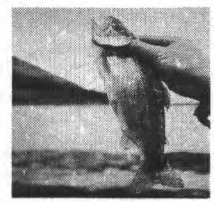
Canada Alberta Northwest Territories

ATHABASCA UNIVERSITY LIBRARY
3 1510 00173 042 4

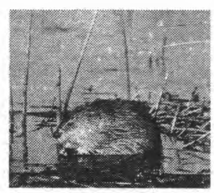
INCLUDES COMPUTER DISK

Northern River Basins Stu...







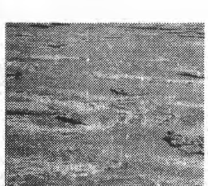




NORTHERN RIVER BASINS STUDY PROJECT REPORT NO. 78

A SYNTHESIS OF INFORMATION ON ECOTOXICITY OF PULP MILL EFFLUENTS

IN THE PEACE, ATHABASCA AND SLAVE RIVER BASINS






TD
899
.W65
S993
1997

TD/899/.W65/S993/1997
A synthesis of information
173042

DATE DUE

BRODART Cat. No 23-221

880216

Prepared for the
Northern River Basins Study
under Project 2112-B1

by

SENTAR Consultants Ltd.

NORTHERN RIVER BASINS STUDY PROJECT REPORT NO. 78

A SYNTHESIS OF INFORMATION ON ECOTOXICITY OF PULP MILL EFFLUENTS IN THE PEACE, ATHABASCA AND SLAVE RIVER BASINS

Published by the
Northern River Basins Study
Edmonton, Alberta
February, 1997

ATHABASCA UNIVERSIT
JUL 18 1997
LIBRARY

CANADIAN CATALOGUING IN PUBLICATION DATA

Main entry under title :

A synthesis of information on ecotoxicity of pulp
mill effluents in the Peace, Athabasca and Slave
River Basins

(Northern River Basins Study project report,
ISSN 1192-3571 ; no. 78)
Includes bibliographical references.
ISBN 0-662-24841-4
Cat. no. R71-49/3-78E

1. Wood-pulp industry -- Waste disposal -- Environmental
aspects -- Alberta -- Athabasca River.
2. Wood-pulp industry -- Waste disposal -- Environmental
aspects -- Peace River (B.C. and Alta.)
3. Wood-pulp industry -- Waste disposal -- Environmental
aspects -- Slave River (Alta. and N.W.T.)
4. Effluent quality -- Alberta -- Athabasca River.
5. Effluent quality -- Peace River (B.C. and Alta.)
6. Effluent quality -- Slave River (Alta. and N.W.T.)
I. Sentar Consultants.
II. Northern River Basins Study (Canada)
III. Series.

TD899.W65S96 1997 363.73'94'0971231 C96-980296-X

Copyright © 1997 by the Northern River Basins Study.
All rights reserved. Permission is granted to reproduce all or any portion of this publication provided the reproduction includes a proper acknowledgement of the Study and a proper credit to the authors. The reproduction must be presented within its proper context and must not be used for profit. The views expressed in this publication are solely those of the authors.

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.

NORTHERN RIVER BASINS STUDY
PROJECT REPORT RELEASE FORM

This publication may be cited as:

SENTAR Consultants Ltd. 1997. ***Northern River Basins Study Project Report No. 78, A Synthesis of Information on Ecotoxicity of Pulp Mill Effluents in the Peace, Athabasca and Slave River Basins,*** **Northern River Basins Study, Edmonton, Alberta.**

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.

(Dr. Fred J. Wrona, Science Director) — 4 Apr 96 (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

(Dr. P. A. Larkin, Ph.D., Chair) — Mar 26/96 (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, Co-chair) — March 22/96 (Date)

(Robert McLeod, Co-chair) — 01/04/96 (Date)

A SYNTHESIS OF INFORMATION ON ECOTOXICITY OF PULP MILL EFFLUENTS IN THE PEACE, ATHABASCA AND SLAVE RIVER BASINS

STUDY PERSPECTIVE

> ***Related Study Questions***
>
> *2) What is the current state of water quality in the Peace, Athabasca and Slave River basins, including the Peace-Athabasca Delta?*
>
> *5) Are the substances added to the rivers by natural and man-made discharges likely to cause deterioration of the water quality?*

The aquatic environments contained within the Northern River Basins Study area (NRBS) were being described and monitored prior to the onset of the Study. Even though effluents arising from pulp and paper mills were the subject of considerable Board and public interest, other municipal and industrial effluents were also identified as potential areas of concern. Difficulties existed in understanding the cumulative effects of development because of disparate information bases and information gaps. Consequently, the NRBS Board identified a need to capitalize on existing knowledge to better understand the influence of effluents on the receiving waters of the Peace, Athabasca and Slave rivers and their major tributaries and assist in directing the future investment of Study funds. It was also acknowledged that an existing scientific literature relating to effluents, particularly as it concerned contaminants and the ecotoxicity of various effluents to the aquatic environment, should complement any data gathering and interpretation. A seven step multifaceted project was initiated under the Contaminants Component to gather together and interpret the significance of existing data, particularly as it related to describing the cumulative effects of effluents arising from development on the aquatic environment. The different facets of this project included: identification of effluent sources, characterization of effluent arising from municipal and non-pulp mill industry sources, preparation of two annotated bibliographies, and three synthesis reports. The two bibliographies were distinct products that supported the preparation of two synthesis reports dealing with contaminants and ecotoxicity of pulp mill effluents.

This report presents an interpretation of the ecotoxicity of effluents arising from pulp mill effluents on the aquatic environment at the organism, population and community levels. Scientific literature and data gathered from various regulatory and industrial sources revealed that while some of the pulp mills had historical problems with effluent toxicity they are less prevalent and no direct correlation could be tied to organochlorine substances or chelating agents. Similarly, while chronic bioassay procedures fail to reveal any substantive issues there are isolated instances of growth and reproduction impairment in algae and a selected invertebrate, respectively. Available data also indicates that nutrient-enrichment effects are detectable below pulp mill sources but toxicity effects appear absent or masked by the enrichment effect. Except for studies on Longnose Suckers on the Lesser Slave River that reveal some alteration of growth and reproduction products, no evidence of acute toxicity or health effects could be discerned from existing information.

This report is one of a series of documents addressing the ecotoxicity of liquid effluents, and is not intended to cover all aspects of effluents discharged into the study area, or their impacts on aquatic ecosystems. The background information contained in this document will be valuable in the development of a comprehensive ecotoxicity strategy and cumulative effects assessment of these northern rivers. Other Northern River Basins Study Project Reports related to this project include: No. 28 (*Nutrient Loading on the Peace, Athabasca and Slave Rivers*), No. 79 (*A Synthesis of Information on Effluent Characteristics of Municipal and Non-Pulp Mill Industrial Sources in the Peace, Athabasca and Slave River Basins*), and No. 144 (*An Annotated Bibliography of Contaminants in the Peace, Athabasca and Slave River Basins*).

REPORT SUMMARY

This synthesis report pertains to the assessment of acute and chronic effects of pulp mill effluents discharged in the northern rivers. It is based on existing reports, data and review papers. It includes a discussion of the ecotoxicological significance of the effluents, information gaps and further monitoring or study needed to fill these gaps. The study area includes the Peace River, the Athabasca River and the Slave River within Alberta and the Northwest Territories as well as their major tributaries.

Ecotoxicology does not merely evaluate the acute and chronic toxicity of the pulp mill effluent on the biological side of an individual organism; it is also concerned with toxic effects on populations and communities within the river receiving the effluent. This report identifies factors affecting the potential toxicity to organisms in the river, and provides a summary of the variety of methods used, including their advantages and disadvantages. Data on the toxicity of pulp mill effluents areas in the Northern River Basins Study (NRBS) are available because:

(1) testing is required under provincial licenses and federal pulp and paper regulations,

(2) baseline studies are required by environmental impact assessment reviews,

(3) Environmental Effects Monitoring (EEM) is required under federal regulations, and

(4) special studies have been conducted by the industry, NRBS and Alberta Environmental Protection.

One of the standard measures of the toxicity of pulp mill effluents is the monthly rainbow trout 96-hour bioassay and the weekly *Daphnia magna* 48-hour bioassay. A review of the effluent from four of the pulp mills (Alberta-Pacific Forest Industries Inc., Alberta Newsprint Company Ltd., Daishowa-Marubeni International Ltd. and Weldwood of Canada Ltd.) shows that they have been essentially non-toxic following mill start-up. The three remaining mills (Millar Western Pulp (Whitecourt) Ltd., Slave Lake Pulp Corporation and Weyerhaeuser Canada Ltd.) have had a significant number of failures of the rainbow trout bioassay at some time, although not recently. There were no failures in 1994. Where causes of the failures could be determined, they were attributed to high concentrations of ammonia and high pH. Conditions that occur in the static bioassay test, increase the toxicity of the effluent. After reviewing contaminant loadings in pulp mill effluent for another NRBS report, McCubbin and Folke (1992) concluded that the remaining acute toxicity is not caused by organochlorine substances or chelating agents.

The concept of toxicity loading to the receiving water (similar to BOD loading or contaminant loading) does not apply. Very few acute bioassays are failed so that there is usually no loading. In addition, pulp mills must begin a toxicity reduction evaluation (TRE) immediately to correct the problem if a failure occurs.

Chronic bioassays are included in the first cycle of the environmental effects monitoring (EEM) required under federal regulation. Results of the chronic bioassays, although preliminary, show little or no effect of pulp mill effluent on larval stages of fathead minnow. Reproduction of the invertebrate *Ceriodaphnia dubia* was impaired by effluents from all mills, although there was little or no mortality. The growth of the algae *Selenastrum capricornutum* was affected by effluents from some of the mills.

A review of the quantity of biofilm data available found that it was limited to mainly epilithic algal biomass, primarily concentrations of chlorophyll *a*. Current monitoring of chlorophyll *a*, which indicates algal biomass, does not provide an early warning of toxicity to algae due to the dominant effect of added nutrients. Only the Slave Lake Pulp Corporation monitored for species richness, a good indicator of toxic effects. The periphyton communities in the Lesser Slave River were diverse and typical of other communities in northern Canada. Improved epilithic algae monitoring is needed to interpret the actual ecological significance of the *Selenastrum capricornutum* laboratory bioassay required in the first cycle of EEM due in 1996.

Benthic invertebrates located downstream of pulp mills are exposed to effluent on an almost continuous basis. Data on contaminant burdens in these invertebrates are only available for the Wapiti-Smoky river system. No significant difference in chlorinated organic compounds (measured as extractable organic chlorine) or dioxins was found among benthic invertebrates at near-field, far-field and control locations. Intensive monitoring of benthic invertebrates at all pulp mills in the NRBS area usually detected a nutrient-enrichment effect causing increased numbers of organisms downstream from the mills and the absence of a toxicity effect as indicated by the lack of changes in species richness of benthic communities. Only one account of a substantive decrease in benthic invertebrates attributed to a pulp mill was found; it occurred in the Wapiti River in 1980.

There is no evidence of acute toxicity, health effects or reproductive effects on fish studied in the Lesser Slave River, the Wapiti-Smoky or the Athabasca River with one possible exception. Impacts on growth and, to a lesser extent, gonad (ovary) weight and egg weight in female longnose suckers were detected in the Lesser Slave River. The only biomarker that was consistently detected in at least some fish species at all three locations was increased EROD activity which indicates induction of the liver detoxification system. This was not correlated to any health effects.

Dioxins and/or furans have been detected in fish in the Peace, Wapiti-Smoky, and Athabasca rivers but concentrations are low in the muscle of all the species monitored. A study on the Wapiti-Smoky rivers found that burbot livers contained much higher concentrations (toxic equivalents of 2,3,7,8-TCDD/TCDF = 8.1-199 ppt). The concentrations of chlorinated phenolics, dioxins and furans in fish fillets were well below acceptable exposure limits for humans consuming large quantities of fish.

This report identifies information gaps and emphasizes the importance of using monitoring methods that are appropriate to the scale of potential environmental effects. This report also recommends monitoring and experiments that will enhance the ecological side of ecotoxicology to ensure that the results of laboratory bioassays are related to instream effects. Biomonitoring should be sufficiently sensitive to detect effects and should be supported by experiments or other integrated data to identify the cause of a suspected effect.

TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

<u>LIST OF FIGURES</u>

DEFINITION OF TERMS

TERM	DEFINITION
ADt	Air Dried tonnes (of pulp)
AEP	Alberta Environmental Protection
AGP	Algal Growth Potential
ALAD	Aminolevulinic Acid Dehydratase
ANC	Alberta Newsprint Company Ltd.
ANOVA	Analysis of Variance
AOX	Adsorbable Organically-bound Halogen
APP	Alkaline-peroxide Pulp
ASB	Aerated Stabilization Basin
AST	Activated Sludge Treatment
ASTM	American Society for Testing and Materials
BKME	Bleached Kraft Mill Effluent
BOD	Biochemicall Oxygen Demand
CEPA	Canadian Environmental Protection Act
CTMP	Chemi-thermo-mechanical Pulp
DHA	Dehydroabietic Acid
DNA	Deoxyribonucleic Acid
DTPA	Pentasodium Diethylene Triamine Pentaacetate
ECG	Electrocardiogram
EDTA	Ethylene Diaminetetraacetic Acid
EEM	Environmental Effects Monitoring
EIA	Environmental Impact Assessment
EOCL	Extractable Organic Chlorine
EPA	Environmental Protection Agency
EROD	Ethoxyresorufin-O-Deethylase
GSI	Gonad Somatic Index
IBI	Index of Benthic Integrity
IC_{25}	Inhibiting Concentration to 25% of the Organisms (growth)

TERM	DEFINITION
IC_{50}	Inhibiting Concentration to 50% of the Organisms (growth)
LC_{50}	Lethal Concentration to 50% of the Organisms
LOEC	Lowest Observed Effect Concentration
LSI	Liver Somatic Index
MAC	Maximum Acceptable Concentration
MFO	Mixed Function Oxygenase
NOEC	No Observed Effect Concentration
NRBS	Northern River Basins Study
PAH	Polyaromatic Hydrocarbons
PCP	Pentachlorophenol
PISCES	Population Indicators of Sublethal Contaminant Effects on Suckers
PO_4	Phosphate
PPER	Pulp and Paper Effluent Regulations
QA	Quality Assurance
QC	Quality Control
RNA	Ribonucleic Acid
SAM	Standardized Aquatic Microcosm
SLPC	Slave Lake Pulp Corporation
SO_4	Sulphate
SPMD	Semipermeable Polymeric Membrane Device
TCDD	2,3,7,8-tetrachlorodibenzodioxin
TCDF	2,3,7,8-tetrachlorodibenzofuran
TEC	Threshold Effect Concentration
TEQ	Toxic Equivilent
TIE	Toxicity Identification Evaluation
TKN	Total Kjeldahl Nitrogen
TRE	Toxicity Reduction Evaluation
TSS	Total Suspended Solids
Tu_a	Toxic Unit (acute)
Tu_c	Toxic Unit (chronic)

1.0 INTRODUCTION

1.1 OBJECTIVES AND SCOPE

1.1.1 Objectives

According to the Terms of Reference of the contract awarded to SENTAR Consultants Ltd. (SENTAR) by the Northern River Basins Study (NRBS), (Appendix A; Section IV, Paragraphs 1, 2.2, 3.2-3.4) the purpose of this project is to prepare a synthesis report pertaining to the acute and chronic toxic effects of pulp mill effluents discharged into the northern rivers.

1.1.2 Scope

According to the Terms of Reference of the contract, the synthesis report is to be prepared from data and information on the ecotoxicity of pulp mill effluents specific to the study area, as well as major review papers on pulp mill effluent toxicity. The report is to include the following:

- consideration of both the actual toxicity and the volume of effluent discharged (i.e. the "load" of toxicity);
- a comparison of the findings to present trends in effluent quality/quantity in the study area;
- a discussion of the ecotoxicological significance, including significance to human health, of pulp mill effluents and their concentrations; and
- a discussion of information gaps regarding the potential toxic effects of pulp mill effluents in the study area, including recommendations for further monitoring and study, etc.
- The three projects include: (i) characterization of municipal and non-pulp mill industry sources, (ii) contaminants in aquatic ecosystems, and (iii) ecotoxicity of pulp mill effluents. Synthesis reports will be produced for all three projects; bibliographies have been compiled and annotated for the latter two (ii and iii); and an electronic database with associated user's guide has been compiled for (i). Therefore, this *Ecotoxicity of Pulp Mill Effluents - Synthesis Report* is one of a series of documents. As such, it is not intended to cover all aspects of aquatic ecotoxicity in the NRBS area, but only the toxicity that can be directly attributed to pulp mill effluents.

An earlier report entitled *Review of Literature on Characteristics of Effluent from Pulp and Paper Mills in Northern River Basins of Alberta, B.C. and Northwest Territories* by N. McCubbin Consultants Inc. (McCubbin and Folke 1992) is directly related to this theme. In a sense, it is the parallel document to (i) above since it was also part of a contract that included preparation of an electronic database. The McCubbin and Folke (1992) report describes pulp manufacturing processes, effluent treatment methods and the nature of the effluent. It emphasizes wastewater contaminants and summarizes existing data on dioxins, AOX, phenols, resin and fatty acids, and metals. For this reason the focus of the *Ecotoxicity of Pulp Mill Effluents - Synthesis Report* is on toxicity rather than contaminants *per se*.

1.2 PULP AND NEWSPRINT MILLS IN THE STUDY AREA

1.2.1 Study Area

The study area includes the Peace River, the Athabasca River and the Slave River within Alberta and the Northwest Territories (Figure 1). The study includes major tributaries to these three rivers: the Wapiti River, the Smoky River and the Lesser Slave River.

The Athabasca River is a large, unregulated, northern river which exhibits seasonal and longitudinal variation in water quality as a result of inputs from relatively large tributaries and anthropogenic sources such as pulp mill, municipal and oil extraction effluents (Hamilton *et al.* 1985; Noton and Shaw 1989). There are five operating pulp mills on the Athabasca River (Figure 2). Four are on the mainstem of the river and one is on its tributary, the Lesser Slave River. The major city is Fort McMurray and the larger towns near the mainstem of the river include Jasper, Hinton and Whitecourt. Logging is the dominant land use activity in the watershed. Most agricultural activity occurs south of the mainstem river between the towns of Athabasca and Edson (Hamilton *et al.* 1985). Although there are sawmills located throughout the basin (Hamilton *et al.* 1985), most do not discharge effluent to the river. Conventional oil and gas development in the basin is extensive. The largest non-pulp mill industrial activity is the surface mining and extraction of tar sands.

Therefore, potential sources of ecotoxicity within the Athabasca River Basin include major point-sources on the mainstem such as pulp mill effluents, continuous municipal discharges and oil extraction effluent. Periodic discharges of municipal effluents (usually from lagoons), gas plants and sawmills are potential sources of minor inputs within the basin generally. Logging and agricultural activities (e.g. the use of herbicides and pesticides) are potential non-point (diffuse) sources of ecotoxicity. Logging and agriculture also impact the aquatic ecosystems of the tributaries through their alteration of the landscape.

The Peace River originates in north-eastern British Columbia and flows through Williston Reservoir before it enters Alberta. It is regulated at the Bennett Dam. The entire Peace River Basin is sparsely populated and largely undeveloped except for areas of agricultural activity. The largest municipality in the Peace River in Alberta basin is Grande Prairie. The three largest industries in the Alberta portion of the basin are associated with forestry; the Weyerhaeuser Canada Ltd. (formerly the Procter & Gamble Cellulose Ltd.) pulp mill, the Daishowa-Marubeni International Ltd.'s pulp mill and the Canadian Forest Products Ltd. sawmill. The largest point-source is the Weyerhaeuser pulp mill at Grande Prairie, which discharges treated effluent to the Wapiti River, a tributary of the Smoky River (Figure 3).

The Slave River Basin is sparsely populated. Fort Smith, located near the Northwest Territories-Alberta border, is the only town discharging treated sewage to the river on a continuous basis (Figure 1). There are no pulp mills or other major industries on the Slave River.

1.2.2 Pulp and Newsprint Mills

There are four operating mills on the mainstem of the Athabasca River and one on its tributary, the Lesser Slave River (Figure 2). Of the five mills on the Peace River, only two are in Alberta; one on the mainstem and the other on the Wapiti-Smoky River system (Figure 3). There are differences in the type of mill process and the wastewater treatment used at Alberta pulp mills (Table 1). Mills in the NRBS area produce kraft pulp and chemi-thermomechanical pulp (CTMP). The two types of wastewater treatment in use are: aerated stabilization basins (ASB), and activated sludge treatment

SENTAR

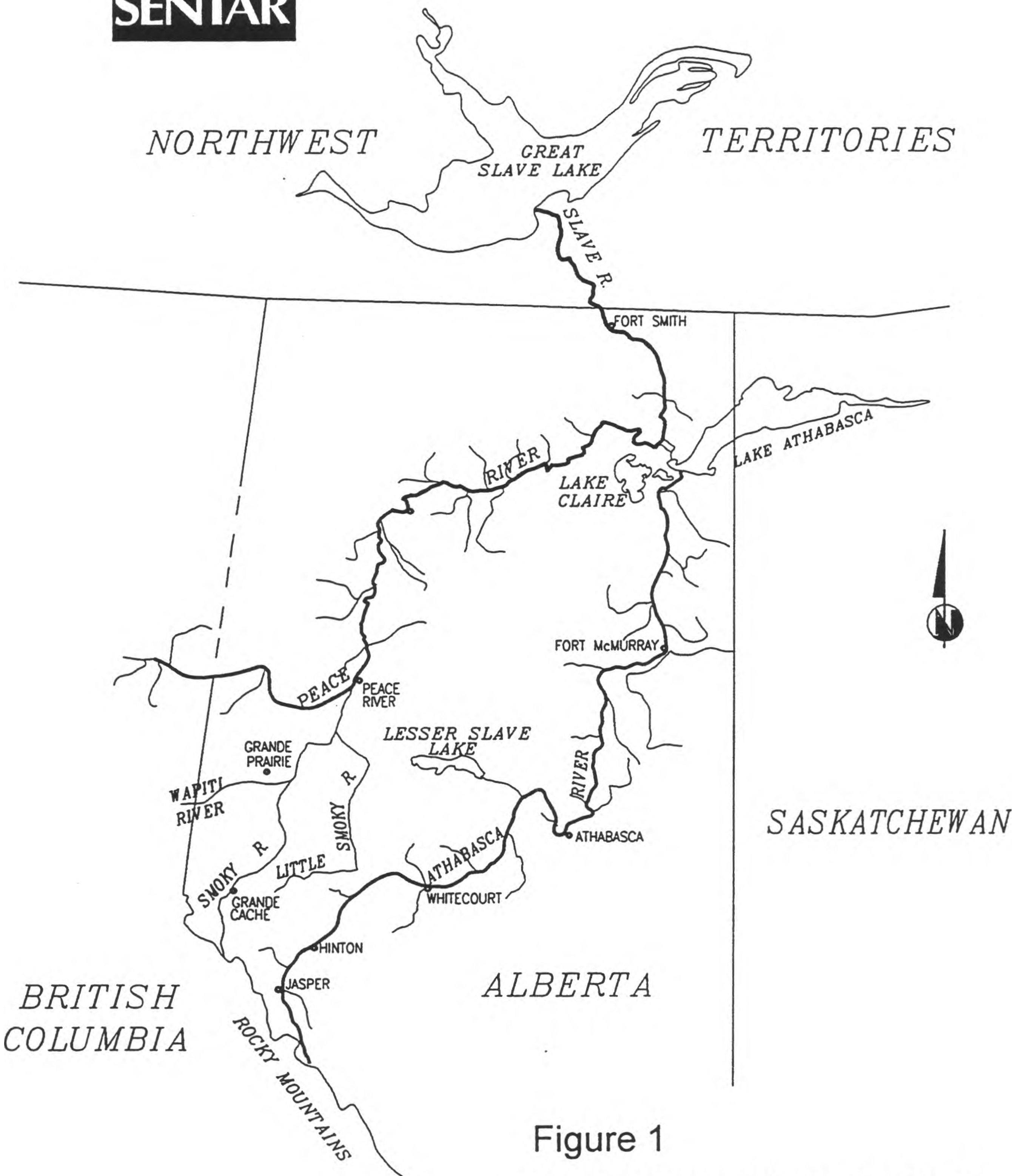


Figure 1

NORTHERN RIVER BASINS STUDY AREA

13-089-31-04

SENTAR

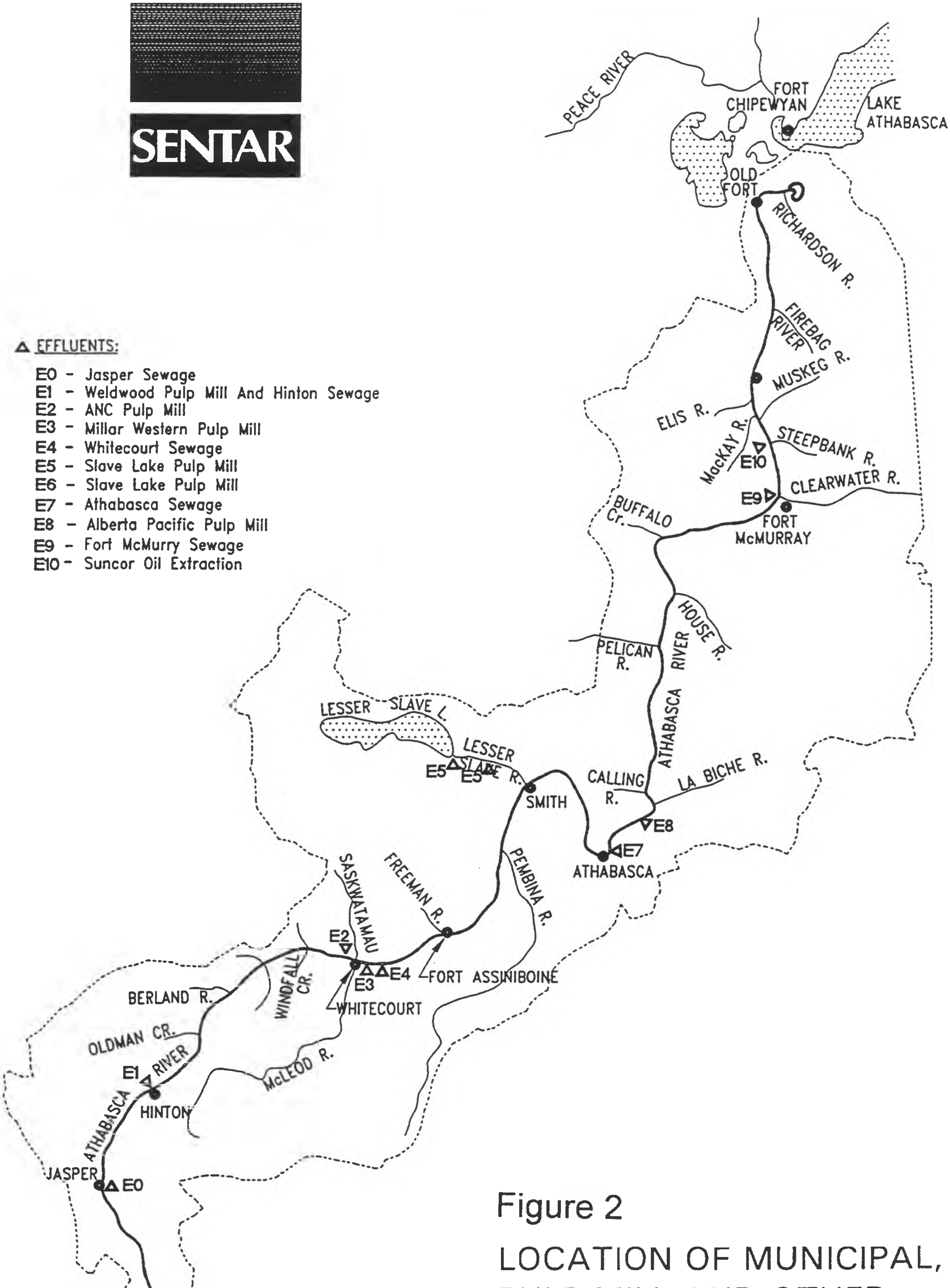


Figure 2

LOCATION OF MUNICIPAL, PULP MILL AND OTHER INDUSTRIAL DISCHARGES TO THE ATHABASCA RIVER

13-089-31-04/13189ab

SENTAR

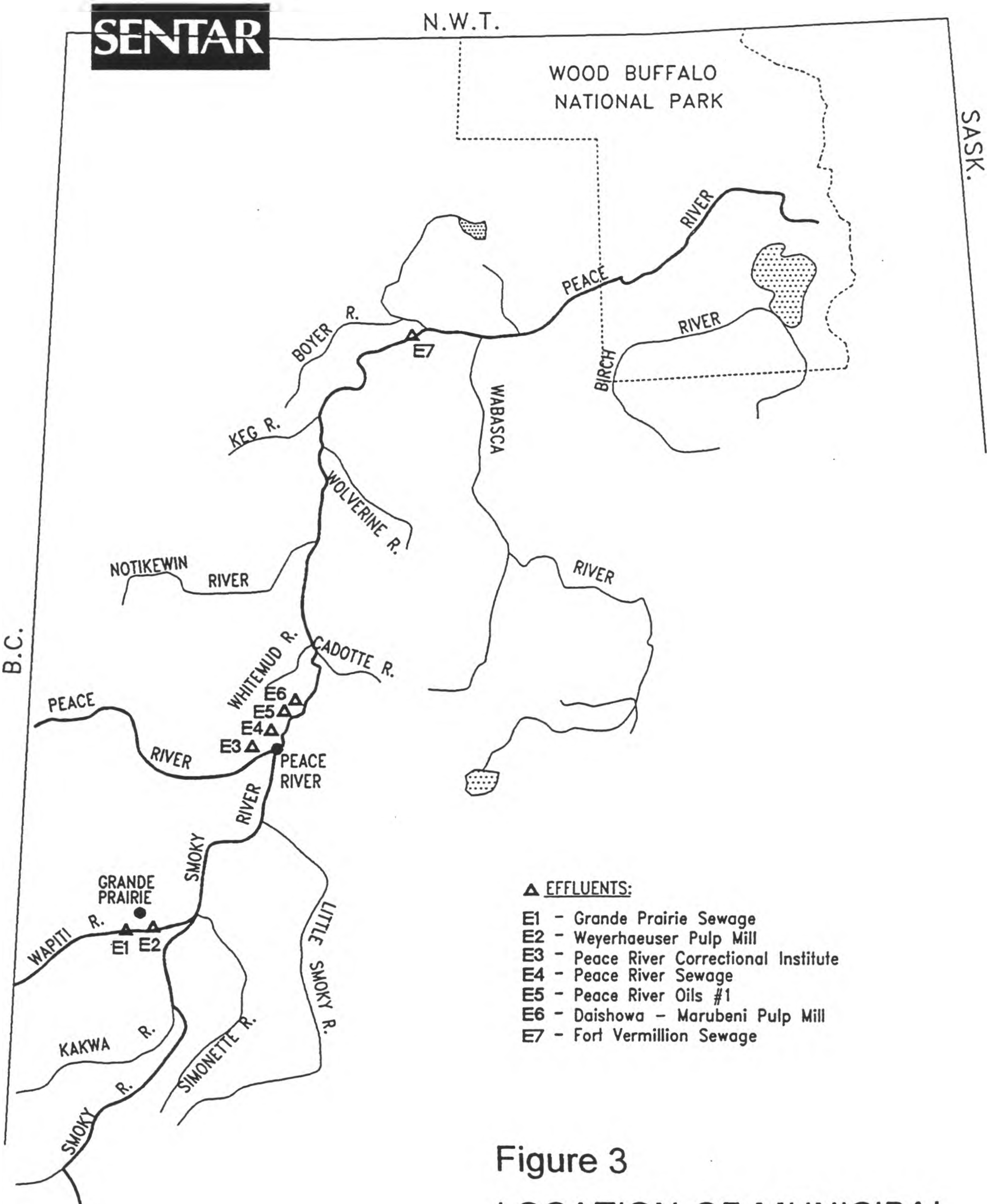


Figure 3

LOCATION OF MUNICIPAL, PULP MILL AND OTHER INDUSTRIAL DISCHARGES TO THE PEACE RIVER IN ALBERTA

(AST) with extended aeration (Table 1). The chemical composition of each pulp mill effluent is dependent on a variety of factors that are mill specific such as the pulping and bleaching technology, the type (i.e. softwood or hardwood) and age of wood chips used, and the wastewater treatment.

The potential loading of toxics from pulp mills is not static; it changes with changes in mill processes, effluent treatment and discharge quantities. Inplant process improvements made at existing mills include extended cooking and oxygen delignification. The process improvements at the Weldwood of Canada Ltd. mill and the substantial improvements in effluent treatment at the Millar Western Pulp Ltd. mill are two examples of recent changes in existing mills. Kraft pulp mills have recently changed their bleaching technology to 100% chlorine dioxide substitution, usually in a step-wise manner. The species and quality of wood being processed at a given time can also influence final effluent toxicity. Experiments using simulated mechanical pulping effluents showed that the acute and chronic lethality to both fathead minnows and *Ceriodaphnia affinis* varied by wood species with hardwood being the least toxic (O'Connor *et al.* 1992). The acute lethality of wood species common in the NRBS area followed the order pine>spruce>aspen. In addition, five of the seven mills have only been in production for a few years (beginning 1988 to 1993). New mills generally experience variations in flow, chemical composition of the effluent and toxicity of the effluent at start-up. All mills reported a continuous tightening of mill operation. For example, both the Daishowa-Marubeni International Ltd. and Slave Lake Pulp Corporation mills report continuous improvement in effluent quality through refinement of operating procedures and practices, plus other modifications. The net effect on the northern rivers is one of rapid change in the overall contaminant loading and potential toxicity from pulp mills in the last few years. Improvements that are specific to each mill are described below.

Alberta Newsprint Company (ANC) ANC operates an integrated chemi-thermomechanical pulp (CTMP) and newsprint mill near Whitecourt, Alberta. The mill began operating in August 1990. The mill was designed to process up to 20% aspen and the balance of white spruce and lodgepole pine. Alberta Newsprint Co. produces a single pulp grade specifically for newsprint furnish; therefore, the degree and conditions of the chemical treatment of the pulp are milder than a conventional CTMP mill. Bleaching does not require the use of chlorine or chlorine derivatives. Water is obtained from the Athabasca River for process use and treated effluent is discharged to the Athabasca River (Figure 2) which also receives treated sewage from the town of Whitecourt and effluent from the Millar Western Pulp Ltd. mill.

The extended aeration activated sludge treatment (AST) system has a retention time of about 2.5 days in the aeration pond and another 2.5 days in the polishing pond. There have been no significant changes to the treatment system since the mill started. In November 1992, a pilot scale de-inking facility was started up. The use of polyphosphorus was discontinued in 1993.

Alberta Pacific Forest Industries Inc. (Alberta Pacific) This bleached kraft pulp mill commenced operations in September of 1993. It is designed as a single-line operation that can process either hardwood or softwood, but it is currently using about 80% hardwood and 20% softwood. Mill features that relate to ecotoxicity include oxygen delignification and 100% substitution of chlorine dioxide. Effluent treatment includes neutralization, primary treatment by two clarifiers which remove suspended solids and secondary treatment by an AST system and secondary clarifiers. The state-of-the-art AST system with extended aeration has two bioreactors and a hydraulic retention time of 38 hours. The effluent treatment system also contains an emergency spill pond, an equalization/cooling pond and a cooling tower. This mill, which is located near Athabasca, discharges to the Athabasca River (Figure 2).

TABLE 1: Pulp and Paper Mills in the Northern River Basins of Alberta

River	Location	Company	Mill Type and 1994 Production ADt/d)[a]	Effluent Treatment and 1994 Discharge (m^3/d)[b]	Start-up and Wastewater Treatment Modifications
Athabasca	Hinton	Weldwood of Canada Ltd.	Kraft Pulp 1035	ASB[c] 110,292	Operated since 1957 with many upgrades. Expansion at present capacity in February 1990. Ceased nutrient addition and increased aeration in 1991. Doubled the size of the quiescent zone in the ASB in 1993.
Athabasca	Whitecourt	Alberta Newsprint Co. Ltd.	CTMP and Paper 655	Extended Aeration AST[d] 16,854[e]	Start-up in August 1990 resulted in high nutrients. Phosphorus addition rates reduced in summer of 1992. Started pilot-scale de-inking facility in November 1992. Use of polyphosphorus discontinued in 1993.
Athabasca	Whitecourt	Millar Western Pulp (Whitecourt) Ltd.	CTMP 800	Extended Aeration AST 12,699	Start-up in August 1988. Original ASB was changed to AST in the autumn of 1989. Second Phoenix sludge press installed June 1991.
Lesser Slave	Slave Lake	Slave Lake Pulp Corp.	CTMP 365	Extended Aeration AST 7,692	Start-up in fourth quarter of 1990. Added a second secondary clarifier to control suspended solid losses in the third quarter of 1992.
Athabasca	Athabasca	Alberta-Pacific Forest Industries Inc.	Kraft Pulp 1,500	Extended Aeration AST 69,120	Start-up in September 1993
Peace	Peace River	Daishowa-Marubeni International Ltd.	Kraft Pulp 1,035	ASB 60,797	Start-up in July 1990. A back-up ASB was added in 1991.
Wapiti-Smoky	Grande Prairie	Weyerhaeuser Canada Ltd.	Kraft Pulp 861	ASB 60,495	Start-up in 1973. Improvements include additional aeration and increased retention time.

a. Adt/d = air dried tonnes per day
b. m^3/d = cubic metres per day
c. ASB = Aerated Stabilization Basin
d. AST = Activated Sludge Treatment
e. Not including non-contact cooling water

Daishowa-Marubeni International Ltd.'s Peace River Pulp Division (Daishowa-Marubeni) This bleached kraft pulp mill can process either hardwood or softwood. It uses hardwood approximately 70% of the time. It is designed as a single-line operation that alternately processes hardwood and softwood pulps in runs lasting several weeks each. They are currently at 70% substitution of chlorine dioxide. Mill features that relate to toxicity reduction include an oxygen delignification system, both a primary clarifier and a secondary (ASB) treatment system with a ten-day retention time for mill effluent, an emergency spill pond, and a collection system for recycling discharges from process upsets. To enhance biological treatment, nutrients (nitrogen and phosphorus) are added to the effluent. The effluent from the ASB is discharged to the Peace River approximately 19 km downstream of the Town of Peace River (Figure 3) which discharges treated sewage. The mill began operations in July 1990 and there have been no notable physical changes to the wastewater treatment process since start-up.

