.3 - <1.7	(0/5)	<0.6
		1234789 -HpCDF	0.8	<0.4 - <1.8	(0/5)	<0.8
		Total TeCDF	0.4	<0.2 - <0.8	(0/5)	<0.4
		Total PeCDF	0.3	<0.2 - <0.6	(0/5)	<0.3
		Total HxCDF	0.6	<0.3 - <1.8	(0/5)	<0.6
		Total HpCDF	0.7	<0.4 - <1.5	(0/5)	<0.7
		OCDF	0.8	<0.5 - 2.0	(0/5)	<0.8
		Lipid		3.1 - 9.7	(5/5)	5.6 ± 2.4
SR1	northern pike	2378 -TCDD	0.3	<0.2 - <0.3	(0/2)	<0.3
		12378 -PeCDD	0.4	<0.3 - <0.5	(0/2)	<0.4
		123478 -HxCDD	0.5	<0.4 - <0.5	(0/2)	<0.5
		123678 -HxCDD	0.5	<0.4 - <0.5	(0/2)	<0.5
		123789 -HxCDD	0.4	<0.4 - <0.4	(0/2)	<0.4
		1234678 -HpCDD	0.5	<0.4 - <0.5	(0/2)	<0.5
		OCDD	1.0	<0.8 - <1.2	(0/2)	<1.0
		Total TCDD	0.3	<0.2 - 0.8	(1/2)	0.4
		Total PeCDD	0.4	<0.3 - <0.5	(0/2)	<0.4
		Total HxCDD	0.4	<0.4 - <0.4	(0/2)	<0.4
		Total HpCDD	0.5	<0.4 - <0.5	(0/2)	<0.5
		2378 -TCDF	0.4	1.8 - 3.6	(2/2)	2.7
		12378 -PeCDF	0.3	<0.2 - <0.3	(0/2)	<0.3
		23478 -PeCDF	0.3	<0.3 - <0.3	(0/2)	<0.3
		123478 -HxCDF	1.2	<0.6 - <1.7	(0/2)	<1.2
		123678 -HxCDF	1.1	<0.6 - <1.6	(0/2)	<1.1
		123789 -HxCDF	1.0	<0.6 - <1.3	(0/2)	<1.0
		234678 -HxCDF	1.0	<0.6 - <1.3	(0/2)	<1.0
		1234678 -HpCDF	0.5	<0.5 - <0.5	(0/2)	<0.5
		1234789 -HpCDF	0.6	<0.5 - <0.6	(0/2)	<0.6
		Total TeCDF	0.4	<0.4 - <0.3	(0/2)	<0.4
		Total PeCDF	0.3	<0.3 - <0.2	(0/2)	<0.3
		Total HxCDF	1.1	<0.6 - <1.5	(0/2)	<1.1
		Total HpCDF	0.5	<0.5 - <0.5	(0/2)	<0.5
		OCDF	0.6	<0.5 - <0.6	(0/2)	<0.6
		Lipid		7.1 - 7.2	(2/2)	7.1
PR1	long-nose suckers	2378 -TCDD	0.3	<0.2 - <0.3	(0/5)	<0.3
		12378 -PeCDD	0.3	<0.2 - <0.3	(0/5)	<0.3
		123478 -HxCDD	0.3	<0.3 - <0.4	(0/5)	<0.3
		123678 -HxCDD	0.4	<0.3 - <0.5	(0/5)	<0.4
		123789 -HxCDD	0.4	<0.3 - <0.4	(0/5)	<0.4
		1234678 -HpCDD	0.4	<0.3 - <0.5	(0/5)	<0.4
		OCDD	0.8	<0.8 - <1.1	(0/5)	<0.8
		Total TCDD	0.3	<0.2 - <0.3	(1/5)	<0.3
		Total PeCDD	0.3	<0.2 - <0.3	(0/5)	<0.3

Location	Species	Congener	DL pg g^{-1}	Min - Max	Frequency	Mean ± SD
		Total HxCDD	0.4	<0.3 - <0.4	(0/5)	<0.4
		Total HpCDD	0.4	<0.3 - <0.5	(0/5)	<0.4
		2378 -TCDF	0.3	<0.2 - <0.3	(5/5)	<0.3
		12378 -PeCDF	0.3	<0.2 - <0.3	(0/5)	<0.3
		23478 -PeCDF	0.3	<0.2 - <0.3	(0/5)	<0.3
		123478 -HxCDF	0.4	<0.3 - <0.4	(0/5)	<0.4
		123678 -HxCDF	0.3	<0.3 - <0.4	(0/5)	<0.3
		123789 -HxCDF	0.5	<0.4 - <0.6	(0/5)	<0.5
		234678 -HxCDF	0.4	<0.3 - <0.4	(0/5)	<0.4
		1234678 -HpCDF	0.3	<0.3 - <0.4	(0/5)	<0.3
		1234789 -HpCDF	0.6	<0.5 - <0.8	(0/5)	<0.6
		Total TeCDF	0.3	<0.2 - <0.3	(0/5)	<0.3
		Total PeCDF	0.3	<0.2 - <0.3	(0/5)	<0.3
		Total HxCDF	0.4	<0.4 - <0.5	(0/5)	<0.4
		Total HpCDF	0.4	<0.3 - <0.5	(0/5)	<0.4
		Total OCDF	0.5	<0.4 - <0.7	(0/5)	<0.5
		Lipid		0.8 - 7.3	(5/5)	4.9 ± 1.4
PR1	northern pike	2378 -TCDD	0.4	<0.2 - <0.5	(0/2)	<0.4
		12378 -PeCDD	0.3	<0.2 - <0.3	(0/2)	<0.3
		123478 -HxCDD	0.3	<0.3 - <0.3	(0/2)	<0.3
		123678 -HxCDD	0.3	<0.2 - <0.4	(0/2)	<0.3
		123789 -HxCDD	0.3	<0.3 - <0.3	(0/2)	<0.3
		1234678 -HpCDD	0.4	<0.4 - <0.4	(0/2)	<0.4
		OCDD	0.6	<0.5 - <0.7	(0/2)	<0.6
		Total TCDD	0.4	<0.2 - <0.5	(0/2)	<0.4
		Total PeCDD	0.3	<0.2 - <0.3	(0/2)	<0.4
		Total HxCDD	0.3	<0.3 - <0.3	(0/2)	<0.3
		Total HpCDD	0.4	<0.4 - <0.4	(0/2)	<0.4
		2378 -TCDF	0.3	<0.2 - <0.4	(0/2)	<0.3
		12378 -PeCDF	0.2	<0.2 - <0.3	(0/2)	<0.3
		23478 -PeCDF	0.2	<0.2 - <0.2	(0/2)	<0.2
		123478 -HxCDF	0.5	<0.2 - <0.7	(0/2)	<0.5
		123678 -HxCDF	0.5	<0.2 - <0.7	(0/2)	<1.1
		123789 -HxCDF	0.4	<0.3 - <0.5	(0/2)	<0.4
		234678 -HxCDF	0.4	<0.2 - <0.5	(0/2)	<0.4
		1234678 -HpCDF	0.4	<0.3 - <0.4	(0/2)	<0.4
		1234789 -HpCDF	0.7	<0.6 - <0.7	(0/2)	<0.7
		Total TeCDF	0.3	<0.2 - <0.4	(0/2)	<0.3
		Total PeCDF	0.2	<0.2 - <0.2	(0/2)	<0.2
		Total HxCDF	0.4	<0.2 - <0.6	(0/2)	<0.4
		Total HpCDF	0.5	<0.4 - <0.6	(0/2)	<0.5
		OCDF	0.4	<0.3 - <0.4	(0/2)	<0.4
		Lipid		6.8 - 6.8	(2/2)	6.8
PR2	long-nose suckers	2378 -TCDD	0.3	<0.1 - <0.4	(0/6)	<0.3
		12378 -PeCDD	0.3	<0.2 - <0.4	(0/6)	<0.3
		123478 -HxCDD	0.4	<0.2 - <0.8	(0/6)	<0.4
		123678 -HxCDD	0.4	<0.2 - <0.9	(0/6)	<0.4
		123789 -HxCDD	0.4	<0.2 - <0.9	(0/6)	<0.4
		1234678 -HpCDD	0.5	<0.3 - <0.7	(0/6)	<0.5
		OCDD	0.8	<0.5 - <1.1	(0/6)	<0.8
		Total TCDD	0.3	<0.1 - <0.4	(0/6)	<0.3
		Total PeCDD	0.3	<0.2 - <0.4	(0/6)	<0.3
		Total HxCDD	0.4	<0.2 - <0.9	(0/6)	<0.4
		Total HpCDD	0.5	<0.3 - <0.7	(0/6)	<0.5
		2378 -TCDF	0.3	<0.1 - 0.5	(3/6)	0.1 ± 0.196638416
		12378 -PeCDF	0.2	<0.1 - <0.4	(0/6)	<0.2
		23478 -PeCDF	0.2	<0.1 - <0.4	(0/6)	<0.2
		123478 -HxCDF	0.4	<0.2 - <1.1	(0/6)	<0.4

Location	Species	Congener	DL pg g^{-1}	Min - Max	Frequency	Mean ± SD
		123678 -HxCDF	0.4	<0.2 - <1.1	(0/6)	<0.4
		123789 -HxCDF	0.5	<0.3 - <1.0	(0/6)	<0.5
		234678 -HxCDF	0.4	<0.2 - <0.9	(0/6)	<0.4
		1234678 -HpCDF	0.3	<0.2 - <0.6	(0/6)	<0.3
		1234789 -HpCDF	0.5	<0.3 - <0.8	(0/6)	<0.5
		Total TeCDF	0.3	<0.1 - <0.6	(0/6)	<0.3
		Total PeCDF	0.2	<0.1 - <0.4	(0/6)	<0.2
		Total HxCDF	0.4	<0.2 - <1.0	(1/6)	<0.4
		Total HpCDF	0.4	<0.2 - <0.7	(0/6)	<0.4
		OCDF	0.4	<0.3 - <0.7	(0/6)	<0.4
		Lipid		3.8 - 9.1	(0/6)	5.7 ± 1.8
PR2	northern pike	2378 -TCDD	0.1		(0/1)	
		12378 -PeCDD	0.1		(0/1)	
		123478 -HxCDD	0.3		(0/1)	
		123678 -HxCDD	0.3		(0/1)	
		123789 -HxCDD	0.3		(0/1)	
		1234678 -HpCDD	0.2		(0/1)	
		OCDD	0.4		(0/1)	
		Total TCDD	0.1		(0/1)	
		Total PeCDD	0.1		(0/1)	
		Total HxCDD	0.3		(0/1)	
		Total HpCDD	0.2		(0/1)	
		2378 -TCDF	0.2		(1/1)	0.2
		12378 -PeCDF	0.1		(0/1)	
		23478 -PeCDF	0.1		(0/1)	
		123478 -HxCDF	0.3		(0/1)	
		123678 -HxCDF	0.2		(0/1)	
		123789 -HxCDF	0.3		(0/1)	
		234678 -HxCDF	0.3		(0/1)	
		1234678 -HpCDF	0.2		(0/1)	
		1234789 -HpCDF	0.2		(0/1)	
		Total TeCDF	0.2		(0/1)	
		Total PeCDF	0.1		(0/1)	
		Total HxCDF	0.3		(0/1)	
		Total HpCDF	0.2		(0/1)	
		OCDF	0.3		(0/1)	
		Lipid			(1/1)	3.7

Table A5. Detection limits for di- and trichloro- PCDD/Fs in livers of long-nose sucker and northern pike (pg g^{-1} wet wt) from Wapiti/ Smoky and Peace Rivers (1994)[1]

Species		Detection limits (pg g^{-1} wet wt)		
		Mean	min	max
longnose suckers	27 -DiCDD	4.7	0.9	13.0
	23 -DiCDD	2.7	0.4	7.8
	237 -TrCDD	0.5	0.2	1.2
	Total -DiCDD	2.7	0.4	7.8
	Total -TrCDD	0.5	0.2	1.2
	28 -DiCDF	1.5	0.4	4.7
	238 -TrCDF	0.4	0.2	1.2
	Total -DiCDF	1.5	0.4	4.7
	Total -TrCDF	0.4	0.2	1.2
northern pike	27 -DiCDD	7.1	1.5	13
	23 -DiCDD	3.7	0.7	6.3
	237 -TrCDD	0.6	0.3	0.8
	Total -DiCDD	3.7	0.7	6.3
	Total -TrCDD	0.6	0.3	0.8
	28 -DiCDF	1.8	0.5	4
	238 -TrCDF	0.5	0.2	0.8
	Total -DiCDF	1.8	0.5	4
	Total -TrCDF	0.5	0.2	0.8

[1]All congeners were below detection limits at all sites (same sites as Table A4)

Table A6. Summary of PCDD/F concentrations (pg g^{-1} wt wt) in burbot liver from the Peace, Smoky and Athab and major tributaries (1994)