Millar Western (Whitecourt) Pulp Ltd. (Millar Western) Millar Western operates a two-line alkaline-peroxide pulp (APP) mill at Whitecourt about 10 km downstream from the ANC mill. Generally, line one produces softwood tissue and towel grades while line two produces hardwood printing and writing grades. The wood chip supply is generally 50% softwood (about 65%-70% spruce and 30%-35% pine) and 50% hardwood (aspen). The McLeod River serves as a source of water for process use. Treated effluent is discharged to the Athabasca River (Figure 2) which also receives treated effluent from the ANC mill and Whitecourt. The mill began operating in July, 1988, but treated effluent volumes were less than capacity during the fall of that year.

The effluent treatment system of the Millar Western mill was originally designed and built as an ASB, but it was changed to an activated sludge treatment (AST) process with extended aeration in the fall of 1989. Wastewater treatment currently comprises three steps: pretreatment, primary treatment and AST secondary treatment. Approximately 30% of the total wastewater flow is directed to pretreatment by a traveling bar screen to remove solids (chips, etc.). Wastewater streams collected in the floor trench system receive treatment in the primary clarifier, a 15,000 m^3/d, 6-hour retention time solids reactor clarifier. The primary clarifier discharge combines with two other streams that do not require clarification to form the influent to the extended aeration AST. The retention time in the 150,000 m^3 biobasin of the AST is approximately 10 days.

Slave Lake Pulp Corporation (SLPC) Construction of the bleached CTMP mill owned by the Slave Lake Pulp Corporation was completed in December, 1990. The mill uses both hardwood and softwood. Pulp bleaching is performed in a two-stage high consistency alkaline peroxide process. The produced pulp is completely chlorine free. Water use for pulp production is very low at only 18 m^3/ADt.

The SLPC mill has an extended aeration AST system which has been modified since 1990 to improve effluent quality. In the summer of 1992, a second secondary clarifier was added to control suspended sediment losses. Optimization of nutrient addition to the biological system has removed the toxicity of the effluent as measured by rainbow trout bioassay. Effluent from this mill is discharged to the Lesser Slave River (Figure 2) which also receives treated sewage from the Town of Slave Lake.

Weldwood of Canada Ltd. (Weldwood) The Hinton bleached kraft pulp mill has been in operation since 1957. The mill has always used softwood (about 75% pine and 25% spruce). Municipal sewage from Hinton is combined with the mill effluent and both are discharged to the Athabasca River (Figure 2). The Hinton mill was originally North Western Pulp and Power, but the name was changed to St. Regis Paper Co. in 1978, Champion Forest Products (Alberta) Ltd. in 1985, and

Weldwood of Canada Ltd., Hinton Division in 1988. The pulp mill's original production has increased over the years (Figure 4).

The Hinton mill has also improved its pollution abatement practices over the years. The effluent system at start-up consisted of a 3-4 day settling basin. A diffuser was installed on the river bottom in 1966. In 1967, a mechanical primary clarifier was installed and the original settling basin was converted to an aerated stabilization basin (ASB) with 5-day retention time. In 1975, the ASB was expanded by deepening to a 6.3 day design retention time and aeration capacity was increased. In 1978, a low-rate steam stripper was installed and, in 1979, a low odour recovery boiler was installed which improved brownstock washing and lowered liquor losses. Further process improvements during 1987 to 1989 included installation of pulp cleaners, a new brownstock screening system and reductions in chlorine use.

In January 1988, Champion Forest Products received a permit to substantially expand and modernize the mill. The expansion and modernization project (1989 and 1990) included oxygen delignification, a new high-rate steam stripper, in-house spill recovery systems, a non-contact cooling water bypass around the ASB, and upgrading of ASB aeration. By 1991, the aeration was increased to a total of 3,000 HP.

More changes have occurred recently. In 1993, the quiescent zone of the ASB was doubled as a means of reducing total suspended solids (TSS) discharges. This modification also increased biochemical oxygen demand (BOD) removal. The Hinton mill also went to continuous 100% chlorine dioxide substitution in June 1993, eliminating the use of elemental chlorine. In 1994, recycling of about 40% of mill contaminated condensates began. Although the production capacity of the mill doubled after 1990, the 1994 discharge of BOD is less than half the 1986 level (Figure 4).

Weyerhaeuser Canada Ltd. (Weyerhaeuser) The Weyerhaeuser (formerly Procter & Gamble Cellulose Ltd.) bleached kraft softwood pulp mill at Grande Prairie became operational in 1973. It discharges effluent to the Wapiti River, a tributary to the Smoky River which also receives treated sewage from Grande Prairie (Figure 3). The mill has been upgraded over the years. Mill process changes include: peroxide reinforced extraction stage, pressure diffuser, "closed" screen room, and digester washing improvements. The most significant process change to occur at this mill in terms of the potential toxicity of the final effluent has been the elimination of molecular chlorine in the bleaching process. The first stage of the bleach plant was significantly altered in the fall of 1990 which resulted in 70% chlorine dioxide substitution. A 100% chlorine dioxide substitution for molecular chlorine was completed in July, 1992. An odour reduction project was completed in September, 1993. Both improvements have further reduced effluent toxicity. The effluent is treated in a primary clarifier and aerated lagoons prior to discharge. Effluent treatment improvements include additional aeration and increased hydraulic retention time in the treatment ponds.

1.3 INTRODUCTION TO ECOTOXICOLOGY

1.3.1 Concepts in Ecotoxicology

Ecotoxicity is a young but rapidly growing field of science. One publisher alone recently listed five new books published in 1994 and 1995 on this topic (Cairns and Niederlehner 1995, Hoffman *et al.* 1995, Landis and Yu 1994, Malins and Ostrander 1994, Newman 1995). It draws on research from many otherwise-unrelated disciplines and looks for answers at scales ranging from subcellular to global. This section of the report is a very brief introduction so that the reader can place the following chapters in context.

SENTAR

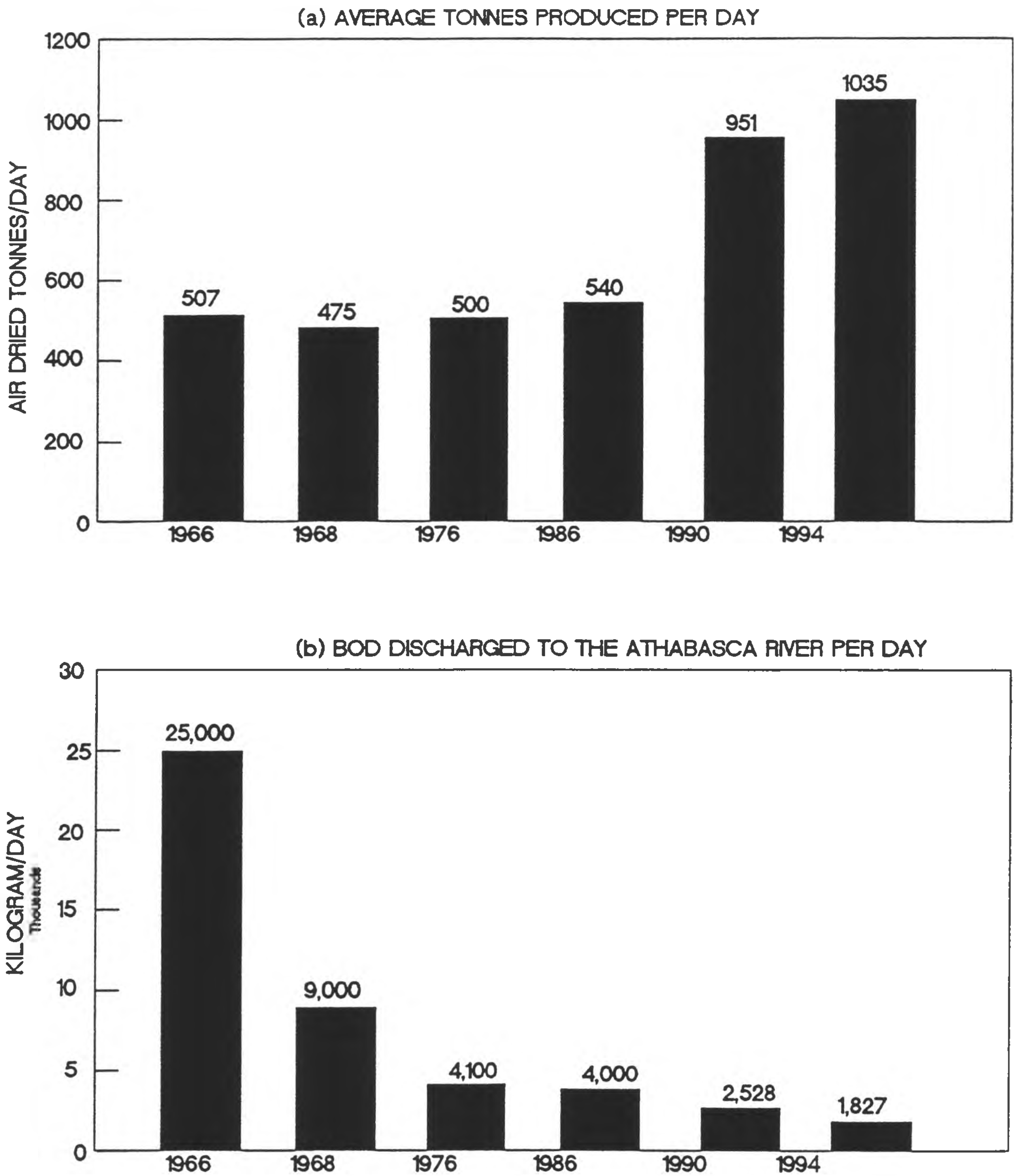


Figure 4
CHANGES IN MILL PRODUCTION AND BOD DISCHARGED AT THE HINTON PULP MILL

13-089-00

Ecotoxicology is concerned with the toxic effects of chemical and physical agents on living organisms, especially populations and communities within defined ecosystems; it includes the transfer pathways of those agents and their interactions with the environment (Butler 1978, Boudou and Ribeyre 1989). Specifically, ecotoxicology pertains to the ways in which polluting agents disturb populations and communities; it is not just concerned with detecting traces of a particular substance contaminating a given environment (Ramade 1987).

Ecotoxicology is not merely human toxicology applied to non-human species (Hope 1993). Although human toxicology and ecotoxicology are most similar in technique and interpretation at the organism level, ecosystems are not organisms and ecosystem health is more difficult to monitor than human health. An understanding of ecological principles is necessary to predict impacts at higher levels of organization. Ecotoxicology should be approached as a discipline formed through the mutual symbiosis of ecology and toxicology, drawing on human toxicology as required, but working to create its own approaches to challenges offered by complex systems (Hope 1993).

1.3.2 Complexity in Ecotoxicology

Virtually any consideration of the ecotoxicity of an effluent released into the environment begins with an understanding of the transport, fate and effects of its constituents. The processes that transport a toxic contaminant in an effluent from the end-of-pipe to the target organism in the receiving stream may be extremely complex. Firstly, the conditions of discharge (e.g. the design of the diffuser) determine the concentration of the contaminant and the initial dilution as it enters the receiving stream. The characteristics of the receiving water, such as turbulence and discharge rate, also affect the mixing and dilution of the contaminant. The physico-chemical properties of the contaminant, such as solubility in water, adsorption onto sediments, resistance to biodegradation, and volatility (i.e. loss to the atmosphere), determine the aquatic pathways. The toxicity of the contaminant may change due to the pH and temperature of the water, speciation of the chemical, or the formation of chemical complexes. The concentration of the toxicant may increase in the food web by processes such as biomagnification. On the other hand, the concentration of the toxicant may decrease due to processes in the aquatic environment such as microbial activity (biodegradation), oxidation, hydrolysis, and photolysis. The dose to an aquatic organism is, therefore, dependent on the remaining concentration and toxicity of the contaminant that reaches the organism and not on the concentration in the effluent that is discharged.

The toxicity to the organism will also depend on characteristics related to the organism itself such as prior acclimation to the toxicant, age, developmental stage, sex and habitat. Organisms may avoid the toxicant due to behavioural responses or habitat preference. Toxicants penetrate an animal by respiration, by contact and by ingestion. In aquatic organisms, different methods of absorption may occur simultaneously. Once inside the organism, the toxicant may be detoxified or excreted before reaching a susceptible tissue or organ.

Ecotoxicology is principally concerned with toxic effects produced, not only by fairly strong doses over short periods of time, but also by exposure to very low concentrations over long periods of time. According to Sheehan (1984), five main responses can be defined for an organism depending on the level of exposure and the degree of damage:

- acute toxicity causing rapid mortality,
- chronically accumulating damage ultimately causing death,

- sub-lethal impairment of various aspects of physiology and morphology,
- sub-lethal behavioural effects, and
- measurable biochemical changes.

Toxicity can also be genetic, affecting the hereditary material of the organism.

Most toxicological tests are performed at the organism level; however, ecotoxicology is also concerned with effects at the community and ecosystem levels. The mortality of organisms belonging to sensitive species is undesirable, but it may not have a significant impact at the ecosystem level. Aquatic ecosystems are generally robust and able to withstand some effects at the organism level. In ecotoxicology, it is important to distinguish between effects of an effluent on individuals or populations of one species in an ecosystem and effects of an effluent on the ecosystem functioning; that is, ecosystem effects that take into account interactions between populations of species within a community (e.g. a benthic community). Immigration, emigration, food resources, predator-prey relationships and competition are important ecological factors that are not taken into account in single-species acute tests.

For the many reasons introduced above, the detection of acute toxicity in the effluent using single species tests may not equal an effect in the aquatic ecosystem. Conversely, the failure to detect acute toxicity at the organism level may not preclude an ecosystem effect.

1.3.3 Methods Used in Ecotoxicology

The following description of methods, including their advantages and their limitations, that are used to assess effects of industrial discharge on a riverine ecosystem is intended as a brief introduction to ecotoxicological methods to show how these methods (i.e. laboratory bioassays, field experiments, routine benthic monitoring, etc.) could be applied. This list does not include all of the methods available.

1.3.3.1 Chemical Analysis of the Effluent

Chemical analysis of the effluent is used to identify and quantify chemicals within the effluent that are potentially toxic. This may be done by analyzing effluent for a predetermined list of chemicals (e.g. ammonia, metals, dioxins, AOX, etc.). The reporting of concentrations of contaminants in the effluent has been the foundation of effluent monitoring programs. Concentrations are then compared to licensed effluent limits to determine exceedances. Concentrations also can be compared to the known toxicity of the pure compound to assess the potential for fish or invertebrate mortality. This method fails when the toxicity of the compound is unknown, and/or when the toxicity of the whole effluent cannot be accounted for by the toxicity of the contaminants being monitored individually. A method designed to overcome this problem is toxicity identification evaluation (TIE) which analyzes the whole effluent by physical and chemical characteristics (such as volatility, solubility in water, pH, etc.) and determines the toxicity of each fraction (volatile fraction, non-filterable fraction, etc.). Only the toxic fractions are tested further. This chemical method is guided by toxicity and does not assume which chemical is causing the toxicity.

1.3.3.2 Biomarkers

Biomarkers are a recent and sophisticated approach to testing the response of an organism living in the receiving environment to an effluent. Biomarker measurements use a very different approach to the assessment of the exposure of an aquatic organism than chemical methods. Biomarkers are biological responses to exposure (Cormier and Racine 1992). Biomarkers do not necessarily detect the actual presence of the toxicant or even its by-products.

A biomarker is a xenobiotically-induced variation in cellular or biochemical components or processes, structures, or functions that is measurable in a biological system or sample (NRC 1987). Typically, these biomarkers are changes in the activity of enzymes or in the level of a specific biogenic compound (Peakall 1992). A broad range of biomarkers are available including biomarkers of the nervous system (inhibition of acetylcholinesterase, catecholamines and neurotransterases), reproductive system (effects on the breeding cycle, embryos, reproductive hormones), genetic material (changes in the RNA:DNA ratio, DNA strand breakage, etc.), hepatic mixed function oxidases (e.g. EROD activity), thyroid function, disruptions of haem biosynthesis (e.g. inhibition of the enzyme ALAD), and the immune system (Peakall 1992). Some biomarkers are non-specific responding to a wide range of pollutants, while others are much more specific. For example, the inhibition of aminolevulinic acid dehydratase (ALAD) is specific to the presence of lead. Use of biomarkers is based on the assumption that contaminant effects occur and can be detected at genetic, cellular, or tissue levels before disturbances occur at population or assemblage levels.

The challenges and obstacles to be addressed when using biomarkers in an ecotoxicity study or monitoring program (McCarthy 1990) are:

- The quantitative and qualitative relationships between chemical exposure, biomarker response and adverse effects must be established.

- Responses due to chemical exposure must be able to be distinguished from natural sources of variability (ecological and physiological variables, species-specific differences, and individual variability).

- The validity of extrapolating between biomarker responses measured in individual organisms and some higher-level effect at a population or community level must be established.

To be useful, biomarkers should respond to effluents, or contaminants in the effluent, in a dose-dependent manner over a range of doses that are relevant to the environment. Biomarker response must be related to adverse effects. If a biomarker shows an abnormal physiological state, this may, or may not, be harmful. For example, Munkittrick *et al.* (1994) has shown that hepatic ethoxyresorufin O-deethylase (EROD) activity levels associated with pulp mill effluents (Munkittrick *et al.* 1993) were not correlated with measurements of reproductive capacity in wild fish such as gonad size and measurements of circulating steroids.

The biomarkers that have been used the most extensively with respect to effects from pulp mill effluents are hepatic mixed function oxygenase (MFO) activity and plasma levels of sex steroids. MFO enzyme activity is measured as EROD induction. Biomarkers have been measured in fish caught in waters receiving pulp mill effluents. Due to the mobility of fish, the number of potential point and non-point sources on a large river, and the complexity of pulp mill effluents, the challenges cited by McCarthy (1990) have not yet been met. However, biomarkers have been successfully used in human toxicology and may become an effective ecotoxicological method, given the current research interest in the use of fish biomarkers.

1.3.3.3 *In Situ* Tests

Single species *in situ* test systems may be used to examine site-specific conditions. *In situ* ecotoxicity tests which yield both lethal and sub-lethal responses can provide important information in the interpretation of aquatic community responses to pollution stress under natural conditions. Fish contained within cages may be placed in the receiving stream upstream and downstream from an effluent under investigation. This procedure may be extended by employing biomonitors to measure immediate physiological response such as fish ECG, opercular rates and cough rates, although biomonitoring is generally too sophisticated and expensive for routine use (Pascoe and Edwards 1989). One of the disadvantages is that cages can be washed away during high flows or vandalized. Another disadvantage is that fish movement and feeding are restricted so that the impact on caged fish is not equal to impacts on natural fish populations.

Invertebrates can also be used for *in situ* test systems. The species selected by Seager *et al.* (1992) as an ecological indicator was the amphipod *Gammarus pulex*. This species is functionally important as a shredder of decomposing leaf material and has also been shown to be sensitive to a range of pollutants. Artificial substrate samplers consist of artificial materials colonized by naturally occurring species; there are benthic invertebrate and epilithic algae samplers. They have the advantage of a known duration of exposure, a fixed location and surface area. They are not representative of the existing assemblage at a location because not all species can colonize the artificial material but they are more representative of the aquatic community than a single-species indicator such as *Gammarus*.

In situ methods do not necessarily employ living organisms. Solvent-filled dialysis membranes which imitate body lipids, mimic the bioaccumulation of organic contaminants in aquatic environments (Södergren 1991). They will accumulate organochlorine contaminants in a manner similar to gill-breathing organisms because contaminant uptake requires transport across a biological membrane which is controlled by a passive process. Since results obtained with living organisms and solvent-filled (e.g. triolein-filled) membranes are similar (Södergren and Okla 1988), a new technology based on configurations of *in situ* semipermeable polymeric membrane devices (SPMDs) has been developed to measure the concentration of contaminants such as dioxins that would be bioaccumulated in a receiving stream.

There are three basic types of toxicity tests: acute single-species tests, chronic single-species tests and multispecies tests. Although single-species tests can be made more ecologically realistic by using a battery of tests or by using *in situ* tests, single species tests cannot measure the effect of a toxicant on the ecological processes that go on between species.

1.3.3.4 Acute and Chronic Bioassays

Acute bioassays are a rapid means of screening complex effluents. They measure the overall toxic effect of the whole effluent on the living organism. Acute tests generally determine the rate of mortality of organisms, such as rainbow trout, as a function of increasing doses of the toxicant, although single tests using 100% effluent may be used for routine toxicity screening. The end point of the test is usually death. In aquatic studies, the median lethal concentration, or LC_{50}, is usually reported as a percentage of the effluent. The exposure of the organism occurs over a fixed period of time, typically 48 hours or 96 hours. The tests may be static, static with renewal of the test solution or flow-through. Flow-through systems greatly improve the constancy of toxicant concentrations and other conditions within test vessels, but static tests are simple, inexpensive and can be performed in large numbers making them more suitable for routine compliance testing.

Chronic bioassays involve exposure to a toxicant over an extended period of time. The effects may be lethal or sub-lethal. They may assess sensitive life stages by exposing the organism over a full life cycle (e.g. *Ceriodaphnia dubia* life cycle test) or a partial life cycle such as the fathead minnow (*Pimephales promelas*) early life stage test. They may assess endpoints other than mortality such as growth (e.g. the growth inhibition test using the freshwater alga *Selenastrum capricornutum*) or reproduction (e.g. the test of reproduction using the cladoceran *Ceriodaphnia dubia*).

The validity of using a single aquatic species such as rainbow trout (*Oncorhynchus mykiss*) to determine the potential hazard of effluents on the total assemblage of aquatic organisms in a river is questionable. Expanding toxicity test requirements to include more than one single-species test (e.g. a fish and an invertebrate) and adding chronic tests greatly enhance the potential of laboratory tests to predict impacts on the aquatic community in a receiving stream. Although more costly and time consuming, a battery of single-species tests can provide information on different species and life stages, as well as effects on growth, survival and reproduction. Laboratory tests do not, however, prove that an effluent, or a contaminant in the effluent, that causes an effect in a laboratory will also cause an effect in the receiving stream.

Single-species laboratory tests offer a cost-effective, replicable, reproducible and interpretable means of assessing chemical safety (La Point *et al.* 1989). Because the tests are standardized and the endpoint is specific (e.g. an LC_{50}), these tests can be incorporated into operating licenses. Failure to comply with the licensed limit can be used for enforcement (e.g. litigation).

Laboratory bioassays have definite advantages for regulatory purposes because the results are available quickly so that a decision can be made in a time frame of days or weeks and corrective action can be taken. This decisiveness may incorrectly equate rapid decisions with well-formed decisions when the results of the tests are used in circumstances to which they do not apply. For example, the standardized conditions of the static test may not reflect receiving water conditions; the test species may not be a suitable surrogate for the riverine species. License compliance based on inappropriate bioassays constitutes legal compliance, but it is not equivalent to environmental protection. Bioassays of effluent cannot assess changes that occur in the receiving stream such as transformation of the toxic compound, cumulative impacts and other factors mentioned in the preceding section.

1.3.3.5 Microcosms

Microcosms are small, usually bench-scale multispecies tests used to investigate the effects of chemical agents on a simplified model aquatic ecosystem. Many sizes and types of microcosms have been used. At one end of the scale, small microbiological systems, similar to one proposed by Beyers (1963) that used microorganisms to simulate ecological functions such as succession, community metabolism, etc., are not realistic in terms of species composition but they do simulate ecological functions. At the other end of the scale, laboratory streams which simulate stream compartments, such as sediment, water and resident flora and fauna resemble more closely the river ecosystem.

Taub (1989) developed a Standardized Aquatic Microcosm (SAM) that is a replicated, reproducible, multitrophic level test. Six replicates of treatment microcosms and simultaneous controls provide enough statistical power to demonstrate significant effluent effects, if present. Interlaboratory tests have shown that this method, which includes sediments, an aqueous medium, ten species of algae and five species of invertebrates, is reproducible. Microcosm tests such as SAM, exhibit greater precision and realism, but this does not mean that they will accurately predict the ecosystem effect (Buikema and Voshell 1993). Microcosm which does not incorporate flowing water, predators and a high degree of similarity to the ecosystems of interest, may lack accuracy and, therefore, have limited value in northern river studies.

Microcosms greatly simplify natural systems. Conclusions drawn from laboratory experiments are related to controlled and constant conditions; consequently, the complexity and change that are characteristic of the natural environment cannot be simulated. Studies of small scale systems (microcosms) underestimate the functional redundancy in natural ecosystems which allows ecosystem function to continue as different species take over the functional role of more sensitive species. Species may also be able to avoid a contaminant by behavioural, or other mechanisms which will not be identified by microcosm research. For the same reason, microcosms may not predict the effects of multiple stresses or cumulative impacts on the ecosystem. The species used in microcosm tests are often species that have adapted to live under laboratory conditions and may not be representative of the range of sensitivities of natural species in the receiving stream.

Microcosms, however, are useful as part of a larger study; for example, in measuring the bioavailability of contaminants in the effluent and routes of uptake. Such factors cannot be easily studied in the field because cause and effect relationships may be difficult to elucidate in the greater complexity of a natural stream.

1.3.3.6 Mesocosms

Physical models of ecosystems such as mesocosms provide an important intermediate step between laboratory tests and full scale field studies. Environmental control can be exerted over these models and they can be replicated allowing statistical analysis of the results.

Mesocosms such as limnocorrals generally allow experimental control over a defined natural habitat providing conditions that are much more realistic than laboratory microcosms. Effects of predation and herbivory can be measured with site-specific *in situ* aquatic mesocosms.

Field-sited experimental streams are normally located near the natural river system which can provide dilution water. These channels are generally much longer than laboratory streams and are subjected to conditions that more closely reflect natural conditions. Tests may include a range of species and are more likely to include natural assemblages. Because they are expensive and time-consuming, artificial streams are better suited to research projects or predictive modelling. As the complexity of the artificial stream becomes greater, the artificial stream becomes more realistic, but more intractable. As the size of the artificial stream becomes greater, it will be more realistic (more likely to include larger predators), but stream replication may be sacrificed.

Complex ecotoxicological test systems may not attain routine use in environmental protection because of the following disadvantages: the lack of standardization of protocols, failure to agree on what constitutes a meaningful endpoint in tests performed at the community or ecosystem level, the intrinsic variation in physical, chemical and biological variables may make complex test systems too insensitive for routine monitoring, higher cost, and the delay in obtaining information needed by decision makers. In spite of these disadvantages, mesocosms are often used to confirm predictions of environmental effects of toxicants based on laboratory tests. Their applications in risk assessments, particularly pesticide assessments, is growing.

1.3.3.7 Ambient Biological Monitoring

Ambient biological monitoring, or biomonitoring, is a direct measure of the impact of an effluent on the assemblages of biota in the receiving stream. The major strength of ambient biomonitoring is that it integrates cumulative impacts from all point sources and non-point sources over time. Instream biological monitoring in the NRBS area has the strong advantage of being a direct measure of the combined effect of both positive (e.g. nutrient enrichment) and negative (e.g. toxicity) effects of the pulp mill effluents on the aquatic organisms in the receiving stream. It overcomes many weaknesses of a contaminant-by-contaminant approach since it measures the combined impact of all contaminants within the effluent. It goes beyond the single species approach because it measures the effect on an assemblage of organisms that interact with each other and the physical and chemical environment of the river. Monitoring programs, however, only show correlations. Their value is greatly improved if they contain sufficient temporal (e.g. before and after) and spatial (e.g. upstream and downstream of a point-source) controls. When population studies are expanded to include the incidence of morphological abnormalities, they are likely to become more sensitive to toxic effects. Nevertheless, controlled experiments are needed to demonstrate that a particular toxicant caused the effect observed in the monitoring. Monitoring records ecosystem effects, but it does not demonstrate the cause. The value of biomonitoring can be greatly enhanced by the addition of controlled experiments.

The main groups of aquatic organisms that could potentially be monitored include fish, invertebrates, aquatic plants and micro-organisms. Fish often form a major component of special studies. They are usually too mobile to act as indicators of effluent effects from any particular mill; however, sentinel fish species that have restricted ranges are being sought. Aquatic plants have not been monitored because they are generally rare in the mainstems of the northern rivers. Algae are often more abundant below effluent discharges and are potentially useful for biomonitoring. Benthic macroinvertebrates have been monitored by all the pulp mills and benthic monitoring is the most common biomonitoring approach. A measure of standardization in benthic invertebrate sampling methods was introduced by Alberta Environment (1990).

Biological monitoring using benthic macroinvertebrates has a number of important advantages. The benthic invertebrate community is present continuously in the receiving stream integrating the combined impacts of the discharge under continually varying instream conditions in contrast to bioassays which are based on grab samples and controlled laboratory conditions. Benthic invertebrate communities are more stationary than fish assemblages and, therefore, more accurately reflect conditions at a particular location. There is a large body of benthic monitoring data available over the operating lifetime of all mills as well as baseline data for the newer mills. The disadvantages are that changes in methods have occurred which make comparisons difficult. A benthic invertebrate monitoring program is also labour-intensive and, therefore, relatively expensive.

Indicators that are well suited to the detection of ecological stress must combine two potentially contradictory characteristics (Frost *et al.* 1992). Because the natural variability exhibited by a parameter provides the benchmark against which change must be measured, an ecological indicator must be sufficiently stable under natural conditions to allow a change with stress to be detected. At the same time, such indicators must be sensitive to agents causing change within an ecosystem. In many cases, sensitive parameters are also likely to exhibit high levels of natural variability. The natural variation in the numbers and species of benthic invertebrates make it more difficult to demonstrate significant effluent effects.

1.3.3.8 Indicators and Indices

There have been, and continue to be, many attempts to simplify biomonitoring; that is, to find a monitor of ecosystem health that is equivalent to taking a patient's temperature in human health. The search for a single number has spawned many benthic invertebrate indices such as the commonly used diversity index (Margalef 1958, Shannon and Weaver 1949). The relationship between diversity and ecosystem stability and, therefore, the value of diversity as a measure of biotic integrity has been questioned (Cairns and Pratt 1993). Green (1979) concluded "...the strongest argument against the use of diversity indices as derived criterion or predictor variables in environmental studies is that other statistical methods retain more of the information in the biological data while reducing them to a more useful and ecologically meaningful form."

A more recent approach is the index of biotic integrity (IBI) based on the sampling of fish communities (Karr *et al.* 1986). Biological criteria are developed, based on an understanding of the potential fauna and designated uses of the stream. The IBI scores are based on species richness and composition, trophic composition, abundance and condition. The IBI has been widely used in Ohio to assess stream reaches under the assumption that the response of fish community attributes reflects changes in stream condition. An invertebrate community index (ICI) has also been developed. Hoefs and Boyle (1992) found that species richness, habitat structure, and overall sensitivity of the fish community were the most responsive to changing stream condition. In general, indicators that responded to stream condition were based on species occurrence rather than individual abundance, suggesting that species composition may be a better indicator of stream condition than the numbers of individuals present. Schindler (1987) found that one of the earliest responses to stress is the change in species composition of small, rapidly-reproducing species. Total taxa richness is the index of choice according to Reice and Wehlenberg (1993); however, resources permitting, species-specific population estimates also should be included.

There is a paramount danger that ecological indicators can be misused if interpreted in too "mechanistic" a mode (Rapport 1992). They should not be rigid "guidelines" for maintaining some perceived "optimal" state of nature. The use of indicators of ecosystem health must always be within the context of dynamic, evolving, and to some extent, unpredictable, ecosystems for which a disturbance may as often signal health as it does "illness" (Rapport 1992).

1.3.3.9 Models

Many of the methods described above, such as artificial streams, are physical models in that they are simplified simulations of the natural environment. Conceptual models improve the theoretical foundations of the ecotoxicological study, and require clear definitions of the problem, the contaminants of concern, the selection of end points, etc. One of the reasons that ecological risk assessment is rapidly gaining favour is the clear conceptual framework on which it is based. Physical, statistical and mechanistic models may be used to predict the transport and fate of contaminants through ecosystem pathways and the determination of the effect of contaminants. The reader is referred to Suter (1993), Calabrese and Baldwin (1993) and Bartell *et al.* (1992) for further information since the subject of models goes beyond this introduction.

1.3.3.10 Ecosystem Studies

The extrapolation of results from one source, such as an acute bioassay, an experimental stream, or another ecosystem is an uncertain undertaking. A single toxicity test may show that a species is sensitive to a contaminant, but the species may increase its population in the natural community because its predators or competitors are more sensitive and are eliminated. Microcosms containing algae grazed by an invertebrate may show an increase in algal biomass when the invertebrate population is reduced in response to the toxicant. In the natural ecosystem, the intebrate assemblage may include some species that are less sensitive to the toxicant and increase, or the algae may be controlled by another factor such as the availability of nutrients. In these cases, the results of the bioassay, microcosm or even mesocosm may not accurately predict the environmental impact.

The final option is a full-scale ecosystem study. Such a study is very expensive, and generally requires years to complete. There is no protocol for an ecosystem study. It would be designed on a site-specific basis. Such studies may include indicators of fish health, tissue concentrations of specific contaminants, measures of reproductive success of fish (e.g. gonad size, plasma sex steroid levels, egg production and egg size), fish movement and population characteristics. In addition, evidence of ecosystem relationships may be obtained by analysis of stomach contents, habitat surveys, etc. Many other components could be added to the study depending on the study objectives.

Ecosystem studies have strong advantages. They can resolve differences in scale by measuring indicators at each scale. They can include measurements of ecological processes as well as populations. They can also include aspects of ecological risk assessment such as the transport and fate of contaminants and the exposure to, and effects on, sentinel species.

2.0 SOURCES OF ECOTOXICITY DATA

2.1 INTRODUCTION

This section will outline the extent and nature of data that are available to assess ecotoxicity directly related to pulp and newsprint mills in the NRBS area. Relevant mill effluent data have been generated primarily as a result of provincial license and approval requirements, federal pulp and paper regulations and environmental effects monitoring (EEM) requirements, monitoring by pulp mills and governments, and special studies conducted by the industry, NRBS and others.

2.2 REGULATORY REQUIREMENTS FOR EFFLUENTS

With the important exception of some special studies and monitoring initiated by the pulp mills, industries collect data because they are required to do so by provincial and federal acts and regulations. These regulations are established to achieve a number of objectives, only some of which are related to ecotoxicity. This section identifies the regulatory requirements pertaining to the potential toxicity of effluent discharged by the pulp and newsprint mills and the impacts on the receiving watercourses directly attributable to this industry. There have been changes in all the relevant legislation in the last few years and industries are meeting the increasing demand for data. The purpose of this section is to provide a summary of the quantity and type of monitoring being done and compliance data currently available.

2.2.1 Environmental Impact Assessments

One of the first environmental regulatory requirements encountered by a new pulp mill is the environmental impact assessment process. In Alberta, the construction and operation of a pulp, paper, newsprint or recycled fibre mill with a capacity of more than 100 tonnes per day is considered a mandatory activity (i.e. an activity for which an EIA is mandatory) under the Environmental Assessment (Mandatory and Exempted Activities) Regulation pursuant to Section 57 of the provincial *Environmental Protection and Enhancement Act*. Therefore, an Environmental Impact Assessment (EIA) report has been mandatory under the new Act since it was given assent on June 26, 1992. (It was amended on June 1, 1994.) Mills constructed prior to 1992 were required to complete an EIA under previous legislation. The federal government has also been involved in assessment processes such as the Alberta-Pacific Forest Industries Inc. public review process.

The EIA report may include data related to baseline conditions at the proposed location, a description of the proposed mill, an assessment of the impact of mill effluent on receiving water and any mitigation proposed to reduce this impact. Since an EIA report is written before a mill has been built, there are never any effluent toxicity data *per se*, although there may be a prediction of the potential sources of toxicity in the effluent.

Two mills in the NRBS area, the Weyerhaeuser Canada Ltd. mill at Grande Prairie and the Weldwood of Canada Ltd. mill at Hinton, started up in 1973 and 1957, respectively, prior to EIA requirements. All other mills operating in the NRBS area started up between 1988 and 1993 and were, therefore, subject to the EIA process. The amount of information required in the EIA has increased over the years. Mills completing EIAs some time ago did not present as much data as is required now.

A brief review of EIAs done by mills indicates that information related to effluent and its impacts is, at best, a very minor source of ecotoxicity data. The EIA reports prepared by mills in the NRBS area (ANC 1988; Alberta-Pacific Forest Industries Inc. 1989; H.A. Simons Ltd. 1986, 1987; Western Research 1989) generally addressed: total suspended solids, biochemical oxygen demand and its effect on the dissolved oxygen of the receiving stream, pH, temperature, colour, and other characteristics of the effluent such as (but not always including) bacteria, EDTA or DTPA, resin acids, dioxins and inorganic ions. A statement that effluent would not exceed the LC_{50} for rainbow trout in the 96 hour bioassay was included in some of the EIAs (ANC 1988, H.A. Simons Ltd. 1986, Western Research 1989), but whole effluent toxicity was not considered further. In general, past EIAs provide little data directly related to ecotoxicity.

Since the data available are primarily related to baseline conditions in the receiving river prior to mill start-up, EIAs, as a data source, are more relevant to another synthesis report in this series, the *Contaminants in Aquatic Ecosystems - Synthesis Report*.

2.2.2 Provincial Effluent License Requirements

2.2.2.1 Introduction

Pulp mills in the NRBS area, Alberta Pacific Forest Industries Inc., Alberta Newsprint Company, Daishowa-Marubeni International Ltd., Millar Western Pulp Ltd., Weyerhaeuser Canada Ltd., Slave Lake Pulp Corporation, and Weldwood of Canada Ltd., are each licensed separately. All seven mills received an Amending Approval under the *Environmental Protection and Enhancement Act* in 1994 requiring them to continue monitoring the acute lethality and sublethal/chronic toxicity of their effluent. There are some site- and mill-specific differences among the approvals, as well as a change in the terms and conditions of past licenses over time.

Except as authorized by the approvals, mills may not discharge any water into a watercourse if it degrades, or is likely to degrade, the chemical or biological quality of the water so that the water in the watercourse is, or is likely to be, rendered harmful to human health or life, fish, wildlife, livestock or plants. Therefore, in addition to meeting the following specific toxicity testing requirements, effluent must also meet this general requirement.

2.2.2.2 Acute Lethality Monitoring and Compliance Using Rainbow Trout

All pulp mills in the NRBS area are required to do acute toxicity testing. In addition to being a monitoring requirement, acute lethality of effluent to rainbow trout has also been one of the conditions of past licenses and is now one of the conditions of the approval. Specifically, the effluent limit is 50% or more survival of rainbow trout in 100% concentration test sample at all times.

For the measurement of acute lethality, 96-hour static acute bioassays using rainbow trout are required monthly on grab samples collected from the effluent and, in the case of the Daishowa-Marubeni mill in Peace River, non-contact cooling water. Measurement of all static acute bioassays must be performed using multiple concentrations to determine the LC_{50}.

In the event that less than 50% of the rainbow trout survive in the 100% concentration test sample, the mill must immediately have another grab sample of effluent taken and assayed for acute lethality using rainbow trout. Measurement of acute lethality must be immediately increased to at least once per week, until three consecutive tests demonstrate 50% or more survival in 100% concentration test sample, in which case, the mill may then revert to a sampling frequency of once per month. The Director of Pollution Control may modify the requirement or frequency of measurement of acute lethality for all follow-up testing with rainbow trout.

In the event that less than 50% of the rainbow trout survive in the 100% concentration test solution, the mill must also implement a Toxicity Reduction Evaluation (TRE) plan as required by the Director of Pollution Control. This plan must continue until completed unless otherwise directed by the Director.

Because the Weyerhaeuser Canada Ltd. mill discharges to the Wapiti River, a river that provides limited dilution of the effluent under low flow conditions, further chronic testing is required. In the event that less than 50% of the rainbow trout survive in the 100% concentration test sample, when the flow of the Wapiti River is estimated (Hydrometric Station #07GE007) to be less than or equal to 20 m^3/s, Weyerhaeuser Canada Ltd. must immediately collect and analyze samples for sublethal/chronic toxicity testing (described in Section 2.2.2.4).

2.2.2.3 Acute Lethality Monitoring Using *Daphnia magna*

All mills in the NRBS area must, at least once per calendar week, perform a 48-hour static acute bioassay using *Daphnia magna* as the test organism on grab samples of effluent and, in the case of the Daishowa-Marubeni mill, non-contact cooling water. This is a monitoring requirement; acute lethality of *Daphnia magna* is not one of the effluent limits requiring compliance. In the event that less than 50% of the *Daphnia magna* test organisms survive in the 100% concentration test sample, the mill must take two steps immediately. Firstly, it must have another grab sample of the effluent taken and measured for acute lethality of the effluent to rainbow trout. If less than 50% of the trout survive in the 100% concentration test sample, the mill must follow the increased monitoring frequency for rainbow trout and the TRE. The director may modify the requirements for, or frequency of, measurement of acute lethality.

Secondly, measurement of static acute bioassays for *Daphnia magna* must be immediately increased to at least three per week at an interval of at least 48 hours between separate grab samples until three consecutive bioassays demonstrate 50% or more of the test organisms survive in 100% concentration test sample, in which case, the mill may revert to a sampling frequency of once per week.

2.2.2.4 Sublethal and Chronic Monitoring

All of the pulp mills in the NRBS area are required to perform 7-day fathead minnow, 4-day *Selenastrum capricornutum* and 7-day *Ceriodaphnia dubia* bioassays on grab samples of effluent for the measurement of sublethal/chronic toxicity. This is a condition of the provincial approval which is directly related to the Environmental Effects Monitoring (EEM) Guidelines. The sublethal/chronic testing must be done at least four times per calendar year once every three years as required under the EEM Guidelines.

The Weyerhaeuser Canada Ltd. mill has an additional monitoring requirement every year. It must, at least once per calendar month for the months of December, January, February and March of each year (at intervals of greater than three weeks), perform the 7-day fathead minnow, the *Selanastrum capricornutum* and the 7-day *Ceriodaphnia dubia* bioassays on grab samples from the effluent.

2.2.2.5 Biomonitoring of the Receiving Water

Benthic invertebrate monitoring by pulp mills has been required for many years. The oldest mill, the Weldwood of Canada Limited mill at Hinton, has routine benthic monitoring data going back to 1972. The period of record varies among mills depending primarily on the baseline monitoring and the start-up date of each mill. The biomonitoring requirements vary slightly from one mill to another due to site-specific differences, differences in the ongoing monitoring program designs and the date the license or approval was issued. The most noticeable change in the wording came in the 1994 approvals which take the EEM Guidelines into account in a more comprehensive manner.

The 1992-1993 Approvals

The Daishowa-Marubeni International Limited mill approval contains only the general condition that the mill must submit benthic invertebrate survey results from the study(ies) required under EEM to the Director of Standards and Approvals (now the Director of Air and Water Approvals). This mill, which discharges into the Peace River, is no longer required to do benthic invertebrate monitoring, although this monitoring has been done in the past.

The terms, conditions and requirements for biomonitoring are more detailed in the current approvals for Alberta-Pacific Forest Industries Inc., Alberta Newsprint Company, Weldwood of Canada Ltd. and Weyerhaeuser Canada Ltd. mills. Each mill must submit to the Director of Air and Water Approvals a proposal to continue the program of the benthic monitoring surveys, prior to each survey (except ANC which continues the program initiated in 1989). The program must be quantitative with the objective of determining significant environmental effects, using methods commonly accepted in biomonitoring studies, with sufficient sites and samples to permit statistical analysis.

The monitoring programs must have the objectives of determining:

- significant changes in the benthic invertebrate community which are attributable to the effects of the effluent, and
- the length of impact zone along the receiving river.

The methods used should be commonly accepted in biomonitoring studies. The study design should:

- include sufficient sites outside and within any zone of influence to determine impacts,
- include sufficient samples at each site to obtain reliable population density estimates and to allow statistical analyses, and
- include QA procedures (Alberta Pacific and ANC only).

Under current approvals, the frequency and scheduling of the benthic invertebrate monitoring program varies among mills, primarily to accommodate an investigation of winter (under ice) monitoring, a change from previous monitoring which was usually done in the fall. The timing for the different mills varies as follows:

- Weldwood the program must be conducted for three of the next five years in February or March prior to significant discharges due to meltwater (the intent is to sample substrates that were continuously submerged all winter); the Director of Air and Water Approvals may reschedule the survey to another time of year if it is determined to be more appropriate;
- Weyerhaeuser biomonitoring surveys must be conducted in February or March of each year prior to breakup;

- Alberta Pacific, ANC the program must be conducted every fall; in addition these mills must submit a proposal to undertake a joint (Environment Quality Monitoring Branch/mill) benthic invertebrate survey during ice cover over one of the next two winters.

At each location, benthic chlorophyll *a* should be sampled with the same number of replicates as invertebrates, to describe potential fertilization effects of the effluent and to describe conditions pertinent to the zoobenthos (Alberta Pacific and ANC only).

The program must account for the influence of river variables such as substrate conditions, flow velocity, water levels, effluent plume distribution and other relevant variables.

The 1994 Approvals

The approvals issued in 1994 separated the tasks into two time periods: years 1-2, and year 3.

In years 1-2, Millar Western must conduct pilot work on winter zoobenthic monitoring to assess the field feasibility and the adequacy of winter taxonomic diversity for impact assessment. Millar Western must review the adequacy of previous reference sites and previous sample sizes for epilithic chlorophyll *a*.

In years 1-2, the SLPC mill must review problems associated with their benthic monitoring that arise from the physical habitat changes in the Lesser Slave River, consider possible solutions to this, carry out any necessary field program to test them and conduct feasibility and pilot work on winter zoobenthic monitoring of any effluent effects. The SLPC mill must inspect and assess aquatic macrophyte conditions in the river with regard to potential effluent effects on them and test means of sampling and documenting any effects. The SLPC mill is the only mill required to monitor aquatic macrophytes which are scarce in the mainstem rivers of the NRBS area.

In year 3, both mills must consider the above, any further AEP information, NRBS findings, Federal EEM results, and the contaminants evaluated in the final effluent and submit a proposal to conduct a fall survey of water quality, sediment quality (metals and nutrient focus)[1], benthic algae and macrophytes[1]; and a winter survey of water quality and zoobenthos, for the purpose of assessing the magnitude, extent, and duration of any effects the mill's effluent may have on these components of the receiving system. The proposal must be approved by the Director of Air and Water Approvals before the surveys proceed.

2.2.2.6 Required Methods

For each measurement taken or sample collected, the mills must record the following information:

- the exact time and place of sampling;
- the type of sample;
- the person who performed the sampling;
- the dates the analyses were performed;
- the laboratory and person who performed the analyses;

---

1 Slave Lake Pulp Corp. only

- the analytical techniques, procedures, or methods used; and
- the results of the analyses.

The proposed benthic invertebrate surveys must be quantitative and use methods generally accepted in effects monitoring studies. They must include:

- proper collection, analytical, and quality control measures;
- sampling of effluent quality and toxicity in coordination with the river work;
- sufficient sites and samples to permit statistical analyses for the purpose of determining effects;
- proper consideration of other environmental variables that may influence findings, such as substrate conditions, velocity, water levels, effluent plume distribution, tributary inflows, ice cover, and any other relevant variables.

Methodology would be part of the proposals that must be submitted to the Director of Standards and Approvals but the benthic invertebrate methods are not specified further in any of the mill approvals.

All samples for static acute bioassays must be transported and received at the laboratory within 48 hours of collection. If the sample has been continuously chilled at a temperature of 1°C to 8°C, then testing can begin no later than five days after collection. Should any control response exceed 10% in any bioassay, that bioassay must be repeated. Any deviations in the recommended conditions and procedures for culturing, test conditions and test procedures must be reported. Significant deviations from these conditions and procedures may be cause for repeating any bioassay.

All samples for sublethal/chronic bioassays must be packed in ice, and transported and received at the laboratory within 48 hours of collection. Testing must be initiated within 72 hours of collection. If the control response exceeds 20% in any of the bioassays, the bioassay must be repeated.

Each license requires that the samples be collected and analyzed in accordance with specific methods, as follows:

Rainbow Trout (Acute Lethality) Tests must be in accordance with *Environmental Protection Series Biological Test Method: Reference Method for Determining the Acute Lethality of Effluent to Rainbow Trout* (Environment Canada 1990a) as amended from time to time.

***Daphnia magna* (Acute Lethality)** Tests must be in accordance with *Environmental Protection Series Biological Test Method: Reference Method for Determining the Acute Lethality of Effluent to Daphnia magna* (Environment Canada 1990b) as amended from time to time.

Selenastrum capricornutum Test must be in accordance with *Environmental Protection Series Biological Test Method: Growth Inhibition Test Using the Freshwater Alga (Selenastrum capricornutum)* (Environment Canada 1992a) as amended from time to time.

Ceriodaphnia dubia Tests shall be in accordance with *Environmental Protection Series Biological Test Method: Test of Reproduction and Survival Using the Cladoceran (Ceriodaphnia dubia)* (Environment Canada 1992b) as amended from time to time.

Fathead Minnows Tests must be in accordance with *Environmental Protection Series Biological Test Method: Test of Larval Growth and Survival using Fathead Minnows* (Environment Canada 1992c) as amended from time to time.

2.2.2.7 Required Reporting

Bioassay results for each species must be reported using statistical analyses specified in the test methods, as 7-day acute LC_{50} (except *Selenastrum capricornutum*) and sublethal/chronic no observable effect concentrations (NOEC) for all sublethal/chronic bioassays.

Each mill must, within 30 days of the end of each calendar month, submit to the Director of Air and Water Approvals a written report for that month, which includes the results of the static acute bioassays and sublethal/chronic multispecies testing, if required. The results must include all the physical testing conditions, as specified in the methods identified including the reference toxicant control chart, temperature, pH, conductivity, ammonia, mortality, residual chlorine concentration (ampertric titration) for fathead minnow and *Ceriodaphnia dubia*, daily young production (*Ceriodaphnia dubia*), initial and final control cell densities (*Selenastrum capricornutum*), daily mortality, final weights (fathead minnows), and the statistical methods used to calculate the LC_{50}, LOEC, NOEC and IC_{25}.

The mill must ensure that all other information required under the test methods for bioassays specified in the sampling and analytical procedures attached to the license are retained on file with the laboratories which performed the bioassays for a period of three years or as otherwise directed by the Director of Air and Water Approvals and that this information is available for inspection by and can be copied for the Director of Air and Water Approvals or the Director of Pollution Control upon request. The Director of Air and Water Approvals reserves the right to request any or all reporting information under the license in an electronic format.

The mill must also submit all of the information required under Annex 1, Aquatic Environmental Effects Monitoring Requirements at Pulp and Paper Mills and Off-site Treatment Facilities, regulated under the Pulp and Paper Effluent Regulations, to the Director of Air and Water Approvals.

Each mill must, by March 31 of each calendar year, submit an annual written report to the Director of Air and Water Approvals containing the results for the past calendar year of the biomonitoring surveys conducted in accordance with the monitoring standards for receiving water attached to the license. The mills must tabulate, provide time series plots, frequency histograms, mean, standard deviations, and coefficient of variations for all of the monitoring data collected for the calendar year. This information must be provided in paper and electronic disk formats (spreadsheet).

2.2.3 Federal Requirements

2.2.3.1 Pulp and Paper Effluent Regulations

In 1971, federal Pulp and Paper Effluent Regulations under the *Fisheries Act* were established to protect fish and fish habitat near pulp mills. These regulations applied to pulp mills built after 1971. New Pulp and Paper Effluent Regulations (PPER) were promulgated in 1991 to widen the application of the regulations to all mills. They included more restrictive *Fisheries Act* discharge limits and monitoring procedures, and new *Canadian Environmental Protection Act* (CEPA) regulations to prevent the formation of dioxins and furans in effluents from mills using chlorine bleaching. A further regulation under CEPA banned the use of contaminated defoamers and woodchips that cause dioxins and furans to be formed.

The Department of Fisheries and Oceans is responsible for PPER under the federal *Fisheries Act*. The regulations allow the operator of a mill to deposit "deleterious substances" in water if the quantity does not exceed the maximums specified in the regulations. The regulations also specify sampling, testing and reporting methods to be used in the monitoring.

The classes of substances that are limited by the regulations include: biochemical oxygen demand (BOD), suspended solids, and acutely lethal effluent. The monitoring required under these regulations includes: BOD, suspended solids, acute toxicity to rainbow trout, pH, and electrical conductivity. The methods that must be used for determining the acute lethality of effluent to rainbow trout and *Daphnia magna*, the frequency of sampling and the type of samples are the same as those given in section 2.2.2 of this report. Therefore, the monitoring of acute toxicity to rainbow trout and the effluent toxicity limit specified in the provincial licenses and approvals (described in Section 2.2.2) are also part of the federal PPER. The regulations also require environmental effects monitoring studies.

2.2.3.2 Environmental Effects Monitoring (EEM)

All mills will be required to provide the Department of the Environment with an interpretative report and supporting data on an Environmental Effects Monitoring (EEM) study to be conducted in accordance with requirements published by the Department of the Environment. These studies will provide information on whether deposits of deleterious substances in waters frequented by fish have altered, disrupted or destroyed fish habitat. As a result, EEM will provide the information to evaluate the need for further control measures by evaluating the adequacy of existing control measures under the *Fisheries Act* and CEPA and by assessing effects on the receiving environment. The adequacy of existing control measures will be determined on the basis of the magnitude of the effects and the spatial extent of the effects. For the purposes of EEM, effects may include, but are not limited to, changes in the health of fish, distortion of fish population structure or the life cycle of fish, deterioration of habitat essential for growth and sustenance of fish, or accumulation of substances in fish to levels prejudicial to human health and/or the marketability of fish.

Identification of specific chemical agents in the effluent is required where knowledge of their occurrence and quantity will aid in identifying and confirming the presence of mill effluent as being responsible for any observed effects in the receiving environment.

To achieve national uniformity in environmental effects studies, all Canadian mills regulated under the amended PPER will be required to conduct EEM at regulate intervals beginning in 1992. Aquatic environmental effects monitoring, as applied to mills, is a sequential series of monitoring and interpretation cycles, wherein the requirements of each cycle are dependent on the findings of the previous cycle. General steps and types of information are defined for mills regulated under the PPER, although the specific requirements may change. Requirements of subsequent EEM cycles will be determined following an evaluation of the first cycle.

Specific monitoring requirements for the pulp and paper sector are in *Annex 1; Aquatic Environmental Effects Monitoring Requirements at Pulp and Paper Mills and Off-Site Treatment Facilities Regulated under the Pulp and Paper Effluent Regulations of the Fisheries Act* (Environment Canada and Department of Fisheries and Oceans 1992). A *Technical Guidance Document* (Environment Canada and Department of Fisheries and Oceans 1993) for EEM has also been published. The guidance document specifies methods and quality control and quality assurance measures (QA/QC) for conducting EEM.

The EEM requirements consist of a pre-design study, the first cycle of EEM due in April 1996, and subsequent cycles of EEM. The EEM Pre-Design requires a description of mill history and operations, the study area and effluent quality (Table 2). The components that are particularly relevant to ecotoxicity include a summary of effluent quality which includes existing data for acute toxicity of rainbow trout and *Daphnia magna* and toxicants in the effluent, as required by the *CEPA* regulations and the *Fisheries Act* regulations.

Table 2: Pre-Design Requirements for EEM

	Information/Variables
Description of Study Area (Receiving Environment)	Delineation of Zone of Effluent Mixing Resource Inventory Habitat Inventory and Classification Historical Receiving Environment Data
Effluent Quality	pH Flow Conductivity Biochemical Oxygen Demand (BOD) Total Suspended Solids (TSS) 96-h Rainbow Trout Lethality 48-h *Daphnia magna* Lethality Chlorinated Dioxin and Furan Congeners
Mill History and Operations	

Some of the EEM first cycle requirements include studies related to ecotoxicity as follows:

- An adult fish survey to assess the health of two "sentinel" fish species (ideally one fish species will be a benthic species that is an integral component of the food web), based on the premise that protection of sensitive fish species will provide protection for the fish community and the aquatic system as a whole. The survey is to include: biological measurements such as length (standard, total or fork length), fresh weight, gonad weight, egg size, liver weight, and sex, where appropriate; collection of aging structures; examinations for grossly evident tumours, neoplasms, and lesions in major organs; and collection and analyses of gut contents. A minimum number of twenty fish of each sex of each of two species is required at a minimum of two locations.

- Confirmation that the samples are representative of the area sampled. This may require analysis of chemical tracer(s) to substantiate exposure of fish to the effluent.

- An intensive[2] benthic community assessment to allow comparisons of reference areas with near-field and far-field areas using calculation of biotic indices and multivariate statistical analyses of the taxa (genus and species wherever feasible) found during quantitative sampling. Intensive sampling must be conducted within a minimum of four areas, where an area is defined to be relatively homogeneous with at least three sampling stations to be sampled within an area. The four areas to be sampled are to include a reference area and both a near-field and a far-field area. If several major habitat classes are present at a given exposure level, then a separate area should be defined for each habitat class. Three replicates are required at each area.

- Sublethal toxicity tests involving exposure of the organisms in a series of effluent dilutions in the laboratory. Three sublethal effluent tests are required in the first cycle: a fish early life stage development test, an invertebrate reproduction test and a plant toxicity test. Acceptable tests and methodologies are given in Table 3. Sublethal effluent tests must be completed quarterly for one year. In situ receiving water, sediment and genotoxicity tests (Table 2) are not required in the first cycle.

2 The EEM requirement for an initial extensive survey consisting of two replicates at twelve locations may be altered to an intensive survey if adequate historical data exist. Therefore, it is unlikely that extensive surveys would be required in the NRBS area given the historical databases available.

Table 3: EEM Methodologies and Reporting Requirements for Effluent, Receiving Water and Sediment Tests

EEM CYCLE	Test Description	Test Species	Acceptable Method(s)
First	Fish Early Life Stage Development Test	Fathead minnow or salmonid spp.[a]	Environment Canada 1992c
First	Invertebrate Reproduction Test	*Ceriodaphnia dubia*	Environment Canada 1992b
First	Plant Toxicity Test	*Selenastrum capricornutum* or *Lemna minor*	Environment Canada 1992a
Subsequent	*In situ* Fish Lethality	Any indigenous species or cultured species relevant to receiver	Appropriate methodology to be selected
Subsequent	Amphipod Survival (Sediment Test)	*Hyallela azteca*	ASTM 1991
Subsequent	Invertebrate Survival and Growth (Sediment Test)	*Chironomus tentans*	ASTM 1991
Subsequent	Genotoxicity	*Salmonella typhimurium* or *E. coli* or *Photobacterium phosphoreum*	Ames *et al.* 1975 or Environmental Biodetection Products Inc. 1992 or Microbics Corp. 1991

a. For Canadian receiving environment locations where fathead minnows are not an indigenous species, a salmonid species must be used.

- Analysis of tissue levels of chlorinated dioxins and furan congeners on edible portions of fish. Pulp mills which use, or have used, chlorine bleaching must analyze one composite sample of ten individuals of a single-species of commercial or recreational importance from a near-field area and one similar composite sample from a reference area. The congeners and QA/QC are specified.

Monitoring requirements for subsequent cycles of EEM are based on the results of the first cycle. Environment Canada and Department of Fisheries and Oceans (1992) summarized possible requirements (Table 4) based on examples of potential effects.

Table 4: Monitoring Requirements for Subsequent Cycles of EEM Based on Examples of Potential Effects[a]

Effect	Variables
Any or no detected effects.	Repeat requirements of first cycle employing statistically-based design.
Significant increases in fish weight, length, reproductive capacity, etc. in exposure area relative to reference area indicating habitat enrichment.	Incorporate far-field sampling site in adult fish survey and/or establish further appropriate fish population studies. Eutrophication tests selected from algal, periphyton surveys, measures of primary productivity. Others
Significant decreases in fish weight, length, reproductive capacity, or reduced availability or absence of fish in exposure area relative to reference area suggesting toxic effects.	Incorporate far-field sampling site in adult fish survey and/or establish further appropriate fish population studies. *In situ* or laboratory toxicity tests to assess direct effects on fish as selected from fish early life stage development test, invertebrate reproduction test, and *in situ* fish lethality test. Others
Significant changes in invertebrate community structure, species dominance or biomass in exposure area relative to reference area(s) suggesting organic enrichment of sediments.	Sediment enrichment tests or variables selected from organic carbon, redox potential, chemical/physical characterization of sediment. Others
Significant changes in invertebrate community structure, species dominance or biomass in exposure area relative to reference area(s) suggesting toxic conditions in sediments.	*In situ* or laboratory tests to assess effects on habitat or indirect effects on fish as selected from invertebrate survival and growth, and amphipod survival. Other sediment toxicity tests.
Accumulation of chemicals in fish tissues at, or approaching, levels prejudicial to human health or utilization of the resource.	Expansion of sampling for dioxins and furans in tissue. Assessment of sediment contamination by dioxins. Others.

a. from Environment Canada and Department of Fisheries and Oceans 1992.

2.3 MONITORING

2.3.1 Government

2.3.1.1 Summaries of Past Monitoring

A water quality overview of the Athabasca River basin was prepared for Alberta Environment in 1985 (Hamilton *et al.* 1985). This was followed by a special study of the winter water quality of the Athabasca River system in 1988 and 1989 by Alberta Environment in response to rapid expansion in the pulp mill industry (Noton and Shaw 1989). Noton (1989, 1990b, Alberta Environment 1993a) continued to address issues related to nutrients in the Athabasca River. The monitoring summarized in these reports is more applicable to the *Contaminants in Aquatic Ecosystems - Synthesis Report* and will not be addressed further in this report.

A number of water quality investigations have been carried out by Alberta Environment on the Wapiti-Smoky River system since the 1983 survey reported by Noton *et al.* (1989). Winter synoptic surveys of water quality were undertaken in March 1989, February to March 1990 and February to March 1991 (Noton 1992a) for the Wapiti-Smoky Rivers. The water quality surveys include sampling of effluents and important tributaries, as well as the mainstem rivers. Except for the October 1989 survey, the sampling progressed downstream at approximately river time-of-travel. The Grande Prairie STP generally discharges for two weeks out of four. The water quality surveys were timed to coincide with the effluent discharge during the 1989-91 work (Noton 1992a). During the late fall and winter of 1990-91 and 1991-92, surveys were conducted on the Wapiti River to assess water quality conditions and effects on zoobenthos when bleached kraft mill effluent (BKME) from the Weyerhaeuser mill comprised 3% to 4% of the river's flow.

An initial overview of the water quality of the Peace River in Alberta was prepared by IEC Beak Consultants Ltd. (1985). The impact of pulp mills on the mainstem of the Peace River was evaluated by Noton and Shaw (1989). The effect of the abandoned Peace River Oils No. 1 flowing well was also evaluated by Alberta Environment (1989). Alberta Environment conducted a one year survey in 1988-89 (Shaw *et al.* 1990) collecting benthic invertebrates at many sites along the mainstem and water samples from ten sites on the mainstem, ten sites on the tributaries and six effluents. Shaw *et al.* (1990) evaluated the water quality data for the mainstem to assess mixing of the Peace and Smoky Rivers, evaluate seasonal, long-term and longitudinal trends in water quality, assess the impact of point and non-point sources on water quality in the mainstem and compare the water quality against objectives and guidelines. Shaw *et al.* (1990) focused primarily on data from one synoptic survey conducted on the Peace River in September-October 1988; its prime objective was to document major longitudinal trends in the river's zoobenthos. These surveys are not directly relevant to pulp mill effluent effects and, therefore, this report.

In a July 20, 1988 news release, the Environment Minister released the results of a preliminary program to test for the presence of dioxins in liquid effluents and sludges from the two kraft pulp mills operating in Alberta at that time and from the rivers downstream of the mills. The investigation involved the analysis of 22 samples, but the Minister indicated that a more comprehensive database was being assembled through the National-Provincial Task Force.

2.3.1.2 Present Monitoring Program[3]

At present, Alberta Environmental Protection collects surface water quality information to support the department's regulatory, water management and environmental assessment functions. This involves mainly the analysis of water samples, but also includes a certain amount of analyses of sediment quality, contaminants in aquatic biota, community analysis of benthos and plankton and bioassays.

Water quality monitoring and studies on northern rivers of relevance to ecotoxicity can be grouped into three categories:

Network of Monitoring Sites This network includes long-term sites, which are monitored monthly, and medium-term sites, which are monitored six times per year. Alberta Environmental Protection operates four long-term sites, and Environment Canada operates several more. Some of these have been in place for more than 80 years. Alberta Environmental Protection also operates 13 medium-term sites, which have been implemented in the last six years in response to continuing developments in the pulp industry. All of these sites are sampled for a wide range of parameters, including (at varying frequency) temperature, oxygen, major ions and related parameters, metals, nutrients, organics, trace organic priority pollutants, pesticides, AOX, chlorinated phenolics and resin acids. Three extra sites in the north are also monitored for pesticides by the department's Pesticide Management Branch. Toxicity testing is not included at long-term and medium-term sites.

Surveys and Assessments River reaches with significant or expanding development are subject to more intensive surveys to assess any impacts of the development. Coal mines, pulp mills, oil sands operations and sewage treatment plant effluents have been surveyed. The surveys may include sampling of water quality, sediment quality and river biota. The latter has involved extensive use of community analysis of zoobenthos to assess effects. From time to time, surveys are also implemented for whole or partial river systems to document existing water quality and factors influencing it (as described in section 2.3.1.1). These may be compiled and reported as water quality overviews for the river in question. Detailed investigations are also sometimes implemented to address specific information needs.

Athabasca River Winter Synoptic Survey An annual water quality survey has been conducted since 1989, from upstream of Hinton to Lake Athabasca, during the critical ice-covered, low-flow period. The survey progresses at the river's time-of-travel, and includes about 60 mainstem, tributary and effluent sampling sites. The purpose is to obtain data for impact assessment and protection planning, particularly with respect to the pulp and paper industry. The synoptic surveys do not include acute or chronic bioassays. An NRBS study did try to coordinate a zoobenthic and fish MFO study with the synoptic survey in 1993 (Leigh Noton, pers. comm.).

2.3.1.3 Future Monitoring Plans[4]

The long-term monitoring sites will be maintained for the foreseeable future, while the medium-term sites will be maintained for a period sufficient to allow understanding of the issues they are addressing. In most cases this is potential pulp mill impact, and pending the findings of the NRBS, some of these sites may be discontinued in 2-3 years. The monitoring variables and frequency at all

3 The description of the present monitoring program has been provided by Leigh Noton, Alberta Environmental Protection.

4 The description of future monitoring plans has been provided by Leigh Noton, Alberta Environmental Protection.

sites are subject to review as new information and needs arise. Surveys and assessments will continue on an "as required" basis. Potentially, some recommendations of the NRBS could be addressed by such work. The winter synoptic survey on the Athabasca River will be carried out one more year (winter 95-96) which will give three winter surveys with the last new pulp mill in operation. At that point, the need for the synoptic survey will be reviewed.

2.3.2 <u>Industrial</u>

Each pulp mill conducts the effluent monitoring and biomonitoring (benthic invertebrate monitoring) required by their Approvals as described earlier in section 2.2.2, as well as receiving stream monitoring, such as winter water quality monitoring, that is not directly relevant to ecotoxicity and, therefore, not described in section 2.2.2. Beyond this level of effort, some mills have conducted special studies, but only the Slave Lake Pulp Corporation and the Alberta-Pacific Forest Industries Inc. mills developed comprehensive monitoring programs related to ecotoxicity that go well beyond the license requirements.

2.3.2.1 Slave Lake Pulp Corporation

The SLPC environmental monitoring program was designed to address a series of data gaps identified during the EIA process. The program consists of a set of baseline surveys followed by instream monitoring of the Lesser Slave River during mill operations.

Baseline studies were conducted in 1989 and 1990, and included monitoring water and sediment chemistry, diurnal dissolved oxygen, bacteria (total and fecal coliform), periphyton (chlorophyll *a* and species identification), benthic invertebrates and fish (longnose sucker and white sucker population data, male and female growth, condition, gonad weight, egg weight, liver weight, fecundity and age). In addition to the primary data collection, information on river hydrology and habitat was compiled in order to collate all information on the Lesser Slave River into a single source. A sentinel fish monitoring framework known as PISCES (Population Indicators of Sublethal Contaminant Effects on Suckers) (Munkittrick and Dixon, 1989a,b) was initiated to assess effects of mill effluent on fish population in the Lesser Slave River. Although, the benthic invertebrate monitoring was common to other mills, the sentinel fish monitoring and other components, such as periphyton species identification, extend beyond that done elsewhere.

2.3.3.3 Alberta-Pacific Forest Industries Inc.

To address information deficiencies identified during the EIA review process, Alberta-Pacific commissioned a baseline monitoring study in the reach of the Athabasca River from the Town of Athabasca downstream to Grand Rapids, a distance of approximately 257 km. The objective of the study was to develop a complete database on the aquatic resources of the study area that would meet all regulatory requirements and serve as a reference for future operational monitoring programs.

The baseline monitoring commenced in April 1991 and continued until mill start-up in 1993, (SENTAR, 1994) using a flexible approach which allowed the study scope to be reviewed and optimized as data became available. The study components and the methods used to collect information about each are outlined in Table 5.

Table 5: Baseline Monitoring Program Conducted by Alberta-Pacific Forest Industries Inc.

Study Component	Study Methods
Aquatic Habitat	–Aquatic habitat surveys throughout the study area
Water Quality	–Field measurements during aquatic habitat surveys
	–Regular seasonal water quality sampling
	–Laboratory analysis including AOX, dioxins and furans, chlorinated phenolics, resin and fatty acids, and volatiles
Bottom Sediments	–Regular seasonal sampling at water quality stations
	–Laboratory analysis, including EOCI, dioxins and furans, chlorinated phenolics, resin and fatty acids, and volatiles
Suspended Sediments	–Seasonal sampling at water quality/bottom sediment stations
	–Laboratory analysis including EOCI, dioxins and furans, chlorinated phenolics, resin and fatty acids, and volatiles
Benthic Invertebrates	–Regular seasonal sampling on Athabasca River using quantitative techniques
	–Qualitative sampling in important tributary streams
	–Standard identification and analysis methods
Fisheries Resources	–Regular seasonal electrofishing surveys
	–Seining
	–Fish traps in tributary streams
	–Radio tracking of fish movements
	–Recaptures of tagged fish
	–Standard aging and data analysis methods
Fish Contaminants	–Analysis of fish fillets, liver tissue and bile for metals, EOCI, dioxins and furans, chlorinated phenolics, resin acids, volatile organics and PAHs
Fish Health	–Documentation of external damage and parasites
	–Histopathological examination of fish tissues
	–Fish liver detoxification systems studies
	–Analysis of blood concentrations of sex steroid indices and comparison with control fish
Fish Taste	–Taste test comparison of study area fish with each other and with control fish

2.3.2.3 Daishowa-Marubeni International Ltd.

A number of monitoring studies, both pre- and post-operational, have been completed by Daishowa-Marubeni International Ltd. In the fall of 1989, the mill commissioned a study to examine contaminant levels in northern pike flesh (Monenco Consultants Ltd. 1992c). Seven northern pike were analyzed for dioxins and furans, chlorinated phenols, fatty acids and resin acids.

A 1991 survey of chlorinated organics in water sediments, suspended solids and fish tissue from the Peace, Smoky and Slave rivers was conducted by Monenco Consultants Ltd. (1991) for the mill. A total of 154 fish (composite samples) of three species (walleye, goldeye and northern pike) were sampled from 110 km upstream to 700 km downstream of the mill site. The study area on the Peace River extended from Dunvegan to Peace Point. One sampling station was located on the Smoky river near the Confluence and two were located on the Slave River (Hay Camp and Fort Smith). The study included age estimates but did not include indicators of chronic effects related to growth or reproduction.

2.4 SPECIAL STUDIES

2.4.1 <u>Pulp Mills</u>

2.4.1.1 Procter & Gamble Cellulose Ltd.

The largest special study in the NRBS area was a two and one-half year, multidisciplinary study of the Wapiti/Smoky River ecosystem initiated by Procter & Gamble Cellulose Ltd. at what is now the Weyerhaeuser Canada Ltd. bleached kraft pulp mill at Grande Prairie (SENTAR, 1993c). This work was complemented by the mill's ongoing benthic invertebrate monitoring program. Major sampling efforts occurred in the summer and fall of 1990, and the spring, summer and fall of 1991. Supplemental sampling for specific parameters took place in the spring and fall of 1992. This study spanned the period from immediately before 70% chlorine dioxide substitution (July 1990) to just prior to implementation of 100% substitution (spring of 1992). Limited supplementary sampling took place in the fall of 1992, after 100% substitution.

The study covered a 300 km stretch of the Wapiti/Smoky River system, ranging fro 65 km upstream of the mill to the mouth of the Smoky River, 230 km downstream of the mill. In addition, the upper North Saskatchewan River above Rocky Mountain House, Alberta was used as the reference reach for the fisheries portion of the study.

The study concentrated on three fundamental questions about the effects of pulp mill effluents on the aquatic environment. First, "where do chlorinated organic compounds go in food chains and how far downstream are these compounds transported?". Chlorinated organic compounds were investigated because some chlorinated organics accumulate in aquatic organisms and some are toxic. Second, "are the fish healthy and have fish populations been affected?". Third, "has the effluent reduced the quality of the habitats in the river such that they are no longer suitable for fish?". The second and third questions express general concerns about ecosystem-level impacts from pulp mill effluents. These impacts may be direct or indirect and may not be immediately apparent.

The focus was on examining possible cause and effect relationships by gathering concurrent data on contaminants in the aquatic environment including contaminant body burdens and health/population response parameters. This allowed direct examination of the question "is chemical concentration x correlated with biological effect y?". The degree of integration in this study is unique in the NRBS area. Researchers rarely have the resources to obtain a full suite of chemical and biological data at the same time and place, especially over several seasons.

In the contaminants portions of the study, water, bottom sediments, suspended sediments, fish and insects were collected for analysis of an extensive list of substances, including metals and chlorinated organic compounds. Mountain whitefish (*Prosopium williamsoni*) and longnose sucker (*Catostomus catostomus*) were the main fish species examined for contaminants.

The "effects" portion of the study included investigations of both individual fish health and overall fish populations. Studies of the health of individual fish included activity of liver enzymes [i.e. induction of the enzyme ethoxyresorufin-O-deethylase (EROD)], both gross and microscopic (histopathological) incidence of disease, blood chemistry, blood cell counts and circulating reproductive hormone levels. Population studies included examination of relative abundance, seasonal distribution, age distribution, condition (the relative "plumpness"), growth, mortality, age-to-maturity, fecundity (number of eggs produced), relative gonad size and recruitment of young into the population.

Mountain whitefish and longnose suckers were examined for several exposure and health indicators (biomarkers). The activation of particular liver enzymes indicates exposure to certain hydrophobic (non-water soluble compounds, including chlorinated organics). A subsample of fish analyzed for biomarkers was also analyzed for contaminants. In addition, general fish population data were collected from the biomarker fish. Thus, a set of data representing exposure, individual health effects and fish population effects was available for the same time and place in the same fish. This allows examination for correlation among several different measures of exposure and effects and establish this study as a landmark ecotoxicity study for the NRBS area.