Congener or homolog		DL[1] pg g^{-1} wet wt	low		high	# of detects	mean	SD	DL[1] pg g^{-1} wet wt	low		high	# of detects	mean	SD
		A4	**Athabasca River at Calling River**						**A3**	**Athabasca River at Ft. Assiniboine**					
2378	-TCDD	1.0	<0.2	to	3	(8/13)	1.4 ± 0.8		2.3	<6.5	to	<13.0	(15/23)	3.0	2.7
12378	-PeCDD	1.5	<0.5	to	<4.1	(0/13)	<1.5		3.6	<0.3	to	<17	(2/23)	3.6	4.1
123478	-HxCDD	1.2	<0.3	to	<2.3	(0/13)	<1.2		2.5	<0.4	to	23	(1/23)	3.4	5.0
123678	-HxCDD	1.6	<0.3	to	10	(10/13)	<2.6		2.6	<0.8	to	23	(17/23)	5.0	5.3
123789	-HxCDD	1.3	<0.3	to	3.2	(0/13)	<1.3		2.5	<0.4	to	9.7	(2/23)	2.8	2.9
1234678	-HpCDD	2.0	<1.2	to	6.3	(7/13)	3.3 ± 1.7		3.9	<1.5	to	330	(14/23)	26.2	75.6
	OCDD	6.4	<3.0	to	19	(6/13)	8.3 ± 4.3		10.5	<3.2	to	1900	(11/23)	109	405
Other	TCDD	1.0	<0.2	to	3	(4/13)	1.1 ± 0.7		2.3	<0.2	to	<13.0	(1/23)	2.3	3.0
Other	PeCDD	1.3	0.5	to	4.1	(0/13)	1.5 ± 0.9		3.6	<0.3	to	<17.0	(0/23)	<3.6	
Other	HxCDD	2.0	0.3	to	3.2	(0/13)	1.3 ± 0.9		2.5	<0.4	to	20	(1/23)	3.3	4.5
Other	HpCDD	8.3	0.6	to	5.6	(0/13)	2.0 ± 1.3		3.9	<0.5	to	160	(1/23)	10.6	33.5
2378	-TCDF	1.0	3.0	to	15	(13/13)	9.4		2.4	4.7	to	38	(23/23)	17.7	9.0
12378	-PeCDF	0.8	<0.2	to	<1.4	(0/13)	<0.8		1.8	<0.4	to	<6.3	(7/23)	1.8	1.6
23478	-PeCDF	0.8	<0.2	to	<1.5	(0/13)	<0.8		1.8	<0.3	to	<5.8	(4/23)	1.9	1.7
123478	-HxCDF	1.2	<0.2	to	3.1	(0/13)	<1.2		2.4	<0.3	to	<9.7	(1/23)	2.4	2.5
123678	-HxCDF	1.2	<0.2	to	<2.8	(0/13)	<1.2		2.2	<0.2	to	<9.8	(1/23)	2.5	2.7
123789	-HxCDF	1.4	<0.3	to	<1.3	(0/13)	<1.4 ± 1.4		2.6	<0.3	to	<13	(0/23)	<2.6	
234678	-HxCDF	1.1	<0.2	to	5.8	(2/13)	1.6		2.3	<0.3	to	<9.7	(6/23)	2.6	2.4
1234678	-HpCDF	1.6	<0.2	to	<2.8	(0/13)	<1.6		2.6	<0.5	to	51	(6/23)	6.1	11.9
1234789	-HpCDF	2.1	<0.2	to	<4.0	(0/13)	<2.1		4.0	<0.7	to	<13.0	(0/23)	<4.0	
Other	TeCDF	1.0	<0.4	to	<2.2	(0/13)	<1.0 ± 0.5		2.4	<0.3	to	<7.8	(0/23)	<2.4	
Other	PeCDF	0.8	<0.2	to	1.7	(1/13)	0.9		1.8	<0.3	to	<6.0	(1/23)	1.8	1.6
Other	HxCDF	1.2	<0.3	to	<3.0	(0/13)	<1.2		2.4	<0.3	to	35	(3/23)	5.0	8.9
Other	HpCDF	1.9	<0.2	to	<3.4	(0/13)	<1.9 ± 16.3		3.3	<0.6	to	130	(1/23)	8.9	27.2
	OCDF	4.4	<1.3	to	<9.0	(0/13)	4.4		7.3	<0.8		240	(1/23)	17.7	50.2
	% lipid		22.6	to	67.2	(13/13)	45.2			29.4	to	87.7	(23/23)	55.2	13.0
		A5	**Athabasca River at Ft. Mackay**						**A1**	**Athabasca River d/s Hinton**					
2378	-TCDD	1.0	<0.3	to	<2.9	(4/18)	1.2 ± 0.6		0.9	3	to	18	(9/9)	10.0	4.6
12378	-PeCDD	2.6	<0.4	to	<3.8	(0/18)	<1.4		1.3	0.7	to	<3.9	(4/9)	1.6	1.1
123478	-HxCDD	2.0	<0.3	to	<4.2	(0/18)	<1.3		1.3	<0.4	to	<3.4	(0/9)	<1.3	
123678	-HxCDD	2.1	<0.5	to	7.3	(9/18)	2.2	1.6	1.1	1.7	to	3.7	(8/9)	2.6	0.7
123789	-HxCDD	2.0	<0.3	to	<4.2	(0/18)	<1.3		1.2	<0.3	to	<3.1	(1/9)	1.2	0.9
1234678	-HpCDD	3.5	<0.7	to	38	(7/18)	4.8 ± 8.5		1.7	1.9	to	7.1	(9/9)	3.8	1.5
	OCDD	9.3	1.3	to	39	(4/18)	8.8 ± 9.1		5.2	2.9	to	22	(5/9)	6.9	5.8
Other	TCDD	1.9	<0.3	to	2.9	(1/18)	1.1 ± 0.7		0.9	<0.3	to	<2.1	(0/9)	<0.9	
Other	PeCDD	2.6	<0.4	to	<3.8	(0/18)	<1.4		1.3	<0.4	to	<3.9	(0/9)	<1.3	
Other	HxCDD	2.0	<0.3	to	<4.2	(0/18)	<1.3		1.2	<0.3	to	<3.2	(0/9)	<1.2	
Other	HpCDD	3.5	<0.7	to	<8.0	(1/18)	2.7 ± 2.1		1.7	<0.7	to	<4.3	(0/9)	<1.7	
2378	-TCDF	1.5	1.2	to	5.2	(18/18)	2.7 ± 1.2		0.8	44	to	110	(9/9)	64.4	20.0
12378	-PeCDF	1.4	<0.3	to	<3.4	(2/18)	1.0 ± 0.7		0.8	0.8	to	2.6	(8/9)	1.7	0.6
23478	-PeCDF	1.4	<0.3	to	<3.4	(1/18)	1.1 ± 0.7		0.8	0.6	to	<2.8	(7/9)	1.5	0.7
123478	-HxCDF	1.8	<0.3	to	<3.3	(0/18)	<1.1 ± 0.7		1.0	<0.5	to	<2.5	(0/9)	1.0	0.7
123678	-HxCDF	1.8	<0.3	to	<3.0	(0/18)	<1.1		1.0	<0.4	to	<2.4	(0/9)	<1.0	
123789	-HxCDF	2.2	<0.4	to	<2.9	(0/18)	<1.3		1.3	<0.5	to	<2.9	(0/9)	<1.3	
234678	-HxCDF	1.9	<0.3	to	4.1	(2/18)	1.5 ± 1.1		1.1	0.5	to	<2.8	(4/9)	1.4	0.7
1234678	-HpCDF	2.1	<0.3	to	9.7	(4/18)	2.4 ± 2.1		1.4	0.6	to	<3.1	(1/9)	1.4	0.9
1234789	-HpCDF	3.5	<0.4	to	<9.4	(0/18)	<2.9		2.2	<0.9	to	<4.9	(0/9)	<2.2	
Other	TeCDF	1.5	<0.3	to	<2.5	(4/18)	1.0 ± 0.6		0.8	<0.3	to	<1.4	(0/9)	<0.8	
Other	PeCDF	1.4	<0.3	to	<3.4	(0/18)	1.0 ± 0.7		0.8	<0.2	to	<2.5	(2/9)	1.0	0.7
Other	HxCDF	1.9	<0.3	to	27	(4/18)	2.8 ± 6.1		1.1	<0.5	to	2.9	(2/9)	1.4	0.9
Other	HpCDF	2.8	<0.3	to	<6.4	(0/18)	<2.3		1.8	<0.7	to	<4.0	(0/9)	<1.8	
	OCDF	7.4	<0.9	to	<19.0	(0/18)	<5.3		4.0	<1.2	to	<13.0	(0/9)	<4	
	% lipid		7.1	to	65.5	(18/18)	32.4 ± 18.1			48.1	to	81.4	(9/9)	59.2	11.7

Congener or homolog		DL[1] $pg\ g^{-1}$ wet wt	low		high	# of detects	mean	SD	DL[1] $pg\ g^{-1}$ wet wt	low		high	# of detects	mean	SD
		A2	**Athabasca River u/s Hinton**						**CW**	**Clearwater River**					
2378	-TCDD	0.7	0.6	to	5	(4/8)	2.0 ± 1.8		1.1	<0.6	to	<1.9	(0/5)	<1.1	
12378	-PeCDD	0.8	<0.6	to	<1.2	(0/8)	<0.8		1.4	<0.9	to	<2.2	(0/5)	<1.4	
123478	-HxCDD	0.7	<0.5	to	<1.1	(0/8)	<0.7		1.5	<0.9	to	<2.8	(0/5)	<1.5	
123678	-HxCDD	0.7	0.5	to	2	(5/8)	1.1 ± 0.5		1.4	1	to	<2.6	(1/5)	1.5	0.7
123789	-HxCDD	0.7	<0.5	to	<1.1	(0/8)	<0.7		1.4	<0.9	to	<2.7	(0/5)	<1.4	
1234678	-HpCDD	1.1	<0.6	to	4.1	(5/8)	1.9 ± 1.0		2.0	<1.4	to	<3.9	(0/5)	<2.0	
	OCDD	3.6	3.8	to	13	(5/8)	6.4 ± 3.4		5.5	<3.3	to	<7.5	(0/5)	<5.5	
Other	TCDD	0.7	<0.3	to	<1.5	(0/8)	<0.7		1.1	<0.6	to	<1.9	(0/5)	<1.1	
Other	PeCDD	0.8	<0.6	to	<1.2	(0/8)	<0.8		1.4	<0.9	to	<2.2	(0/5)	<1.4	
Other	HxCDD	0.7	<0.5	to	<1.1	(0/8)	<0.7		1.4	<0.9	to	<2.7	(0/5)	<1.4	
Other	HpCDD	1.1	<0.6	to	<1.8	(0/8)	<1.1		2.0	<1.4	to	<3.9	(0/5)	<2.0	
2378	-TCDF	0.5	1.8	to	18	(8/8)	7.9 ± 6.7		0.9	<0.6	to	<1.3	(2/5)	1.0	0.3
12378	-PeCDF	0.5	<0.3	to	<0.9	(0/8)	<0.5		0.8	<0.6	to	<1.2	(0/5)	<0.8	
23478	-PeCDF	0.6	<0.3	to	<1.0	(0/8)	<0.6		0.8	<0.5	to	<1.2	(0/5)	<0.8	
123478	-HxCDF	0.7	<0.4	to	<1.0	(0/8)	<0.7		1.1	<0.7	to	<1.6	(0/5)	<1.1	
123678	-HxCDF	0.7	<0.3	to	<1.0	(0/8)	<0.7		1.1	<0.7	to	<1.7	(0/5)	<1.1	
123789	-HxCDF	0.9	<0.4	to	<1.3	(0/8)	<0.9		1.4	<0.9	to	<1.9	(0/5)	<1.4	
234678	-HxCDF	0.8	0.5	to	2.3	(4/8)	1.3 ± 0.6		1.1	<0.7	to	2	(1/5)	1.3	0.6
1234678	-HpCDF	1.1	<0.8	to	<1.7	(1/8)	1.2 ± 0.3		1.5	<1.0	to	<2.5	(0/5)	<1.5	
1234789	-HpCDF	1.8	<1.2	to	<2.6	(0/8)	<1.8		2.3	<1.6	to	<3.9	(0/5)	<2.3	
Other	TeCDF	0.5	<0.4	to	<0.9	(0/8)	<0.5		0.9	<0.6	to	<1.3	(0/5)	<0.9	
Other	PeCDF	0.5	<0.3	to	<0.9	(0/8)	<0.5		0.8	<0.5	to	<1.2	(0/5)	<0.8	
Other	HxCDF	0.8	<0.4	to	<1.1	(0/8)	<0.8		1.2	<0.8	to	<1.8	(0/5)	<1.2	
Other	HpCDF	1.4	<1.0	to	<2.1	(0/8)	<1.4		1.9	<1.4	to	<3.2	(0/5)	<1.9	
	OCDF	3.0	<1.6	to	<5.1	(0/8)	<3.0		4.9	<2.4	to	<6.3	(0/5)	<4.9	
	% lipid		37.2	to	69.2	(8/8)	55.4 ± 11.8			19.6	to	33.6	(5/5)	24.7	5.5
		JV	**Jackfish Village (Athabasca delta)**						**LA**	**Western Lake Athabasca**					
2378	-TCDD	0.45	<0.2	to	<0.7	(0/2)	<0.5		0.6	<0.4	to	<0.8	(0/2)	<0.6	
12378	-PeCDD	0.7	<0.4	to	<1.0	(0/2)	<0.7		1.5	<1.3	to	<1.7	(0/2)	<1.5	
123478	-HxCDD	0.5	<0.4	to	<0.7	(0/2)	<0.55		1.3	<0.6	to	<2.0	(0/2)	<1.3	
123678	-HxCDD	0.55	<0.4	to	<0.7	(0/2)	<0.55		1.1	<0.5	to	<1.7	(0/2)	<1.1	
123789	-HxCDD	0.55	<0.4	to	<0.7	(0/2)	<0.55		1.2	<0.6	to	<1.8	(0/2)	<1.2	
1234678	-HpCDD	0.8	<0.6	to	1	(0/2)	<0.8		2	<0.8	to	<3.2	(0/2)	<2.0	
	OCDD	1.7	2.1	to	<2.4	(1/2)	2.25 ± 0.2		3.2	<1.8	to	<4.5	(0/2)	<3.2	
Other	TCDD	0.45	0.5	to	4.8	(2/2)	2.65 ± 3		0.6	2.3	to	2.3	(2/2)	2.3	
Other	PeCDD	0.7	<0.4	to	<1.0	(0/2)	<0.7		1.5	<1.3	to	<1.7	(0/2)	<1.5	
Other	HxCDD	0.55	<0.4	to	2.6	(1/2)	1.3 ± 1.8		1.2	<0.6	to	<1.8	(0/2)	<1.2	
Other	HpCDD	0.8	<0.6	to	<1.0	(0/2)	<0.8		2	<0.8	to	<3.2	(0/2)	<2.0	
2378	-TCDF	0.4	<0.2	to	2.9	(1/2)	1.55 ± 1.9		0.5	<0.3	to	<0.7	(0/2)	<0.5	
12378	-PeCDF								0.8	<0.4	to	<1.1	(0/2)	<0.8	
23478	-PeCDF	0.45	<0.3	to	<0.9	(0/2)	<0.6		1	<0.5	to	<1.4	(0/2)	<1.0	
123478	-HxCDF	0.55	<0.4	to	<0.7	(0/2)	<0.55		1.1	<0.6	to	<1.5	(0/2)	<1.1	
123678	-HxCDF	0.45	<0.3	to	<0.6	(0/2)	<0.45		0.9	<0.5	to	<1.3	(0/2)	<0.9	
123789	-HxCDF	0.65	<0.4	to	<0.9	(0/2)	<0.65		1.2	<0.6	to	<1.8	(0/2)	<1.2	
234678	-HxCDF	0.55	<0.3	to	<0.8	(0/2)	<0.55		1	<0.5	to	<1.4	(0/2)	<1.0	
1234678	-HpCDF	0.8	<0.5	to	<1.1	(0/2)	<0.8		1.2	<0.8	to	<1.5	(0/2)	<1.1	
1234789	-HpCDF	0.75	<0.4	to	<1.1	(0/2)	<0.75		1.1	<0.7	to	<1.4	(0/2)	<1.1	
Other	TeCDF	0.4	<0.2	to	<0.6	(0/2)	<0.4		0.5	<0.3	to	<0.7	(0/2)	<0.5	
Other	PeCDF	0.55	<0.3	to	<0.8	(0/2)	<0.55		0.8	<0.4	to	<1.2	(0/2)	<0.8	
Other	HxCDF	0.55	<0.4	to	<0.7	(0/2)	<0.55		1.1	<0.6	to	<1.5	(0/2)	<1.1	
Other	HpCDF	0.8	<0.5	to	<1.1	(0/2)	<0.8		1.2	<0.8	to	<1.5	(0/2)	<1.2	
	OCDF	1.9	1	to	<2.8	(0/2)	<1.9		3.1	<2.6	to	<3.6	(0/2)	<3.1	
	% lipid		0.8	to	21.5	(0/2)	11.2 ± 14.6			0.760	to	29.9	(0/2)	15.4	20.6