2.4.1.2 Paprican and Alberta Newsprint Company

The chronic effects of secondary-treated effluent from the ANC thermomechanical pulp (TMP) mill were assessed by Paprican (Kovacs *et al.* 1994 manuscript) by means of long-term and short-term laboratory toxicity tests. In the long-term test, the effects of the effluent on the life cycle of fathead minnows (*Pimephales promelas*) were studied beginning with the egg stage and continuing through to sexual maturity and reproduction. The fish were exposed in the laboratory to well water (control) and five concentrations (1.25%, 2.5%, 5%, 10% or 20%) of effluent for 202 days. The study examined:

- hatching of the eggs,
- mortality, weight, length, gonad size, gender balance and reproduction of the hatched fish,
- the prevalence of gross morphological and histopathological changes, and
- the hatchability of the first generation eggs.

Two short-term sublethal chronic tests of the effluent, each lasting seven days, were also performed: the survival/growth of minnow larvae and the survival/reproduction of *Ceriodaphnia*.

2.4.2 NRBS

The NRBS is involved in many special studies; some of these address data gaps identified in this report. Many other studies are nearing completion; however, they were not available for incorporation in this report.

3.0 TOXICITY OF PULP MILL EFFLUENTS

3.1 ACUTE TOXICITY

3.1.1 Results

The data presented in this section have been supplied to SENTAR by the pulp mills directly. Each mill supplied hardcopy data summaries with varying amounts of detail from the voluminous quantity of toxicity reports that they receive from the laboratories. The data have been summarized further to a common format that would accommodate most of the data.

Data from the mills are sent to Alberta Environmental Protection where a compliance database showing pass or fail is maintained. An electronic copy of this database was supplied to SENTAR from which Appendix B was prepared.

3.1.1.1 Historical Data

A study dealing specifically with the toxicity of the Weldwood of Canada Ltd. mill's effluent was published by Environment Canada (Sergy and Ruggles, 1975). Four waste streams were tested for their acute toxicity. The lagoon stream was the least toxic with an LC_{50} of between 60-80% whole effluent. This stream did not show a reduced pH. The acid stream, as indicated by its name, was the most acidic with a pH of 1.9. Bioassays were performed with neutralized effluent to determine if any other toxic elements were present. Lethal responses were observed at every concentration tested down to 20% effluent. The barkpile runoff had an LC_{50} of 40% effluent. The final effluent showed an LC_{50} of 65% effluent concentration. The researchers strongly suspected that low pH was responsible for the majority of the toxicity observed, although no data was available to confirm this. They also did not discount the possible additive or synergistic toxicity of compounds such as sulphides (0.04-0.14 mg/L), resin acids (5.2-61.9 mg/L), phenols (0.245-2.6 mg/L) and zinc (0.03-3.6 mg/L). Substantial improvements in waste treatment have occurred at this mill since 1975. This report is of historical interest only; however, it provides a comparison of historical findings to present trends.

3.1.1.2 Recent Data

As part of their license agreement, pulp mills are required to conduct acute toxicity bioassays using standard protocols defined by Alberta Environmental Protection (see also section 2.2.2.6). Rainbow trout 96-h LC_{50} at 100% effluent is generally conducted once a month. In the event of mill failure (LC_{50} <100%), mills may conduct additional tests to ascertain the problem. *Daphnia magna* 48-h LC_{50} at 100% effluent is also a standard protocol test, which up until November 1992, was also conducted on a monthly basis. After November 1992, these tests were required to be conducted on a weekly basis. Again, if failures occurred (LC_{50} <100%), additional tests were done by the mill.

Alberta-Pacific Forest Industries Inc. mill has passed all acute toxicity tests for rainbow trout since start-up in August 1993 (Table 6). One *Daphnia magna* failure (LC_{50} = 22%) occurred during start-up on August 30, 1993 (Table 7). However, pulp mills are generally allowed a window of compliance during mill start-up. Tests were subsequently conducted bi-weekly for the month of September with no failures occurring. Also, as a result of the failure of the *Daphnia magna* test in August 1993, three trout bioassays were conducted on different dates in September with no failures.

Table 6: Acute Toxicity Bioassay Results for Final Effluent from Alberta-Pacific Forest Industries Inc. from 1993 to 1995 (rainbow trout 96-h LC_{50} at 100% effluent)

Month	1993 No. of Tests	1993 Lab[a]	1993 No. of Failures	1994 No. of Tests	1994 Lab[a]	1994 No. of Failures	1995 No. of Tests	1995 Lab[a]	1995 No. of Failures
January				1	H	0	1	H	0
February				1	H	0	1	H	0
March				1	H	0			
April				1	H	0			
May				1	H	0			
June				1	H	0			
July				1	H	0			
August	1	N	0	1	H	0			
September	3	N	0	1	H	0			
October	1	H	0	1	H	0			
November	1	H	0	1	H	0			
December	1	H	0	1	H	0			
Total	7		0	12		0	2		0

a. H = HydroQual Laboratories Ltd.; N = Norwest Labs
Data provided by Alberta-Pacific Forest Industries Inc.

Table 7: Acute Toxicity Bioassay Results for Final Effluent from Alberta-Pacific Forest Industries Inc. from 1993 to 1995 (*Daphnia magna* 48-h LC_{50} at 100% effluent)

Month	1993 No. of Tests	1993 Lab[a]	1993 No. of Failures	1994 No. of Tests	1994 Lab[a]	1994 No. of Failures	1995 No. of Tests	1995 Lab[a]	1995 No. of Failures
January				4	H	0	5	H	0
February				3	H	0	4	H	0
March				6	H	0			
April				4	H	0			
May				5	H	0			
June				4	H	0			
July				4	H	0			
August	4	N	1	5	H	0			
September	8	N	0	4	H	0			
October	4	H	0	5	H	0			
November	6	H	0	4	H	0			
December	4	H	0	3	H	0			
Total	26		1	51		0	9		0

a. H = HydroQual Laboratories Ltd.; N = Norwest Labs
Data provided by Alberta-Pacific Forest Industries Inc.

Alberta Newsprint Company Ltd. (ANC) routinely splits effluent samples and sends samples to two different laboratories each month. ANC failed trout toxicity testing in only one sample on September 9, 1991 (Table 8). However, duplicate sample of the effluent sent to a second laboratory was found to be non-toxic. All subsequent trout bioassays have passed. *Daphnia magna* failures have only occurred twice in the operation of the mill (Table 9).

During the start-up period (July 1990), the Daishowa-Marubeni International Ltd. pulp mill experienced acute toxicity as indicated by two trout bioassay failures (Table 10). Subsequent testing showed no mortality. A third failure occurred a little over one year later (September 4, 1991). Since that time, 1992-1994, there have been no rainbow trout bioassay failures of the mill effluent. One

Daphnia magna failure occurred over the five years of testing. The failure occurred on December 15, 1994 (Table 11). Subsequent testing showed no additional mortality.

Millar Western pulp mill started operations in August of 1988. During the first two years, particularly 1989, the mill experienced significant numbers of failures in their trout bioassays (Table 12). These bioassay failures were attributed to high levels of total ammonia in the effluent. Increases in pH levels over 96 hours, typical of standard protocol testing, caused an increase in un-ionized ammonia. From February 1991 onward, failure rates decreased to four in over 107 bioassays (Table 12). Those that did occur were determined to be the result of deviations in tests between laboratories, rather than mill operations. Due to differences in laboratory results for the same effluent sample, Millar Western routinely splits each effluent sample between two laboratories each month; thereby doubling the amount of testing done.

Results from *Daphnia magna* acute toxicity bioassays have been recorded since 1991 (Table 13). Until 1994, the ratio of test failures to number of tests was minimal and was determined to be the result of ammonia toxicity. In 1994, the failure rate increased to 25%. The mill is currently investigating the cause. In view of the fact that trout results show no mortality, mill authorities have suggested that severe nutrient deficiency although no data exist with which to confirm this suggestion.

Data from rainbow trout bioassays of Slave Lake Pulp Corporation (SLPC) effluent are available for 1991 through 1994 (Table 14). There has been one failure out of a total of 104 rainbow trout bioassays in the last two years. This failure can be attributed to the laboratory since only one of the split samples of the effluent failed. Failure rates for trout bioassays were highest in 1992. All failures are attributed to ammonia toxicity. However, some of the failures may result, in part, from pH shifts during standard protocol tests. SLPC is a CTMP mill with a high pH effluent which causes a pH shift in the static test vessel during the bioassay. The failures of standard protocol tests were twice the number of failures in tests where pH was maintained. SLPC routinely has four bioassays done each month. The effluent sample is split between two laboratories and each laboratory runs both a standard protocol test and a pH controlled test.

Daphnia magna data are available for 1993 and 1994 only (Table 15). Out of a total of 195 *Daphnia magna* tests, 26 (7.5%) failures have occurred.

Table 8: Acute Toxicity Bioassay Results for Final Effluent from Alberta Newsprint Company Ltd. from 1990 to 1994 (rainbow trout 96-h LC_{50} at 100% effluent)

Month	1990			1991			1992			1993			1994		
	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures
January				1	B	0	2	B, C	0	3	B, N	0	2	C, N	0
February				1	B	0	2	B, C	0	2	B, N	0	2	C, N	0
March				1	B	0	2	B, C	0	2	B, N	0	2	C, N	0
April				1	B	0	2	B, C	0	2	C, N	0	2	C, N	0
May				1	B	0	2	B, C	0	2	C, N	0	2	C, N	0
June				1	B	0	2	B, C	0	2	C, N	0	2	C, N	0
July	1		0	1	B	0	2	B, C	0	2	C, N	0	2	C, N	0
August	1		0	2	B, C	0	2	B, H	0	2	C, N	0	2	C, N	0
September	1		0	4	B, C	1	2	B, C	0	2	C, N	0	2	C, N	0
October	1		0	2	B, C	0	2	B, C	0	2	C, N	0	2	C, N	0
November	1		0	2	B, C	0	2	B, C	0	2	C, N	0	2	C, N	0
December	1		0	2	B, C	0	2	B, C	0	2	C, N	0	2	C, N	0
Total	6		0	19		1	24		0	25		0	24		0

a. B = Beta Research Labs Ltd.; C = Chemex Labs Alberta Inc.; H = HydroQual Laboratories Ltd.; N = Norwest Labs

Data provided by Alberta Newsprint Company Ltd.

Table 9: **Acute Toxicity Bioassay Results for Final Effluent from Alberta Newsprint Company Ltd. from 1990 to 1994 (*Daphnia magna* 48-h LC_{50} at 100% effluent)**

Month	1990			1991			1992			1993			1994		
	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures
January				1	B	0	2	B, C	0	5	B, N	1	2	C, N	0
February				1	B	0	2	B, C	0	5	B, N	0	2	C, N	0
March				1	B	0	2	B, C	0	5	B, N	0	2	C, N	0
April				1	B	0	2	B, C	1	6	C, N	0	2	C, N	0
May				1	B	0	2	B, C	0	5	C, N	0	2	C, N	0
June				1	B	0	2	B, C	0	5	C, N	0	2	C, N	0
July	1		0	1	B	0	2	B, C	0	5	C, N	0	2	C, N	0
August	1		0	2	B, C	0	2	B, H	0	6	C, N	0	2	C, N	0
September	1		0	4	B, C	0	2	B, C	0	5	C, N	0	2	C, N	0
October	1		0	2	B, C	0	2	B, C	0	6	C, N	0	2	C, N	0
November	1		0	2	B, C	0	2	B, C	0	5	C, N	0	2	C, N	0
December	1		0	2	B, C	0	2	B, C	0	5	C, N	0	2	C, N	0
Total	6		0	19		0	24		1	63		1	24		0

a. B = Beta Research Labs Ltd.; C = Chemex Labs Alberta Inc.; H = HydroQual Laboratories Ltd.; N = Norwest Labs

Data provided by Alberta Newsprint Company Ltd.

Table 10: Acute Toxicity Bioassay Results for Final Effluent from Daishowa-Marubeni International Ltd., Peace River Pulp Division from 1990 to 1994 (rainbow trout 96-h LC_{50} at 100% effluent)

Month	1990			1991			1992			1993			1994		
	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures
January				1	CG	0	1	CG	0	1	H	0	1	H	0
February				1	CG	0	1	CG	0	1	H	0	1	H	0
March				1	CG	0	2	CG	0	1	H	0	1	H	0
April				1	CG	0	1	CG	0	1	H	0	1	H	0
May				1	CG	0	1	CG	0	1	H	0	1	H	0
June				1	CG	0	1	CG	0	1	H	0	1	H	0
July	3	CG, E	2	1	CG	0	1	CG	0	1	H	0	1	H	0
August	3	CG, E	0	1	CG	0	1	CG	0	1	H	0	1	H	0
September	1	CG	0	9	CG, H, C	1	1	H	0	1	H	0	1	H	0
October	1	CG	0	1	CG	0	1	H	0	1	H	0	1	H	0
November	1	CG	0	1	CG	0	1	H	0	1	H	0	1	H	0
December	1	CG	0	1	CG	0	1	H	0	1	H	0	1	H	0
Total	10		2	20		1	13		0	12		0	12		0

a. C = Chemex Labs Alberta Inc.; CG = C&G Labs; E = EVS Consultants Ltd.; H = HydroQual Laboratories Ltd.

Data provided by Daishowa-Marubeni International Ltd., Peace River Pulp Division.

Table 11: Acute Toxicity Bioassay Results for Final Effluent from Daishowa-Marubeni International Ltd., Peace River Pulp Division from 1990 to 1994 (*Daphnia magna* 48-h LC_{50} at 100% effluent)

Month	1990			1991			1992			1993			1994		
	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures
January				1	E	0	1	ET	0	4	H	0	4	H	0
February				1	E	0	1	H	0	4	H	0	4	H	0
March				1	E	0	1	H	0	5	H	0	5	H	0
April				1	E	0	1	H	0	4	H	0	4	H	0
May				1	E	0	1	H	0	4	H	0	4	H	0
June				1	E	0	1	H	0	4	H	0	5	H	0
July	1	E	0	1	E	0	1	H	0	5	H	0	4	H	0
August	1	E	0	1	E	0	1	H	0	4	H	0	4	H	0
September	1	E	0	2	E	0	1	H	0	4	H	0	5	H	0
October	1	E	0	1	E	0	1	H	0	5	H	0	4	H	0
November	1	E	0	1	E	0	4	H	0	4	H	0	4	H	0
December	1	E	0	1	H	0	4	H	0	5	H	0	7	H	1
Total	6		0	13		0	18		0	52		0	54		1

a. E = EVS Consultants Ltd.; ET = Enviro-Test Laboratories; H = HydroQual Laboratories Ltd.

Data provided by Daishowa-Marubeni International Ltd., Peace River Pulp Division.

Table 12: Acute Toxicity Bioassay Results for Final Effluent from Millar Western Pulp (Whitecourt) Ltd. from 1988 to 1994 (rainbow trout 96-h LC_{50} at 100% effluent)

Month	1988 No. of Tests	1988 Lab[a]	1988 No. of Fails	1989 No. of Tests	1989 Lab[a]	1989 No. of Fails	1990 No. of Tests	1990 Lab[a]	1990 No. of Fails	1991 No. of Tests	1991 Lab[a]	1991 No. of Fails	1992 No. of Tests	1992 Lab[a]	1992 No. of Fails	1993 No. of Tests	1993 Lab[a]	1993 No. of Fails	1994 No. of Tests	1994 Lab[a]	1994 No. of Fails
Jan				-	-	-	5	A, AEC	1	7	A, AEC, AQ, C	3	2	CG, C	0	2	CG, C	0	2	C, N	0
Feb				1	A	0	1	A	0	3	A, CG, C	0	2	CG, C	0	3	CG, C	0	2	C, N	0
Mar				2	A, CG	0	1	A	1	2	AEC, CG, C, EC	1	2	CG, C	0	2	CG, C	0	2	C, N	0
Apr				-	-	-	1	A	0	3	CG	0	2	CG, C	0	2	CG, C	0	2	C, N	0
May				2	A, CG	1	1	A	1	4	CG	0	2	CG, C	0	3	CG, C	0	2	C, N	0
June				1	CG	1	5	A, AEC, EC	3	1	CG	0	2	CG, C	0	2	CG, C	0	2	C, N	0
July				3	CG	3	5	A, AEC	0	2	CG	1	2	CG, C	0	2	CG, C	0	2	C, N	0
Aug	1	A	0	5	A, AEC	3	1	A	0	2	CG	0	2	CG, C	0	2	CG, C	0	2	C, N	0
Sept	1	A	0	2	A	2	3	A, AQ, EC	0	2	CG	0	2	CG, C	0	2	CG, C	0	2	C, N	0
Oct	1	A	0	1	A	1	2	A, AQ	0	3	CG	0	2	CG, C	0	2	CG, C	0	2	C, N	0
Nov	1	A	0	1	A	1	2	A, AQ	1	2	CG	0	2	CG, C	0	2	CG, C	0	2	C, N	0
Dec	-	A	-	2	A	2	3	A, AQ, C	0	2	CG	0	2	CG, C	0	9	CG, C	2	2	C, N	0
Total	4		0	20		14	30		7	33		5	24		0	33		2	24		0

a. C = Chemex Labs Alberta Inc.; CG = C&G Labs; E = EVS Consultants Ltd.; H = HydroQual Laboratories Ltd.
Data provided by Millar Western Pulp (Whitecourt) Ltd.

Table 13: Acute Toxicity Bioassay Results for Final Effluent from Millar Western Pulp (Whitecourt) Ltd. from 1991 to 1994 (*Daphnia magna* 48-h LC_{50} at 100% effluent)

Month	1991			1992			1993			1994		
	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures
January				1	C	0	4	C	0	4	C	0
February				1	C	0	6	C	2	4	C	1
March				1	C	0	7	C	0	10	C	6
April				1	C	0	5	C	0	7	C	1
May				1	C	0	6	C	0	4	C	0
June				1	C	0	5	C	0	4	C	0
July	1	C	0	1	C	0	4	C	0	9	C, N	2
August	1	C	0	1	C	0	5	C	0	5	C	0
September	1	C	0	1	C	0	4	C	0	6	C	2
October	2	C, EC	2	1	C	0	5	C	0	9	C	3
November	1	C	0	2	C	0	4	C	0	7	C	1
December	1	C	0	4	C	0	8	C	2	9	C	3
Total	7		2	16		0	63		4	78		19

a. C = Chemex Labs Alberta Inc.; EC = Environment Canada Labs; N = Norwest Labs

Data provided by Millar Western Pulp (Whitecourt) Ltd.

Table 14: Acute Toxicity Bioassay Results for Final Effluent from Slave Lake Pulp Corporation from 1991 to 1994 (rainbow trout 96-h LC_{50} at 100% effluent)

Month	1991			1992					1993					1994				
	No. of Tests	Lab[a]	No. of Fails	No. of Tests		Lab[a]	No. of Fails		No. of Tests		Lab[a]	No. of Fails		No. of Tests		Lab[a]	No. of Fails	
	SP		SP	SP	pH		SP	pH	SP	pH		SP	pH	SP	pH		SP	pH
January	1	C	0	2	1	C, CG	0	0	1	1	C	0	0	1	1	A	0	0
February	1	C	0	3	2	A, C, H	2	2	1	1	A	0	0	3	3	A, N	0	0
March	1	C	0	7	4	A, C, CG, H	5	1	2	2	A, C	0	0	2	1	A, C	0	0
April	1	C	0	15	15	A, C, CG	2	1	1	1	C	0	0	8	8	A, C	0	0
May	1	C	1	10	10	A, C, CG	3	2	2	1	C, N	0	0	2	2	A, C	0	0
June	4	C	2	4	4	C, CG	4	1	3	3	A, C	1	0	2	2	A, C	0	0
July	5	C	2	7	7	A, C, CG	3	2	2	2	A, C	0	0	2	2	A, N	0	0
August	2	C	0	3	3	C, CG	0	0	2	2	A, C	0	0	2	2	A	0	0
September	1	C	0	4	4	C, CG	0	0	1	1	A	0	0	2	2	A, N	0	0
October	1	C	0	4	4	C	0	0	2	2	A	0	0	2	2	A	0	0
November	1	C	0	1	1	C, CG	0	0	2	2	A, C	0	0	4	4	A, C	0	0
December	1	C	0	-	-	-	-	-	2	2	A, C	0	0	2	2	A	0	0
Total	20		5	60	55		19	9	21	20		1	0	32	31		0	0

a. A = Alpha Laboratory Services Ltd.; CG = C&G Labs; C = Chemex Labs Alberta Inc.; H = HydroQual Laboratories Ltd.; N = Norwest Labs

SP = Standard Protocol

Data provided by Slave Lake Pulp Corporation

Table 15: Acute Toxicity Bioassay Results for Final Effluent from Slave Lake Pulp Corporation from 1990 to 1994 (*Daphnia magna* 48-h LC_{50} at 100% effluent)

Month	1993			1994		
	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures
January	4	C	0	5	A, C	0
February	7	A, C, N	0	10	A, H	2
March	6	A, C	1	8	A, C, N	0
April	10	A, C, N	2	15	A, C, H	4
May	9	A, N	2	10	A, C, H	0
June	9	A, C	1	5	A, C	1
July	8	A, C	1	10	A, C	0
August	4	A	0	10	A, C	0
September	5	A	0	8	A, C, N	0
October	8	A	2	8	A, C	1
November	5	A	0	18	A, C	5
December	5	A	0	8	A, C	2
Total	80		9	115		15

a. A = Alpha Laboratory Services Ltd., C = Chemex Labs Alberta Inc.; H = HydroQual Laboratories Ltd.; N = Norwest Labs

Data provided by Slave Lake Pulp Corporation

The Weyerhaeuser Canada Ltd. mill at Grande Prairie experienced rainbow trout bioassays failures (Table 16) in December 1991 and January 1992. Weyerhaeuser conducted an intensive TIE of the effluent. Weyerhaeuser has not had a rainbow trout bioassay failure from February 1992 to 1995. Multiple *Daphnia magna* toxicity test failures also occurred in January 1993 (Table 17).

The data summaries for Weldwood Canada Ltd., Hinton Division, for both trout (Table 18) and *Daphnia magna* (Table 19) bioassays were derived from the EEM Pre-Design report. All acute toxicity tests have been non-toxic for both trout and *Daphnia magna* over the last five years. The exception was a *Daphnia magna* bioassay failure in May 1993.

3.1.2 Discussion

Four mills have effluent that has not been acutely toxic. Three mills (Millar Western, SLPC and Weyerhaeuser) have had significant failures of the rainbow trout bioassay at some time, although not recently. Where causes of the failures could be determined, they were attributed to concentrations of ammonia at elevated pH levels. In some cases, the cause of test failures is unknown. Two of the mills identified problems related to their strategy for toxicity control as summarized below.

The CTMP process creates an effluent with a moderately high pH level averaging 8.0 to 8.8. Due to the low water use, the effluent loses much of its pH buffering capacity. During the course of the 96-hour acute trout toxicity test, the pH of the solution rises to levels as high as 9.5. With this pH rise, the effluent can become toxic due to the equilibrium shift of the total ammonia in the solution. This equilibrium shift is the change of ammonium ion (NH_4+) to non-ionic free ammonia (NH_3). The pH rise is attributable mostly to the stripping of carbon dioxide by aeration of the effluent in the bioassay test vessel. The carbon dioxide is stripped via conversion of carbonate and bicarbonate in the effluent to carbon dioxide gas. The carbonate-bicarbonate system is the primary buffer in the effluent. The pH rise is also attributable to the creation of total ammonia through the decomposition of organic forms of nitrogen which are measured as total Kjeldahl nitrogen (TKN). The increased total ammonia works as a high pH ion causing the solution pH to rise. The increase in pH coupled with the increase in total ammonia during the 96-hour test combine to create a toxic effluent sample.

Table 16: Acute Toxicity Bioassay Results for Final Effluent from Weyerhaeuser Canada Ltd. from 1990 to 1995 (rainbow trout 96-h LC_{50} at 100% effluent)

Month	1990			1991			1992			1993			1994			1995		
	No. of Tests	Lab[a]	No. of Fails	No. of Tests	Lab[a]	No. of Fails	No. of Tests	Lab[a]	No. of Fails	No. of Tests	Lab[a]	No. of Fails	No. of Tests	Lab[a]	No. of Fails	No. of Tests	Lab[a]	No. of Fails
January				2	BK, H	0	34	BK, H	14	2	BK, H	0	2	BK, H	0	2	BK, H	0
February	1	H	0	1	H	0	30	BK, H	0	6	BK, H	0	2	BK, H	0	2	BK, H	0
March	1	H	0	1	H	0	12	BK, H	0	2	BK, H	0	2	BK, H	0	2	BK, H	0
April	1	H	0	1	H	0	1	H	0	2	BK, H	0	2	BK, H	0			
May	1	H	0	1	H	0	1	H	0	2	BK, H	0	2	BK, H	0			
June	1	H	0	1	H	0	1	H	0	2	BK, H	0	2	BK, H	0			
July	4	BK, H	1	1	H	0	2	BK, H	0	2	BK, H	0	4	BK, H	0			
August	1	H	0	1	H	0	2	BK, H	0	2	BK, H	0	2	BK, H	0			
September	1	H	0	1	H	0	2	BK, H	0	2	BK, H	0	2	BK, H	0			
October	1	H	0	1	H	0	2	BK, H	0	4	BK, H	0	2	BK, H	0			
November	1	H	0	1	H	0	2	BK, H	0	4	BK, H	0	2	BK, H	0			
December	4	BK, H	2	25	BK, H	15	2	BK, H	0	2	BK, H	0	2	BK, H	0			
Total	17		3	37		15	91		14	32		0	26		0	6		0

a. BK = Beak Consultants Ltd.; H = HydroQual Laboratories Ltd.

Data provided by Weyerhaeuser Canada Ltd.

Table 17: Acute Toxicity Bioassay Results for Final Effluent from Weyerhaeuser Canada Ltd. from 1990 to 1995 (*Daphnia magna* 48-h LC_{50} at 100% effluent)

Month	1990			1991			1992			1993			1994			1995		
	No. of Tests	Lab[a]	No. of Fails	No. of Tests	Lab[a]	No. of Fails	No. of Tests	Lab[a]	No. of Fails	No. of Tests	Lab[a]	No. of Fails	No. of Tests	Lab[a]	No. of Fails	No. of Tests	Lab[a]	No. of Fails
January				1	H	0	8	BK, H	0	11	BK, H	7	4	BK, H	0	4	BK, H	0
February				1	H	0	5	BK, H	0	13	BK, H	0	4	BK, H	0	4	BK, H	0
March				1	H	0	5	BK, H	0	5	BK, H	0	5	BK, H	0	1	H	0
April				1	H	0	1	H	0	4	BK, H	0	4	BK, H	0			
May				1	H	0	1	H	0	3	BK, H	0	4	BK, H	0			
June	1	H	0	1	H	1	1	H	0	5	BK, H	0	5	BK, H	0			
July	1	H	0	1	H	0	1	BK, H	0	4	BK, H	0	4	BK, H	0			
August	1	H	0	1	H	0	1	BK, H	0	4	BK, H	0	5	BK, H	0			
September	1	H	0	1	H	0	1	BK, H	0	5	BK, H	0	4	BK, H	0			
October	1	H	0	1	H	0	1	BK, H	0	4	BK, H	0	4	BK, H	0			
November	1	H	0	1	H	0	1	BK, H	0	5	BK, H	0	5	BK, H	0			
December	1	H	0	6	BK, H	2	4	BK, H	1	5	BK, H	0	4	BK, H	0			
Total	7		0	17		3	30		1	68		7	52		0	9		0

a. BK = Beak Consultants Ltd.; H = HydroQual Laboratories Ltd.

Data provided by Weyerhaeuser Canada Ltd.

Table 18: Acute Toxicity Bioassay Results for Final Effluent from Weldwood Canada Ltd., Hinton Division from 1990 to 1994 (rainbow trout 96-h LC_{50} at 100% effluent)

Month	1990			1991			1992			1993			1994		
	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures
January	1	H	0	1	H	0	1	H	0	1	H	0	1	H	0
February	1	H	0	1	H	0	1	H	0	1	H	0	1	H	0
March	1	H	0	1	H	0	1	H	0	1	H	0	1	H	0
April	1	H	0	1	H	0	1	H	0	1	H	0	1	H	0
May	1	H	0	1	H	0	1	H	0	1	H	0	1	H	0
June	1	H	0	1	H	0	1	H	0	1	H	0	1	H	0
July	1	H	0	1	H	0	1	H	0	1	H	0	1	H	0
August	1	H	0	1	H	0	1	H	0	1	H	0	1	H	0
September	1	H	0	1	H	0	1	H	0	1	H	0	1	H	0
October	1	H	0	1	H	0	1	H	0	1	H	0	1	H	0
November	1	H	0	1	H	0	1	H	0	1	H	0	1	H	0
December	1	H	0	1	H	0	1	H	0	1	H	0	1	H	0
Total	12		0	12		0	12		0	12		0	12		0

a. H = HydroQual Laboratories Ltd.

Data provided by Weldwood Canada Ltd., Hinton Division

Table 19: Acute Toxicity Bioassay Results for Final Effluent from Weldwood Canada Ltd., Hinton Division from 1990 to 1994 (*Daphnia magna* 48-h LC_{50} at 100% effluent)

Month	1990			1991			1992			1993			1994		
	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures	No. of Tests	Lab[a]	No. of Failures
January	1	H	0	1	H	0	1	H	0	1	H	0	1	H	0
February	1	H	0	1	H	0	1	H	0	1	H	0	1	H	0
March	1	H	0	1	H	0	1	H	0	1	H	0	1	H	0
April	1	H	0	1	H	0	1	H	0	1	H	0	1	H	0
May	1	H	0	1	H	0	1	H	0	1	H	0	1	H	0
June	1	H	0	1	H	0	1	H	0	1	H	0	1	H	0
July	1	H	0	1	H	0	1	H	0	1	H	0	1	H	0
August	1	H	0	1	H	0	1	H	0	1	H	0	1	H	0
September	1	H	0	1	H	0	1	H	0	1	H	0	1	H	0
October	1	H	0	1	H	0	1	H	0	1	H	0	1	H	0
November	1	H	0	1	H	0	1	H	0	1	H	0	1	H	0
December	1	H	0	1	H	0	1	H	0	1	H	0	1	H	0
Total	12		0	12		0	12		0	12		0	12		0

a. H = HydroQual Laboratories Ltd.

Data provided by Weldwood Canada Ltd., Hinton Division

SLPC believes that this phenomena is characteristic of CTMP effluents during this test and is not indicative of conditions in the river environment which is buffered. If the reason for the trout test is that it tests for a possible acute effect upon organisms in the river environment, then the test is meant to simulate the ability of trout to survive for 96 hours in effluent as it is discharged to the receiving stream. The purpose is not to test the ability of trout to survive in effluent as it changes over a 96-hour period in a small laboratory test vessel. SLPC believes that the bioassay should relate to conditions that would occur in the receiving stream given dilution, aeration and river water buffering.

The pH maintained trout bioassay protocol used by SLPC involves pH control of the bioassay to the initial conditions of the effluent. In this manner, the sample is corrected for pH periodically during the test to the pH value first measured upon receipt of the sample by the laboratory. At 0, 24, 48 and 72-hours, an aliquot of each test concentration is removed, the pH measured, and the required amount of 1N hydrochloric acid added to each tank to return the pH to the initial measured value. If no pH rise occurs, no acid addition is performed. Thus, the effluent is similar in characteristics throughout the test to effluent that is being discharged to the Lesser Slave River.

The control strategy for nutrients has changed significantly at Millar Western and continues to develop. Millar-Western recently purchased a Dionex Ion Chromatograph to measure ammonia residuals in the system. The mill now tries to maintain 0 ppm to 0.5 ppm of ammonia nitrogen because levels over 1.0 ppm result in ammonia toxicity to rainbow trout. This toxicity is due to the highly alkaline effluent. Carbon dioxide is stripped off during the bioassay and the pH rises from about 8.5 to above 9.0, as already discussed. Millar-Western believes that the standard test protocol does not represent conditions that are relevant beyond the confines of the static test vessel. To meet the legal requirements of their approval, the mill is forced to run the wastewater treatment system nutrient deficient. If poor treatment occurs, it could jeopardize the reduction in BOD and TSS levels in the final effluent, the primary purpose of the secondary treatment. Millar Western investigated the *Daphnia magna* toxicity and believes it is related to extreme nutrient deficiency.

Because passing the rainbow trout bioassay is a condition of their Environmental Protection and Enhancement Act Approval, the failure of any bioassay has important legal implications. To protect themselves from false test failures (i.e. an apparent failure in a non-toxic effluent), four pulp mills (SLPC, Weyerhaeuser, Millar Western, ANC) split effluent samples each month and send portions of the sample to two different laboratories and sometimes three laboratories (Brian Steinback pers. comm.). Recent experience has shown that laboratory problems such as unhealthy fish are not always detected by the reference toxicant. In September 1991, the effluent from two different pulp mills (ANC, Daishowa-Marubeni) sent to the same laboratory failed the bioassay, while the other portion of each sample sent to other laboratories caused no mortality.

3.2 CHRONIC/SUBLETHAL TOXICITY TESTING

3.2.1 Introduction

Today, effluents from most North American pulp mills undergo secondary treatment before being discharged into the aquatic environment and generally are not lethal to aquatic species at 100% concentration (Expert Panel 1994). Thus, emphasis has more recently been directed at identifying the causal agents of nonlethal effects, including alterations in growth and reproduction, developmental effects, teratogenicity, biochemical alternations, and changes in population diversity, that have been reported in aquatic species downstream of bleached and nonbleached kraft mill effluent discharges (although not necessarily in Alberta).

Environment Canada's EEM guidelines outline a series of protocols to be used throughout the course of chronic or sublethal toxicity testing. These typically involve the evaluation of growth data for organisms exposed to effluent concentrations that did not cause a significant reduction in survival. The highest concentration at which no observable effects on growth are observed (NOEC) and the lowest concentration at which growth is affected (LOEC) should be identified. According to the guidelines, these can then be used to determine the threshold effect concentration (TEC): that concentration above which an effect on survival or growth may be expected.

3.2.2 Results

Summaries of chronic toxicity reports provided to SENTAR by the seven pulp mills were highly varied in both presentation and composition of data (see Tables 20 - 25). At the time of writing, chronic toxicity data were unavailable from the Millar Western pulp mill. Mills are not required to submit this EEM data until the end of the first cycle; therefore, the data provided at this time is preliminary. Some mills have not completed the first cycle.

Table 20: Summary of Chronic Toxicity Results (as % effluent) for the Alberta Newsprint Company Ltd. Effluent

		Date (month only)	NOEC
***Ceriodaphnia dubia* 7-day**	Mortality	March	>100
		June	100
	Reproduction	March	50
		June	25
Fathead Minnow 7-day	Mortality	March	100
		June	100
	Growth	March	100
		June	100
Algal Growth (*Selenastrum*)	Growth	March	12.5
72-hour		June	12.5

Summary data provided by Alberta Newsprint Company Ltd.

Table 21: Summary of Chronic Toxicity Results (as % effluent) for Alberta-Pacific Forest Industries Inc. Effluent

		Date (D-M-Y)	LC_{50}
***Ceriodaphnia dubia* 7-day**	Mortality	09-11-93	100
		23-11-93	100
		24-11-93	100
		02-03-93	80
		06-06-94	80
		06-09-94	100
Fathead Minnow 7-day	Mortality	09-11-93	100
		24-11-93	100
		02-03-94	100
		06-06-94	100
		09-06-94	100
		12-12-94	85
Algal Growth (*Selenastrum*)	Growth	09-11-93	100
72-hour		06-06-94	100
		06-09-94	86
		12-12-94	8.9[a]
		25-01-95	86

a Lab error

Summary data provided by Alberta-Pacific Forest Industries Inc.

Table 22: Summary of Chronic Toxicity Results (as % effluent) for the Daishowa-Marubeni International Ltd., Peace River Pulp Division

		Date (D-M-Y)	NOEC	LOEC	LC_{25}[a]		LC_{50}[a]	
Ceriodaphnia dubia	Mortality	23-09-92	100	NA	>100		>100	
7-day		09-03-93	100	NA	>100		>100	
		22-07-93	100	NA	>100		>100	
		01-12-93	100	NA	>100		>100	
		03-02-94	100	NA	>100		>100	
					IC_{25}		IC_{50}	
	Reproduction	23-09-92	6.25	12.5	6	(5-7)	9	(6-10)
		09-03-93	<6.25	6.25	5	(4-9)	14	(10-18)
		22-07-93	6.25	12.5	7	(4-15)	16	(-21)
		01-12-93	12.5	25	9.1	(5.9-10.5)	13.3	(11.1-15.5)
		03-02-94	12.5	25	23	(17-28)	37	(34-41)
Fathead Minnow					LC_{25}		LC_{50}	
7-day	Mortality	23-09-92	100	NA	>100		>100	
		03-09-93	100	NA	>100		>100	
		22-07-93	100	NA	>100		>100	
		26-10-93	100	NA	>100		>100	
		24-01-94	100	NA	>100		>100	
					IC_{25}		IC_{50}	
	Reproduction	23-09-92	100	NA	>100		>100	
		03-09-93	100	NA	>100		>100	
		22-07-93	100	NA	>100		>100	
		26-10-93	6.25	12.5	46	(35-50)	>100	
		24-01-94	100	NA	>100		>100	
Algal Growth					IC_{25}		IC_{50}	
(*Selenastrum*)	Growth	23-09-92	13	25	23	(21-25)	42	(39-45)
72-hour		03-09-93	50	100	45	(34-59)	>100	
		10-09-93	50	100	79	(67-93)	>100	
		27-07-93	3	6	9	(8-9)	21	(19-22)
		26-10-93	50	100	79	(70-91)	>100	
		24-01-93	100	NA	>100		>100	

a. 95% confidence limits bracketed.

Data for summary table provided by Daishowa-Marubeni International Ltd., Peace River Pulp Division

Table 23: Summary of Chronic Toxicity Results (as % effluent) for Slave Lake Pulp Corporation

		Date (D-M-Y)	NOEC	LOEC	LC_{25}	LC_{50}
Ceriodaphnia dubia	Mortality	23-02-94	12.5	25	15	26
7-day		21-04-94	25	50	39	56
		02-05-94	100	N/A	>100	>100
		08-07-94	50	100	41	63
		21-11-94	25	50	12	60
					IC_{25}	**IC_{50}**
	Reproduction	23-02-94	6.25	12.5	8	11
		21-04-94	12.5	25	17	22
		02-05-94	25	50	29	41
		08-07-94	12.5	25	15	20
		21-11-94	25	50	12	33
Fathead Minnow					**LC_{25}**	**LC_{50}**
7-day	Mortality	23-02-94	100	N/A	>100	>100
		21-04-94	100	N/A	>100	>100
		02-05-94	-	-	-	-
		08-07-94	100	N/A	>100	>100
		21-11-94	100	N/A	>100	>100
					IC_{25}	**IC_{50}**
	Growth	23-02-94	100	N/A	>100	>100
		21-04-94	50	100	97	100
		02-05-94	-	-	-	-
		08-07-94	100	N/A	>100	>100
		21-11-94	100	N/A	>100	>100
Algal Growth					**IC_{25}**	**IC_{50}**
(*Seleneastrum*)	Growth	23-02-94	6.25	12.5	4	10
72-hour		21-04-94	25	50	25	35
		02-05-94	-	-	-	-
		08-07-94	25	50	30	41
		21-11-94	25	50	44	71

Data for summary table provided by Slave Lake Pulp Corporation

Table 24: Summary of Chronic Toxicity Results (as % effluent) for Weldwood of Canada Limited, Hinton Division

		Date (D-M-Y)	NOEC	LOEC	LC_{25}[a]	LC_{50}[a]
Ceriodaphnia dubia	Mortality	03-08-93	100	NA	>100	>100
7-day		01-03-94	60	80	68 (40-75)	78 (77-79)
		28-06-94	60	80	64 (59-66)	70 (66-72)
		02-08-94	100	NA	>100	>100
		04-10-94	80	100	82 (68-95)	>100
					IC_{25}	**IC_{50}**
	Reproduction	03-08-93	80	100	79 (57-88)	>100
		01-03-94	60	81	54 (31-68)	69 (60-76)
		28-06-94	40	60	51 (45-55)	62 (56-65)
		02-08-94	20	40	41 (34-49)	56 (48-63)
		04-10-94	60	80	67 (54-71)	75 (80-82)
Fathead Minnow					**LC_{25}**	**LC_{50}**
7-day	Mortality	03-08-93	80	100	>100	>100
		01-03-94	100	NA	>100	>100
		28-06-94	100	NA	>100	>100
		02-08-94	100	NA	>100	>100
		04-10-94	100	NA	>100	>100
					IC_{25}	**IC_{50}**
	Growth	03-08-93	100	NA	>100	>100
		01-03-94	100	NA	>100	>100
		28-06-94	100	NA	>100	>100
		02-08-94	100	NA	>100	>100
		04-10-94	80	100	98 (92-100)	>100
Algal Growth					**IC_{25}**	**IC_{50}**
(*Selenastrum*)	Growth	03-08-93	100	>100	>100	>100
72-hour		01-03-94	6.25	12.5	14 (5-40)	>100
		28-06-94	100	>100	>100	>100
		02-08-94	25	50	>100	>100
		04-10-94	>100	NA	>100	>100

a. 95% confidence limits bracketed.
Summary data provided by Weldwood of Canada Limited, Hinton Division

Table 25: Summary of Chronic Toxicity Results (as % effluent) for Weyerhaeuser Canada Ltd., Grande Prairie Operations

		Date (D-M-Y)	NOEC	NOEC Duplicate	LOEC	LOEC Duplicate	LC_{25}[a]	LC_{25} Duplicate	LC_{50}[a]	LC_{50} Duplicate
Ceriodaphnia dubia 7-day	Mortality	09-12-92	>100				>100		>100	
		07-01-93	12.5		25		16		33	
		24-01-93	50		100		38		63	
		02-01-93	25		50		16		42	
		02-02-93	25		50		28		45	
		05-02-93	>100		>100		>100		>100	
		07-02-93	100		>100		>100		>100	
		09-02-93	100		>100		21		100	>100
		11-02-93	100		>100		>100		>100	>100
		14-02-93	50		100		22		35	>100
		16-02-93	100		>100		>100		>100	50
		18-02-93	100		>100		>100		>100	52.6
		21-02-93	100		>100		>100		>100	100
		23-02-93	100		>100		>100		>100	100
		26-02-93	100		>100		>100		>100	100
		01-03-93	100		>100		>100		>100	50
		03-03-93	100		>100		>100		>100	
		05-03-93							>100	
		08-03-93							>100	
		10-03-93							>100	
		01-12-93	50						>100	
		05-01-94	100						>100	
		02-02-94	100						>100	
		02-03-94	100						>100	
		08-11-94	100		>100					
		14-12-94	100						>100	
		04-01-95	100						>100	
		01-02-95	100						>100	
		01-03-95	100						>100	
							IC_{25}		IC_{50}	
	Reproduction	09-12-92	12.5		25		18		26	
		07-01-93	12.5							
		24-01-93	<6.25		6.25		2		4	
		02-01-93	<3.125		>100		2		5	
		02-02-93	3.125		6.25		4		5	
		05-02-93	9.375		12.5		7		11	
		07-02-93	9.375		12		9		12	
		09-02-93	9.375	12.5	12.5	25	7	25.7	9	35.7
		11-02-93	25	50	50	100	17	38.7	32	59.5
		14-02-93	12.5	25	25	50	7	20.1	9	31.7
		16-02-93	12.5	9.37	25	12.5	8	9.2	18	17.5
		18-02-93	12.5	6.25	25	9.37	15	7.32	24	10.6
		21-03-93	25	50	50	100	34	62.6	57	85.2
		23-02-93	100	50	>100	100	>100	63.5	>100	84.7
		26-02-93	100	50	--	100	74	69.5	>100	90.6
		01-03-93	50		100		42		61	
		03-03-93	25	25	50	50	36 (31-40)	48.4	55 (48-61)	70
		05-03-93	50		100		65		88.5	
		08-03-93	25		50		36.4		58.1	
		10-03-93	12.5		25		29.1		47.2	
		01-12-93	25		50		37.5			
		05-01-94	25		50		32			
		02-02-94	50		100		38			
		02-03-94	50		100		59		73.2	
		08-11-94	25		50					
		14-12-94	50		100		56.1		88.3	
		04-01-95	50		100		59.1 (51.7-65.5)		82 (77.4-86.6)	
		01-02-95	50		100		47.7		66.4	
		01-03-95	12.5		25		23.1		37.6	

Continued

Table 25: Concluded

		Date (D-M-Y)	NOEC	NOEC Duplicate	LOEC	LOEC Duplicate	LC25	LC25 Duplicate	LC50	LC50 Duplica[…]
Fathead Minnow 7-day	Mortality	09-12-92	>100				>100		>100	
		07-01-93	>100				>100		>100	
		02-01-93	>100				>100		>100	
		02-02-93	>100				>100		>100	
		01-02-93	>100				>100			
		22-03-93	>100				>100		>100	
		01-12-93	>100				>100		>100	
		05-01-94	>100				>100		>100	
		02-02-94	>100				>100		>100	
		02-03-94	>100				>100		>100	
		14-12-94	>100				>100		>100	
		04-01-95	100		>100		>100		>100	
		27-01-95	100						>100	
		01-02-95	100				>100		>100	
		05-03-95	100				>100		>100	
							IC25		**IC50**	
	Growth	09-12-92	>100				>100		>100	
		07-01-93	>100				>100		>100	
		02-01-93	>100				>100		>100	
		02-02-93	>100				>100		>100	
		14-02-93	>100				>100		>100	
		22-03-93	>100				>100		>100	
		01-12-93	>100				>100		>100	
		05-01-94	>100				>100		>100	
		02-02-94	>100				>100		>100	
		02-03-94	>100				>100		>100	
		06-04-94	>100				>100		>100	
		14-12-94	>100				>100		>100	
		04-01-95	100		>100		>100		>100	
		27-01-95	NC		NC		>100		>100	
		26-02-95	100							
Algal Growth (*Seleneastrum*) 72-hour							**IC25**		**IC50**	
	Growth	09-12-92	12.5		25		15		29	
		07-01-93	6.3		12.5		12		20	
		02-01-93	6.25		12.5		7		13	
		02-02-93	1.56		3		4		5	
		11-02-93	6		13		7		17	
		22-03-93	6		13		26		46	
		31-03-93	6		13		11		20	
		01-12-93	<1.5		1.5		1.0 (0.8-1.3)		2.2 (1.8-2.8)	
		05-01-94	<1.5		1.5		0.9 (0.7-1.2)		2.7 (2.1-34)	
		02-02-94	1.6	1.6	3.1	3.1	2 (2-3)	4 (2-8)	20 (14-29)	16 (13-19)
		02-03-94	3.13		6.25		9 (3-15)		>100	
		06-04-94	6.25		6.25					
		14-12-94	1.56		3.125		2.6 (2.3-2.9)		5.0 (4.3-5.6)	
		04-01-95	1.56		3.13		8 (7-9)		24 (23-25)	
		27-01-95	56		100				96 (91.8-99.2)	
		01-02-95	1.56		3.1		3.3 (2.8-3.8)		6.1 (5.7-6.9)	
		22-02-95	100		>100					
		15-03-95	56		100				97.3 (93.9-99.8)	

a. 95% confidence limits bracketed.
Data for summary table was provided by Weyerhaeuser Canada Ltd.

If the preliminary data presented here are indicative of the results that will be presented at the end of the first EEM cycle, several tentative observations can be made. The LC_{50}'s of 100% or greater for the fathead minnow test appear to indicate that modern pulp mill effluents do not usually affect fish larval growth and survival. The algal growth test is not necessarily a toxicity test since the additional nutrients in pulp mill effluents can be expected to stimulate the growth of algae, and therefore, cause an observable effect, at low concentrations. The *Ceriodaphnia* results are variable and more difficult to interpret. The effluent appears to have little or no effect on survival (except SLPC) but a definite effect on reproduction.

3.2.3 Discussion

The results of the chronic bioassays, although preliminary, provide important new information. Data from at least three of the mills (ANC, SLPC and Weyerhaeuser) show an effect on algal growth. The results of the *Selenastrum capricornutum* test should be compared to the chlorophyll *a* results for epilithic algae in the receiving stream which show a more general increase in chlorophyll *a* below pulp mills. From an ecotoxicity perspective, the nature of the effect (inhibition versus stimulation) is critical; more detailed information about the test will be necessary to evaluate them.

The chronic bioassays on effluent from all mills are detecting a reduction in *Ceriodaphnia dubia* reproduction. This result is interesting in that it is occurring in effluent from all mills in the NRBS area even though they differ in many significant ways. The reduced reproduction is in contrast with the benthic invertebrate monitoring results which generally show increased numbers of organisms.

The fathead minnow tests indicate no mortality at the larval stage. In situations where bioassay results indicate no chronic toxicity, but contaminants are known to be present in the receiving environment from chemical analysis of the effluent being discharged, the challenge is then to assess the potential, long-term chronic toxicity of these contaminants on the biological community. Chronic bioassays, cover only a small fraction of the known chronic toxicity potential of pulp and paper mill effluents. For example, some of the adverse effects (chronic) observed in adult fish exposed to pulp and paper mill effluents include decreased growth rates, fin darkening, necrosis, erosion and deformation, while others show signs of cutaneous and lateral body wall haemorrhage, lateral line lesions, cranial deformations, difficulty swimming, body wall ulcers, exophthalmia, fat loss, hyperpigmentation and edema (Cook *et al.* 1991). At the population level other researchers, such as Munkittrick *et al.* (1992), have observed delayed sexual maturity, smaller gonads, reduced egg size, reduced secondary sexual characteristics, increased liver size, increased condition factor, and a smaller length at age when compared to control fish. Physiological changes observed include reduced levels of plasma sex steroids (testosterone, 11-ketotestosterone, 17B-estradiol and 17a,20B-dihydroxy-4-pregnen-3-one). Elevated levels of MFO activity have also been found. This is not to say that these symptoms are occurring presently in Alberta rivers, but the point is that chronic bioassay tests are insufficient in their scope to predict all of these possible impacts of effluent exposure. Conversely, the presence of a chronic effect in the laboratory, particularly in concentrated effluents from CTMP mills, may not be indicative of an effect in the receiving streams because of the many factors outlined in section 1.3.2.

3.3 WHOLE EFFLUENT TOXICITY LOADING

3.3.1 Calculation of Whole Effluent Toxicity Loading

The United States Environmental Protection Agency (U.S. EPA) has developed a standard format for the calculation of whole effluent toxicity (U.S. EPA 1991). The first step is to convert concentration-based toxicity measurements into Toxic Units (TUs). The EPA's technical support document states that "the number of toxic units in an effluent is defined as 100 divided by the effluent concentration measured" where:

$$TU_a = 100/LC_{50} \text{ and } TU_c = 100/NOEC$$

$_a$ = acute toxicity, $_c$ = chronic toxicity

For example, an effluent with an LC_{50} equal to 50% effluent would be an effluent containing 2 TU_a.

The next step is to calculate whole effluent toxicity (dilution estimate) using effluent and river flows and the toxic units. The formula presented by the EPA (1991) is as follows:

$$C = \frac{C_s Q_s + C_e Q_e}{Q_e + Q_s}$$

where:

C	=	downstream concentration (TU_c or TU_a)
C_s	=	upstream concentration (TU_c or TU_a)
Q_s	=	upstream flow (cfs)
C_e	=	effluent concentration (TU_c or TU_a)
Q_e	=	effluent flow (cfs)

The rational behind this formula was explained as follows: "Without specific information concerning the persistence of toxicity, it is recommended that effluent toxicity be limited to dilution estimates and that toxicity be assumed to be additive and conservative. Toxicity is expected to be additive even when the toxicity of a downstream discharge affects different biota.

3.3.2 Application of Toxicity Loading to Alberta Pulp Mills

This equation can be used assuming completely mixed conditions which is the case for all Alberta mills discharging into rivers. However, when actual values from NRBS mills are considered, very few acute toxicity tests failed which means the actual values for the LC_{50} are usually 100% effluent or >100% effluent. The acute toxic unit would, therefore, be equal to 1 or <1.

In Alberta, a failed bioassay would immediately initiate a TRE request from the regulators and the mill would then take action to remove the toxicity. Although there are bioassay failures occasionally, most of the results are "pass" (100% or greater) results. Unlike other forms of loading, such as BOD and suspended solids which are continuous, acute toxicity loading is infrequent and of short duration. For example, there was no acute toxicity loading from any mill in 1994. In practice, Alberta Environment would not permit "toxicity loading" for any extensive period of time.

An example of how the formula developed in 3.3.1 could be applied to this data set is as follows: On January 15, 1990 the LC_{50} for the mill at Hinton was 100% effluent or a TU of 1.0. Effluent flow was 1.13 m^3/s and river flow was 45.9 m^3/s. The upstream effluent concentration C_s (i.e. toxicity of an effluent upstream of this discharge) is not applicable and thus given a value of 0 although this component of the equation could be used in many situations in Alberta rivers. The most common example is a municipal discharge upstream of a pulp and paper mill discharge. The effluent concentration C_e, as shown earlier, is 1 TU. The resulting equation is simply the effluent flow divided by the combined effluent and river flow (i.e. effluent loading).

$$C = \frac{0 \times 45.9 + 1 \times 1.13}{1.13 + 45.9}$$
$$= 0.02$$

The preceding example calculation was presented to show how whole effluent toxicity can be calculated for either acute or chronic effects. It also shows that effluent that is non-toxic according to the bioassay will have a toxicity load according to this formula which will vary with effluent volume.

The effluent limit for acute toxicity of 100% or greater included as a condition in all mill approvals and the fact that mills have non-toxic effluents most of the time mean that the concept of acute toxicity loading doesn't apply in the NRBS area. There is insufficient data to determine chronic toxicity loading. The most direct application for bioassays is to trigger a regulatory action when distinct acute or chronic toxicity is observed.

3.4 LOADING OF CONTAMINANTS IN THE EFFLUENT

Loading of contaminants to a river (usually in kg/d) is an important concept because it includes effluent volume as well as concentration. Kraft mills and CTMP mills differ substantially in their effluent volume (Table 1). The CTMP process is characterized by low water use per unit of production as compared with other pulp and paper manufacturing processes. Due to this low water use, the concentration of organics and wastes from the pulping process is very high with average BOD_5 concentration in inflow to the treatment plant being 5000 mg/L (Rick Denton, pers. comm.). As a result, the effluent is highly concentrated, but with less impact on the receiving stream than other pulp mills due to the substantially lower volumes released. Impact of an effluent upon the receiving stream is based upon the loading of substance discharged and not the concentration of the substance in the discharge pipe. It is desirable to encourage low volume effluents and not the continuation of high volumes as a means to dilute any measurable toxicity.

Loading of metals, chlorinated organic compounds and other potentially toxic constituents can be calculated individually from concentrations measured during effluent monitoring. This has been done for NRBS by McCubbin and Folke (1992). They provided both concentrations (in mg/L) and loadings (in g/d) of AOX, phenols, chlorinated phenol, resin and fatty acids, metals and dioxins in effluents for all mills in the NRBS area for which there were data. An effluent quality database was also prepared by N. McCubbin Consultants Inc. Since the McCubbin and Folke (1992) report is available as another NRBS report, the reader is referred to that report for the data.

McCubbin and Folke (1992) concluded that internal measures taken at kraft pulp mills combined with external secondary treatment prevent acute toxicity. Also the remaining sub-acute toxicity is not caused by any organochlorine substances, but rather by neutral non-chlorinated compounds. Colodey (1989) published a review pointing towards chlorinated organics as the most important group responsible for the toxicity of bleached kraft mill effluents; however, McCubbin and Folke (1992) believed that a more recent review (Colodey *et al.* 1991) is more in line with the recent Scandinavian studies including mesocosm studies (Lehtinen 1991a,b) which suggest that non-chlorinated substances are significant in modern mills that have reduced discharges of organochlorines.

In the past, a major fraction of the toxicity towards fish originated from fatty and resin acids (McLeay 1987) that were frequently released during spills. Current spill containment methods (see also section 1.2.2) included in Alberta mills reduce the potential of toxicity from this source.

Chelating agents (e.g. EDTA, DTPA) are used extensively for bleaching in CTMP and some kraft pulp mills and are, therefore, discharged with the effluent (McCubbin and Folke 1992). Sprague *et al.* (1991) searched the literature without finding any evidence of harmful environmental effects of chelating agents used in pulp mills. Millar Western's BCTMP mill had, in 1989, about 38 mg/L of DTPA and 12 mg/L of EDTA in the effluent, but concentrations in the river were never found to be above the detection limit of 0.5 mg/L (Noton 1989). No particular harmful effect was credited to the sequestering agents (IVL 1989, Sprague 1991). EDTA complexes so strongly with ferric ions in the process water that it does not exchange with other ions in the receiving water.

The reaction of chlorine and/or hypochlorite with lignin residuals from the cooling process at kraft mills creates organochlorine compounds. McCubbin and Folke (1992) concluded that, today, adsorbable organically-bound halogen (AOX) is no longer a useful regulatory parameter because there is no longer a relationship between the AOX content and biological/ecological effects (Charlet 1991, O'Connor *et al.* 1991, Carey *et al.* 1992). Because AOX is not specific to chlorinated organics (i.e. it includes bromated organics, sulphur-containing compounds, etc.), this measure has been replaced by extractable (in non-polar solvents) organochlorine (EOCL) which is intended to estimate the portion of the total chlorinated organics with the potential to bioaccumulate. Process improvements such as oxygen delignification, 100% chlorine dioxide substitution and secondary treatment of the effluent reduce AOX loading below levels known to cause effects. Compounds other than chlorinated organics significantly contribute to the overall toxicity of pulp mill effluents, if AOX discharges are under about 4 kg/t (McCubbin and Folke 1992). This is the case in Alberta, where mean AOX loading was 0.84-1.66 kg/t.

More than 300 organochlorine compounds have been identified but chlorophenolics are the best known. Bleach effluent from softwood normally contain the highest amount of chlorophenolics (McCubbin and Folke 1992). The effect of major process changes on polychlorinated phenols was studied at the Grande Prairie, Alberta mill. An increase in chlorine dioxide substitution from 25% to 70% reduced polychlorinated phenols from 3 g/ADt to 1 g/ADt in the treated effluent (McCubbin and Folke 1992). When substitution was increased from 70% to 100%, chlorinated phenolics were reduced by 98% (SENTAR. 1993). Chlorine dioxide substitution effectively reduces the concentration of polychlorinated dioxins and furans (TCDD/TCDF) in the effluent, as well.

Environment Canada regulatory compliance limits are 15 ppg for 2,3,7,8-TCDD and 50 ppg for 2,3,7,8-TCDF. McCubbin and Folke (1992) reported average concentrations of 1.8-7.3 ppg for TCDD and 4.5-28.4 ppg for TCDF in effluent from the kraft mills at Hinton, Grande Prairie and Peace River during 1990-91 which is prior to 100% chlorine dioxide substitution.

Chlorate is present in the effluents from bleached kraft mills practicing a high percentage of chlorine dioxide substitution which includes the Alberta mills. Chlorate was not considered significant until the destruction of benthic flora below a Swedish bleached kraft mill was reported by Lehtinen *et al.* (1988). Chlorate was shown to be lethal to a marine brown algae, bladder-wrack, due to its molecular similarity to nitrate. The disappearance of the alga reduced the production of benthic microfauna. Receiving waters that are nitrogen deficient will be the most vulnerable. There is insufficient information on the effects of chlorate in freshwater to assess with confidence its long-term ecosystem effects.

The U.S. EPA (1991) stated that "impact from toxics would only be suspected where effluent concentrations after dilution are at or above the toxicity effect concentration". In Alberta rivers, where pulp and paper mill effluents are quickly diluted to a minor fraction of the water volume, the potential for toxicity is low. Environmental variables, such as flooding, temperature fluctuations and droughts can also adversely affect a biological community. Bioassessment of the biological community in the receiving environment is still the only true method of determining the presence or absence of chronic toxicity on the organism or population level. Separating environmental effects (i.e. habitat changes and weather extremes) from effects induced by the presence of contaminants is a complex and often difficult task facing researchers.

4.0 ECOTOXICOLOGICAL SIGNIFICANCE OF PULP MILL EFFLUENTS

Chapter 3.0 described the acute and chronic toxicity of pulp mill effluents, and also referenced contaminants in the effluent that may cause toxicity. As briefly described in Section 1.3.2, there are many factors that alter toxicity when the effluent leaves the diffuser and is dispersed in the receiving stream. The detection of toxicity in the effluent does not necessarily mean that there will be ecotoxicity; that is, a toxic effect in the aquatic ecosystem receiving the discharge.

Conversely, the failure to detect either acute or chronic toxicity in a single-species bioassay does not preclude an ecosystem effect. Organisms living in the receiving water are subject to a variety of conditions over varying periods of time that are almost always different than the laboratory test. Biota living in rivers such as the Athabasca River or the Wapiti River which receive point discharges from pulp mill effluents, municipal sewage treatment plant effluents and tributaries may experience accumulated long-term impacts. Monitoring and special studies that include fish, invertebrates and algae living in the receiving river are necessary to determine the ecotoxicological significance of pulp mill effluents. There has been a vast quantity of data collected over the years by instream monitoring programs and special studies. The results that are particularly relevant to toxic effects on organisms have been highlighted in this chapter. The reader is also referred to other, more detailed, reports.

4.1 BENTHIC ASSEMBLAGES

The biofilm is the biological community which adheres to the surface of riverbed material. It is primarily epilithic algae (algae attached to rocks), but the term biofilm gives a broader perspective to this community which may also contain aquatic bacteria, fungi and other microscopic organisms. Unfortunately the data available on biofilm are limited to epilithic algae (SENTAR 1993a). Rooted aquatic plants (macrophytes) are not abundant in the mainstems of the major rivers of the NRBS area.

The benthic macroinvertebrate assemblages have been monitored by Alberta Environment and all of the pulp mills. With the exception of two mills, the data have been collected using comparable methods. There are, therefore, good quality data on the number of organisms per taxa for assemblages of benthic macroinvertebrates found in replicated samples collected at multiple locations upstream and downstream of many point sources. Most of the information summarized here was synthesized for NRBS by SENTAR Consultants Ltd. (1993a); more details including tables and figures are available in that report.

4.1.1 Biofilm Monitoring

Biofilm data available for the NRBS area were tabulated and synthesized in Section 4.2 of the *Nutrient Loading on the Athabasca, Peace and Slave Rivers - Synthesis Report* prepared for NRBS by SENTAR (1993a). The reader wishing to review the data is referred to the SENTAR (1993a) report.

Because there is a direct relationship between epilithic chlorophyll *a* content and cell biomass, this photosynthetic pigment has been used by Alberta Environment and others, as an indirect measure of algal biomass (Anderson 1989). The epilithic chlorophyll *a* samples were obtained by scraping defined areas of rocks from the river substrate. Only a few studies have identified the algal species present in the biofilm (e.g. EVS 1991, 1993).

Samples of epilithic algae may not represent the nutrient-related growth potential of the site or a history of toxicity because algae are removed when the riverbed is scoured by high water velocities or ice. In rivers, water velocity is often the factor limiting plant biomass; the nutrient-related growth potential may not be realized and ecotoxicological effects may be obscured. Other factors limiting plant biomass such as turbidity, light penetration, grazing, sediment type and temperature may also be difficult to distinguish from toxicity.

4.1.1.1 Athabasca River

The Athabasca River generally has high flows, high turbulence and, therefore, high levels of suspended solids during the summer months, resulting in poor light penetration and scouring. Epilithic algal densities are relatively low in the summer, in spite of the optimum temperature conditions. Flows and suspended solids decrease in the fall and epilithic algal densities generally increase (Noton 1990a). With minor exceptions, Anderson (1989) found that epilithic chlorophyll *a* levels, for both mainstem and tributary sites were highest in September and October. Densities were extremely low during June and July when river flows, and therefore substrate scour, were high.

Epilithic chlorophyll *a* data are available from a survey on the upper Athabasca River by Anderson (1989) which evaluated the effects of the combined pulp mill and municipal effluent discharged at Hinton. All sites sampled downstream of the effluent had epilithic chlorophyll *a* values greater than 30 mg/m^2, whereas the concentration upstream was below 15 mg/m^2 (Anderson 1989). Overall maximum densities occurred downstream of Hinton during October.

Epilithic algae were scraped from the upper surface of randomly selected rocks collected by TAEM (1991b, 1991c, 1992b) and analyzed for chlorophyll *a* as part of the annual biological and water quality surveys conducted for Weldwood of Canada Ltd., Hinton. TAEM also found that levels of chlorophyll *a* are higher downstream than at the control sites for 22 km, although the data are variable.

The amount of algal growth in the Athabasca River in the vicinity of the Millar Western and ANC pulp mills, and the Town of Whitecourt exhibited three trends (SENTAR 1992a). Firstly, the continued heavy growth of algae at the control site on the McLeod River indicates that the McLeod River is likely an important point source of nutrients to the Athabasca River. The second trend is an increase in algae downstream of the combined point source inputs. The third trend is seasonal with light to non-detectable growth of algae in the spring compared to heavier in the fall. It is evident that algal biomass varies seasonally due to scouring by high velocity and suspended sediments, and also on an annual basis in high flow years such as the spring of 1991 (SENTAR 1992a). The algal growth classification was based on the thickness of the algal mat on the substrate. Measurement of epilithic chlorophyll *a* began at these locations in 1993.

EVS Consultants Ltd. (1990, 1991) conducted an environmental baseline survey of river periphyton prior to the start-up of the Slave Lake Pulp Corporation (SLPC) mill on the Lesser Slave River. In 1990, an order of magnitude increase in periphyton chlorophyll *a* with distance downstream in the Lesser Slave River was measured (EVS 1991), but in 1991, there was no predictable trend in chlorophyll *a* with distance downstream, or with respect to the location of the mill outfall. No trend related to the mill outfall was found in the 1992 and 1993 data (EVS 1993, 1995).

The monitoring by SLPC is the only biofilm monitoring which included identification of algal taxa. Many of the taxa found in the survey are indicative of alkaline water or water with high levels of mineral content. *Cladophora* was the most common algal taxon, and it is normally found in eutrophic waters. Diatoms were a major component of the algal taxa found in the survey. The algae identified in the samples have a widespread distribution in North America; some are more commonly found in lakes and probably originated in Lesser Slave Lake which appears to exert a large influence on variations in periphyton distribution in the Lesser Slave River (EVS 1995).

The most recent analysis of the distribution and relative abundance of periphyton species indicated that most species were similar to those found in previous years (EVS 1995). There were some minor presence/absence differences of periphyton species between 1990, 1991, 1992 and 1993, although there is no spatial pattern to suggest any influence from the mill. Work at the experimental lakes area of north-western Ontario indicated that among the earliest responses to stress are changes in species composition of small, rapidly reproducing species with wide dispersal powers such as phytoplankton, and the disappearance of sensitive organisms from aquatic communities (Schindler 1987). If this response is also true for epilithic algae, the lack of a spatial pattern of periphyton species related to the SLPC mill indicates the absence of a toxic effect on the biofilm from the mill effluent.

4.1.1.2 Peace River and Wapiti-Smoky Rivers

Environmental monitoring by the Daishowa-Marubeni mill in the vicinity of the Town of Peace River did not include measurement of epilithic algae or chlorophyll *a* (HBT Agra Ltd. 1992).

A study of the water quality of the Wapiti-Smoky River system, a tributary to the Peace River, in 1983 included an algal growth potential (AGP) test of the water from the lower Wapiti River, the Smoky River, and the Peace River near the confluence with the Smoky River (Noton *et al.* 1989). Algal growth tests are assays in which a test species *Selenastrum capricornutum* is incubated in a water sample in the laboratory. The results were quite variable and there was no consistent effect of the pulp mill wastewaters on AGP. Sites downstream of the mill had AGP that were higher, lower or no different than sites upstream of the mill. There was a poor correlation between AGP and total phosphorus within each sampling period. This 1983 test is the only example of biofilm testing in the NRBS area that might relate to ecotoxicity (SENTAR 1993b).

A benthic chlorophyll *a* survey of the Smoky-Wapiti rivers in October 1989 and February 1991 indicated that chlorophyll *a* tended to be more abundant downstream of the Grande Prairie sewage treatment plant and the Weyerhaeuser pulp mill effluents, at least in the shallow waters where sampling was carried out. The data were, however, quite variable. Concentrations of chlorophyll *a* returned to a baseline level in the Wapiti River upstream of the confluence with the Smoky River (Noton 1992a,b).

Chlorophyll *a* was measured by TAEM (1991a) during surveys of the Wapiti River in October 1990 and April 1991 but not the January 1992 study (TAEM 1992a). Chlorophyll *a* levels showed an increase below the sewage treatment plant outfall which was most apparent in October 1990 when chlorophyll *a* levels increased from <1 mg/m^2 above the sewage treatment plant to 225 mg/m^2 below (TAEM 1991a). There was a further increase in chlorophyll *a* levels at all stations below the pulp mill effluent. The greatest levels were found at sampling stations downstream from Bear Creek.

4.1.1.3 Ecotoxicological Significance

A review of the biofilm data collected in the vicinity of pulp mills (summarized in SENTAR 1993a) shows that:

- Biofilm data were limited to epilithic algae.
- Prior to 1993, chlorophyll *a* data were limited to three mills.
- Algal taxa were identified in the vicinity of only one mill.
- An experimental approach has only been attempted once (unsuccessfully).
- Epilithic algae, as measured by chlorophyll *a*, generally increased below point source discharges including pulp mill effluents, sewage treatment plant effluents and tributaries.
- Epilithic chlorophyll *a* was generally low during spring and summer (attributed to scouring), and reached a maximum in the fall.
- Epilithic chlorophyll *a* was generally low in sand or silt substrates.
- Chlorophyll *a* is now being measured at more locations to provide a better database in the future.

The ecotoxicological significance of pulp mill effluents cannot be determined from existing biofilm data with the exception of data for the Lesser Slave River. Monitoring of the Lesser Slave River includes the identification of algal species and has shown that the periphyton community is diverse and the species present are typical of other alkaline waters in northern Canada (EVS 1993). Without additional monitoring data on species richness or experiments to differentiate toxic effects from nutrient effects, the presence of toxicity could be masked by the enhanced algal growth due to nutrients in the effluent.

Now that chlorophyll *a* is included in the benthic monitoring at six of the mills, more data will be available to indicate algal biomass. Catastrophic events (e.g. high flows or spills of toxic chemicals) would be recorded as a decrease in biomass; however, significant changes in biomass could not be considered an "early warning" of chronic toxicity. Chlorophyll *a* measurements are useful in assessing nutrient effects, if a dose-response relationship can be established, but they are less useful in determining chronic toxicity. The inclusion of the growth inhibition bioassay (using the alga *Selenastrum capricornutum*) in the chronic/sublethal effluent testing under EEM and in the Weyerhaeuser mill provincial approval adds the results of a single-species bioassay to the database. Chlorophyll *a* monitoring of the receiving stream can be used to assess whether growth inhibition/enhancement data from a single-species bioassay of the effluent are indicative of growth inhibition/enhancement in the receiving waters.

4.1.2 Invertebrate Monitoring

The benthic invertebrate monitoring in the NRBS area was summarized in Section 4.1 in the *Nutrient Loading on the Athabasca, Peace and Slave Rivers - Synthesis Report* prepared for NRBS by SENTAR (1993a). The reader wishing to review a synthesis of these data is referred to this report. Benthic invertebrate data have been analyzed in more detail by the pulp mills individually and their results are presented in annual reports included in the annotated bibliography (SENTAR 1993b). A quantitative analysis of benthic invertebrate community structure and other benthic invertebrate studies have been undertaken by NRBS (see also section 2.3). This section is therefore limited to a brief summary of the effects of the pulp mill effluents at each of the six mill sites and the toxicological significance of the existing monitoring results.

The pulp mill effluents and the treated municipal sewage discharged to rivers in the NRBS area generally cause an increase in the number of benthic invertebrates downstream. The number of invertebrate taxa (e.g. species), including both pollution tolerant and intolerant taxa, usually does not change, although an increase in the number of taxa has been reported below the Hinton and SLPC mills. The population of enrichment-sensitive species, such as *Rithrogena* sp., declined in mixing zones below effluent discharges. The diversity of the benthic invertebrate community generally decreases below point source discharges due to relative increases in the numbers of organisms in some taxa compared to others. This decrease in diversity is not usually due to a decrease in the number of taxa. Statistical and taxonomic analyses of the data indicate mild to moderate enrichment without evidence of toxicity. The natural changes in the river are equal to, or greater than, the changes caused by the effluents discharged to the river. Longitudinal trends in the benthic community from the headwaters to the river mouth, and seasonal and annual fluctuations are apparent in the data. Natural events such as the high flows in the spring of 1991 have a profound effect on benthic invertebrates causing changes in species dominance and abundance. Tributaries such as the McLeod River affect benthic communities in the mainstem.

The following sections 4.1.2.1 and 4.1.2.2 summarize the effects of effluent for the six pulp mills on the benthic invertebrate assemblages in the receiving waters of the Athabasca River, the Peace River and their tributaries.

4.1.2.1 Athabasca River

The benthic invertebrate communities in the Athabasca River were assessed by Alberta Environment (Anderson 1989, 1991; Gregoire and Anderson 1987) and monitored by Weldwood of Canada Ltd., Alberta Newsprint Company and Millar Western Pulp Ltd. Because a measure of standardization was introduced into the sampling methods, sampling frequency and sample replication by Alberta Environment (1990) and because the level of sampling and identification effort by different consultants was similar on the mainstem, it is possible to compare the Athabasca River data. Lesser Slave River data are not comparable due to differences in substrate and methodology.

The results of the 1991 monitoring on the Athabasca River were graphed by SENTAR Consultants Ltd. (1993a). In the spring of 1991, the total number of invertebrate taxa (Figure 5) was greatest at Hinton and decreased significantly in the vicinity of Whitecourt. In contrast, samples from Whitecourt in the fall of 1991 contained approximately twice as many taxa as spring samples. This striking seasonal difference is independent of point source impacts. The reduction in the total number of taxa was probably due to high spring flows. The response of the benthic invertebrate community to point source discharges also differs from one reach of the river to the other and one season to another. At Hinton, the number of taxa increased downstream of the combined mill and municipal effluents. The epilithic periphyton and the benthic community it supports may be limited by the amount of nutrients available at locations above Hinton. In the spring, the number of taxa decreased slightly below the ANC and Millar Western effluents, although the number of taxa exceeded upstream (control) numbers at stations located 20 to 30 km downstream. In the fall, the total number of taxa remained unchanged below the ANC mill and increased below the Millar Western mill. In general, the effect of point-source discharges on the number of taxa is slight. An increase in species richness is usually present at 20 to 40 km downstream. The total number of organisms increased downstream of the point sources at Hinton (Figure 6). This increase did not occur at Whitecourt in the spring, probably due to high flows, but did occur in the fall.