Congener or homolog		DL[1] pg g^{-1} wet wt	low		high	# of detects	mean	SD	DL[1] pg g^{-1} wet wt	low		high	# of detects	mean	SD
		LSV	**Lesser Slave River**						**LSR2**	**Little Smokey River**					
2378	-TCDD	0.9	0.4	to	<3.8	(6/19)	1.1 ± 0.9		3.9				(0/1)	<3.9	
12378	-PeCDD	1.3	<0.4	to	<4.6	(1/19)	1.3 ± 1.0		4.3				(0/1)	<4.3	
123478	-HxCDD	1.3	0.2	to	<0.6	(0/19)	<1.3		5.8				(0/1)	<5.8	
123678	-HxCDD	1.2	0.9	to	7.1	(16/19)	2.9 ± 1.6		5.3				(0/1)	<5.3	
123789	-HxCDD	1.2	<0.2	to	<5.6	(16/19)	1.4 ± 1.3		5.5				(0/1)	5.5	
1234678	-HpCDD	2.0	2	to	180	(18/19)	14.0 ± 41.5		6.6				(0/1)	6.6	
	OCDD	4.8	1.9	to	580	(9/19)	37.9 ± ###		8.6				(0/1)	<8.6	
Other	TCDD	0.9	0.8	to	<3.8	(14/19)	2.0 ± 0.7		3.9				(0/1)	<3.9	
Other	PeCDD	1.3	<0.3	to	<4.6	(0/19)	<1.3		4.3				(0/1)	<4.3	
Other	HxCDD	1.2	<0.2	to	17	(1/19)	2.1 ± 3.9		5.5				(0/1)	<5.5	
Other	HpCDD	2.0	0.6	to	67	(2/19)	6.0 ± 15.6		6.6				(0/1)	<6.6	
2378	-TCDF	0.8	1.6	to	10	(18/19)	5.9 ± 2.6		2.1				(1/1)	2.9	
12378	-PeCDF	0.9	0.2	to	2.6	(17/19)	0.9 ± 0.6		2.8				(0/1)	<2.8	
23478	-PeCDF	0.9	<0.3	to	<2.4	(0/19)	<0.9		3.1				(0/1)	<3.1	
123478	-HxCDF	1.0	0.3	to	5.7	(1/19)	1.0 ± 1.2		3				(0/1)	<3.0	
123678	-HxCDF	1.0	<0.3	to	<6.1	(1/19)	1.0 ± 1.3		3.6				(0/1)	<3.6	
123789	-HxCDF	1.4	<0.5	to	<8.0	(0/19)	<1.4		4				(0/1)	<4.0	
234678	-HxCDF	1.1	<0.4	to	<6.3	(6/19)	1.5 ± 1.5		3.2				(0/1)	<3.2	
1234678	-HpCDF	1.6	0.7	to	<8.9	(2/19)	1.8 ± 1.9		4.8				(0/1)	<4.8	
1234789	-HpCDF	2.7	<0.9	to	<20	(0/19)	<2.7		4.2				(0/1)	<4.2	
Other	TeCDF	0.8	<0.2	to	<3.0	(3/19)	1.0 ± 0.7		2.1				(0/1)	<2.1	
Other	PeCDF	0.9	<0.3	to	2.9	(2/19)	1.1 ± 0.7		3				(0/1)	<3.0	
Other	HxCDF	1.1	<0.4	to	<0.65	(9/19)	1.6 ± 1.4		3.4				(0/1)	<3.4	
Other	HpCDF	2.1	<0.8	to	<14.0	(1/19)	2.7 ± 3.5		4.5				(0/1)	<4.5	
	OCDF	3.8	<1.1	to	<17.0	(1/19)	4.5 ± 4.5		15				(0/1)	<15	
	% lipid		6.8	to	65.7	(19/19)	48.3 ± 14.3						(1/1)	15	
		LSR3							**MCR2**	**McLeod River**					
2378	-TCDD	2.7				(0/1)	<2.7		1.2	<0.3	to	<2.3	(0/7)	<1.2	
12378	-PeCDD	2.8				(0/1)	<2.8		1.5	<0.5	to	<2.9	(0/7)	<1.5	
123478	-HxCDD	3.1				(0/1)	<3.1		1.3	<0.7	to	<2.0	(0/7)	<1.3	
123678	-HxCDD	2.7				(0/1)	<2.7		1.3	0.5	to	1.8	(0/7)	1.2	0.5
123789	-HxCDD	2.9				(0/1)	<2.9		1.3	<0.6	to	,1.8	(0/7)	<1.3	
1234678	-HpCDD	3.3				(0/1)	<3.3		2.5	1.8	to	11	(5/7)	5.0	3.1
	OCDD	12.0				(0/1)	<12.0		5.5	3.1	to	12	(3/7)	7.8	2.7
Other	TCDD	2.7				(0/1)	<2.7		1.2	<0.3	to	4.1	(1/7)	1.7	1.3
Other	PeCDD	2.8				(0/1)	<2.8		1.5	<0.5	to	<2.9	(0/7)	<1.5	
Other	HxCDD	2.9				(0/1)	<2.9		1.3	<0.6	to	2.3	(1/7)	1.5	0.6
Other	HpCDD	3.3				(0/1)	<3.3		2.5	<0.5	to	<4.2	(0/7)	<2.5	
2378	-TCDF	2.1				(1/1)	12		0.9	1.2	to	4.2	(6/7)	2.4	1.2
12378	-PeCDF	2.5				(0/1)	<2.5		0.7	<0.2	to	<1.3	(0/7)	<0.7	
23478	-PeCDF	2.9				(0/1)	<2.9		0.8	<0.3	to	<1.4	(1/7)	0.8	0.4
123478	-HxCDF	2.4				(0/1)	<2.4		1.6	<0.8	to	<2.3	(0/7)	<1.6	
123678	-HxCDF	2.6				(0/1)	<2.6		1.5	<0.7	to	<2.4	(0/7)	<1.5	
123789	-HxCDF	2.0				(0/1)	<2.0		1.8	<0.9	to	<3.0	(0/7)	<1.8	
234678	-HxCDF	2.0				(0/1)	<2.0		1.6	1.1	to	16	(5/7)	4.8	5.3
1234678	-HpCDF	2.6				(0/1)	<2.6		2.7	<1.6	to	<4.6	(1/7)	2.9	1.1
1234789	-HpCDF	1.9				(0/1)	<1.9		3.7	<1.0	to	<5.4	(0/7)	<3.7	1.8
Other	TeCDF	2.1				(0/1)	<2.1		0.9	<0.4	to	<1.5	(0/7)	<0.9	
Other	PeCDF	2.7				(0/1)	<2.7		0.8	<0.2	to	6.5	(1/7)	1.5	2.2
Other	HxCDF	2.2				(0/1)	<2.0		1.6	0.8	to	<2.6	(0/7)	<2.1	1.5
Other	HpCDF	2.3				(0/1)	<2.3		3.2	<0.9	to	<4.8	(0/7)	<3.2	
	OCDF	9.1				(0/1)	<9.1		3.1	0.9	to	<4.8	(0/7)	<3.1	
	% lipid					(1/1)	22.7			6	to	20.5	(7/7)	14.6	5.6