SENTAR

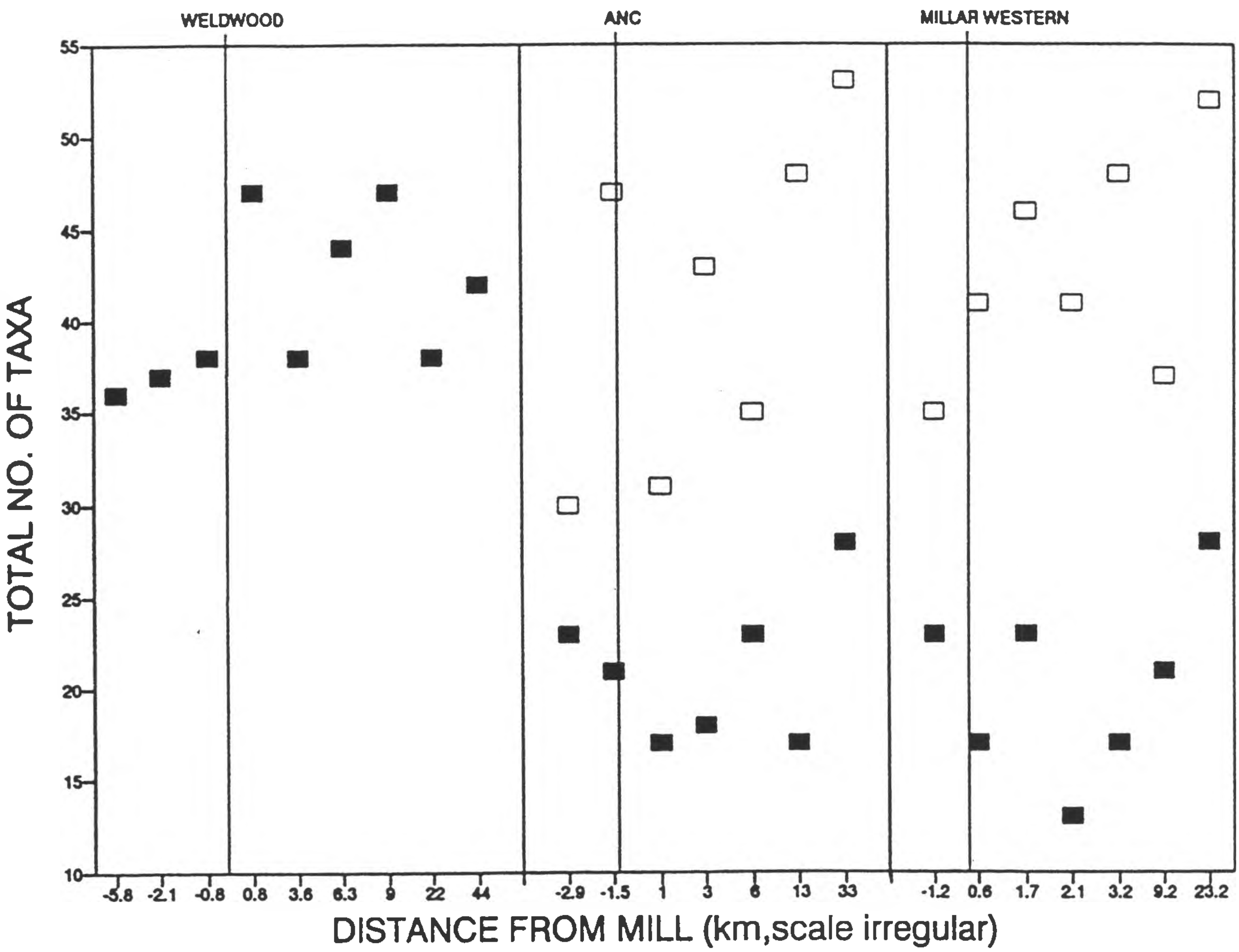


Figure 5
TOTAL NUMBER OF BENTHIC INVERTEBRATE TAXA AT SAMPLING LOCATIONS ON THE ATHABASCA RIVER IN THE SPRING (■) AND FALL (□), 1991
(data from TAEM 1991c and SENTAR Consultants Ltd. 1992b,c)

SENTAR

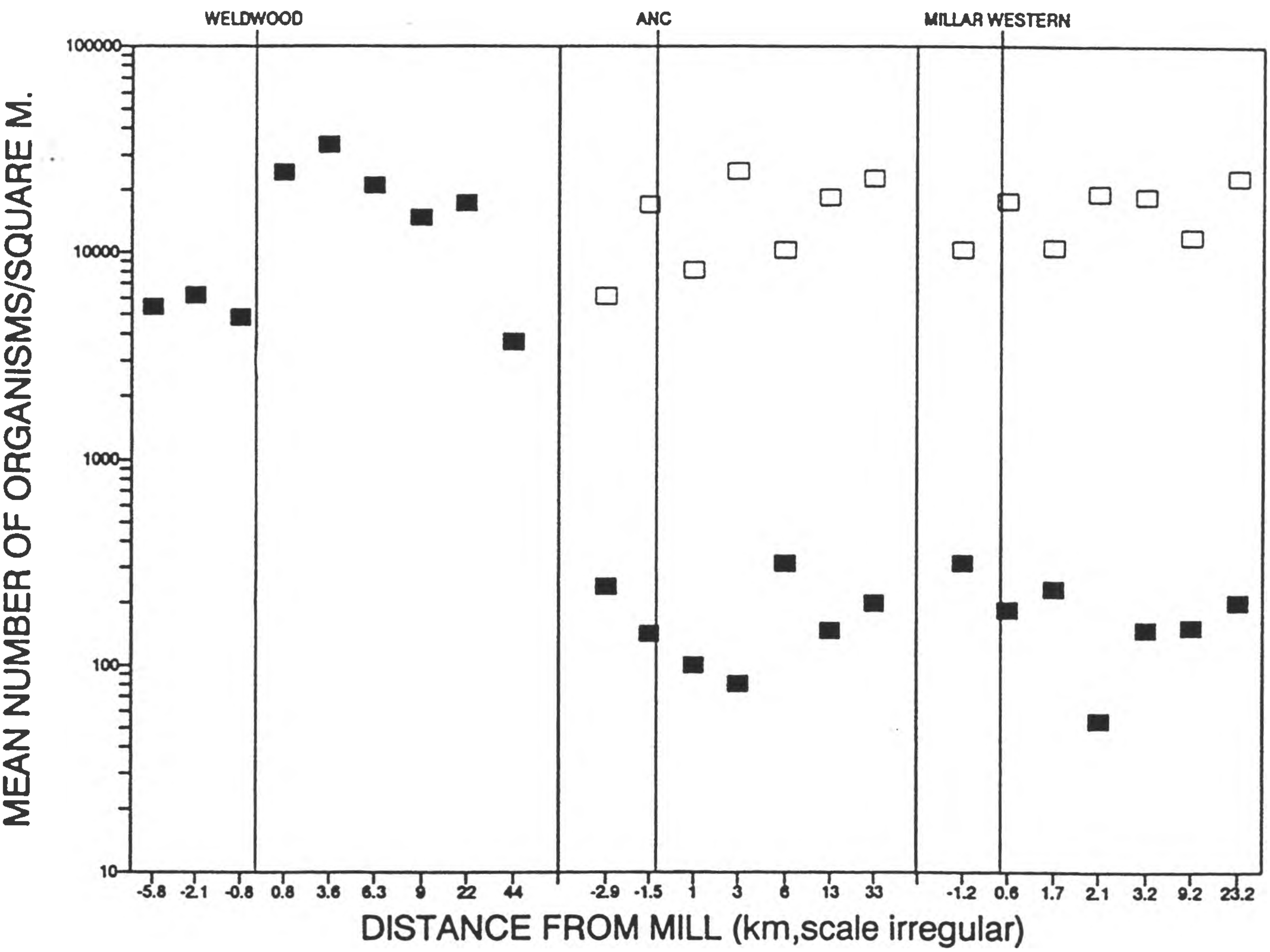


Figure 6
MEAN NUMBER OF BENTHIC INVERTEBRATES PER SQUARE METRE AT SAMPLING LOCATIONS ON THE ATHABASCA RIVER IN THE SPRING (■) AND FALL (□), 1991
(data from TAEM 1991c and SENTAR Consultants Ltd. 1992b,c)

Athabasca River Near Hinton

Trend analysis of long-term monitoring near Hinton is difficult because of changes in methods from artificial substrates to instream sampling of natural benthic communities (Beak 1975, 1977, 1978, 1980; TAEM 1989, 1991b,c, 1992b). Another important factor is the alteration between spring or fall sampling. Anderson (1989) and TAEM (1992b) found that invertebrates were generally much more abundant in the fall. In 1992, both spring and fall samples were collected for the first time in the same year. As described in Section 2.2.2.5, monitoring is now being changed to winter sampling. Because many insects have seasonal patterns of emergence, a change of season can affect the results.

Changes in the zoobenthos immediately below the combined effluent discharge were described by Anderson (1989) as typical of moderate organic enrichment. The change in total invertebrate numbers was highly significant (ANOVA $p<0.0001$) (Anderson 1989). Anderson (1991) also analyzed long-term monitoring results (1983 to 1986) and confirmed that there were higher numbers of organisms and invertebrate taxa (including both tolerant and intolerant taxa) at the 1 km site over this period.

Weldwood of Canada Ltd. monitoring surveys also showed a consistent increase in the number of organisms at stations below the treated effluent (1984 - 1992). There was an order of magnitude increase in the number of organisms found 0.8 km to 9 km downstream, during most spring surveys (TAEM 1992b). The variety (richness) of taxa remained high in all years and the species identified each year were similar to the species found in earlier surveys(TAEM 1992b). Multivariate analysis of the 1991 and 1992 data showed an effluent effect on the benthic community that is indicative of moderate nutrient enrichment according to TAEM (1992b).

There was an increase in the number of taxa at some of the downstream stations in 1991 and 1992, following the mill expansion. Since the mill expansion included improvement in wastewater treatment, the increase in the number of taxa could be related to a reduction in toxicity as a result of the improvements.

At the control stations, the benthic community was usually dominated by Ephemeroptera (mayflies) and Chironomidae (midges). Below the effluent, the number of midges increased in 1990 and 1991, although this change was not accompanied by a decrease in mayflies. Therefore, there was an overall increase in numbers of organisms. These results were attributed by TAEM to nutrient enrichment in the absence of toxicity. The 1992 taxonomic analysis identified several enrichment-sensitive species that showed population declines below the effluent discharge.

In 1992, the Chironomidae dominated the upstream samples as well as the downstream samples. This dominance of Chironomidae at the control stations was different than previous findings and underscores the importance of adequate controls in the monitoring program.

Athabasca River Near Whitecourt

A baseline benthic invertebrate monitoring program was conducted during the spring and fall of 1987, and the spring of 1988 (Beak Associates 1988a, 1989a) to establish pre-operational conditions on the Athabasca River and the McLeod River. The Millar Western Pulp Ltd. CTMP mill began operating in August 1988. Treated effluent was released at partial capacity during the first post-operational monitoring in the fall of 1988. The monitoring program has continued since (Beak Associates 1989a, 1990a, 1991a, SENTAR Consultants 1992b).

Statistical analyses of the baseline benthic invertebrate monitoring program conducted during 1987 indicated that there were significant differences in numbers of taxa and numbers of organisms among sites and among sampling times which appeared to be due to the influence of the McLeod River. The benthic community structure at the McLeod River site differed from sites on the Athabasca River. The mean number of taxa and organisms varied seasonally with higher values in the fall. The seasonal and annual changes overshadowed impacts of the effluent discharge. Decreases in the number of organisms occurred at both upstream (control) and downstream stations in the fall of 1989, the spring of 1990 and the spring of 1991. The number of taxa also varied.

Biannual benthic monitoring studies were conducted for Alberta Newsprint Company (ANC) on the Athabasca River (Beak Associates 1990b, 1991b; SENTAR 1992b) beginning in June 1989 to provide pre-operational data. The CTMP mill began operating near Whitecourt in August, 1990. Surveys from October 1990 to the present provide post operational data. High flows occurring in the spring of 1991 were the probable cause of an overall reduction in the mean number of taxa and organisms at all locations (SENTAR 1992c).

The ANC baseline data showed that most sites were supporting a complex and diverse benthic community dominated by Ephemeroptera (mayflies) and Chironomidae (midges), and sometimes oligochaeta (aquatic worms). The benthic community structure at all sites on the Athabasca River indicated the presence of mild organic enrichment which was naturally occurring (or at least originating upstream) except at the most downstream site which was influenced by the Millar Western and Whitecourt sewage treatment plant effluents. In 1991 (SENTAR 1992b), the mean number of both taxa and organisms were significantly greater at the most downstream site which is impacted by effluent from ANC, Millar Western and the Town of Whitecourt.

4.1.2.2 Lesser Slave River

Baseline benthic invertebrate surveys were conducted in the spring and fall for two years before the Slave Lake Pulp Corporation began operating its CTMP mill on the Lesser Slave River in December 1990 (EVS 1990, 1991). Benthic sampling has continued (EVS 1992, 1993). The minimum taxonomic level of identification for organisms was higher (e.g. family, genus) resulting in fewer taxa being identified near this mill than other mills. The number of replicate samples at each site and the type of samples used were also different so that comparisons with other mills cannot be made readily.

The type of substrate changes substantially along the length of the Lesser Slave River with fine sediments dominating the upper reaches and cobble areas occurring in the lower reaches. Generally, fewer invertebrate species and lower numbers of invertebrates tend to colonize the depositional substrates of the upper reaches compared to gravel or stone (cobbles) in the lower reaches.

The 1990 baseline monitoring found that total abundance of benthic organisms and taxonomic richness were significantly different among stations and between sampling seasons (May and September). On average, there was a 142% increase in invertebrates collected in September relative to values reported for May (EVS 1991). Comparisons between operational (1991 and 1992) and baseline (1990) data showed that, in general, species richness was higher at the near-field depositional stations during the operational surveys (EVS 1993). For the riffle habitats, the near-field station had higher numbers of most taxa, including pollution-sensitive groups such as mayflies, stoneflies and caddisflies after the mill began operations (EVS 1992). Richness increased slightly in the near-field riffle habitats after operation, but increased dramatically at the far-field stations (EVS 1993).

4.1.2.3 Peace River

The Environmental Quality Monitoring Branch, Alberta Environment, has conducted benthic invertebrate surveys in the Peace River. Shaw *et al.* (1990) focused primarily on major longitudinal trends in the river's zoobenthos prior to 1990 when the Daishowa-Marubeni International Ltd. mill began operations.

Benthic invertebrate surveys were conducted for the Daishowa-Marubeni International Ltd. by Monenco Consultants Ltd. (1990a,b,d; 1991; 1992a,b) at Peace River, Alberta. Benthic monitoring began July 1989 (Monenco 1990a) with subsequent monitoring each spring and fall. Benthic invertebrate densities were extremely low with a complete absence of organisms at some locations. Stream flow fluctuations resulting from the operation of the WAC Bennet Dam have probably had the greatest influence upon the benthic community in this area of the Peace River. The continued inundation and dewatering of riffle habitats over relatively short periods of time markedly reduce invertebrate colonization and the availability of periphyton. Analyses of benthic diversity and community structure have been done for each survey from 1989 to 1992. They have failed to demonstrate any definite pattern related to the mill location.

4.1.2.4 Wapiti-Smoky Rivers System

A study of the Smoky River was carried out by Alberta Environment in 1983 to assess the impact of the pulp mill and to augment the database and understanding of the Smoky River system (Noton *et al.* 1989). Benthic surveys were carried out by Alberta Environment on the Wapiti-Smoky River system in October 1989, and February 1991. Benthic invertebrate surveys of the Wapiti River have also been conducted by TAEM since 1987 (TAEM 1990, 1991a, 1992a) for Weyerhaeuser Canada Ltd. and the previous owner, Procter & Gamble.

In 1980, following low river flows, water quality impacts occurred at the town of Peace River. Benthic monitoring by Alberta Environment indicated that the pulp mill effluent was causing a noticeable reduction in numbers of the zoobenthos in the Wapiti River. This is the only account of a substantial reduction in benthic invertebrates encountered by SENTAR during the preparation of an annotated bibliography of monitoring and other reports from the NRBS area (SENTAR 1993b). The cause of the impact was not investigated.

The 1983 Alberta Environment study showed impact had lessened since 1980. Benthic macroinvertebrates in the Smoky River and lower Wapiti River appeared to be enriched in numbers and to some extent in taxa. The number of organisms and number of taxa increased downstream of the Weyerhaeuser pulp mill and Grande Prairie sewage treatment plant outfall to about Watino (Noton *et al.* 1989). Direct toxicity to aquatic life did not appear to be occurring (Noton *et al.* 1989). Effluents from the Weyerhaeuser pulp mill appear to be the main cause of the impacts although treated sewage and urban runoff from Grande Prairie as well as tributary inflows also contribute nutrients (Noton 1992a). The two benthic surveys of October 1989 and February 1991 both indicated that the main effect on benthic biota in the Wapiti River is one of enrichment (Noton 1992a). Total numbers were higher downstream of the effluents while the number of taxa were approximately the same upstream and downstream. There appeared to be some decline in mayflies and stoneflies downstream of the effluents but it is not known whether this was due to eutrophication or toxicity. These groups are known to decline in enriched situations whereas chironomids and aquatic worms generally increase, as was the case.

In a review of the data from earlier benthic surveys (1970-1988), TAEM (1990) showed a trend to increasing river productivity based on the increasing number of organisms found at control sites and sites downstream of the pulp mill. An historical analysis of the biotic indices showed the continuation of a complex and diverse community. More recently, the treated pulp effluent has had either a positive influence (e.g. October 1990) on the number of taxa found or no effect (e.g. April 1991 and January 1992).

The City of Grande Prairie began releasing sewage effluent into the Wapiti River upstream of the pulp mill's effluent in 1987. The 1982-87 results show that the numbers of organisms above and below the pulp mill were much lower than the numbers for 1988 onwards. Studies by TAEM (1990, 1991a and 1992a) showed a substantial increase in the total number of organisms found per unit area as a result of the municipal and pulp mill effluents.

TAEM (1991a) did a taxonomic analysis of the effect of treated pulp effluent on the biological condition of the Wapiti River by reviewing the response (presence/absence and abundance) of indicator taxa (species or genus) to treated pulp effluent in the river and by comparing this response with information known about those taxa (species or genus) from the literature and from relevant pollution studies conducted elsewhere. Although the previous biomonitoring survey of October 1988 found only a limited response to sewage effluent, the October 1990 and April 1991 surveys showed a clear response to city sewage. This was realized by an increase in number of all the indicator species monitored during both surveys. Only *Rhithrogena* sp., a species that appears to be more sensitive to organic loading, showed a negative response to sewage effluent.

The taxonomic analysis also suggested that water from Bear Creek contributes organic loading of the Wapiti River. The October 1990 and April 1991 data indicates that those species that are encouraged by mild organic enrichment increased in number at a sampling station located below Bear Creek. *Rhithrogena* sp., a species sensitive to organic loading, was reduced in number at these stations.

4.1.3 Ecotoxicological Significance

Benthic invertebrates, downstream of a pulp mill, are exposed to effluent on an almost continuous basis. Their potential for accumulating harmful contaminants depends on the length of the larval stage and the lipid content of the animal. Muir *et al.* (1985) reviewed the literature available on TCDD accumulation by benthic animals from sediment and water and found little work had been done. These researchers exposed five species of benthic invertebrates (*Chironomus, Hexagenia, Paragnetina, Acroneuria* and *Pteronarcys*) to both tetra- and octa-dioxins using two types of sediments (sand, silt). The animals most closely associated with the sediments (*Chironomus* and *Hexagenia*) showed greater accumulations of dioxins. Depuration rates were higher in the predatory species (*Paragnetina* and *Acroneuria*). Overall, *Hexagenia* displayed the greatest ability of accumulate dioxins. These results show that benthic organisms are susceptible to accumulation of contaminants and, consequently, potentially susceptible to their toxic effects.

At present, no data are available within the study area on contaminant burdens in benthic invertebrates apart from the information presented by SENTAR (1993c). Dioxins and EOCL (Extractable Organic Chlorine) levels in insects were not statistically different when near- and far-field sites were compared. No significant difference was found when these samples were compared to the control site insects. A 100% sample of hydropsychid caddisflies, which are filter feeders and thus more exposed to the suspended sediments where the majority of the chlorinated hydrocarbons were found, showed low dioxin/furan levels but detectable levels of chlorinated phenolics. Fifteen compounds in total were detected in these insects, the highest being 3,4,5-trichlorocatechol at 12 ppb. A correlation was found between the concentration of compounds in the suspended sediment and concentrations in the caddisflies.

There is a large body of evidence related to effects at the community level for benthic invertebrates located downstream from pulp mills as a result of the monitoring just summarized. The presence of a diverse assemblage of species that is similar to (and occasionally greater than) the number of species at control stations has been cited by authors of monitoring reports (SENTAR 1992a,b; TAEM 1992a,b) and special studies (Noton *et al.* 1989) as evidence of the absence of toxicity due to mill effluent. Monitoring reports also provide data on the presence of species that are considered pollution intolerant; there has not been a shift away from pollution-sensitive species except *Rhithrogenia* which is sensitive to organic loading (i.e. high BOD). The importance of species richness as an indicator of ecotoxicity has been emphasized in review papers by Reice and Wehlenburg (1993) and Hoefs and Boyle (1992).

The benthic invertebrate results are influenced by an increase in the number of organisms below the pulp mills which has been attributed to a moderate nutrient effect of the effluent. There have been no experiments to differentiate between the overriding nutrient effect and toxic effects which may be masked. The authors of the monitoring reports have used multivariate analyses of their data to identify the effects of high flows, tributaries and substrates as well as nutrient effects of the effluent. Localized or subtle toxic effects may not be detected due to the natural variability of the assemblages.

In 1980, benthic monitoring of the Wapiti River by Alberta Environment indicated that the pulp mill effluent was causing a noticeable reduction in numbers of zoobenthos in the Wapiti River. This is the only account of an environmental effect of pulp mill effluent on benthic invertebrates that could be due to toxicity that was encountered by SENTAR (1993b) during a review of monitoring reports and literature from the NRBS area. Subsequent monitoring showed that the number of organisms and number of taxa increased by 1983.

The literature review for this report did not find any studies done in the NRBS area related to effects of pulp mill effluent at the organism level, such as an increase in morphological abnormalities.

4.2 FISH STUDIES

4.2.1 Introduction

The majority of fisheries studies that are potentially of ecotoxicological significance carried out in the NRBS study area have focused on two main themes. The first are the studies which examined the general population characteristics of fisheries resources at a particular site. The second are the studies which have collected fish for contaminants analysis (usually 2,3,7,8-TCDD and 2,3,7,8-TCDF) in relation to public health concerns (i.e. consumption guidelines). Few studies, apart from the major studies conducted on the Lesser Slave River (EVS Consultants 1989, 1990) and the Wapiti River (SENTAR, 1993c), have examined the fish populations in sufficient detail to understand the true nature of the results of effluent exposure.

4.2.2 Identification of Acute and Chronic Effects

The purpose of this section is to review what acute and chronic effects, if any, are elicited in fish when they are exposed to pulp mill effluents. It is an explanation of the symptoms which have been exhibited in previous studies which could be used to determine if the same type of effects are occurring in the NRBS area.

4.2.2.1 Acute Effects

Acute effects are intuitively easy to identify but inherently difficult to monitor in the field. Fish killed by a toxic effluent, are exceedingly difficult to identify in the field. To observe acute effects in the field, the timing of the sampling must coincide exactly with the event. Otherwise, these animals are likely to either sink directly to the bottom where they remain undetected or are consumed by scavengers. McLeay (1987) found no reports of fish kills in the United States due to discharge of biotreated pulp and paper mill effluents to freshwater. Reported fish kills, 14 from 1977 to 1981, were due to spills of pulping chemicals. Acute toxicity occurring sporadically over a long period of time, although exceedingly rare (McLeay 1987), is more easily identified by either the reoccurring presence of carcasses, altered population characteristics of the fish species affected, or a complete absence of the fish species affected. Acute effects are often species specific so the most sensitive individuals within a community must be identified.

A confounding aspect to the determination of acute toxicity in the field is that, if this event does occur, it is most likely to affect the early life stages of fish first. The early life stages of fish, such as gametes, embryos, fry and juveniles are known to be more sensitive to toxic substances than their adult counterparts (Rand and Petrocelli 1985, von Westernhagen 1988). The threshold for acute toxicity to these life stages is often far lower than for adults. Consequently, early life stages will be affected at lower toxicant concentrations than adults. However, the early life stages of fish are much more difficult to monitor than adults. Early life stages are often of short duration making the timing of sampling critical. Behavioral changes, such as larval drift, also make the monitoring difficult. Interpretation of the samples collected requires extensive experience to determine if mortality was due to effluent or other sources.

The effect of TCDD on the early life stages of common fish species is a good example. The LC_{50} of TCDD, a chlorinated hydrocarbon associated with kraft mill effluents, in adult yellow perch (*Perca flavescens*), carp (*Cyprinus carpio*), bullhead (*Ameiurus nebulosus*), rainbow trout (*Oncorhynchus mykiss*), largemouth bass (*Micropterus salmoides*) and bluegill (*Lepomis macrochirus*) ranges from 3,000 to 16,000 pg TCDD/g fish (Cook *et al.* 1991). Cook *et al.* (1991) also conducted a series of experiments where developing eggs and sac fry of lake trout (*Salvelinus namaycush*) were exposed for 48 hours to varying concentrations of waterborne 2,3,7,8-TCDD. Sac fry were observed to be more sensitive to TCDD toxicity than the developing eggs. Egg hatchability was reduced at egg TCDD concentrations greater or equal to 226 pg/g. The NOEC for sac fry mortality was 34 pg TCDD/g, and the LOEC was 55 pg TCDD/g. Symptoms related to toxicity included severe subcutaneous yolk sac edema and hemorrhages. Mortality in rainbow trout fry and carp juveniles was observed to occur at approximately 1000 pg TCDD/g (Mehrle *et al.* 1988) and 2200 pg TCDD/g (Cook *et al.* 1991), respectively.

4.2.2.2 Chronic Effects

A number of studies in Canada and abroad have examined fish populations exposed to pulp mill effluent in order to determine if they were displaying any signs of chronic toxicity. The focus of these studies has been on the effluents originating from kraft mills because of the presence of chlorinated hydrocarbons, most notably 2,3,7,8-TCDD and TCDF and their congeners. Within kraft pulp mill effluents, TCDD is the most toxic halogenated aromatic chemical known (Cook *et al* 1991).

Cook *et al.* (1991) reviewed the sublethal effects of TCDD exposure in fish. Most fish exposed as juveniles or adults to high levels of TCDD display decreased growth rates, fin darkening, necrosis, erosion and deformation, while others show signs of cutaneous and lateral body wall haemorrhage, lateral line lesions, cranial deformations, difficulty swimming, body wall ulcers, exopthalmia, fat loss, hyperpigmentation and edema. Histopathological symptoms of TCDD exposure include epithelial, lymphomyeloid and cardiac lesions (pericarditis and myocardial necrosis). The epithelial lesions observed in TCDD-exposed yellow perch and rainbow trout are exhibited in the liver, pancreas, gills (gill filament epithelium) and fins whereas the lymphomyeloid lesions include thymic involution, splenic lymphoid depletion and hypocellularity of head kidney hematopoietic tissue. These symptoms take time to develop after exposure and are species-dependent in their severity. Cook *et al.* (1991), quoting Spitsbergen *et al.* (1988a,b), added that the TCDD body burden in fish required to produce these morphologic lesions appears to be in the same range as that needed to produce gross signs of toxicity. Other symptoms observed in rainbow trout at body burden concentrations that caused overt toxicity included immunosuppression and decreased resistance to viral disease. Neither of these symptoms has been observed at sublethal exposure levels. Cook *et al.* (1991) concluded that overt signs of chronic toxicity in adult fish as a result of long term exposure to TCDD did not occur until a body burden of 1,000 pg/g was accumulated. Mehrle *et al.* (1988) observed adverse effects on survival, growth and behaviour of rainbow trout swim-up fry which had accumulated body burdens of 990 pg/g TCDD.

Södergren (1989) observed reduced gonad growth but higher body growth in Eurasian perch (*Perca fluviatilis*) exposed to bleached pulp mill effluents. Fin abrasions and lesions were also observed to be more frequent in exposed fish. Exposed larvae showed a higher rate of skeletal deformations in the jaw regions. The occurrence of these abnormalities could not be conclusively linked to exposure to bleached pulp mill effluents although they were suspected as being a primary cause.

More recent studies in Canada have concentrated on the reproductive capacity of fish exposed to Bleached Kraft Mill Effluent (BKME). Hodson *et al.* (1992) observed increased MFO activity and decreased testosterone levels in male white suckers (*Catostomus commersoni*) exposed to BKME at La Tuque, Quebec. Increased MFO activity in Ontario white suckers as a result of BKME exposure has also been reported by Smith *et al.* (1991) and Servos *et al.* (1992). A long term study was done in Jackfish Bay of Lake Superior on the effects of primary, and now recently secondary, treated BKME on the resident fish populations (McMaster *et al.* 1991, 1992, Munkittrick *et al.* 1989a, 1991). White suckers exposed to BKME exhibited delayed sexual maturity, smaller gonads, reduced egg size, reduced secondary sexual characteristics, increased liver size, increased condition factor, and a smaller length at age when compared to control fish. Physiological changes observed include reduced levels of plasma sex steroids (testosterone, 11-ketotestosterone, 17B-estradiol and 17a,20B-dihydroxy-4-pregnen-3-one). Elevated levels of MFO activity have also been found.

Munkittrick *et al.* (1992b) expanded their studies in Jackfish Bay to include lake whitefish (*Coregonus clupeaformis*) exposed to BKME. The results showed that many of the symptoms observed in the white sucker population, such as reduced gonad size, delayed age to sexual maturity, decreased levels of plasma testosterone and 17B-estradiol, decreased liver size and increased MFO activity, were observed in the lake whitefish as well. Many of these symptoms of exposure continued to express themselves after the installation of a secondary effluent treatment system. One characteristic exhibited by a portion of the whitefish population (20%) which was previously un-reported in the literature was the presence of lateral, slash-like lesions. Although these lesions penetrated the body cavity, no infection of the wound was detected. No cause for the wounds could be determined.

Contrary to the information in the above reports, a number of studies have shown no association between concentrations of AOX in water and toxicity to aquatic organisms. Controlled ecosystem studies of fish exposed to concentrations of up to 18% of bleached kraft mill effluent (after secondary treatment) showed little or no detrimental effects (NCASI 1989; Hall *et al.* 1991), although liver enzyme activities (e.g. EROD) were not measured in these studies. Borton (1992) has demonstrated that fish exposed to 8% effluent concentrations (after secondary treatment) showed significant changes in EROD and MFO activity.

Recent studies (van den Heuvel *et al.* 1994; Munkittrick *et al.* 1994; Robinson *et al.* 1994; Servos *et al.* 1994) have documented that fish in waters receiving effluents from bleached kraft mills with and without secondary effluent treatment, and from sulfite mills with primary treatment only, all showed increases in MFO enzyme activity in their livers, decreased reproductive organ sizes in females, and reduced plasma steroid concentrations. Differences in liver size were inconsistent among the sites; however, significant changes were observed in fish from sites with and without chlorine bleaching. Although the fish downstream of mills using chlorine bleaching had greater tissue concentrations of chlorinated dioxins and furans, there was no correlation between concentrations of chlorinated dioxins and furans in fish tissues and adverse effects. Substantial increases in enzyme activities were observed in fish with small concentrations of chlorinated dioxins and furans downstream from unbleached kraft mills. Similar results have been recently found in field studies from Finland, in which the activity of MFO enzymes, comparable to that observed in fish exposed to bleached kraft mill effluents, was observed in rainbow trout exposed to unbleached sulfite mill effluents, as well as in wild perch caught in the receiving waters of the mill effluent, and in rainbow trout caged in receiving waters near the mill discharge (Lindstrom-Seppa *et al.* 1992).

Field studies demonstrate that various nonlethal, physiological effects can occur in fish exposed to pulp mill effluents, independent of the use of chlorine in the pulping process. In some cases these physiological/biochemical effects were reversible following the cessation of exposure, with a relatively short (<10 day) recovery period, an observation that is not consistent with effects induced by chemicals with long biological and environmental persistence. Furthermore, the factors causing these effects were not removed by secondary effluent treatment systems. These observations do not consistently correlate with AOX or concentrations of chlorinated dioxins and furans in mill effluents or in fish tissues.

An assessment of the concentrations of individual chemicals currently monitored in receiving waters has not identified the causal agents for the effects observed in wild fish populations exposed to mill effluents. Concentrations of known contaminants in receiving waters were considerably less than the lowest concentrations having adverse effects on aquatic and terrestrial wildlife as defined by the limited data available. The ratio of the chemical concentration in water associated with adverse effects in wildlife to the chemical concentration in the receiving water indicated that current concentrations in the receiving water are generally lower than those measured in the early 1980s (Expert Panel 1994). In addition, the individual chlorinated chemicals or chemical groups selected for assessment are not at sufficiently high concentrations in the receiving waters to be casually related to the effects observed in wild fish. Field data indicated that reproductive and biochemical effects reported for wild fish exposed to mill effluents may not be directly linked to the use of chlorine in the production of bleached pulp (Expert Panel 1994). This conclusion is based on the observation of similar effects in fish exposed to nonbleached kraft mill effluents and to oxygen bleached effluents. Although the majority of monitoring and research efforts have targeted chlorinated dioxins and chlorinated furans in aquatic environments receiving bleached kraft mill effluents, the causative agent(s) may actually be a result of the pulping process itself or may be related to previously uncontrolled spills of black liquor. Continued efforts are being taken by industry and government scientists to identify and characterize the causative agent(s) in the pulp mill effluents and the receiving environment.

4.2.3 Fisheries Studies

The following is a review of the fisheries studies completed on the Peace, Slave or Athabasca Rivers and their tributaries in relation to the ecotoxicity of pulp and paper mill effluents. Emphasis will be placed on studies where sampling protocols were comprehensive enough to include testing for the parameters known to be characteristic of chronic toxicity due to effluent exposure.

4.2.3.1 Lesser Slave River

Prior to the construction of the SLPC mill, there were no comprehensive fisheries studies on the Lesser Slave River. Before the mill began operations, a two-year study was commissioned to establish the pre-operational conditions on the river (EVS 1990). The following is a summary of their findings.

The upper portion of the Lesser Slave River is characterized by a slow moving current and silt substrates. The lower portion is a series of shallow riffles with cobble/gravel substrates. Sampling of the fish community in 1989 revealed that longnose sucker males and females were significantly heavier for the same length in the upstream reaches than downstream. Females were larger than males in both reaches. The gonad and liver weight:body weight regressions showed no difference for both males and females between sites. Fecundity versus weight showed no significant difference between sites and fecundity versus standard length showed a slight significant difference between sites (lower in downstream). Condition factors, LSIs, GSIs and fecundities were within the ranges obtained for other sucker populations.

White sucker showed the same relationship for all parameters examined just described for as longnose suckers. Lack of fish in downstream areas prevented the use of this fish for the sentinel species. Few mountain whitefish in spawning condition could be caught. The fisheries data available showed little difference between the sexes or sites. Spawning probably occurred in tributary streams. Trichoptera were principle food item for all three species. Suckers also feed on Hemiptera whereas the mountain whitefish diet was supplemented by Plecoptera and Ephemeroptera.

Results of the second year of pre-operational monitoring (EVS 1990) showed little difference compared to the previous year's results and helped strengthen the database already compiled. All three fish species under consideration for sentinel species (longnose sucker, white sucker and mountain whitefish) showed variability in fecundity and liver weights from year to year, but the same trends associated with habitats were observed. Organics were tested in water and fish flesh and found to be below detection limits.

The final phase of the study was to sample the Lesser Slave River after operations began at the mill (EVS 1991, 1993). Operational monitoring performed from May-September 1991. The metal content of fish flesh was similar in both downstream and upstream sites. Most fatty acids were higher in concentration in the flesh of downstream fish. Only female suckers and male mountain whitefish showed increased MFO activity. No consistent elevation of MFO downstream of the SLPC mill was observed in mountain whitefish in 1991 (EVS 1993).

There was no evidence of acute toxicity or chronic toxicity in the Lesser Slave River fish population as a result of effluent exposure. The monitoring of sex steroid hormone levels and other reproductive parameters (i.e. fecundity, egg size) were not measured, but would have been useful in determining if any chronic effects on the reproductive capacity of the fish were occurring. A tracer should be used to assess residency and differences in exposure to mill effluent. Resin acids in bile would be the best tracer, if concentrations are high enough to be detectable. Other tracers may be available by 1995 or 1998, as investigators begin other fish surveys.

For longnose sucker, there was no evidence of mill impacts on mean age, male growth, condition ("fatness"), liver weight, and fecundity (number of eggs). There was evidence of impacts on female growth, and to lesser extent, gonad (ovary) weight and egg weight. Prior to operation, females in Reach 2, immediately below the mill, grew faster than females in Reach 3, further downstream. The apparent impact on growth was relative, not absolute. Growth of females below the mill actually increased slightly (0% to 10%) after the mill began discharging, but growth of females further downstream increased even more (10% to 20%). The response pattern for female longnose suckers was similar to responses indicative of food resource depletion, increased competition or metabolic disruption. After operation, females immediately below the mill had reduced growth, ovary weight and egg weight relative to females further downstream.

There was weak or no evidence of impacts on white sucker since the SLPC mill start-up. This conclusion was based on only one year of post-operational data (1992) as few white sucker were caught below the mill in 1991. Differences in mean age and condition of female white suckers between reaches reversed after operation began. There were linear trends in age (increase) and ovary weight (decrease) of female white suckers from 1989-1992, if 1991 data are ignored. (The few female white suckers sampled in 1991 were younger than in any other year.)

It is premature to draw firm conclusions about the presence or absence of effects on fish from the 1989-1992 data. The mill has been in operation for only two years, a short portion of the life cycle of these fish, and natural short-term changes can obscure interpretation or may be misinterpreted as impacts. For example, population effects attributed to sampling mortality (EVS 1991) changed with the addition of the 1992 data (EVS 1993), and conclusions about impacts could change as more data are added in the future. It will take additional data covering a greater portion of the fish's life cycle to be able to state conclusively if the effects observed to date are real and persistent. Like other components of the Lesser Slave River ecosystem, the characteristics of the fish populations exhibit a great deal of natural variability, and detection of variations caused by the mill presence will require data from at least one life cycle.

4.2.3.2 Peace River

A number of monitoring studies, both pre- and post-operational, have been completed by the Daishowa-Marubeni International Ltd. When addressing the potential toxicity of this mill's effluent on the fish communities of the Peace River it is important to note that other sources of dilute effluent, both from British Columbia mills and Weyerhaeuser Canada Ltd. (via the Smoky), are present in the river. There is also the potential toxicity of the municipal sewage from the town of Peace River.