Congener or homolog		DL[1] pg g^{-1} wet wt	low		high	# of detects	mean	SD	DL[1] pg g^{-1} wet wt	low		high	# of detects	mean	SD
		PR1	**Peace River at Many Islands**						**PR3**	**Peace River at Ft. Vermilion**					
2378	-TCDD	2.4	<0.3	to	<5.8	(0/11)	<2.4		2.3	<0.3		12	(0/7)	<2.3	
12378	-PeCDD	3.6	<0.3	to	<9.4	(0/11)	<3.6		2.7	<0.4	to	<13.0	(0/7)	<2.7	
123478	-HxCDD	3.3	<0.5	to	<7.0	(0/11)	<3.3		2.8	<0.3	to	<15.0	(0/7)	<2.8	
123678	-HxCDD	3.3	0.8	to	<8.2	(2/11)	3.6		2.6	<0.3	to	<13.0	(0/7)	<2.6	
123789	-HxCDD	3.3	<0.5	to	<7.6	(0/11)	<3.3		2.7	<0.3	to	<14.0	(0/7)	<2.7	
1234678	-HpCDD	5.4	1.2	to	10	(3/11)	5.8		4.5	<0.5	to	<24.0	(0/7)	<4.5	
	OCDD	9.2	<2.4	to	<28.0	(0/11)	<9.2		18.4	<1.1	to	<97.0	(0/7)	<18	
Other	TCDD	2.4	<0.3	to	<5.8	(2/11)	2.6		2.3	<0.3	to	64	(1/7)	9.8	
Other	PeCDD	3.6	<0.3	to	<9.4	(0/11)	<3.6		2.7	<0.4	to	<13	(0/7)	<2.7	
Other	HxCDD	3.3	<0.5	to	<7.6	(0/11)	<3.3		2.7	<0.3	to	34	(1/7)	5.6	
Other	HpCDD	5.4	<0.6	to	<10	(0/11)	<5.4		4.5	<0.5	to	<24.	(0/7)	<4.5	
2378	-TCDF	2.0	1.0	to	12	(9/11)	4.5		1.7	0.5	to	11	(5/7)	2.4	
12378	-PeCDF	2.3	<0.2	to	<4.8	(0/11)	<2.3		1.6	<0.3	to	<7.4	(0/7)	<1.6	
23478	-PeCDF	2.4	<0.2	to	<5.8	(0/11)	<2.4		1.9	<0.3	to	<10.0	(0/7)	< 1.9	
123478	-HxCDF	3.0	<0.3	to	<6.2	(0/11)	<3.0		2.6	0.5	to	12	(0/7)	2.6	
123678	-HxCDF	3.1	<0.3	to	<6.1	(0/11)	<3.1								
123789	-HxCDF	4.5	<0.4	to	<9.6	(0/11)	<4.5		3.3	<0.4	to	<16.0	(0/7)	<3.3	
234678	-HxCDF	3.3	<0.3	to	<6.6	(0/11)	<3.3		2.5	<0.4	to	<12.0	(0/7)	<2.5	
1234678	-HpCDF	3.4	<0.6	to	<8.8	(1/11)	3.5		2.9	<0.5	to	<11.0	(0/7)	<2.9	
1234789	-HpCDF	6.0	<0.8	to	<14.0	(0/11)	<6.0		4.0	<0.7	to	<14.0	(0/7)	<4.0	
Other	TeCDF	2.0	<0.3	to	<4.2	(0/11)	<2.0		1.7	<0.3	to	<7.5	(0/7)	<1.7	
Other	PeCDF	2.4	<0.2	to	<4.8	(0/11)	<2.4		1.8	<0.3	to	<8.8	(0/7)	<1.8	
Other	HxCDF	3.5	<0.3	to	<7.1	(0/11)	<3.5		2.7	<0.4	to	<13.0	(0/7)	<2.7	
Other	HpCDF	4.7	<0.7	to	<11.0	(0/11)	<4.7		3.5	<0.6	to	<13.0	(0/7)	<3.5	
	OCDF	6.7	<0.8	to	<27.0	(0/11)	<6.7		13.0	<0.7	to	<69	(0/7)	<13.0	
	% lipid		5.05		39.2	(11/11)	28.9			0.5	to	19.4	(7/7)	12.4	
		PR2	**Peace River at Notikewin River**						**P**	**Pembina River**					
2378	-TCDD	1.2	<0.3	to	<3.0	(2/9)	1.3		1.4	0.3	to	4.6	(1/7)		
12378	-PeCDD	2.0	<0.5	to	<5.1	(0/9)	<2.0		1.9	<0.7	to	<2.9	(0/7)	<1.9	
123478	-HxCDD	1.4	<0.3	to	<4.0	(1/9)	1.5		2.7	<0.8	to	<5.9	(0/7)	<2.7	
123678	-HxCDD	1.3	0.6	to	4	(6/9)	2.6		2.3	1.5	to	6	(5/7)	3.3	
123789	-HxCDD	1.4	<0.4	to	<3.8	(1/9)	1.5		2.5	<0.6	to	<5.0	(0/7)	<2.5	
1234678	-HpCDD	2.0	1.3	to	62	(6/9)	9.9		2.9	1.7	to	19	(6/7)	6.6	
	OCDD	4.3	2.4	to	390	(7/9)	49.4		9.3	8.5	to	29	(3/7)	14.4	
Other	TCDD	1.2	<0.3	to	<3.0	(0/9)	<1.2		1.4	<0.3	to	<3.7	(0/7)	<1.4	
Other	PeCDD	2.0	<0.5	to	<5.1	(0/9)	<2.0		1.9	<0.7	to	<2.9	(0/7)	<1.9	
Other	HxCDD	1.4	<0.4	to	<3.8	(0/9)	<1.4		2.5	<0.7	to	,5.0	(0/7)	<2.5	
Other	HpCDD	2.0	<0.5	to	24	(8/9)	4.6		2.9	<1.0	to	,6.9	(0/7)	,2.9	
2378	-TCDF	1.2	1.4	to	9.7	(9/9)	4.5		1.2	1	to	19	(6/7)	5.2	
12378	-PeCDF	1.1	<0.2	to	<2.4	(0/9)	<1.1		1.5	<0.4	to	<2.8	(0/7)	<1.5	
23478	-PeCDF	1.1	<0.3	to	<2.4	(0/9)	<1.1		1.8	<0.4	to	<4	(0/7)	<1.8	
123478	-HxCDF	1.2	<0.3	to	<2.3	(0/9)	<1.2		2.0	<0.4	to	<4.4	(0/7)	<2.0	
123678	-HxCDF	1.2	<0.3	to	<2.3	(0/9)	<1.2		2.0	<0.4	to	<4.0	(0/7)	<2.0	
123789	-HxCDF	1.4	<0.3	to	<3.3	(0/9)	<1.4		2.6	<0.5	to	<6.0	(0/7)	<2.6	
234678	-HxCDF	1.2	<0.3	to	3.7	(2/9)	1.6		2.3	0.8	to	<4.9	(1/7)	2.4	
1234678	-HpCDF	1.6	<0.5	to	9.1	(1/9)	2.5		3.1	<1.2	to	<7.9	(0/7)	<3.1	
1234789	-HpCDF	2.5	<0.8	to	<9.3	(0/9)	<2.5		4.9	<1.5	to	<14.0	(0/7)	<4.9	
Other	TeCDF	1.2	<0.3	to	<3.5	(0/9)	<1.2		1.2	<0.3	to	<2.7	(0/7)	<1.2	
Other	PeCDF	1.1	<0.3	to	<2.3	(1/9)	1.2		1.7	<0.4	to	<3.4	(0/7)	<1.7	
Other	HxCDF	1.2	<0.3	to	8.2	(2/9)	2.1		2.2	<0.4	to	<4.8	(0/7)	<2.2	
Other	HpCDF	2.0	<0.6	to	26	(1/9)	4.8		4.0	<1.3	to	<11.0	(0/7)	<4.0	
	OCDF	3.4	<0.9	to	48	(0/9)	8.6		6.0	<1.7	to	<16.0	(0/7)	<6.0	
	% lipid					(1/9)	52			8.2	to	56.1	(8/8)	33.0	
		QF	**Quatre Fourches**						**SR**	**Slave River Delta at Fort Resolution**					

Congener or homolog		DL[1] $pg\ g^{-1}$ wet wt	low		high	# of detects	mean	SD	DL[1] $pg\ g^{-1}$ wet wt	low		high	# of detects	mean	SD
2378	-TCDD	0.5	<0.4	to	<0.6	(0/2)	0.0		0.5	0.3		<1.8	(11/20)	0.7	
12378	-PeCDD	0.65	<0.5	to	<0.8	(0/2)	<0.6		0.6	<0.3	to	<1.8	(0/20)	0.6	
123478	-HxCDD	0.7	<0.5	to	<0.9	(0/2)	<0.7		0.7	<0.3	to	<2.1	(0/20)	<0.6	
123678	-HxCDD								0.6	0.4	to	<1.8	(15/20)	0.9	
123789	-HxCDD	0.7	<0.5	to	<0.9	(0/2)	<0.7		0.6	0.35	to	1.9	(20/20)	0.6	
1234678	-HpCDD	0.8	<0.6	to	<0.9	(0/2)	<0.8		0.9	0.5	to	1.7	(20/20)	0.9	
	OCDD	1.5	1	to	2	(0/2)	1.5		2.3	<1.2	to	5.3	(7/20)	2.6	
Other	TCDD	0.5	0.4	to	0.6	(1/2)	0.5		0.5	0.04	to	3.3	(11/20)	1.0	
Other	PeCDD	0.7	<0.5	to	<0.8	(0/2)	<0.7		0.6	<0.3	to	<1.8	(0/20)	<0.6	
Other	HxCDD	0.7	0.5	to	0.9	(1/2)	0.7		0.6	<0.4	to	<1.9	(0/20)	<0.6	
Other	HpCDD	0.8	<0.6	to	<0.9	(0/2)	<0.8		0.9	<0.5	to	<1.7	(0/20)	<0.9	
2378	-TCDF	0.4	<0.3	to	<0.4	(0/2)	<0.4		0.5	3.1	to	13	(20/20)	6.2	
12378	-PeCDF	0.6	<0.3	to	<0.8	(0/2)	<0.5		0.4	<0.2	to	1.3	(16/20)	0.6	
23478	-PeCDF	0.7	<0.4	to	<0.9	(0/2)	<0.6		0.5	<0.2	to	1.5	(9/20)	0.5	
123478	-HxCDF	0.7	<0.4	to	1	(0/2)	<0.7		0.5	<0.3	to	<1.3	(1/20)	0.5	
123678	-HxCDF	0.6	<0.3	to	<0.8	(0/2)	<0.6		0.5	,0.3	to	<1.2	(1/20)	0.5	
123789	-HxCDF	0.8	<0.4	to	1.2	(0/2)	<0.8		0.7	<0.3	to	<1.5	(0/20)	<0.7	
234678	-HxCDF	0.6	<0.4	to	<0.8	(0/2)	<0.6		0.5	0.3	to	1.4	(6/20)	<0.6	
1234678	-HpCDF	0.8	<0.5	to	<1.1	(0/2)	<0.8		0.6	<0.3	to	<1.6	(0/20)	<0.6	
1234789	-HpCDF	0.8	<0.4	to	<1.1	(0/2)	<0.8		0.7	<0.4	to	<2.0	(0/20)	<0.7	
Other	TeCDF	0.4	<0.3	to	<0.4	(0/2)	<0.4		0.5	<0.2	to	2.1	(8/20)	0.7	
Other	PeCDF	0.6	<0.3	to	<0.8	(0/2)	<0.6		0.5	<0.2	to	<1.4	(2/20)	0.5	
Other	HxCDF	0.7	<0.4	to	<0.9	(0/2)	<0.7		0.6	<0.3	to	<1.4	(0/20)	<0.6	
Other	HpCDF	0.8	<0.5	to	<1.1	(0/2)	<0.8		0.6	<0.3	to	<1.8	(0/20)	<0.6	
	OCDF	1.9	1.2	to	2.5	(0/2)	1.9		2.0	<0.6	to	<6.5	(0/20)	<2.0	
	% lipid		0.76		44.8	(2/2)	22.8			18.7	to	62.6	(20/20)	46.3	
		SR3	**Smokey River at Canfor Bridge**						**SR1**	**Smokey River at Watino**					
2378	-TCDD	0.8				(1/1)	3		0.9	0.8		3.7	(16/19)	1.5	
12378	-PeCDD	1.7				(0/1)	<1.7		1.3	0.3	to	5.2	(3/19)	1.3	
123478	-HxCDD	1.4				(0/1)	<1.4		1.2	<0.2	to	<6.3	(0/19)	<1.2	
123678	-HxCDD	1.4				(1/1)	3.2		1.1	0.8	to	13	(14/19)	2.9	
123789	-HxCDD	1.4				(0/1)	<1.4		1.1	0.3	to	<5.7	(7/19)	1.5	
1234678	-HpCDD	2.2				(1/1)	3.9		1.9	1.3	to	7.8	(13/19)	3.6	
	OCDD	11				(0/1)	<11		6.0	2.2	to	20	(6/19)	6.6	
Other	TCDD	0.8				(1/1)	9.2		0.9	<0.2	to	7.2	(5/19)	1.2	
Other	PeCDD	1.7				(0/1)	<1.7		1.3	<0.2	to	<5.3	(0/19)	<1.3	
Other	HxCDD	1.4				(0/1)	<1.4		1.1	<0.2	to	<5.7	(1/19)	1.2	
Other	HpCDD	2.2				(0/1)	,2.2		1.9	0.4	to	6.6	(0/19)	1.9	
2378	-TCDF	1.1				(1/1)	48		0.9	10	to	50	(19/19)	19.8	
12378	-PeCDF	0.7				(0/1)	<0.7		0.7	<0.2	to	<2.8	(7/19)	0.9	
23478	-PeCDF	0.9				(0/1)	<0.9		0.9	<0.2	to	<4.2	(4/19)	0.9	
123478	-HxCDF	0.9				(0/1)	<0.9		0.9	<0.3	to	<4.0	(0/19)	<0.9	
123678	-HxCDF	0.9				(0/1)	<0.9		1.0	<0.3	to	<5.1	(1/19)	1.0	
123789	-HxCDF	1.2				(0/1)	<1.2		1.3	<0.3	to	<5.7	(0/19)	<1.3	
234678	-HxCDF	1.1				(0/1)	<1.1		1.0	<0.4	to	<4.6	(9/19)	1.2	
1234678	-HpCDF	1.1				(0/1)	<1.1		1.0	<0.3	to	<3.2	(6/19)	1.1	
1234789	-HpCDF	1.7				(0/1)	<1.7		1.5	<0.5	to	<4.5	(0/19)	<1.5	
Other	TeCDF	1.1				(0/1)	<1.1		0.9	<0.2	to	<4.2	(0/19)	<0.9	
Other	PeCDF	0.8				(0/1)	<0.8		0.8	<0.1	to	<3.5	(0/19)	<0.8	
Other	HxCDF	1				(0/1)	<1.0		1.1	<0.3	to	<4.9	(4/19)	1.2	
Other	HpCDF	1.4				(0/1)	<1.4		1.3	<0.4	to	<3.9	(0/19)	<1.3	
	OCDF	7.3				(0/1)	<7.3		4.9	<0.9	to	<21.0	(0/19)	<4.9	
	% lipid					(1/1)	57.4			42.6	to	81.1	(19/19)	60.0	
		WAB1	**Wabasca River**						**WR**	**Wapiti River d/s Grand Prairie**					
2378	-TCDD	2.1	<1.0	to	<3.1	(0/5)	<2.1		1.3	0.7	to	<5.4	(9/13)	2.1	