In the fall of 1989, a study was commissioned by the mill to examine contaminant levels in northern pike flesh (Monenco 1992c). Northern pike (n=7) were selected on the assumption that large predatory fish had a higher potential to accumulate contaminants originating from the mill than other fish lower on the food chain. Contaminant concentrations in the flesh were generally low. The only chlorinated dioxin or furan detected was 4.7 pg/g of 2,3,7,8-TCDF in one specimen. Four of the fish sampled contained various levels of chlorinated phenols, the highest value observed being pentachlorophenol at 6.0 ng/g. Fatty acids concentrations ranged from 0.10 μg/g to 1.56 mg/g. Resin acids were also detected at maximal concentrations of 358 mg/g and 115 mg/g for pimaric acid and dehydroabietic acid (DHA) respectively.

Several studies have shown that large predatory fish such as northern pike or walleye (*Stizostedion vitreum*) accumulate pulp mill contaminants at a lower rate than other species. Accumulation of chlorinated hydrocarbons has been linked to lipid content of the animal (Thomann 1992). Fish with higher lipid content tend to accumulate greater concentrations of various compounds. During the Wapiti/Smoky river ecosystems study (SENTAR, 1993c), a number of fish from various trophic levels and of varying lipid content were analyzed for contaminants. Mountain whitefish (*Prosopium williamsoni*) and burbot (*Lota lota*) showed the highest contaminant burdens whereas walleye and northern pike from the same system displayed negligible amounts. Future monitoring of fish flesh for contaminants at the Daishowa-Marubeni International Ltd. mill should be focused at more susceptible species.

A 1991 survey of chlorinated organics in water, sediments, suspended solids and fish tissue from the Peace, Smoky and Slave Rivers were surveyed by Monenco Consultants Ltd. (1991, 1991b) for the mill. A total of 154 fish (composite samples) of three species including walleye, goldeye (*Hiodon alosoides*) and northern pike were sampled from 110 km upstream to 700 km downstream of the mill site. The study area located on the Peace River extended from Dunvegan to Peace Point. One sampling station was on the Smoky River near the confluence and two were on the Slave River (Hay Camp and Fort Smith). Average daily discharge was recorded for each sampling site. Fish were captured by gill net and electroshocking. Goldeye were the most abundant fish followed by walleye and pike. Burbot were only captured in numbers near pulp mill site and were not used in the study. Longnose sucker were more abundant as adults than white sucker. The researchers observed low concentrations of dioxin, furan and chlorophenolics in all three fish species. Resin acids were highest in walleye, whereas none were detected in goldeye. Goldeye did, however, show considerably higher concentrations of fatty acids than the other two species. Goldeye showed low concentrations of dioxins and moderate amounts of 2-3-7-8 furans (5.9 pg/g at site 1) and tetra chlorophenol (3.0 ng/g). A great range of values was detected for all fish species when fatty acids were analyzed. Northern pike did not have detectable concentrations of chlorinated dioxins, chlorinated furans, chlorinated phenols and resin acids. Two deficiencies were uncovered in SENTAR's review of this report:. walleye were aged with scales which are subject to inaccuracy after age 7 or 8, and the aluminum foil used to wrap fillets was heat treated only, not rinsed in acetone and hexane. In addition, further information on the fish habitat for each species under study would be helpful.

There was no evidence of acute toxicity or chronic toxicity in the Peace River fish populations as a result of effluent exposure from the Daishowa-Marubeni International Ltd. mill. However, the amount and type of information collected on the fish community was insufficient to be able to detect chronic effects. Fisheries information and analyses such as growth, age-class distribution, gonad weights, GSIs, egg diameters, etc., would have been helpful.

4.2.3.3 Wapiti River

Several studies have been conducted on the Wapiti River with the goal of assessing the effects of effluent exposure to the fish community. Paetkau and Bishop (1971) conducted a benthic invertebrate and fisheries survey of the Wapiti River in 1970 and 1971, prior to the mill's startup. Walleye were found to be the most abundant game species. A total of 15 fish species were detected. The majority of the Wapiti River walleye population was observed to spawn in the Simonette River, a tributary of the Smoky River. Although no water quality data were collected, the authors suggested that the presence of arctic grayling (*Thymallus arcticus*) and mountain whitefish was an indication of relatively clean waters.

Alberta Energy and Natural Resources (1985) conducted a survey of the Wapiti River in 1984 that examined the fish populations present and their habitats. A total of 12 fish species were caught. Sampling upstream and downstream of the mill showed considerable differences in the presence and abundance of fish species. All of the fish, except for walleye, that were found upstream of the mill were also found downstream. These changes in fish abundance can be attributed to varying habitat characteristics along the river. The authors cited the re-occurring flooding of the Wapiti River as the major factor controlling fish densities in the river. No adverse effects, due to effluent exposure, were detected.

A study that is more applicable to this review was done by the Alberta Environmental Centre in 1982 (Alberta Environmental Centre 1987). Fish and water samples were collected in the Wapiti River in October 1992 and analyzed for a series of contaminants. A total of twelve fish species were observed in the same proportions and distribution as they were in the 1984 study conducted by Alberta Energy and Natural Resources (1985). It was determined that the effluent was not usually acutely toxic to fish under either laboratory (LC_{50} results from mill) or natural conditions, although the assessment of acute toxicity in the river was mostly speculative. Reproductive ability of fish downstream of the mill was deemed satisfactory based on the numbers of young-of-the-year fish present from several resident fish species. Subtle changes in hepatic glycogen and lipid content between upstream and downstream fish were detected. These differences were attributed to habitat characteristics between the two sites and physiological status of individual fish. Contaminants originating from the effluent that were found in fish flesh included alkanes, fatty acids, chlorophenols and guaiacols. Their concentrations ranged from trace amounts to 5 mg/kg except for a,a'-dichlorodimethyl-sulphone which was found at a concentration of 26 mg/kg. The levels of contaminants found in the fish were not suspected of causing a health risk to the fish.

In October 1987, <5 to 17 ppt of 2,3,7,8-TCDD (TCDD) and 17 to 290 ppt 2,3,7,8-TCDF (TCDF) were found in whole, individual longnose suckers (Alberta government news release 1990). In October 1989, the same testing program found in Table 26. No information was available on the effects of the TCDD/TCDF concentrations on the health of the fish tested.

The most comprehensive study to examine the long-term effects of pulp mill effluents on aquatic biota performed in the NRBS area to date was initiated by the Proctor and Gamble Company in April 1990.

This study, entitled the "Wapiti/Smoky River Ecosystem Study" (SENTAR, 1993c), focused primarily on the health of the fish populations downstream of the mill. The study area extended from Wapiti Gardens on the Wapiti River (67 km upstream of the point of effluent discharge) to the confluence of the Smoky and Peace Rivers. A number of components of the river were examined as to their chemical characteristics including: water, bottom sediments, suspended sediments, benthic invertebrates, fish muscle, fish liver and fish bile. Among the chemical parameters tested were: major ions (Na, Cl, SO_4, etc.), nutrients (PO_4, TKN, etc.), BOD, colour, chlorate, texture, % organic carbon, metals (including mercury, chlorinated organics (AOX, EOCL), dioxins (7 congeners + total TCDD), furans (7 congeners + total TCDF), chlorinated phenolics (phenols, catechols, guaiacols, veratroles, vanillins, aldehydes and syringols), chlorinated phenolics metabolites, resin acids (chlorinated and non-chlorinated) and fatty acids (chlorinated and non-chlorinated). The physical characteristics of the Wapiti River portion of the study area (habitat mapping) were also described.

In the fisheries portion of the study, two sentinel species were chosen: longnose sucker and mountain whitefish. Adult fish were captured throughout the open-water season (whenever possible), primarily by electroshocking. Young-of-the-year and forage fish were captured by seining. Longnose sucker were chosen as a sentinel species because they were representative of bottom feeders which have, in some cases, been shown to accumulate higher body burdens of contaminants due to their proximity to the bottom. Mountain whitefish were chosen because previous studies had shown (Alberta government news release 1990) that this species was susceptible to dioxin/furan accumulation.

Comparison of population characteristics between the Wapiti River and control site (North Saskatchewan River at Rocky Mountain House) sentinel species populations showed no significant differences. Longnose suckers from the Wapiti River did show higher condition factors that those from the control site, but differences can be attributed to a richer habitat in the exposed site (*Swanson et al*, 1994). None of the symptoms of exposure to BKME listed (see description section 4.2.2) by Munkittrick *et al.* (1991) were observed except increased EROD activity. Radiotelemetry and floy-tag studies showed that both species were highly mobile at various times of the year depending on flow, temperature and life cycle (i.e. spawning).

Reproductive potential, as measured by mean age of mature fish, gonad somatic indices (GSI) and fecundity were also not found to differ significantly although insufficient samples from mountain whitefish were obtained to make a comparison of fecundity. Reproductive success was confirmed by young-of-the-year of both sentinel species which were plentiful downstream of the effluent discharge at various times of the year.

A number of "biomarkers" were collected from each specimen examined including blood chemistry and hematology, sex steroid hormone levels, histopathology and EROD (ethoxyresorufin-O-deethylase) measurements and direct determinations of the levels of the specific EROD catalytic protein, cytochrome P4501A (Kloepper-Sams and Benton 1994). Looking for signs of gross pathology was also part of the sampling protocols. Among the blood chemistry parameters measured were serum chloride, potassium, gamma globulin, total protein, and albumin. Statistical differences existed but only between the near and far field reaches of the Wapiti River and not between the Wapiti and the control site. In addition, none of changes in blood chemistry were typical of results obtained by previous researchers examining the effects of more toxic effluents (Södergren 1989). The same trends were observed for hemoglobin. Plasma enzymes were within the ranges reported for non-exposed fish. In the spring of 1991, sex steroid hormone levels (testosterone and 17ß-estradiol) in female longnose suckers showed no difference between sites although the protracted spawning period in the Wapiti River did make obtaining specimens in spawning condition difficult. This difficulty in obtaining females in peak spawning condition may have accounted for the differences observed in 17,20-DHP levels which were lower in the Wapiti River fish. Alternatively, this may have been a consequence of effluent exposure although the other steroid hormones did not show the same trend. Testosterone levels in male suckers were not significantly different between sites and showed the typical profile of decline after spawning. A more comprehensive sex steroid hormone study is in progress which will compare non-spawning (August 1993) and pre-spawning, spawning and post-spawning (spring 1994) levels from both the Wapiti and North Saskatchewan River longnose sucker populations. No significant difference was detected in testosterone, 17ß-estradiol and 17,20-DHP levels of female mountain whitefish from both sites. The same was true for testosterone and 17,20-DHP levels in males of this species.

Visible signs of gross pathology, such as fin erosion and lesions, showed the same frequency of occurrence in both sites, for both sentinel species. The only pathology observed by histological examination (histopathology) was bile duct proliferation and cytoplasmic vacuolization of the liver (Kloepper-Sams *et al.* 1994). The significance of these minor aberrations is unknown since they could not be correlated to contaminant burden or higher P4501A induction.

Control fish showed low EROD activities whereas fish from the exposed site displayed a broad range of values. Induction was observed in fish as far as 230 km downstream of the mill and upstream of the effluent discharge. This may be evidence of the high mobility of these fish in such river systems. Mountain whitefish showed higher EROD activities than longnose suckers. Only the spring 1991 mountain whitefish showed a positive correlation between EROD activity and contaminant content (principally dioxin/furan) of the flesh and EOCL. Samples taken of mountain whitefish at other times did not show as strong a correlation. There was also no correlation between EROD activity and a number of other parameters tested such as LSIs (liver somatic index), GSIs and condition factor. Prespawning and spawning longnose suckers displayed an apparent reduction in EROD inducibility which has been linked to increased estradiol levels.

In summary, the only "biomarker" that was consistently observed at significant levels in either sentinel species was increased EROD activity. However, correlations between EROD activity and contaminant burden of the flesh or bile were not apparent in longnose sucker and only marginally correlated in mountain whitefish. Other indicators of fish health showed no signs of distress in either species exposed to the effluent.

The best example of how mill process changes (increased effluent quality by reduction of chlorinated hydrocarbons) can affect downstream contaminant burdens in fish comes from the Weyerhaeuser Canada Ltd. mill at Grande Prairie. As described in a previous section, this mill has undergone a number of process changes since 1989 designed at reducing usage of molecular chlorine. In summary, chlorine substitution was increased to 25% in 1989. In the fall of 1990, chlorine dioxide substitution was increased to 70%. This, along with other process changes, resulted in an effluent with TCDD/TCDF values at or below detection limits by the spring of 1991.

Mean 2,3,7,8-TCDD/TCDF (TEQ) (ppt) concentrations in mountain whitefish flesh and burbot livers have been monitored by-annually since the summer of 1990 and 1991 respectively. These two specific locations in the tissues of these fish were chosen because they showed the greatest potential for accumulation of these contaminants. The concentrations that were observed in the flesh of mountain whitefish and in the livers of burbot taken from the Wapiti River are shown in Figure 7. Sample sizes for these means were usually 3-5 fish. There has been a gradual reduction in 2,3,7,8-TCDD/TCDF in both the livers of burbot and flesh of mountain whitefish over time. The decline, however, has not been as rapid as would have been expected from the literature. Previous research found the biological half life of 2,3,7,8-TCDD to be in the order of 15 days for short-term low level exposures and up to 320 days for long-term exposures (Kuehl *et al.* 1987, Mehrle *et al.* 1988). Extrapolation of the results obtained in this study shows that the biological half-life for mountain whitefish is in the order of 180-210 days or greater. Burbot have shown the slowest depuration rates of 2,3,7,8-TCDD in the Wapiti River and this is most likely due to the high lipid content of their livers (45-63% lipid). Overall, a reduction in the contaminants in fish has been observed with the change in mill process. The reduction has been slower than anticipated and so monitoring will continue (pers. comm. Weyerhaeuser Canada Ltd.).

4.2.3.4 Athabasca River

There is a lack of adequate studies on the potential ecotoxicity of pulp mill effluents on this major river system. Wallace and McCart (1984) reviewed the available information on the fisheries of the

SENTAR

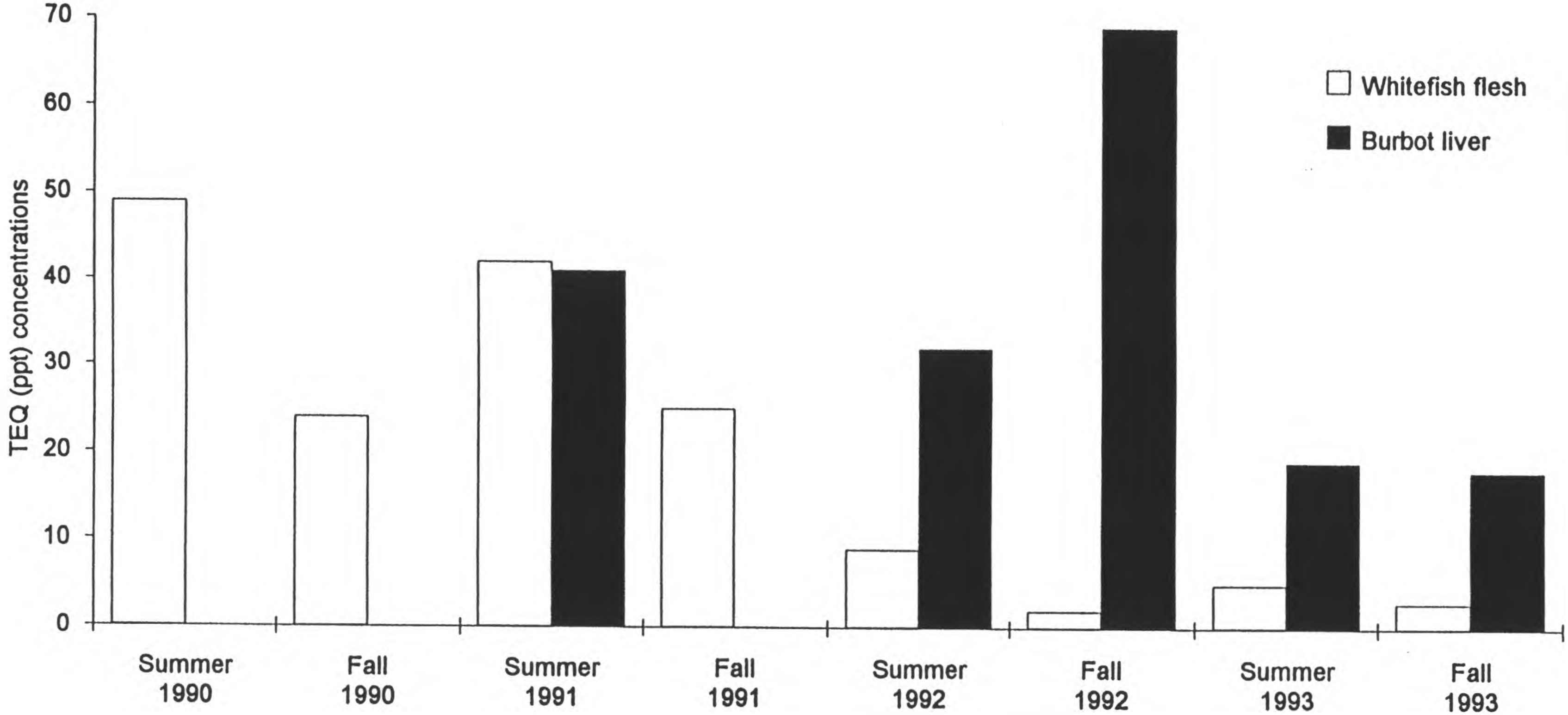


Figure 7
MEAN 2,3,7,8-TCDD/TCDF TEQ CONCENTRATIONS IN MOUNTAIN WHITEFISH AND BURBOT COLLECTED FROM THE WAPITI RIVER SINCE 1990 AND 1991

Athabasca River. This report summarized all of the available fisheries and fisheries habitat data for the Athabasca River. The focus of the report was on fisheries management as a resource for both private and commercial uses. They determined that this river can be divided into three major ecological reaches: the first 1,500 km is cold water habitat capable of supporting trout and whitefish, the second is a transitory zone (640 km) where the habitat changes from cold to warm water. This area supports a fish fauna which is a mixture between the two others, The third (2,250 km) is a warm water habitat supporting walleye, goldeye and pike. When considering the potential toxicity of an effluent on a river such as the Athabasca, it is important to distinguish changes in fish populations due to habitat differences from those due to other causes. Several recommendations were made by Wallace and McCart (1984). They recommended that more basic, ecological data be collected on the fish and fisheries of this river and that these surveys should encompass all aspects of the aquatic ecosystem.

Alberta-Pacific conducted a baseline aquatic monitoring study on the Athabasca River between the town of Athabasca and Grande Rapids from 1991 to 1993 (*Swanson et al.* 1994). The fish study was only one component of this extensive investigation of water and sediment (suspended and bottom) quality, benthic invertebrates and fish.

The fish species assemblage in the study area was similar to that of the lower Athabasca River downstream of Fort McMurray. Longnose sucker, trout-perch, flathead chub and mountain whitefish were the most common species. Fish were more abundant in the fall than in the spring or summer surveys. Radiotelemetry data indicated extensive seasonal movements through and within the study area by longnose sucker and mountain whitefish. Larger tributary streams such as the La Biche and House rivers provide important feeding areas and spawning habitat for the fish populations of the Athabasca River.

Low concentrations of 2,3,7,8-TCDF were detected in muscle (0.2-0.6 pg/g) and liver tissue (0.7-1.3 pg/g) of fish in the study area, but not in fish from a control location. No other dioxin or furan compounds were detected in fish. EOCL concentrations ranged from non-detectable to 1.1 µg/g in the muscle tissue (fillets) of all species. EOCL concentrations in liver tissue were higher (maximum = 3.3 µg/g), but there were no consistent differences between species or between near-field and far-field sites. Chlorinated phenolics were detected once in fish muscle, frequently in bile, but never in liver tissue. Volatiles were detected in fish muscle and PAHs in fish bile. No resin or fatty acids were detected in fish.

Metals concentrations in muscle tissue showed no consistent differences between species or between near-field and far-field sites; however, concentrations of mercury, zinc, chromium and lead in study area samples were higher than in control samples.

The findings of the external examinations and histopathological studies of fish were typical of normal damage, disease and parasite patterns. The EROD studies indicated that there is an existing level of induction of the liver detoxification system in fish from the study area. The contaminant data suggest dioxins/furans, other chlorinated organic compounds and PAHs as potential causative agents.

There were no significant differences in mean Liver Somatic Index (LSI) between male and female longnose suckers in either the Athabasca River or the control river, or between the rivers for either males or females. Mean LSI was significantly lower in the Athabasca River than in the control river for both male and female walleye. In the Athabasca River, there was no significant difference in mean LSI between male and female walleye, but in the control river males had significantly higher LSIs than females.

The amount of information that can be drawn from the results of the sex steroid hormone analysis is limited by the facts that no control site was sampled and data on "normal" hormone levels are limited. Within these limitations, the study data did not indicate any abnormalities. Gonad Somatic Index (GSI) values for female longnose suckers and walleye were significantly lower in the Athabasca River than for fish from a control river (Beaver/Cowan River). This was attributable to a smaller proportion of mature fish being captured in the Athabasca River.

4.2.4 Ecotoxicological Significance

From the data reviewed, a number of conclusions can be made concerning the ecotoxicity of pulp and paper mill effluents within the NRBS study area:

- Mortality of natural fish populations due to pulp mill effluents have not been documented for the NRBS area. The majority of effluents are quickly diluted by the substantial flows of the rivers they are discharged into, thereby reducing the chances of an acutely toxic effluent causing mortality in the receiving environment. Effluents that are acutely toxic to fish are rare and of short duration.

- Chronic toxicity, as observed by other researchers in Canada and Sweden, has not been observed within the NRBS study area. No significant changes in incidence of diseases as a result of exposure to pulp mill effluents have been found. Elevated EROD activity was found in fish in the Wapiti/Smoky rivers and the Athabasca River, but was not correlated with health effects.

- Only one mill (Weyerhaeuser Canada Ltd.) has conducted a study in sufficient detail to confirm or deny the presence of chronic toxicity due to effluent exposure. The SLPC monitoring of sentinel fish species provides population-level data for the Lesser Slave River and some data such as liver weight at the organism level, but histopathology, contaminant concentrations and biomarkers data are not available. Insufficient information is available at the other mill sites to determine if impacts are present in aquatic organisms in the receiving environment. Alberta-Pacific has completed a baseline study in sufficient detail to allow future monitoring to identify significant changes in the fisheries of the Athabasca River if they occur.

4.3 INTEGRATED STUDIES

SENTAR (1993c) pointed out that the cornerstone of the Procter & Gamble Cellulose Ltd. study was "integration". The focus was on examining possible cause and effect relationships by gathering concurrent data on contaminant body burdens and health/population response parameters. This allowed direct examination of the question "is chemical concentration x correlated with biological effect y?" The degree of integration in this study was a first for the NRBS area. Researchers rarely have the resources to obtain a full suite of chemical and biological data at the same time and place, especially over several seasons. The Alberta-Pacific baseline study also integrates data on fish health, contaminant burdens, population characteristics and movement with suspended and bottom sediment quality, water quality and benthic invertebrates.

Integrated studies are also necessary to determine contaminant pathways (Figure 8). For example, the Procter & Gamble Cellulose Ltd. data suggested that dioxins and furans were transported largely through suspended sediments. This finding, together with fish stomach content data, indicated that choice of food by different species of fish was an important determinant of contaminant body burden.

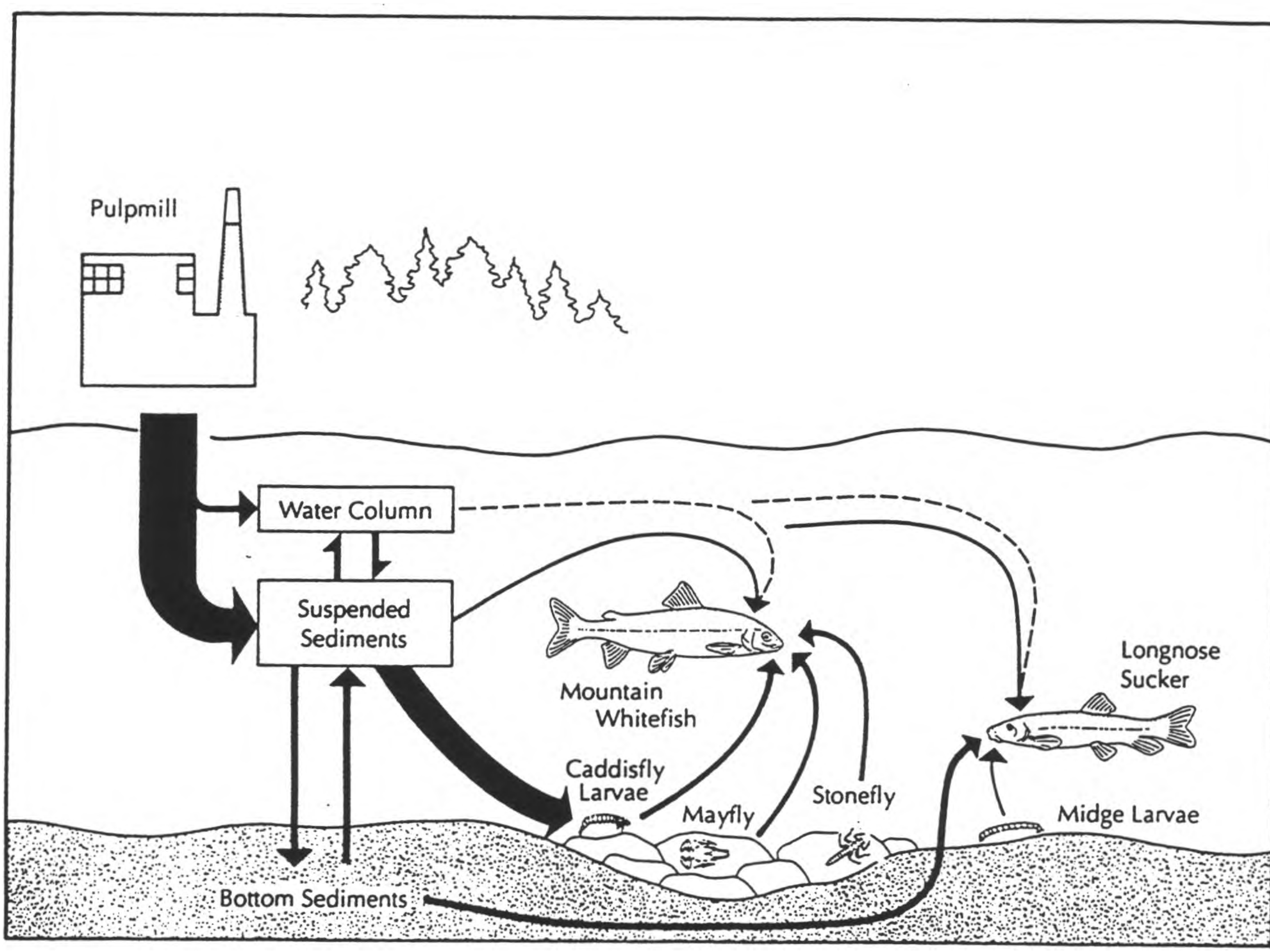


Figure 8
POSTULATED DIOXIN/FURAN MOVEMENT IN FOOD CHAINS
(taken from Swanson *et al.* 1993)

Thus, mountain whitefish, which primarily select filter-feeding insects, had higher body burdens than either bottom-feeding suckers or predatory walleye. This indicated a key connection between mountain whitefish body burden and suspended sediments (which are consumed by the filter-feeding insects). This also helped explain why lipid content was not the only explanation for dioxin/furan concentrations in mountain whitefish.

Although substantial effort is expended on the benthic invertebrate monitoring of pulp mill effluents, this monitoring could be enhanced by a more integrated approach such as the sediment quality triad (Triad) (Chapman and Long 1983, Long and Chapman 1985), which is an effects-based method incorporating measures of sediment chemistry, sediment toxicity and benthic community structure. The Triad has been used in several ways: (a) to identify and differentiate pollution-degraded areas, (b) to determine concentrations of contaminants associated with effects, and (c) to predict where degradation may occur based on chemistry and toxicity (Canfield *et al.* 1994). Sediment spiking studies may be needed to confirm cause-and-effect relationships.

4.4 HUMAN HEALTH

4.4.1 Exposure Limits

This section on exposure limits has been taken mainly from an Expert Panel (1994) report on the potential adverse effects of chlorinated organic chemicals from the pulp and paper industry.

4.4.1.1 Chlorinated Phenolics

Tetra- and pentachlorophenol are considered to be persistent chemicals; therefore, exposures of humans to pentachlorophenol (PCP) through the consumption of fish must be considered. The PCP exposure limit recommended by Health and Welfare Canada (60 µg/kg body wt/d; HWC 1989) is approximately 750-fold greater than that recommended by the U.S. EPA (0.08 µg/kg body wt/d; EPA 1992). At the U.S. EPA exposure limit of 0.08 µg PCP/kg body wt/d, the total allowable intake of PCP by a 70-kg person would be 5.6 µg/d. Based on this daily intake value, the maximum allowable concentrations of PCP in fish would be 28 ppb to ensure that individuals consuming large quantities of fish (e.g. natives consuming up to 200 g of fish per day) did not exceed the exposure limit. The maximum acceptable concentration (MAC) of PCP in fish to ensure that sport fish consumers (consuming 22 g of fish per day) did not exceed the exposure limit would be approximately 250 ppb.

4.4.1.2 Chlorinated Dioxins and Furans

A wide range in exposure limits for chlorinated dioxins and furans have been established by various agencies. The maximum acceptable exposure limit established by Environment Canada (CEPA 1990) and the Ontario Ministry of the Environment (MOE 1985) is 0.00001 µg 2,3,7,8-T_4CDD/kg body wt/d, or 10 pg/kg body wt/d. This exposure limit is based on the application of a 100-fold safety factor to the NOAEL for reproductive dysfunction in rats of 0.001 µg 2,3,7,8-T_4CDD/kg body wt/d (Murray *et al.* 1979) and is based on the premise that an exposure threshold exists for the adverse effects on reproductive performance observed from exposure to chlorinated dioxins and furans. In contrast, the exposure limit established by the U.S. EPA (1984) is 0.006 pg/kg body wt/d, based on the dose-response extrapolation of the liver tumor incidence, as reported in the study of Kociba *et al.*(1978). This exposure limit is based on the premise that there is no exposure threshold for the occurrence of liver tumors in response to exposure to 2,3,7,8-T_4CDD.

Comparison of the estimated rates of exposure from background sources, excluding food, to the maximum permissible threshold-derived exposure limit of 10 pg/kg/body wt/d indicated that no adverse health effects would be expected in the general North American population from background sources of chlorinated dioxins and furans. However, the comparison of these same estimated rates of exposure to the U.S. EPA's nonthreshold-derived exposure limit of 0.006 pg 2,3,4,8-T_4CDD/kg body wt/d indicated that current exposures to 2,3,7,8-T_4CDD TEQs of the general North American population would exceed the exposure limit by approximately 83 to 218-fold. This rate of exposure would be equivalent to a risk of liver cancer between 8.3 and 21.8 per hundred thousand, since the U.S. EPA exposure limit is based on a risk of one per million. The report of an Expert Panel (1994) concluded that these predictions of cancer risk appear to be unrealistic given that the age-standardized incidence of liver cancer due to all causes in North America is only 2 to 3 per hundred thousand (Statistics Canada 1988).

It is important to note that there is considerable scientific controversy over what is an acceptable exposure limit for 2,3,7,8-T_4CDD. The weight of available evidence supports the conclusion that a threshold mechanism of toxic action exists for 2,3,7,8-T_4CDD and other chlorinated dioxins and furans. This scientific consensus has been reflected in the derivation of regulatory limits in Canada and Europe.

Food consumption, including freshwater fish, has been reported to contribute the major portion of daily exposures to chlorinated dioxins and furans (Birmingham *et al.* 19898a), and the Ontario Ministry of the Environment has defined the maximum amount of 2,3,7,8-T_4CDD from food sources alone, including fish to be 80% of the 10 pg/kg body wt/d exposure limit, or 8 pg/kg body wt/d. If the entire acceptable dietary intake of chlorinated dioxins and furans was from fish, the maximum acceptable continuous consumption rate for a 70-kg adult and a 13-kg child would be 352 and 65 g/d, respectively, of fish fillets containing a mean concentration of 4.68 ppt. These consumption rates are approximately tenfold greater than typical rates of fish consumption for North Americans.

4.4.2 <u>Tissue Concentrations</u>

4.4.2.1 Chlorinated Phenolics

Chlorinated phenolics were rarely detected in fish fillets from the Wapiti River (SENTAR, 1993c). Pentachlorophenol was detected in four of six mountain whitefish analyzed, ranging from 1.0 ppb to 4.0 ppb. In the fall of 1989, a study commissioned by Daishowa-Marubeni investigated contaminants in fish from the Peace, Slave and Smoky rivers. Four of the fish sampled contained chlorinated phenols; the highest concentration was 6.0 ng/g of pentachlorophenol (Monenco 1990a). The Alberta-Pacific baseline study (*Swanson et al.* 1994) of the Athabasca River detected chlorinated phenolics frequently in bile, but only once in fish muscle.

Recent data showed that juvenile chinook salmon and eulachon near pulp and paper mills in the Upper Fraser River accumulated tetra- and pentachlorophenols in the range of 2 ppb to 62 ppb and 20 ppb to 22 ppb, respectively (Rogers *et al.* 1990).

Based on the more stringent U.S. EPA exposure limit and the assumption that persons might eat 200 g of fish per day, the concentrations detected by SENTAR (1993c) and Monenco (1990a) were well within the acceptable range.

4.4.2.2 Chlorinated Dioxins and Furans

On July 27, 1990, the Alberta government issued a news release which banned the consumption of mountain whitefish from the Wapiti and Smoky rivers as a result of sampling from 1987 to 1990 (Alberta government news release 1990). In October of 1987, <5 to 17 ppt of 2,3,7,8-TCDD (TCDD) and 17 to 290 ppt 2,3,7,8-TCDF (TCDF) were found in whole, individual longnose suckers. In October 1989, the same testing program found the concentrations shown in Table 26.

Table 26: Results of Testing for TCDD/TCDF on Fish from the Wapiti River Conducted by Alberta Environment

Species	Sample Type	TCDD (ppt)	TCDF (ppt)
White Sucker	5 composite fillets	2.3	7.5
	5 composite whole fish	5.5	23.2
	5 composite fillets	5.7	12
Mountain Whitefish	5 composite fillets	11.4	73.5
	5 composite fillets	26.0	240
Walleye	5 composite fillets	1.8	4.3
Northern Pike	4 composite fillets	<1.3	10.3
	4 composite fillets	1.7	8.6

Note: Samples collected in October 1989 by Alberta Environment.

The result which initiated the ban on mountain whitefish was the 26 ppt of TCDD which is above Health and Welfare Canada's limit for safe consumption.

The Procter & Gamble Cellulose Ltd. study (SENTAR 1993c) detected dioxin and furan in mountain whitefish fillets and liver from the Wapiti-Smoky river system as well as the control location of the North Saskatchewan River (Table 27) and in walleye fillets, burbot fillets and burbot livers from the Wapiti River (Table 28). The concentrations of dioxin and furan in fillets from all species of fish are well below the 4.68 ppt mean concentration used in the Expert Panel (1994) calculations, indicating that a continuous diet made up entirely of fish would not exceed the acceptable dietary intake for these organochlorine compounds. Burbot livers were found to have elevated concentrations of dioxins and furans, which may be valuable as a monitoring tool but would not represent a human health hazard. SENTAR (1993c) found that EOCL levels in fish fillets declined after implementation of 70% chlorine dioxide bleaching at the Procter & Gamble (pre- Weyerhaeuser) mill. With increased chlorine dioxide substitution (to 100%), the dietary intake of dioxins and furans will decrease further.

Table 27: Dioxin/Furan Congeners Detected in Mountain Whitefish from the Wapiti/Smoky and North Saskatchewan River Systems, 1990-1991

Congener	Tissue	Season/Year	Number of Fish	Mean Concentration (±standard deviation) (ppt)
1,2,3,7,8-PeCDF	Fillet	Summer 1990	1	1.2
	Fillet	Fall 1990	1	0.53
	Fillet	Summer 1991	3	0.50±0.1
	Fillet	Fall 1991	1	0.6
	Fillet	Summer 1990	1	0.4
2,3,4,7,8-PeCDF	Fillet	Summer 1990	1	1.5
	Fillet	Fall 1990	1	1.2
	Fillet	Summer 1991	6	1.1±0.7
	Fillet	Summer 1991	1	0.1
	Liver	Summer 1991	2	1.1
	Fillet	Summer 1991	1	0.3
	Fillet	Fall 1991	2	2.1
	Liver	Fall 1991	1	1.2
1,2,3,7,8-PeCDD	Fillet	Summer 1991	6	1.2±0.8
2,3,4,7,8-PeCDD	Fillet	Summer 1991	1	1.0
1,2,3,4,7,8-HxCDD	Fillet	Summer 1991	1	1.6
1,2,3,6,7,8-HxCDD	Fillet	Summer 1991	1	1.0
1,2,3,4,6,7,8-HpCDD	Fillet	Summer 1991	1	1.0
OCDD	Fillet	Summer 1991	1	1.7

Note: Table from SENTAR 1993c.