Congener or homolog		DL[1] pg g^{-1} wet wt	low		high	# of detects	mean	SD	DL[1] pg g^{-1} wet wt	low		high	# of detects	mean	SD
12378	-PeCDD	2.6	<1.5	to	<3.8	(0/5)	<2.6		1.7	<0.2	to	<5.7	(0/13)	<1.7	
123478	-HxCDD	2.7	<1.5	to	<5.2	(0/5)	2.7		1.6	<0.2	to	<5.2	(0/13)	<1.6	
123678	-HxCDD	2.7	<1.5	to	<5.5	(0/5)	2.7		1.5	0.7	to	<4.5	(9/13)	2.0	
123789	-HxCDD	2.7	<1.5	to	<5.3	(0/5)	2.7		1.5	<0.2	to	<4.9	(0/13)	<1.5	
1234678	-HpCDD	3.4	2.4	to	6.2	(2/5)	4.1		2.4	1	to	<8.1	(5/13)	2.9	
	OCDD	9.3	5.3	to	<13.0	(1/5)	9.7		7.4	2	to	<21.0	(7/13)	8.3	
Other	TCDD	2.1	<1.0	to	<3.1	(0/5)	<2.1		1.3	<0.2	to	12	(1/13)	2.1	
Other	PeCDD	2.6	<1.5	to	<3.8	(0/5)	<2.6		1.7	<0.2	to	<5.7	(0/13)	<1.7	
Other	HxCDD	2.7	<1.5	to	<5.3	(0/5)	<2.7		1.5	<0.2	to	<4.9	(0/13)	<1.5	
Other	HpCDD	3.4	<1.7	to	<4.0	(0/5)	<3.4		2.4	<0.3	to	<8.1	(0/13)	<2.4	
2378	-TCDF	1.7	1.4	to	<2.4	(1/5)	2		1.3	11	to	52	(13/13)	25.2	
12378	-PeCDF	2.0	<0.7	to	<3.8	(0/5)	<2.0		1.1	<0.2	to	<4.5	(1/13)	1.1	
23478	-PeCDF	2.2	<1.0	to	<3.9	(0/5)	<2.2		1.2	<0.2	to	<4.2	(2/13)	1.2	
123478	-HxCDF	3.0	<2.0	to	<4.7	(0/5)	<3.0		1.3	<0.2	to	<4.1	(0/13)	<1.3	
123678	-HxCDF	2.7	<1.9	to	<4.0	(0/5)	<2.7		1.3	<0.2	to	<3.9	(0/13)	<1.3	
123789	-HxCDF	3.6	,2.4	to	<5.9	(0/5)	<3.6		1.6	<0.3	to	<5.2	(0/13)	<1.6	
234678	-HxCDF	3.2	2.5	to	<5.2	(1/5)	3.5		1.3	<0.3	to	4.8	(5/13)	1.6	
1234678	-HpCDF	4.0	<1.1	to	<6.5	(0/5)	<4.0		1.9	<0.2	to	<7.2	(1/13)	<2.0	
1234789	-HpCDF	5.5	<1.5	to	<8.8	(0/5)	<5.5		2.4	<0.3	to	<8.6	(0/13)	<2.4	
Other	TeCDF	1.7	<0.8	to	<2.4	(0/5)	<1.7		1.3	<0.2	to	<4.4	(3/13)	1.4	
Other	PeCDF	2.1	<0.8	to	<3.8	(0/5)	<2.1		1.1	<0.2	to	<4.4	(1/13)	1.2	
Other	HxCDF	3.1	<2.0	to	<4.9	(0/5)	<3.1		1.4	<0.3	to	<4.2	(1/13)	1.5	
Other	HpCDF	4.8	<1.3	to	<7.7	(0/5)	<4.8		2.2	<0.3	to	<7.8	(0/13)	<2.2	
	OCDF	7.2	<4.6	to	<10.0	(0/5)	<7.2		5.3	<1.1	to	<17.0	(0/13)	<5.3	
	% lipid		8.4		57.8	(5/5)	34.3			34.8	to	60.6	(13/13)	48.8	
		WR1	**Wapiti River u/s Grand Prairie**												
2378	-TCDD	1.5	0.4	to	3.1	(2/5)	1.6								
12378	-PeCDD	2.9	0.7	to	<5.8	(0/5)	<2.9								
123478	-HxCDD	2.8	<0.7	to	<7.1	(0/5)	<2.8								
123678	-HxCDD	2.4	0.8	to	5.6	(2/5)	3.0								
123789	-HxCDD	2.6	<0.7	to	<6.3	(0/5)	<2.6								
1234678	-HpCDD	3.5	1.3	to	8.9	(3/5)	4.6								
	OCDD	16.0	<3.0	to	<33.0	(0/5)	<16.0								
Other	TCDD	1.5	<0.3	to	6	(2/5)	2.3								
Other	PeCDD	2.9	<0.7	to	<5.8	(0/5)	<2.9								
Other	HxCDD	2.6	<0.7	to	<6.3	(0/5)	<2.6								
Other	HpCDD	3.5	<1.1	to	<5.4	(0/5)	<3.5								
2378	-TCDF	1.5	3.5	to	17	(5/5)	11.5								
12378	-PeCDF	1.3	0.5	to	2.7	(1/5)	1.3								
23478	-PeCDF	1.5	0.5	to	<3.0	(1/5)	1.5								
123478	-HxCDF	1.5	<0.4	to	<2.6	(0/5)	<1.5								
123678	-HxCDF	1.7	<0.3	to	<3.1	(0/5)	<1.7								
123789	-HxCDF	2.2	<0.5	to	<3.9	(0/5)	<2.2								
234678	-HxCDF	1.7	<0.4	to	<2.9	(0/5)	<1.7								
1234678	-HpCDF	1.7	<0.6	to	<3.0	(0/5)	<1.7								
1234789	-HpCDF	2.3	<0.9	to	<3.9	(0/5)	<2.3								
Other	TeCDF	1.5	<0.4	to	<4.0	(0/5)	<1.5								
Other	PeCDF	1.4	<0.3	to	<2.9	(0/5)	<1.4								
Other	HxCDF	1.8	<0.4	to	<3.1	(0/5)	<1.8								
Other	HpCDF	2.0	<0.8	to	<3.4	(0/5)	<2.0								
	OCDF	12.4	<2.0	to	<29.0	(0/5)	<12.4								
	% lipid		46.6		78.6	(5/5)	57.3								

[1] Sample detection limit

Table A7. Results of the least squares means test of lipid-adjusted concentrations of 2,3,7,8-TCDF in burbot liver from the Peace-Athabasca-Slave basins[1]

General Linear Models Procedure: Least Squares Means

SITE	LTCDF LSMEAN	Std Err LSMEAN	Pr > |T| H0:LSMEAN=0	LSMEAN Number
A1	1.74420298	0.16624498	0.0001	1
A2	0.71007036	0.15175639	0.0001	2
A3	1.13351623	0.09594168	0.0001	3
A4	0.93010932	0.11317248	0.0001	4
A5	0.11355836	0.10485234	0.2804	5
CW	-0.35831443	0.19592847	0.0693	6
LSV	0.52679152	0.10005520	0.0001	7
MCR	0.24043542	0.18864235	0.2043	8
P	0.34473210	0.17571490	0.0515	9
PR1	0.29190073	0.17842844	0.1038	10
PR3	-0.65093228	0.18795095	0.0007	11
SR	0.73980436	0.09995150	0.0001	12
SR1	1.18797130	0.10455988	0.0001	13
WAB1	-0.70483677	0.19119952	0.0003	14
WR	1.24263885	0.10365159	0.0001	15

Pr > |T| H0: LSMEAN(i)=LSMEAN(j)

i/j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	.	0.0001	0.0012	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0034	0.0001	0.0101
2	0.0001	.	0.0172	0.2459	0.0019	0.0001	0.3121	0.0620	0.1230	0.0821	0.0001	0.8696	0.0084	0.0001	0.0039
3	0.0012	0.0172	.	0.1709	0.0001	0.0001	0.0001	0.0001	0.0002	0.0001	0.0001	0.0047	0.6864	0.0001	0.4323
4	0.0001	0.2459	0.1709	.	0.0001	0.0001	0.0083	0.0021	0.0058	0.0030	0.0001	0.2091	0.0946	0.0001	0.0430
5	0.0001	0.0019	0.0001	0.0001	.	0.0295	0.0054	0.5353	0.2484	0.3737	0.0002	0.0001	0.0001	0.0002	0.0001
6	0.0001	0.0001	0.0001	0.0001	0.0295	.	0.0001	0.0214	0.0069	0.0122	0.2573	0.0001	0.0001	0.1992	0.0001
7	0.0001	0.3121	0.0001	0.0083	0.0054	0.0001	.	0.1872	0.3720	0.2563	0.0001	0.1332	0.0001	0.0001	0.0001
8	0.0001	0.0620	0.0001	0.0021	0.5353	0.0214	0.1872	.	0.6750	0.8348	0.0004	0.0218	0.0001	0.0004	0.0001
9	0.0001	0.1230	0.0002	0.0058	0.2484	0.0069	0.3720	0.6750	.	0.8294	0.0001	0.0535	0.0001	0.0001	0.0001
10	0.0001	0.0821	0.0001	0.0030	0.3737	0.0122	0.2563	0.8348	0.8294	.	0.0002	0.0310	0.0001	0.0002	0.0001
11	0.0001	0.0001	0.0001	0.0001	0.0002	0.2573	0.0001	0.0004	0.0001	0.0002	.	0.0001	0.0001	0.8364	0.0001
12	0.0001	0.8696	0.0047	0.2091	0.0001	0.0001	0.1332	0.0218	0.0535	0.0310	0.0001	.	0.0021	0.0001	0.0006
13	0.0034	0.0084	0.6864	0.0946	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0021	.	0.0001	0.7036
14	0.0001	0.0001	0.0001	0.0001	0.0002	0.1992	0.0001	0.0004	0.0001	0.0002	0.8364	0.0001	0.0001	.	0.0001
15	0.0101	0.0039	0.4323	0.0430	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0006	0.7036	0.0001	.

[1] Site PR2 is omitted because % lipid results were unavailable.

APPENDIX B.

CONCENTRATIONS OF PCDD/F CONGENERS IN EFFLUENT, SUSPENDED SOLIDS, RIVER WATER (CENTRIFUGATE) AND BOTTOM SEDIMENTS DOWNSTREAM OF THE HINTON COMBINED EFFLUENT, FEBRUARY/MAY 1993.

Table B1. Levels of Higher Chlorinated PCDD/Fs in Hinton Combined Effluent from the Athabasca River, February 11, 1993

Congener or Homolog	Suspended Solids (centrifuged) pg g^{-1}	DL[1]	Aqueous phase (centrifugate) pg L^{-1}	DL
TCDD-Total	35	0.16	0.35	0.21
2,3,7,8	24	0.16	0.35	0.21
P5CDD-Total	11	0.68	<0.10	0.10
1,2,3,7,8-	2.1	0.68	<0.10	0.10
H6CDD-Total	8.9	0.46	<0.10	0.10
1,2,3,4,7,8-	0.8	0.46	<0.10	0.10
1,2,3,6,7,8-	1.1	0.46	<0.10	0.10
1,2,3,6,7,9-	1.3	0.46	<0.10	0.10
H7CDD-Total	24	0.52	0.16	0.11
1,2,3,4,6,7,8	12	0.52	0.16	0.11
OCDD-Total	130	0.91	0.60	0.12
TCDF-Total	250	0.10	76	0.10
2,3,7,8	56	0.10	0.78	0.10
P5CDF-Total	24	0.39	0.60	0.10
1,2,3,7,8-	2.5	0.39	<0.10	0.10
2,3,4,7,8-	2.0	0.39	<0.10	0.10
H6CDF-Total	9.2	0.93	<0.10	0.10
1,2,3,4,7,8-	1.0	0.93	<0.10	0.10
1,2,3,6,7,8-	0.0	0.93	<0.10	0.10
2,3,4,6,7,8-	0.0	0.93	<0.10	0.10
1,2,3,7,8,9-	0.0	0.93	<0.10	0.10
H7CDF-Total	12	0.44	<0.10	0.10
1,2,3,4,6,7,8	6.0	0.44	<0.10	0.10
1,2,3,4,7,8,9	0.0	0.44	<0.10	0.10
OCDF-Total	15	0.58	<0.10	0.10

[1] Sample detection limit

Table B2. Levels of lower chlorinated PCDD/Fs in Hinton Combined Effluent, February 11, 1993

Congener or Homolog grou	Suspended Solids (centrifuged) pg L^{-1}	DL[1]	Aqueous phase (centrifugate) pg L^{-1}	DL
1-MoCDD	<0.67	0.67	<0.14	0.14
2-MoCDD	<0.67	0.67	<0.14	0.14
MoCDD-Total	<0.67	0.67	<0.14	0.14
27/28-DiCDD	13	1.5	<0.91	0.91
23-DiCDD	3.2	1.5	<0.91	0.91
28-DiCDD	N/R	0	N/R	0
27-DiCDD	N/R	0	N/R	0
DiCDD-Total	13	1.5	<0.91	0.91
124-TrCDD	<1.1	1.1	<0.1	0.1
237-TrCDD	24	1.1	0.38	0.1
123-TrCDD	3.8	1.1	<0.1	0.1
TrCDD-Total	30	1.1	0.38	0.1
2-MoCDF	390	0.40	10	1.4
4-MoCDF	25	0.40	<1.4	1.4
MoCDF-Total	430	0.40	12	1.4
24-DiCDF	50	0.61	1.4	0.12
28-DiCDF	3000	0.61	73	0.12
26-DiCDF	500	0.61	6.5	0.12
DiCDF-Total	3600	0.61	94	0.12
246/248-TrCD	85	1.0	5.9	0.20
238-TrCDF	640	1.0	12	0.20
TrCDF-Total	1500	1.0	30	0.20

[1] Sample detection limit

Table B3. Levels of Higher Chlorinated PCDD/Fs in Water (centrifugate) from the Athabasca River, February 1993

	Obed Coal Br. (02/12/93)		Knight Bridge/ Berland (02/14/1993)	
	pg L^{-1}	DL[1]	pg L^{-1}	DL
TCDD-Total	<0.10	0.10	<0.10	0.10
2,3,7,8	<0.10	0.10	<0.10	0.10
P5CDD-Total	<0.10	0.10	<0.10	0.10
1,2,3,7,8-	<0.10	0.10	<0.10	0.10
H6CDD-Total	<0.10	0.10	<0.10	0.10
1,2,3,4,7,8-	<0.10	0.10	<0.10	0.10
1,2,3,6,7,8-	<0.10	0.10	<0.10	0.10
1,2,3,6,7,9-	<0.10	0.10	<0.10	0.10
H7CDD-Total	0.25	0.20	0.35	0.20
1,2,3,4,6,7,8	<0.20	0.20	<0.20	0.20
OCDD-Total	0.70	0.50	1.40	0.50
TCDF-Total	0.24	0.10	0.14	0.10
2,3,7,8	<0.10	0.10	<0.10	0.10
P5CDF-Total	<0.10	0.10	<0.10	0.10
1,2,3,7,8-	<0.10	0.10	<0.10	0.10
2,3,4,7,8-	<0.10	0.10	<0.10	0.10
H6CDF-Total	<0.10	0.10	<0.10	0.10
1,2,3,4,7,8-	<0.10	0.10	<0.10	0.10
1,2,3,6,7,8-	<0.10	0.10	<0.10	0.10
2,3,4,6,7,8-	<0.10	0.10	<0.10	0.10
1,2,3,7,8,9-	<0.10	0.10	<0.10	0.10
H7CDF-Total	<0.10	0.10	<0.10	0.10
1,2,3,4,6,7,8	<0.10	0.10	<0.10	0.10
1,2,3,4,7,8,9	<0.10	0.10	<0.10	0.10
OCDF-Total	<0.10	0.20	<0.10	0.20

[1] Sample detection limit

Table B4. Levels of lower chlorinated PCDD/Fs in water (centrifugate) from the Athabasca River, February 1993

	Athabasca @ Obed Br. 12-Feb-93		Athabasca u/s Knight Br. 14-Feb-93	
	pg L^{-1}	DL[1]	pg L^{-1}	DL[1]
1-MoCDD	<0.17	0.17	<0.18	0.18
2-MoCDD	<0.17	0.17	<0.18	0.18
MoCDD-Total	<0.17	0.17	<0.18	0.18
27/28-DiCDD	<0.54	0.54	<0.70	0.70
23-DiCDD	<0.54	0.54	0.90	0.70
28-DiCDD	N/R		N/R	
27-DiCDD	N/R		N/R	
DiCDD-Total	<0.54	0.54	<0.70	0.70
124-TrCDD	<0.10	0.10	<0.10	0.10
237-TrCDD	<0.10	0.10	<0.10	0.10
123-TrCDD	<0.10	0.10	<0.10	0.10
TrCDD-Total	<0.10	0.10	<0.10	0.10
2-MoCDF	<1.2	1.2	<1.2	1.2
4-MoCDF	<1.2	1.2	<1.2	1.2
MoCDF-Total	<1.2	1.2	<1.2	1.2
24-DiCDF	<0.18	0.18	<0.17	0.17
28-DiCDF	<0.18	0.18	4.2	0.17
26-DiCDF	<0.18	0.18	0.36	0.17
DiCDF-Total	<0.18	0.18	4.2	0.17
246/248-TrCDF	<0.20	0.20	<0.20	0.20
238-TrCDF	<0.20	0.20	0.59	0.20
TrCDF-Total	<0.20	0.20	1.4	0.20

[1] Sample detection limit

Table B5. Levels of Higher Chlorinated PCDD/Fs in Suspended Sediments from the Athabasca River, February 1993

	Upstream (control) (02/11/93)		Weldwood Haul Br (02/11/93)		Obed Coal Br. (02/12/1993)		Obed Coal Br. (02/12/1993)		Obed Coal Br. (02/12/1993)		Emerson Lake Br. (02/13/1993)	
	pg g^{-1}	DL[1]			pg g^{-1}	DL[1]	pg g^{-1}	DL[1]	pg g^{-1}	DL[1]	pg g^{-1}	DL[1]
TCDD-Total	0.41	0.10	3.1	0.1	3.8	0.20	4.2	0.15	3.9	0.15	6.4	0.10
2,3,7,8	<0.10	0.10	3	0.1	3.2	0.20	3.2	0.15	2.9	0.15	3.7	0.10
P5CDD-Total	<0.10	0.10	0.33	0.16	0.50	0.18	0.60	0.20	0.62	0.15	0.66	0.11
1,2,3,7,8-	<0.10	0.10	0.33	0.16	0.27	0.18	0.30	0.20	0.34	0.15	0.35	0.11
H6CDD-Total	0.14	0.10	1.7	0.13	2.3	0.11	1.6	0.11	2.0	0.11	2.0	0.14
1,2,3,4,7,8-	<0.10	0.10	0.18	0.13	0.19	0.11	0.21	0.11	0.19	0.11	0.26	0.14
1,2,3,6,7,8-	<0.10	0.10	0.31	0.13	0.36	0.11	0.29	0.11	0.30	0.11	0.46	0.14
1,2,3,6,7,9-	<0.10	0.10	0.34	0.13	0.35	0.11	0.22	0.11	0.28	0.11	0.46	0.14
H7CDD-Total	2.8	0.20	8.8	0.14	11	0.13	9.6	0.16	9.7	0.15	14	0.17
1,2,3,4,6,7,8	1.5	0.20	4.2	0.14	5.7	0.13	4.6	0.16	4.6	0.15	7.2	0.17
OCDD-Total	12	0.20	37	0.42	50	0.46	40	0.56	42	0.51	69	0.53
TCDF-Total	0.51	0.10	28	0.12	32	0.11	32	0.12	34	0.10	33	0.10
2,3,7,8	0.13	0.10	6.5	0.12	8.0	0.11	7.6	0.12	8.3	0.10	10	0.10
P5CDF-Total	0.13	0.10	3.4	0.11	3.2	0.10	3.4	0.10	3.3	0.11	5.1	0.11
1,2,3,7,8-	<0.10	0.10	0.22	0.11	0.36	0.10	0.36	0.10	0.32	0.11	0.44	0.11
2,3,4,7,8-	<0.10	0.10	0.22	0.11	0.29	0.29	0.31	0.10	0.27	0.11	0.38	0.11
H6CDF-Total	0.81	0.10	2	0.2	2.8	0.21	2.3	0.30	2.5	0.30	3.6	0.16
1,2,3,4,7,8-	<0.10	0.10	0	0.2	<0.21	0.21	<0.30	0.30	<0.30	0.30	0.23	0.16
1,2,3,6,7,8-	<0.10	0.10	0	0.2	<0.21	0.21	<0.30	0.30	<0.30	0.30	<0.16	0.16
2,3,4,6,7,8-	0.19	0.10	0.4	0.2	0.56	0.21	0.55	0.30	0.43	0.30	0.50	0.16
1,2,3,7,8,9-	0.00	0.10	0	0.2	<0.21	0.21	<0.30	0.30	<0.30	0.30	<0.16	0.16
H7CDF-Total	1.0	0.20	3.5	0.21	3.3	0.30	3.2	0.20	3.2	0.19	4.9	0.15
1,2,3,4,6,7,8	0.66	0.20	1.4	0.21	2.2	0.30	2.2	0.20	1.9	0.19	2.6	0.15
1,2,3,4,7,8,9	<0.10	0.10	0	0.21	<0.30	0.30	<0.20	0.20	<0.19	0.19	<0.15	0.15
OCDF-Total	1.1	0.20	3.4	0.26	4.4	0.29	4.0	0.25	3.6	0.32	5.9	0.25

[1] Sample detection limit

Table B6. Levels of lower chlorinated PCDD/Fs in suspended sediments from the Athabasca River, May 1993

Congener or Homolog group	Upstream (control) pg g^{-1}	DL[1]	Athabasca @ Obed 5-May-93 pg g^{-1}	DL[1]	Athabasca @ Obed 5-May-93 pg g^{-1}	DL[1]	Athabasca @ Obed 5-May-93 pg g^{-1}	DL[1]	Athabasca @ Emerson Lakes 5-May-93 pg g^{-1}	DL[1]
1-MoCDD	<0.14	0.14	<0.77	0.77	<1.0	1.0	<0.71	0.71	<0.45	0.45
2-MoCDD	<0.14	0.14	<0.77	0.77	<1.0	1.0	<0.71	0.71	<0.45	0.45
MoCDD-Total	<0.14	0.14	<0.77	0.77	<1.0	1.0	<0.71	0.71	<0.45	0.45
27/28-DiCDD	7.7	0.31	18	3.1	21	4.3	21	3.7	30	1.8
23-DiCDD	<0.3	0.30	<3.0	3.0	<4.0	4.0	<4.0	4.0	<4.0	4.0
28-DiCDD	N/R		N/R		N/R		N/R		N/R	
27-DiCDD	N/R		N/R		N/R		N/R		N/R	
DiCDD-Total	7.7	0.31	18	3.1	21	4.3	21	3.7	30	1.8
124-TrCDD	<0.11	0.11	<0.11	0.11	0	0.12	<0.15	0.15	<0.12	0.12
237-TrCDD	<0.11	0.11	2.8	0.11	3.3	0.12	3.3	0.15	3.4	0.12
123-TrCDD	<0.11	0.11	0.42	0.11	0.48	0.12	0.52	0.15	0.37	0.12
TrCDD-Total	0.37	0.11	3.5	0.11	6.2	0.12	4.7	0.15	4.9	0.12
2-MoCDF	1.4	0.50	55	0.50	68	0.50	63	0.50	70	0.50
4-MoCDF	<0.50	0.50	3.5	0.50	4.7	0.50	4.0	0.50	4.8	0.50
MoCDF-Total	2.7	0.50	62	0.50	77	0.50	71	0.50	79	0.50
24-DiCDF	<0.50	0.10	<0.28	0.28	0	0.53	<0.51	0.51	<0.29	0.29
28-DiCDF	4.5	0.10	370	0.10	440	0.1	420	0.10	460	0.10
26-DiCDF	1.1	0.10	64	0.28	72	0.53	69	0.51	76	0.29
DiCDF-Total	5.6	0.10	460	0.28	550	0.53	510	0.51	570	0.29
246/248-TrCDF	0.51	0.35	19	0.35	24	0.35	24	0.35	24	0.35
238-TrCDF	0.47	0.35	85	0.35	110	0.35	110	0.35	110	0.35
TrCDF-Total	2.9	0.35	190	0.35	250	0.35	240	0.35	260	0.35

[1] Sample detection limit

Table B7. Levels of Higher Chlorinated PCDD/Fs in Bottom Sediments from the Athabasca River, May 1993

Congener or	Upstream control (05/05/93)		Weldwood Haul Br. (5/05/1993)		Obed Coal Br. (05/05/1993)		Emerson Lake Br. (05/05/1993)		Knight Bridge (5/6/1993)		Windfall Bridge (5/6/1993)		Windfall Bridge (DUP (5/6/1993)	
Homolog group	$pg\ g^{-1}$	DL[1]	pg/g	DL[1]	pg/g	DL[1]	pg/g	DL[1]	pg/g	DL[1]	pg/g	DL[1]	pg/g	DL[1]
TCDD-Total	<0.13	0.13	0.23	0.12	0.14	0.11	0.22	0.12	0.52	0.12	0.42	0.11	0.40	0.11
2,3,7,8	<0.13	0.13	0.23	0.12	0.14	0.11	0.22	0.12	0.29	0.12	0.17	0.11	0.16	0.11
P5CDD-Total	<0.10	0.10	<0.10	0.10	<0.10	0.10	<0.10	0.10	<0.10	0.10	<0.10	0.10	<0.10	0.10
1,2,3,7,8-	<0.10	0.10	<0.10	0.10	<0.10	0.10	<0.10	0.10	<0.10	0.10	<0.10	0.10	<0.10	0.10
H6CDD-Total	<0.20	0.20	0.52	0.11	0.29	0.11	0.38	0.10	0.72	0.10	0.17	0.10	0.29	0.10
1,2,3,4,7,8-	<0.20	0.20	<0.11	0.11	<0.11	0.11	<0.10	0.10	<0.10	0.10	<0.10	0.10	<0.10	0.10
1,2,3,6,7,8-	<0.20	0.20	<0.11	0.11	<0.11	0.11	<0.10	0.10	0.20	0.10	<0.10	0.10	<0.10	0.10
1,2,3,6,7,9-	<0.20	0.20	<0.11	0.11	<0.11	0.11	<0.10	0.10	<0.10	0.10	<0.10	0.10	<0.10	0.10
H7CDD-Total	1.4	0.20	4.50	0.12	2.9	0.11	3.7	0.12	4.6	0.12	2.3	0.10	2.7	0.11
1,2,3,4,6,7,8	1.7	0.20	2.30	0.12	1.4	0.11	1.9	0.12	2.2	0.12	1.3	0.10	1.2	0.11
OCDD-Total	14	0.20	20	0.30	10	0.30	18	0.30	14	0.30	8.9	0.20	8.8	0.30
TCDF-Total	<0.13	0.13	2.5	0.12	1.3	0.12	2.9	0.12	4.6	0.12	2.1	0.12	2.1	0.12
2,3,7,8	<0.13	0.13	1.0	0.12	0.48	0.12	0.91	0.12	1.2	0.12	0.77	0.12	0.76	0.12
P5CDF-Total	<0.12	0.12	0.11	0.11	0.11	0.11	0.21	0.10	0.63	0.10	0.20	0.11	0.20	0.10
1,2,3,7,8-	<0.12	0.12	<0.11	0.11	<0.11	0.11	<0.10	0.10	<0.10	0.10	<0.11	0.11	<0.10	0.10
2,3,4,7,8-	<0.12	0.12	<0.11	0.11	<0.11	0.11	<0.10	0.10	<0.10	0.10	<0.11	0.11	<0.10	0.10
H6CDF-Total	<0.24	0.24	1.1	0.24	0.54	0.23	1.0	0.25	0.77	0.25	0.46	0.20	0.36	0.10
1,2,3,4,7,8-	<0.20	0.20	<0.11	0.11	<0.11	0.11	<0.10	0.10	<0.10	0.10	<0.10	0.10	<0.10	0.10
1,2,3,6,7,8-	<0.24	0.24	<0.24	0.24	<0.23	0.23	<0.25	0.25	<0.25	0.25	<0.20	0.20	<0.10	0.10
2,3,4,6,7,8-	<0.24	0.24	0.26	0.24	<0.23	0.23	0.28	0.25	<0.25	0.25	<0.20	0.20	<0.10	0.10
1,2,3,7,8,9-	<0.24	0.24	<0.24	0.24	<0.23	0.23	<0.25	0.25	<0.25	0.25	<0.20	0.20	<0.10	0.10
H7CDF-Total	1.2	0.26	1.70	0.22	0.90	0.23	1.4	0.25	1.1	0.24	0.84	0.16	0.84	0.18
1,2,3,4,6,7,8	1.2	0.26	1.90	0.22	1.1	0.23	2.1	0.25	1.6	0.24	1.0	0.16	0.93	0.18
1,2,3,4,7,8,9	<0.26	0.26	<0.22	0.22	<0.23	0.23	<0.25	0.25	<0.24	0.24	<0.16	0.16	0.0	0.18
OCDF-Total	1.10	0.30	1.60	0.30	0.77	0.40	1.2	0.40	0.82	0.30	0.72	0.30	0.69	0.30

[1] Sample detection limit

Table B8. Levels of lower chlorinated PCDD/Fs in bottom sediments from the Athabasca River, May 1993

Congener or Homolog group	Upstream control 5-May-93 pg g^{-1}	DL[1]	Athabasca @ Weldwood Br 5-May-93 pg g^{-1}	DL[1]	Athabasca @ Obed 5-May-93 pg g^{-1}	DL[1]	Athabasca @ Emerson 5-May-93 pg g^{-1}	DL[1]	Athabasca u/s Berland River 6-May-93 pg g^{-1}	DL[1]	Athabasca @ Windfall 6-May-93 pg g^{-1}	DL[1]	Athabasca @ Windfall 6-May-93 pg g^{-1}	DL[1]
1-MoCDD	<0.25	0.25	<0.30	0.30	<0.26	0.26	<0.23	0.23	<0.40	0.40	<0.30	0.30	<0.30	0.30
2-MoCDD	<0.25	0.25	<0.30	0.30	<0.26	0.26	<0.23	0.23	<0.40	0.40	<0.30	0.30	<0.30	0.30
MoCDD-Total	<0.25	0.25	<0.30	0.30	<0.26	0.26	<0.23	0.23	<0.40	0.40	<0.30	0.30	<0.30	0.30
27/28-DiCDD	10	0.97	5.6	0.64	5.1	1.1	14	0.76	23	0.79	11	0.38	11	0.51
23-DiCDD	<0.97	0.97	0	0.64	<1.1	1.1	<0.76	0.76	<0.79	0.79	<0.38	0.38	<0.51	0.51
28-DiCDD	N/R		N/R		N/R		N/R		N/R		N/R		N/R	
27-DiCDD	N/R		N/R		N/R		N/R		N/R		N/R		N/R	
DiCDD-Total	10	0.97	5.6	0.64	5.1	1.1	14	0.76	23	0.79	11	0.38	11	0.51
124-TrCDD	<0.70	0.70	<0.50	0.50	<0.40	0.40	<0.50	0.50	<0.50	0.50	<0.20	0.20	<0.20	0.20
237-TrCDD	<0.70	0.70	<0.50	0.50	<0.40	0.40	0.60	0.50	0.80	0.50	<0.20	0.20	<0.20	0.20
123-TrCDD	<0.70	0.70	<0.50	0.50	<0.40	0.40	<0.50	0.50	<0.50	0.50	<0.20	0.20	<0.20	0.20
TrCDD-Total	1.1	0.70	0.80	0.50	0.70	0.40	1.4	0.50	2.0	0.50	0.50	0.20	0.40	0.20
2-MoCDF	1.2	0.30	5.6	0.30	2.8	0.30	5.5	0.30	8.0	0.20	4.2	0.20	3.4	0.20
4-MoCDF	<0.30	0.30	0.6	0.30	<0.30	0.30	0.60	0.30	0.70	0.20	0.4	0.20	0.40	0.20
MoCDF-Total	1.9	0.30	6.8	0.30	3.6	0.30	6.7	0.30	9.0	0.20	5.1	0.20	4.3	0.20
24-DiCDF	<0.35	0.35	<0.20	0.20	<0.22	0.22	3.5	0.30	6.6	0.20	3.1	0.20	2.8	0.20
28-DiCDF	<0.35	0.35	27	0.35	11	0.35	30	0.35	43	0.35	18	0.35	18	0.35
26-DiCDF	<0.35	0.35	4.0	0.20	1.6	0.22	4.7	0.30	5.7	0.20	2.4	0.20	2.6	0.20
DiCDF-Total	<0.35	0.35	31	0.20	13	0.22	37	0.30	52	0.20	23	0.20	24	0.20
246/248-TrCDF	0.59	0.10	1.7	0.20	1.0	0.20	2.2	0.10	2.8	0.20	1.7	0.20	1.5	0.20
238-TrCDF	0.3	0.10	6.8	0.20	3.2	0.20	7.4	0.10	10	0.20	5.8	0.20	5.0	0.20
TrCDF-Total	1.5	0.10	16	0.20	7.1	0.20	17	0.10	23	0.20	14	0.20	12	0.20

[1] Sample detection limit

Table B9. Calculation of fraction dissolved and the organic carbon partition coefficients (K_{POC}) for 2,3,7,8-TCDD and -TCDF

			Up stream (11/02/93)	HCE (02/11/93)	Weldwood (02/11/93)	Obed Coal Br. (02/12/1993)	Obed Coal Br. (02/12/1993)	Obed Coal Br. (02/12/1993)	Emerson Lake Br. (02/13/1993)
2,3,7,8-TCDF	suspended solids (dry wt)	pg g^{-1}	0.13	56.0	6.50	8.00	7.60	8.3	10
in suspended	water (centrifugate)	pg L^{-1}	0.05	0.78	0.1	0.1	0.1	0.1	0.1
solids	Total suspended solids	mg L^{-1}	19.6	32.4	7.5	7.5	7.5	7.5	2.2
	% organic carbon in SS		0.94	31.1	4.6	4.6	4.6	4.6	6.2
	DOC in centrifugate	mg L^{-1}	0.6	112	3.2	3.2	3.2	3.2	3.2
	K_{POC} (using centrifugate)[1]		2.76E+05	2.31E+05	1.42E+06	1.72E+06	1.64E+06	1.79E+06	1.62E+06
	Fraction dissolved		0.86	0.04	0.18	0.15	0.16	0.15	0.16
	suspended solids (OC basis)	pg g^{-1}	13.8	180.1	141.8	172.2	163.5	178.6	162.0
	K_{POC} (adjusted for fract dissolved)		3.21E+05	6.20E+06	7.85E+06	1.12E+07	1.02E+07	1.20E+07	1.00E+07
2,3,7,8-TCDF	sediment (dry wt)	pg g^{-1}	0.13		1.0	0.48	0.48	0.48	0.91
in sediment	Sediment OC basis	pg g^{-1}	22.8		188.7	59.1	59.1	59.1	134.2
	Fraction Org Carb		0.0057		0.0053	0.00812	0.00812	0.00812	0.00678
2,3,7,8-TCDD	suspended solids	pg g^{-1}	0.10	24.00	3.00	3.00	3.20	2.9	3.7
in suspended	water (centrifugate)	pg L^{-1}	0.01	0.35	0.025	0.025	0.025	0.025	0.025
solids	K_{POC} (using centrifugate)[1]		1.06E+06	2.20E+05	2.62E+06	2.58E+06	2.75E+06	2.50E+06	2.40E+06
	Fraction dissolved		0.61	0.04	0.11	0.11	0.10	0.11	0.12
	K_{POC} (adjusted for fract dissolved)		1.74E+06	5.67E+06	2.45E+07	2.39E+07	2.70E+07	2.24E+07	2.08E+07
2,3,7,8-TCDD	sediment (dry wt)	pg g^{-1}	0.13		0.23	0.14	0.14	0.14	0.22
in sediment	Sediment OC basis	pg g^{-1}	22.81		43.4	17.2	17.2	17.2	32.4
	suspended solids (OC basis)	pg g^{-1}	5.30		65.4	64.6	68.9	62.4	59.9

[1] Assumes $K_{DOC}=K_{POC}$

Table B10. Calculation of BSAFs and BSSAFs of 2,3,7,8-TCDD and -TCDF for mountain whitefish and northern pike from spring 1992 and 1993 data

Species/year	Location	Fraction lipid	TCDD (pg g^{-1} lipid wt)	TCDF (pg g^{-1} lipid wt)	Bottom sed fraction OC	Susp sed fraction OC	Conc in sediment OC TCDD (pg g^{-1} dry wt)	Conc in sediment OC TCDF (pg g^{-1} dry wt)	Conc in Susp sed OC TCDD (pg g^{-1} dry wt)	Conc in Susp sed OC TCDF (pg g^{-1} dry wt)	BSAF TCDD	BSAF TCDF	BSSAF TCDD	BSSAF TCDF
1993														
Mtn whitefish	U/S	0.038	6.11	5.00	0.006	0.009	11.4	11.4	5.3	13.8	0.536	0.439	1.15	0.36
	Weldwood	0.069	8.80	20.51	0.005	0.046	43.4	188.7	65.4	65.4	0.203	0.109	0.13	0.31
	Obed Coal	0.085	20.53	49.32	0.008	0.046	17.2	59.1	62.4	172.2	1.191	0.834	0.33	0.29
	Emerson	0.074	93.56	174.1	0.007	0.062	32.4	134.2	59.9	162.0	2.883	1.297	1.56	1.07
1992														
Mtn whitefish	U/S	0.027	15.0	32.3	0.002	0.010	42.6	42.6	0.2	0.3	0.353	0.760	75.19	107.8
	Weldwood	0.058	131.9	225.9	0.003	0.031	69.4	138.9	9.7	74.2	1.899	1.626	13.63	3.04
	Obed Coal	0.053	151.7	234.0	0.004	0.029	76.9	205.1	27.6	89.7	1.972	1.141	5.50	2.61
	Emerson	0.065	130.5	210.0	0.004	0.035	114.7	435.8	28.6	91.4	1.138	0.482	4.57	2.30
	Knight Br.	0.041	72.7	89.8	0.007	0.036	59.3	474.8	22.2	77.8	1.225	0.189	3.27	1.15
	Windfall Br	0.051	74.9	168.6	0.007	0.034	59.3	474.8	17.6	67.6	1.262	0.355	4.24	2.49
Northern Pike	U/S	0.006	28.3	81.7	0.002	0.010	42.6	42.6	0.2	0.3	0.666	1.919	141.7	272.2
	Weldwood	0.007	42.9	85.7	0.003	0.031	69.4	138.9	9.7	67.7	0.617	0.617	4.43	1.27
	Obed Coal	0.000												
	Emerson	0.018	157.3	443.8	0.004	0.035	114.7	435.8	28.6	91.4	1.372	1.018	5.51	4.85
	Knight Br.	0.010	207.0	620.0	0.007	0.036	59.3	474.8	22.2	77.8	3.488	1.306	9.32	7.97
	Windfall Br	0.007	100.0	371.4	0.007	0.034	59.3	474.8	17.6	67.6	1.685	0.782	5.67	5.49

APPENDIX C. TERMS OF REFERENCE

NORTHERN RIVER BASINS STUDY

APPENDIX C - TERMS OF REFERENCE

2381-D3/E3: Review and Interpretation of Organochlorine Data in Fish and Other Media - 1993 and 1994 Data Sets

I. BACKGROUND & OBJECTIVES

One of the major objectives of the Northern River Basins Study is to determine the levels of contaminants released by industrial effluents, and measure their impacts on the aquatic ecosystems of rivers in northern Alberta. Organochlorine compounds are of a particular concern, including polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs), polychlorinated biphenyls (PCBs), and other persistent organochlorines such as some pesticides (e.g., toxaphene). Dioxins and furans are highly persistent compounds with a strong affinity for sediments and a high potential for accumulating in biological tissues. They have been found in all compartments of the ecosystem including air, water, soil, sediments, animals and foods. Dioxins and furans enter the environment from four major sources: commercial chemicals (e.g., pentachlorophenol), pulp and paper mills that use chlorine bleaching, incineration, and both accidental fires and spills involving PCBs (Environment Canada 1990). PCBs were once used in a variety of industrial applications, but were never intended to be released directly into the environment. PCBs are extremely persistent in the environment and are bioaccumulated throughout the food chain (Eisler 1986). Many organochlorine pesticides were used in large quantities in North America for over a decade and may still be present in sediments at high concentrations. Similar to PCDD/Fs and PCBs, organochlorine pesticides are not easily degraded or metabolized and, therefore, persist and bioaccumulate in the environment.

A previous NRBS project (project 2381-C5) interpreted analytical results to determine the impact of contaminants, from industrial and municipal effluents, on the aquatic ecosystem of the Athabasca and Peace rivers. This study summarized and mapped the levels of PCDD/Fs in water, sediment, suspended sediment, invertebrates and fish samples collected during the spring of 1992 as part of the Reach Specific Study on the upper Athabasca River downstream of Hinton. Concentrations of PCDD/Fs in fishes collected further downstream on the Athabasca River and from the Peace River (including the Wapiti-Smoky rivers) were also discussed.

Since then, the pulp and paper industry has reduced the use of molecular chlorine. Weldwood Canada Ltd. at Hinton and Weyerhaeuser Canada at Grand Prairie have almost completely restricted the use of molecular chlorine by substituting chlorine dioxide in the bleaching process. These changes in the pulp bleaching technology were expected to reduce the concentrations of PCDD/Fs emitted to the Wapiti and Athabasca rivers.

The purpose of this project is to interpret and summarize results for PCDD/Fs, PCBs and other organochlorines in abiotic and biotic samples collected downstream from bleached kraft pulp and paper mills on the Peace and Athabasca river systems during 1993 and 1994. This study will determine whether the current levels of contaminants in water, sediment, benthic invertebrates and fish have changed from results found in 1987-88, and 1991-92 (Alberta Environment 1988, Trudel 1991, Swanson *et al.* 1992, Pastershank and Muir 1994). The study will also elaborate on the partitioning, fate and bioaccumulation of this group of compounds following their discharge into northern Alberta river systems. These data will also be particularly relevant for the contaminant fate and food chain models being developed for the northern rivers by NRBS scientists (project 2381-D1).

II. GENERAL REQUIREMENTS

The contractor is required to interpret analytical data for organochlorines and produce comprehensive reports relative to the four tasks outlined in these terms of reference. The format of the reports should be consistent with Pastershank and Muir (1994; project 2381-C5) to facilitate inter-basin and inter-year comparisons of organochlorine data, and to allow for an assessment of ecosystem health in the northern rivers. The reports should include, but not necessarily be limited to, the following:

a) a background information section, including a review of physiochemical parameters of compounds, their persistence in the environment, toxicity, sources, fate, transport and biomagnification,
b) a methods section describing the types of samples, numbers, locations (include maps where appropriate), analytical procedures conducted by laboratories (include QA/QC), and statistical analyses,
c) a results and discussion section that presents the information, with the aid of tables and figures, in a manner enhancing the discussion and comparison of spatial and temporal trends of contaminant levels found in samples of effluent, water, sediments, benthic invertebrates and fish within the northern rivers, and
d) include appendices for the analytical data results from laboratories.

To obtain the necessary field collections reports, laboratory analyses reports and Laboratory Analysis Approval (LAA) numbers, the contractor is to contact Dr. Brian Brownlee [NWRI, Burlington (905) 336-4706] or the Component Coordinator at NRBS.

Task 1. Dioxins/Furans - 1993 Data Set

The results of dioxin/furan analyses for 1993 (including the fall 1992 fish collections) should be presented and interpreted as both congener specific and TEQs for each of the sample media analyzed. The focus of the fish results will be on the 2,3,7,8-substituted congeners of dioxins/furans because of their prominence in the fish tissues sampled in 1992. The contractor is also expected to report on the variations in the contaminant levels of fish caused by species, sex, sample location and lipid content. The report is to include predictions of bioaccumulation potential of specific contaminants (particularly 2,3,7,8-TCDD/F) by estimating Bioconcentration Factors (BCF) in fish and sediments. Comment on the levels of PCDD/Fs TEQs in effluent, water, sediment, invertebrates and fish and compare with the guideline limits recommended by Canadian Environmental Quality Guidelines (Environment Canada 1993).

Under this task, the contractor is required to interact on a regular basis with Golder Associates Ltd. [contact Gordon Macdonald at (403) 299-5600], providing them with 2,3,7,8-TCDF data from biotic and abiotic samples for use in the contaminant fate and food chain models.

Task 2. Other Organochlorines - 1992-93 Data Sets

This task will require the combined 1992-93 data on PCBs and other persistent organochlorines measured in biota by NRBS. The contractor is required to review and interpret PCB analyses conducted by laboratories on media samples, whether the PCBs have been analyzed as Aroclor equivalents (Schwartz *et al.* 1987) or as individual congeners which are summed to determine the total PCB concentration (McFarland and Clarke 1989).

Other organochlorine data that may be available from the analytical results include some organochlorine pesticides. The following organochlorine pesticides and metabolites are recommended as target analytes in screening studies by U.S.EPA (1993):

total chlorodane	heptachlor epoxide
dicofol	hexachlorobenzene
dieldrin	lindane (γ-hexachlorocyclohexane)
endosulfan (I and II)	mirex
endrin	toxaphene
total DDT (including its metabolites DDD and DDE)	

Comment on the levels of total PCBs and other persistent organochlorines in effluent, water, sediment, invertebrates and fish and how these compare with the guideline limits recommended by Canadian Environmental Quality Guidelines (Environment Canada 1993).

Task 3. Dioxins/Furans - 1994 Data Set

Interpret and present the results of dioxin/furan analyses for the 1994 data set, as the analytical information becomes available. The contractor should be aware that all of the PCDD/F samples collected in 1994 might not be analyzed in time for incorporation into this task. Similar to Task 1, the contractor is required to interact on a regular basis with Golder Associates Ltd. [contact Gordon Macdonald at (403) 299-5600], providing them with 2,3,7,8-TCDF data from biotic and abiotic samples for use in the contaminant fate and food chain models.

Task 4. Other Organochlorines - 1994 Data Set

Review and interpret the results of PCB and other organochlorine data for the 1994 data set, as the analytical information becomes available. The contractor should be aware that all of the PCB and other organochlorine samples collected in 1994 might not be analyzed in time for incorporation into this task.

III. REPORTING REQUIREMENTS

1. The contractor is to provide the study office with four reports as specified by the tasks outlined in these terms of reference. The following reports are proposed:

    a) Dioxins and Furans - 1993 Data Set
    b) Other Organochlorines - 1992-93 Data Set

c) Dioxins and Furans - 1994
d) Other Organochlorines - 1994 Data Set

If the data for other organochlorines (task 2 and task 4) is insufficient, a review of the 1992-1994 data sets may have to be combined into one report.

2. A progress report is to be submitted to the study office by **January 31, 1994**.

3. Ten copies of each of the two Draft Reports III.1.a and III.1.b (1993 data set) along with electronic disk copies are to be submitted to the Component Coordinator by **March 31, 1995**.

   The Study Office recognizes that a complete set of the 1994 analytical data may not be available for preparation of two additional comprehensive draft reports by March 31, 1995. Nonetheless, the contractor is to make an effort to review and interpret as much of the 1994 laboratory results as possible in the given time period. After March, 1995, progress will be reviewed by the Component Leader and Science Directors to determine if the contract should be extended into the next fiscal year.

4. Three weeks after the receipt of review comments on the draft reports, the contractor is to provide the Component Coordinator with two unbound, camera ready copies and ten cerlox bound copies of each final report along with an electronic version.

5. The Contractor is to provide draft and final reports in the style and format outlined in the NRBS document, "A Guide for the Preparation of Reports," which will be supplied upon execution of the contract.

   The final report is to include the following: an acknowledgement section that indicates any local involvement in the project, Report Summary, Table of Contents, List of Tables, List of Figures and an Appendix with the Terms of Reference for this project.

   Text for the report should be set up in the following format:

   a) Times Roman 12 point (Pro) or Times New Roman (WPWIN60) font.
   b) Margins; are 1" at top and bottom, 7/8" on left and right.
   c) Headings; in the report body are labelled with hierarchical decimal Arabic numbers.
   d) Text; is presented with full justification; that is, the text aligns on both left and right margins.
   e) Page numbers; are Arabic numerals for the body of the report, centred at the bottom of each page and bold.

   - If photographs are to be included in the report text they should be high contrast black and white.
   - All tables and figures in the report should be clearly reproducible by a black and white photocopier.
   - Along with copies of the final report, the Contractor is to supply an electronic version of the report in Word Perfect 5.1 or Word Perfect for Windows Version 6.0 format.

- Electronic copies of tables, figures and data appendices in the report are also to be submitted to the Project Liaison Officer along with the final report. These should be submitted in a spreadsheet (Quattro Pro preferred, but also Excel or Lotus) or database (dBase IV) format. Where appropriate, data in tables, figures and appendices should be geo-referenced.

6. All figures and maps are to be delivered in both hard copy (paper) and digital formats. Acceptable formats include: DXF, uncompressed E⌀⌀, VEC/VEH, Atlas and ISIF. All digital maps must be properly geo-referenced.

7. All sampling locations presented in report and electronic format should be geo-referenced. This is to include decimal latitudes and longitudes (to six decimal places) and UTM coordinates. The first field for decimal latitudes / longitudes should be latitudes (10 spaces wide). The second field should be longitude (11 spaces wide).

8. A presentation package of 35 mm slides is to comprise of one original and four duplicates of each slide.

IV. DELIVERABLES

1. A report summarizing and interpreting the dioxin/furan data for biotic and abiotic samples collected in 1993 (including the fall 1992 fish samples).

2. A report summarizing and interpreting other organochlorine data for biotic and abiotic samples collected in 1992-93.

3. A report summarizing and interpreting the dioxin/furan data for biotic and abiotic samples collected in 1994.

4. A report summarizing and interpreting other organochlorine data for biotic and abiotic samples collected in 1994.

5. Ten to twenty-five 35 mm slides that can be used at public meetings to summarize the project, methods and key findings.

V. CONTRACT ADMINISTRATION

This project has been proposed by the Contaminants Component of the NRBS (Contaminants Component Leader - Dr. John Carey, NWRI, Burlington).

The Scientific Authorities for this project are:

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Questions of a technical nature should be directed to them.

The Component Coordinator for this project is:

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Questions of an administrative nature should be directed to him.

VI. LITERATURE CITED

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