Table 28: 2,3,7,8-TCDD/TCDF (TEQ) in Walleye Fillets, Burbot Fillets and Burbot Livers from the Wapiti River, 1990-1992

Species	Sample Type	Season/Year	TEQ[a] (ppt)	Detection Limit TCDD (ppt)	Detection Limit TCDF (ppt)	% Liquid
Walleye	Fillet	Summer 1990	(0.31)[b]	0.1	0.1	1.2
	Fillet	Summer 1990	0.12	0.1	0.2	1.2
	Fillet	Spring 1991	0.21	0.2	0.1	0.6
	Fillet	Spring 1991	0.11	0.1	0.1	0.7
Burbot	Fillet	Summer 1991	0.23	0.1	0.1	0.39
	Fillet	Summer 1991	0.80	0.1	0.1	0.35
	Fillet	Summer 1991	0.28	0.2	0.1	0.36
	Fillet	Summer 1991	0.27	0.2	0.1	0.39
	Fillet	Summer 1991	0.44	0.1	0.1	0.71
Burbot	Liver	Summer 1991	15.0	0.3	0.2	44.9
	Liver	Summer 1991	139.0	0.3	0.2	63.5
	Liver	Summer 1991	38.0	0.3	0.3	45.1
	Liver	Summer 1991	(2.3)[b]	0.2	0.2	49.7
	Liver	Summer 1991	18.3	0.2	0.2	34.6
	Liver	Spring 1992	41.0	0.2	0.3	52.0
	Liver	Spring 1992	10.3	0.3	0.3	61.5
	Liver	Spring 1992	88.0	0.3	0.3	50.2
	Liver	Spring 1992	12.9	0.3	0.4	53.8
	Liver	Spring 1992	13.3	0.2	0.4	51.6
	Liver	Fall 1992	30.0	0.8	0.7	59.0
	Liver	Fall 1992	97.0	1.2	1.5	59.0
	Liver	Fall 1992	199.0	0.9	0.8	52.0
	Liver	Fall 1992	8.1	0.7	0.5	56.0
	Liver	Fall 1992	8.2	0.9	0.9	20.0

Note: Table from SENTAR 1993c.

a. TEQ = 2,3,7,8-TCDD + (0.1 x 2,3,7,8-TCDF)

b. ( ) = listed as non-detectable due to the criteria of incorrect ratio. The exact value is not known because one of the several criteria used for the determination of dioxin/furans has not been satisfied. The exact value would not exceed this number.

In the fall of 1989, a study was commissioned by Daishowa-Marubeni to examine contaminant levels in northern pike flesh in the Peace River system (Monenco Consultants Ltd. 1990a). Contaminant concentrations in the flesh were generally low. The only chlorinated dioxin or furan detected was 4.7 pg/g of 2,3,7,8-TCDF in one specimen.

The Alberta-Pacific Forest Industries Inc. baseline study of the Athabasca River found low concentrations of 2,3,7,8-TCDF in fish fillets (Table 29) and liver tissue in the study area (*Swanson et al.* 1994). These concentrations are well below the concentration used in the Expert Panel (1994) calculations. Thus, contaminant concentrations observed in fish from the Peace and Athabasca river systems do not pose a threat to human health.

Table 29: Dioxin and Furan Content (pg/g or ppt) of Fish Fillets from the Alberta-Pacific Industries Ltd. Baseline Study Area, Spring 1992

Species	Near-Field N	Near-Field Congener	Near-Field Range	Far-Field N	Far-Field Congener	Far-Field Range
Longnose Sucker	5 (2)	2,3,7,8-TCDF	ND - 0.6	5 (2)	2,3,7,8-TCDF	ND - 0.6
Walleye	5 (0)	-	ND	5 (0)	-	ND
Goldeye	5 (0)	-	ND	5 (1)	2,3,7,8-TCDF	ND - 0.2

N = number of samples. Numbers in brackets represent the number of samples with detectable concentrations

ND = not detected. Detection limit for 2,3,7,8-TCDF ranged from 0.1 to 0.2 pg/g and for all other congeners from 0.1 to 9.2 pg/g.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 INFORMATION GAPS AND OPPORTUNITIES

5.1.1 Biofilm/Algae

During the review of biofilm data for this report, the following information gaps were identified:

- There are no data on biofilm other than epilithic algae.
- Existing information on epilithic algae are primarily chlorophyll *a* data and algal mat thickness data, although collection of the latter was discontinued in 1992 in favour of chlorophyll *a* data. Since algal species have been identified only for the Lesser Slave River, a decrease in species richness, usually one of the most sensitive indicators of ecotoxicity, cannot be determined.
- Until recently, there was no field experimental work done to identify decreases in the algal biomass or species richness due to toxicity that may be masked by increases due to nutrient enrichment from point sources such as pulp mills, municipal sewage treatment plants and tributaries. NRBS has now initiated experimental work at Hinton to address this point.
- Preliminary chronic bioassay results do not differentiate between the presence of toxicity and other effects. Preliminary EEM results indicate inhibition/stimulation effects due to effluent on *Selenastrum capricornutum.* These effects could indicate that the effluent is either toxic, an inadequate growth medium, or an especially good growth medium. Effluent should not be required to be a growth medium, but effluent should be non-toxic. Further testing is required to determine whether the "early warning" provided by the *S. capricornutum* test is due to toxicity.

Biofilm monitoring has been of low priority in the past. The inhibition of algal growth has not been a concern when chlorophyll *a* data show increased biomass below pulp mills and higher sediment oxygen demands have been measured below pulp mills as a result.

There are three reasons why an epilithic algal study may deserve a higher priority. Firstly, the preliminary results of the *Selenastrum capricornutum* growth test required under EEM indicate that effluents from some of the pulp mills have a significant effect on this alga. In some cases, this bioassay shows the most pronounced effect of the three chronic bioassays required under EEM. Secondly, the Swedish discovery of chlorate toxicity to brown algae in the Baltic Sea was a warning that very little is known about potential negative environmental effects of the recent and rapid changes that have occurred in the pulp and paper industry. Thirdly, plants have received much less attention than animals even though they are the foundation of the aquatic ecosystem.

5.1.2 Invertebrates

5.1.2.1 Benthic Invertebrate Assemblages

The review of benthic invertebrate data for the NRBS area identified both strengths and weaknesses in the monitoring programs.

A review of the EEM monitoring requirements quickly shows that Alberta mills have maintained a much higher standard of monitoring than the standard required under EEM (described in section 2.2.3.2). The credit goes to Alberta Environment biologists for recommending and following the monitoring methods most often used (e.g. Alberta Environment 1990) and also to the pulp mills for maintaining a consistent level of quality over many years. Some common (although not universal) features of the monitoring include:

- selection of sampling sites that are consistent with respect to substrate, velocity and depth. Because there are always minor differences, detailed descriptions, including epilithic algae, velocity, depth and particle size, are often provided.

- the large number of control, near-field and far-field stations. Most monitoring programs include two or three control stations which are particularly valuable when assessing natural differences among years, seasons and habitat types.

- generally, five samples are collected from each location to determine the within-station variance.

- the Neill cylinder has been used at many of the mills allowing a comparison of data among mills without having to estimate sampling efficiencies, etc.

- the high level of effort, and the continuity of taxonomic identifications (generally to species or genus level) at five of the mills are important in maintaining the consistent data quality needed for trend analysis. QA/QC is more difficult to evaluate in biological analysis than in chemical analysis, but it is equally important.

- multivariate analysis techniques as well as a suite of indices (species richness, diversity, etc.) are usually employed in data analysis. Other techniques such as trophic guild analysis are features of some of the monitoring.

This review also identified deficiencies in the database and opportunities to enhance benthic invertebrate monitoring in the future. Deficiencies include:

- changes in the season when annual samples are collected (usually at the request of the regulators). Significant differences among seasons have been demonstrated using northern rivers data. Therefore, sampling in the same season reduces one of the largest natural variables.

- changes in sampling methods. Currently, sampling methods have been consistent but the usefulness of historical data has been affected by changes in methods.

Opportunities include:

- determination of causal relationships through direct experimental work. Multivariate analysis may identify some benthic assemblages as being different from others, but most monitoring programs do not go to the next step of demonstrating the cause of these differences.

- consideration of accuracy and precision during the design of any biomonitoring study (Rosenberg and Resh 1993). Conclusions regarding impact too often have been based on significant differences in main-effect means that really resulted from the influence of either covariate factors or sampling bias, or both. With small sample sizes, the ability to detect differences between means of benthic measures over space or time (usually the objective in the biomonitoring study) can be enhanced by using more powerful techniques such as ANOVA (as compared to, for example, estimates of means and confidence intervals). Set precision and error risk rates appropriate to the questions asked: P=0.05 is not the only level available.

- maintenance of reference collections for taxonomic identification. A reference collection of species identified from the study area will reduce incorrect identification, particularly if several researchers are involved over time. Rosenberg and Resh (1993) recommend that biologists doing the monitoring retain voucher specimens and prepare a reference collection that will be placed in a depository, such as an established university department or government museum. Such institutions also should expect some compensation for this service.

- evaluation of the frequency of environmental effects at the organism level. Additional study of the frequency of morphological deformities or other health or reproduction effects would provide effects data at the scale of the individual organism. Current monitoring provides data at the community level.

- expansion of the monitoring to an integrated approach. The triad approach includes determination of sediment contaminant concentrations, sediment toxicity and benthic invertebrate populations. This approach may be useful in determining cause-and-effect should multivariate analysis identify an effect of pulp mill effluent on the benthic community.

- improvements in data handling. Benthic invertebrate monitoring produces copious data which are currently handled differently by each biologist. Consideration should be given to developing a more uniform database format and data quality control procedures. Then, data for the same watershed collected by different biologists could be compiled and synthesized electronically.

5.1.2.2 Invertebrate Bioassays

Invertebrate bioassays are a large component of the effluent monitoring required by provincial Approval and EEM. The *Daphnia magna* 48-hour bioassays are conducted weekly, and *Ceriodaphnia dubia* sublethal bioassays are required quarterly for one year by EEM. Thus, mills in the NRBS area are presently conducting a substantial number of bioassays. The following are recommended as opportunities to enhance the ongoing program:

- selection of more relevant species. Toxicity testing with standard species provides a uniform information base; however, the test species chosen should still be relevant to the ecosystem to which the data are to be applied. Buikema and Voshell (1993) reported a global need to develop acute toxicity test methods for baetid and burrowing mayflies, caddisflies and stoneflies. These organisms are sensitive to pollution, good indicators of ecosystem health and much more relevant to large river ecosystems than Ceriodaphnia dubia. For example, SENTAR (1993c) found a correlation between the concentration of compounds in suspended sediments and concentrations in caddisflies, which are filter feeders. The mayfly Hexagenia has been shown to accumulate dioxins when exposed to contaminated sediments. Acute and chronic tests using Hexagenia spp. are available from ASTM (Bedard and Henry 1992).

- differentiation between toxic effects and effects related to effluent as a growth medium. For example, Millar Western has been unable to find a toxicity-related cause of recent Daphnia magna test failures and has tentatively attributed the failures to the lack of nutrients in the effluent due to recent steps to reduce ammonia. Bioassays are indicators of lethality or sublethal effect, but further study is needed to determine whether the cause is toxicity.

- verification of ecotoxicity. The preliminary results of the Ceriodaphnia dubia assay indicate that the pulp mill effluents inhibit reproduction, while biomonitoring indicates increased numbers of organisms downstream of pulp mill effluents. This apparent contradiction needs to be addressed.

- improved data handling. Due to the extensive quality control and data reporting requirements, the final result of each acute test consists of three to five pages of paper. With the large number of tests being done, the data can quickly fill filing cabinets and become virtually inaccessible in any cost-effective manner. An electronic database that has a standardized format, a standardized quality control for data entry, is maintained on a monthly basis, and is used by all mills is recommended. At present, an ever-increasing amount of expensive data is becoming unavailable; this situation will get worse as the mills continue to operate.

- data QA/QC. In presenting the data supplied by the mills in chapter 3.0, a small number of transcription errors were found. Quality control is stipulated at the sampling and analysis steps, but currently no quality control is specified at the data handling stage. It is not necessary when the original results are submitted to Alberta Environmental Protection, but it would be needed if a database were developed.

5.1.3 Fish

The techniques and sampling protocols used in monitoring fish populations exposed to pulp mill effluents have evolved considerably over the past few years. The simple monitoring of contaminant levels in fish flesh is no longer adequate to meet the information needs of both industry and government. Although assessment of the potential risk to fish consumers is still warranted, the emphasis of this type of work is shifting towards understanding the effects of these contaminant burdens on the organism and population levels. Consequently, a more rigorous set of standard parameters need to be examined (i.e. biomarkers) so that contaminant burdens can be correlated to general fish health. These parameters, such as length, weight, age, gonad weight, state of sexual maturity, liver weight, histology of vital organs, steroid hormone levels, analysis of bile for contaminants, stomach contents and lipid content, could be used not only to give a better understanding of fish health, but also serve as a basis of comparison when fish from different rivers are sampled. McLeay (1987) found that few studies prior to 1987 had examined the histology of indigenous fish in the vicinity of pulp and paper mill effluent discharges. Many of the parameters which are now common practice in the study of fish populations exposed to pulp and paper mill effluents (i.e. mixed function oxidase, steroid hormone levels, bile analysis) have only been in use for the past few years.

A review of the information on fish bioassays, fish populations and the effect of pulp mill effluent on fish health, immediately shows that there is a wide range in the quantity of data available to assess ecotoxicity in different regions of the NRBS area. Information gaps include:

- the lack of ecotoxicity in toxicity testing. Mills with alkaline effluents reported that some rainbow trout bioassay failures are due to increases in effluent pH during the bioassay which would not occur when effluent is discharged to a receiving stream. Mills also do two, three or even four rainbow trout bioassays on each effluent sample to protect themselves from the repercussions of what they believe are false positive results (generally failures related to test fish health or conditions in the test vessel). Toxicity testing should not be an end in itself, but should be only one of the tools for environmental protection. Overemphasis on one method (particularly in situations where the method may not be relevant) may not be beneficial to protection of the rivers in the NRBS area.

- insufficient information on the natural fish populations in the Athabasca River has been identified (Wallace and McCart 1984). The Alberta-Pacific Forest Industries Inc. baseline study added information as far upstream as the Town of Athabasca but information on natural fish populations in the upper Athabasca River is still limited.

- development and verification of methods demonstrating residency of fish in the vicinity of the effluent. Possible methods of demonstrating residency include tagging, reconstructed growth rates and chemical or physiological tracers.[1] Radiotagging is costly and other tags are probably too ineffective to be useful. Reconstructed growth rates are only useful if there are significant differences in growth between reaches. Potential tracers include concentrations of resin acids (or other measurable pulp mill constituents) in fish bile, and enzyme induction (e.g. mixed function oxygenases). Bioconcentration factors for resin acids in bile are considerably greater than for other tissues, organs or media (Oikara and Kunnamo-Ojala 1987). Laboratory exposures indicate that elevated MFO levels do not occur when fish are exposed to CTMP effluent (Martel *et al.* 1993). Also, MFO levels drop rapidly when exposure ceases (Munkittrick *et al.* 1992b), so it is impossible to use MFO to establish residency for more than the last few days or weeks. A disadvantage of resin acids, MFOs or any other tracer, is that there is no certainty that the tracer will be similar in terms of solubility and loss rates to the compounds causing effects. Also, contaminant tracers specific to pulp mills may be below detection limits in fish tissues, based on preliminary data from the NRBS area.

- the effects of pulp mill effluents on anything other than adult fish. Early life stages (gametes, embryos, fry and juveniles) of freshwater fish are known to be more sensitive to contaminants (Rand and Petrocelli 1985, von Westernhagen 1988) but few, if any, biomonitoring studies have been conducted on early life stages in the NRBS area.

- the lack of information on the transfer of contaminants from aquatic to terrestrial environments. The potential bioaccumulation of contaminants in mammals and birds that feed in aquatic habitats receiving effluents is an area of research that has received little attention, not only in the NRBS area, but across Canada. Cook et al. (1991) stated that "species associated with aquatic food webs, especially fish and fish-eating birds and mammals, appear to be very sensitive to polyhalogenated aromatic hydrocarbon toxicity". The Expert Panel (1994) found that, in many cases, data on the effects of chlorinated chemical constituents of pulp mill effluent in wildlife using the fisheries resource were not identified.

---

1 Part of this summary taken from EVS 1993.

- habitat mapping. Many of the fisheries studies reviewed included some form of habitat mapping in their results. The information presented varied in quality and quantity. Some studies simply presented photos of sampling sites while others gave detailed description of the physical characteristics of the sites examined. This review has shown that varying habitat characteristics can have dramatic effects on fish species presence and abundance. Consistent attention to this type of information is needed if impacts due to effluent exposure are to be distinguished from environmental variables.

- integrated monitoring. There currently are no integrated monitoring requirements for fish. EEM guidelines will fill much of this gap but they fall short of an integrated monitoring program. Biomarkers such as sex steroids and fish health indicators, for example, are not included.

- other ecological factors. The recent emphasis on ecotoxicity, even though it is only one ecological factor out of many, may divert attention from other factors such as habitat alteration (e.g. effect of forestry practices on spawning habitat in small tributaries). These factors may have a greater impact on the fisheries resource.

The NRBS has already commissioned a number of studies to address the aforementioned information gaps.

5.1.4 Abiotic Component

The ecosystem consists of both biotic and abiotic components. Monitoring of water quality, the major abiotic component, is covered in ongoing programs. Other abiotic compartments of the ecosystem, such as the suspended and bed sediments, have received less attention. Although contaminants in the ecosystem are addressed in another NRBS report, data gaps are included here for completeness of the ecosystem approach.

- The Triad monitoring approach includes monitoring of contaminants in sediments since benthic invertebrates are in close contact with this medium (both suspended and bed sediments). Addition of this component would allow correlation of contaminant concentrations to invertebrate effects (e.g. chronic toxicity, population changes).

- Toxicity tests measure only the immediate bioavailability of toxicants; they cannot measure persistence or fate of the toxicant. The limited understanding of fate and transfer of hydrophobic chemicals from sediments into the aquatic food chain needs to be expanded (Expert Panel 1994). The differences between field observations of Swedish and North American studies of the environmental effects of bleached kraft mill effluent demonstrate the importance of the receiving water characteristics (such as rates of mixing, dispersion, flushing, and water chemistry), on the fate and transport of chemicals, and on the respective sensitivity of the environment to the introduction of bleached kraft mill effluent constituents.

5.1.5 Ecosystem Processes

Ecology is the study of the interactions between species and assemblages; it is more than the study of each species in isolation. Yet, most of the monitoring and studies in the NRBS area pertain to effects on individuals or populations of each species in the ecosystem rather than the ecosystem processes. There are a few exceptions such as the benthic trophic guild analysis done for some of the pulp mills, and a description of food chain transfer of dioxins and furans by SENTAR (1993c), but none of the routine monitoring methods required by regulations measure ecological process. A number of methods described in Chapter 1 can be used for this purpose (e.g. multi-species tests, artificial streams, etc.).

Because of functional redundancy and resilience within the biological community, ecosystems respond to stress by maintaining essential functions at the expense of sensitive species. Gross functions like decomposition or primary production reflect the contributions of many species, which may change according to environmental conditions or toxicity without affecting the overall rate of the function. Primary and secondary productivity are surprisingly stable under all but the most extreme conditions (Reice and Wohlenberg 1993). An ecosystem that has just begun to show a decline in system function has already exhausted its capacity to deflect stress through species replacements or other mechanisms. More importantly, a site might show no reduction in rates of nutrient cycling yet still harbour toxic contaminants and have only a limited capacity to cope with further stress. Sensitive species or populations begin to show toxic effects at much lower levels of contamination. Thus, species-level toxicity testing and species richness indices permit early remedial or preventive action and provide a higher level of protection for ecosystems. For these reasons, no specific recommendations have been made to include process monitoring in this section.

5.2 SCALE AND INTEGRATION

The concept of scale is an ever-present dilemma. An example is when ecotoxicological endpoints are large scale, such as effects on populations of fish or assemblages of benthic invertebrates, but the measured indicators often come from the molecular (contaminant burdens), tissue (liver EROD activity) and organism (acute and chronic bioassay) levels. This paradox creates interpretive uncertainties. An alternative approach is to develop ecological endpoints and their respective indicators at the same biological scales (Gentile and Slimak 1992). The use of scale-dependent indicators would reduce the need to extrapolate across biological scales.

The majority of the monitoring required by provincial approvals in the NRBS area currently have endpoints at the smaller scales (concentration of contaminants, bioassays). Besides being less expensive and easier, the relatively high precision of these tests make them more suitable for use by regulatory agencies. However, having a high degree of precision does not mean that the test results accurately predict the effect on the natural ecosystem. Precision does not ensure accuracy, particularly across biological scales. The major exception to the small-scale endpoints referred to above is the benthic invertebrate monitoring.

When the provincial monitoring requirements are evaluated from the perspective of the major biological categories of plants, invertebrates, and vertebrates, the discrepancies in scale and effort become apparent. The only scale monitored for the plant category is assemblages (epilithic algae as chlorophyll *a*) and the level of effort is minimal. Invertebrates are monitored at the organism (*Daphnia magna* acute toxicity) and assemblages scales. Smaller scales have been examined in special studies such as contaminant concentrations SENTAR (1993c); these studies are site-specific and limited in scope. Nevertheless, the invertebrate monitoring includes different scales and the level of effort is substantial (weekly bioassays and intensive annual biomonitoring). The only scale routinely monitored for fish is the organism scale (acute lethality assays). Two major baseline studies initiated by the EIA process and operational studies/monitoring by two mills, Procter & Gamble Cellulose Ltd. and SLPC (now Weyerhaeuser) provide the only data at the population level. For other locations, particularly other parts of the Athabasca River, no population scale monitoring data are available. It is here that the problem of extrapolating across scales and from the laboratory to the field is greatest.

Monitoring underway as a result of federal EEM requirements will fill in some of the gaps with respect to the scales being monitored. The *Selenastrum capricornutum* bioassay will strengthen plant monitoring at the organism scale. The *Ceriodaphnia dubia* chronic bioassay is particularly relevant to ecotoxicology because of its emphasis on reproduction. The species is not important to large rivers; zooplankton generally are of less importance in rivers than lakes.

Alberta appears to lead the rest of Canada in benthic monitoring. If the minimum benthic invertebrate monitoring requirement under EEM were followed by the pulp mills in Alberta, it would substantially reduce the quality of the data, the amount of data available and the option for future trend analysis. The sentinel species and biomarker components of EEM will provide population scale data for fish and, therefore, fill a serious data gap.

5.3 ECOLOGY AND ECOTOXICOLOGY

In a recent letter to the editor of SETAC News, Crane (1995) asked "Is there a place for ecology in ecotoxicology?" His answer was a definitive NO! because of difficulties encountered by ecotoxicologists when they stray from the usual path of toxicology and embrace an ecological approach. Crane argued that ecotoxicology is much better when left to its biological, chemical and clinical (i.e. human toxicology) roots. (Not to mention its legal applications.) Crane (1995) pointed out that ecologists are even unable to agree upon what constitutes a stable biological community. Ecological theory has had its difficulties, and his argument would be persuasive if it were not for the fact that fish live in the complex and unpredictable northern rivers of Alberta. There has always been the desire to find a single numerical index or single laboratory test that will measure "ecosystem health", much like taking the temperature of a person. The very expression "ecosystem health" expresses the yearning that an ecosystem with hundreds of species can be thought of as a single individual.

The fundamental objective of environmental protection should be to protect the ecological integrity of the northern rivers. Ecological integrity is the sum of the biological elements (populations, species, assemblages) and ecological processes. Water chemistry and toxicity tests, the core of environmental protection programs, are not in themselves adequate to protect ecological integrity (Karr 1993). They must be verified and supplemented by direct assessment, such as biomonitoring, field experiments (e.g. experimental streams) or ecosystem studies.

The current interest in ecotoxicology in this report and many new publications tends to obscure the fact that toxicity is only one of the risks facing organisms in northern rivers. Karr (1993) identified five major classes of variables influenced by human actions that may result in the degradation of water resources. Ecotoxicity is only a small part of this list:

- water quality - temperature, turbidity, dissolved oxygen, organic and inorganic chemicals (heavy metals, toxic organic substances, etc.),
- habitat structure - substrate type, water depth and current velocity, spatial and temporal complexity of physical habitat,
- flow regime - water volume, temporal distribution of flows,
- energy source - type, amount and particle size of organic material entering stream, seasonal pattern of energy availability, and

- biotic interactions - competition, predation, disease, parasitism.

Successful efforts to protect aquatic resources (e.g. predictive models, monitoring) should incorporate the following characteristics: biological complexity, geographic variation in the watershed from the headwaters to the river mouth, and dynamic conditions at a variety of spatial and temporal scales. This is another way of saying that the "eco" must remain in ecotoxicology.

6.0 LITERATURE CITED

Alberta Energy and Natural Resources. 1985. *Wapiti River Survey, 1984.* Fish and Wildlife Division, Alberta Energy and Natural Resources, Peace River Region.

Alberta Environment. 1989. *Peace River Oils #1 Study.* Environmental Assessment Division, Alberta Environment.

Alberta Environment. 1990. *Selected Methods for the Monitoring of Benthic Invertebrates in Alberta Rivers.* Environmental Quality Monitoring Branch, Environmental Assessment Division, Edmonton.

Alberta Environment. 1993a. *Nutrient Data, Northern Rivers Study Area.* Environmental Assessment Division, Environmental Protection Services, Alberta Environment.

Alberta Environmental Centre. 1987. *Toxicity and Environmental Chemistry of Wastewater from a Kraft Pulp and Paper Mill*: Fish Toxicity Studies. Report AECV87. R4.

Alberta Newsprint Company Ltd. (ANC). 1988. *Environmental Impact Assessment of the Proposed Whitecourt Newsprint Mill.* Alberta Newsprint Company Ltd., Edmonton.

Alberta-Pacific Forest Industries Inc. 1989. *Environmental Impact Assessment - Bleached Kraft Pulp Mill.* Main Report. Alberta-Pacific Forest Industries Inc., Edmonton.

American Society for Testing and Materials (ASTM). 1991. *Standard Guide for Conducting Sediment Toxicity Tests with Freshwater Invertebrates.* Reference Method 47E030102. American Society for Testing and Materials, Philadelphia.

Ames, B.N., J. McCann and E. Yamaasaki. 1975. *Methods for Detecting Carcinogens and Mutagens with Salmonella/Mammalian-Microsome Mutagenicity Test.* Mutagenicity Research 31:347-364.

Anderson, A.M. 1989. *An Assessment of the Effects of the Combined Pulp Mill and Municipal Effluents at Hinton on the Water Quality and Zoobenthos of the Athabasca River.* Environmental Quality Monitoring Branch, Alberta Environment, Edmonton.

Anderson, A.M. 1991. *An Overview of Long-Term Zoobenthic Monitoring in Alberta Rivers (1983-1987).* Environmental Quality Monitoring Branch, Environmental Assessment Division, Alberta Environment.

Bedard, D.C. and M.G. Henry. 1992. *Hexagenia Sp. Section A5.* ASTM Standard Practice (draft). Prepared for Committee E-47.

Bartell, S.M., R.H. Gardner and R.V. O'Neill. 1992. *Ecological Risk Estimation.* Lewis Publishers, Boca Raton.

Beak Associates. 1988a. *Baseline Benthic Invertebrate Monitoring Study on the Athabasca and McLeod Rivers Near Whitecourt, Alberta, 1987.* Beak Associates Consulting Ltd., Calgary, Alberta.

Beak Associates. 1989a. *Baseline Benthic Invertebrate Monitoring Study on the Athabasca and McLeod Rivers Near Whitecourt, Alberta, 1988.* Beak Associates Consulting Ltd., Calgary, Alberta.

Beak Associates. 1990a. *Benthic Invertebrate Monitoring Study on the Athabasca and McLeod Rivers Near Whitecourt, Alberta, 1989.* Beak Associates Consulting Ltd., Calgary, Alberta.

Beak Associates. 1990b. *Benthic Invertebrate Monitoring Study and Fish Habitat Assessment on the Athabasca River, Whitecourt, Alberta, 1989.* Beak Associates Consulting Ltd., Calgary, Alberta.

Beak Associates. 1991a. *Benthic Invertebrate Monitoring Study on the Athabasca and McLeod Rivers Near Whitecourt, Alberta, 1990.* Beak Associates Consulting Ltd., Calgary, Alberta.

Beak Associates. 1991b. *Benthic Invertebrate Monitoring Study on the Athabasca River, Whitecourt, Alberta, 1990.* Beak Associates Consulting Ltd., Calgary, Alberta.

Beak Consultants Limited. 1975. *A Biological and Chemical Survey of the Athabasca River, 1974.* Beak Consultants Limited, Vancouver, B.C.

Beak Consultants Limited. 1977. *Biological and Water Quality Survey of the Athabasca River 1976.* Beak Consultants Limited, Calgary, Alberta.

Beak Consultants Limited. 1978. *Biological and Water Quality Survey of the Athabasca River 1977.* Beak Consultants Limited, Calgary, Alberta.

Beak Consultants Limited. 1980. *Biological and Water Chemistry Survey of the Athabasca River, 1979.* Beak Consultants Limited, Calgary, Alberta.

Beyers, R.J. 1963. The Metabolism of Twelve Aquatic Laboratory Microcosms. *Ecological Monographs* 33:281-306.

Borton, D. 1992. *An NCASI Overview of Biomarker Research with Pulp and Paper Industry Effluents.* 7th Colloquium of Pulp & Paper Mill Effluents. Toronto, ON.

Boudou, A. and F. Ribeyre. 1989. Fundamental Concepts in Aquatic Ecotoxicology. p35-76 **In** A. Boudou and F. Ribeyre (eds.) *Aquatic Ecotoxicology: Fundamental Concepts and Methodologies.* Volume 1. CRC Press, Inc., Boca Raton, Florida.

Buikema, A.L.,Jr. and J.R Voshell Jr. 1993. Toxicity Studies using Freshwater Benthic Macroinvertebrates. P344-398 **In** Rosenberg, D.M. and V.H. Resh (eds) *Freshwater Biomonitoring and Benthic Macroinvertebrates.* Chapman & Hall, New York.

Butler, G.C., (ed.). 1978. *Principles of Ecotoxicology.* John Wiley & Sons, Chichester.

Cairns, J., Jr. 1989. Applied Ecotoxicology and Methodology. p275-292 **In** A. Boudou and F. Ribeyre (eds.) *Aquatic Ecotoxicology: Fundamental Concepts and Methodologies.* Volume 2. CRC Press, Inc. Boca Raton, Florida.

Cairns, J., Jr. and J.R. Pratt. 1993. A History of Biological Monitoring Using Benthic Macroinvertebrates. p.10-27 **In** Rosenberg, D.M. and V.H. Resh (eds) *Freshwater Biomonitoring and Benthic Macroinvertebrates*. Chapman & Hall, New York.

Cairns, J.,Jr. and B.R. Niederlehner. 1995. *Ecological Toxicity Testing Scale, Complexity, and Relevance*. Lewis Publishers, Boca Raton.

Calabrese, E.J. and L.A. Baldwin. 1993. *Performing Ecological Risk Assessments*. Lewis Publishers, Boca Raton.

Canfield, T.J., N.E. Kemble, W.G. Brumbaugh, F.J. Dwyer, C.G. Ingersoll and J.F. Fairchild. 1994. Use of Benthic Invertebrate Community Structure and the Sediment Quality Triad to Evaluate Metal-Contaminated Sediment in the Upper Clark Fork River, Montana. *Environmental Toxicology and Chemistry* 13(12):1999-2012.

Chapman, P.M. and E.R. Long. 1983. The Use of Bioassays as a Part of a Comprehensive Approach to Marine Pollution Assessment. *Marine Pollution Bulletin*. 14:81-84.

Colodey, A.G. 1989. *Environmental Impact of Bleached Pulp and Paper Mill Effluents in Sweden, Finland and Norway. Implications to the Canadian Environment*. A discussion paper prepared for Environment Canada, Conservation and Protection, Pacific and Yukon Region (cited in McCubbin and Folke 1992).

Colodey, A.G., L.E. Harding, P.G. Wells and W.R. Parker. 1991. Effects of Pulp and Paper Mill Effluents on Estuarine and Marine Environments in Canada: A Brief Review. Proceedings of the Seventeenth Annual Aquatic Toxicity Workshop, Vancouver, B.C. *Canadian Technical Report of Fisheries and Aquatic Sciences* No. 1774, p. 725-763..

Cook, P.M., M.K. Walker, D.W. Kuehl and R.E. Peterson. 1991. Bioaccumulation and Toxicity of 2,3,7,8-tetrachlorodibenzo-p-dioxin and Related Compounds in Aquatic Ecosystems. pp.143-163 **In** *Banbury Report: Biological Basis for Risk Assessment of Dioxins*. Cold Spring Harbour Laboratory Press, New York.

Cormier, S.M. and R.N. Racine. 1992. Biomarkers of Environmental Exposure and Multivariate Approaches for Assessment and Monitoring. p229-242 **In** McKenzie, D.H., D.E. Hyatt and V.J. McDonald (eds). *Ecological Indicators*. Elsevier Applied Science, London.

Crane, M. 1995. Is There a Place for Ecology in Ecotoxicology? *SETAC News*. 15(2):19-20.

Decamps, H. and O.Decamps. 1989. River Ecosystems:Ecological Concepts and Dynamics. p3-20 **In** A. Boudou and F. Ribeyre (ed.) *Aquatic Ecotoxicology: Fundamental Concepts and Methodologies*. Volume 1. CRC Press, Inc. Boca Raton, Florida.

Emans, H.J.B., E.J.v.d. Plassche, J.H. Canton, P.C. Okkerman and P.M. Sparenburg. 1993. Validation of Some Extrapolation Methods Used for Effect Assessment. *Environmental Toxicology and Chemistry* 12:2139-2154.

Environment Canada. 1990a. *Environmental Protection Series Biological Test Method: Reference Method for Determining Acute Lethality of Effluents to Rainbow Trout*. EPS 1/RM/13. Environmental Protection, Conservation and Protection, Environment Canada.

Environment Canada. 1990b. *Environmental Protection Series Biological Test Method: Reference Method for Determining Acute Lethality of Effluents to Daphnia magna*. EPS 1/RM/14. Environmental Protection, Conservation and Protection, Environment Canada.

Environment Canada. 1992a. *Environmental Protection Series Biological Test Method: Growth Inhibition Test Using the Freshwater Alga Selenastrum capricornutum*. EPS 1/RM/25. Environmental Protection, Conservation and Protection, Environment Canada.

Environment Canada. 1992b. *Environmental Protection Series Biological Test Method: Test of Reproduction and Survival Using the Cladoceran Ceriodaphnia dubia*. EPS 1/RM/21. Environmental Protection, Conservation and Protection, Environment Canada.

Environment Canada. 1992c. *Environmental Protection Series Biological Test Method: Test of Larval Growth and Survival Using Fathead Minnows*. EPS 1/RM/22. Environmental Protection, Conservation and Protection, Environment Canada.

Environment Canada and Department of Fisheries and Oceans. 1992. *Annex 1: Aquatic Environmental Effects Monitoring Requirements at Pulp and Paper Mills and Off-Site Treatment Facilities Regulated Under the Pulp and Paper Effluent Regulations of the Fisheries Act.*

Environment Canada and Department of Fisheries and Oceans. 1993. *Technical Guidance Document for Aquatic Environmental Effects Monitoring Related to Federal Fisheries Act Requirements.*

Environmental Biodetection Products Inc. (EPBI). 1992. *The SOS Chromotest Blue Kit*. SOS Chromotest (blue). Vol. 5.3, Brampton, Ontario.

EVS Consultants Ltd. (EVS). 1990. *Volume I Baseline Environmental Studies of the Lesser Slave River*. EVS Consultants, North Vancouver, B.C.

EVS Consultants Ltd. (EVS). 1991. *Volume II Baseline Environmental Studies of the Lesser Slave River*. EVS Consultants Ltd., North Vancouver, B.C.

EVS Consultants Ltd. (EVS). 1992. *Volume III - 1991 Operational Monitoring of the Lesser Slave River*. EVS Consultants Ltd., North Vancouver, B.C.

EVS Environment Consultants (EVS). 1993. *1992 Operational Monitoring of the Lesser Slave River. Volume IV.* Prepared for Slave Lake Pulp Corporation, Edmonton. EVS Consultants Ltd., North Vancouver, B.C.

EVS Environment Consultants (EVS). 1995. *1993 Operational Monitoring of the Lesser Slave River. Volume V.* Prepared for Slave Lake Pulp Corporation, Edmonton. EVS Consultants Ltd., North Vancouver, B.C.

Expert Panel. 1994. Pulp and Paper. Chapter 6 **In** Interpretive Review of the Potential Adverse Effects of Chlorinated Organic Chemicals on Human Health and the Environment. *Regulatory Toxicology and Pharmacology*. 20(1):5308-5415.

Frost, T.M., S.R. Carpenter and T.K. Kratz. 1992. Choosing Ecological Indicators: Effects of Taxonomic Aggregation on Sensitivity to Stress and Natural Variability. p.215-227 **In** McKenzie, D.H., D.E. Hyatt and V.J. McDonald (eds). *Ecological Indicators*. Elsevier Applied Science, London.

Gentile, J.H. and M.W. Slimak. 1992. Endpoints and Indicators in Ecological Risk Assessments. p.1385-1400 **In** McKenzie, D.H., D.E. Hyatt and V.J. McDonald (eds). *Ecological Indicators*. Elsevier Applied Science, London.

Green, R.H. 1979. *Sampling Design and Statistical Methods for Environmental Biologists*. John Wiley, New York.

Gregoire, P.E. and A.M. Anderson. 1987. *Athabasca River Zoobenthic Survey in the Vicinity of Athabasca, Fall 1985*. Alberta Environment, Pollution Control Division, Edmonton.

H.A. Simons Ltd. 1986. *Millar Western Pulp Ltd., Environmental Impact Assessment of the Proposed Whitecourt Pulp Mill.*

H.A. Simons Ltd. 1987. *Environmental Assessment Report, Daishowa Canada Co. Ltd. Peace River Kraft Pulp Mill.*

Halfon, E. 1989. Mathematical Models for Predicting the Fate of Contaminants in Freshwater Ecosystems. p257-274 **In** A. Boudou and F. Ribeyre (eds.) *Aquatic Ecotoxicology: Fundamental Concepts and Methodologies*. Volume 2. CRC Press, Inc., Boca Raton, Florida.

Hall, T.J., R.K. Haley, L.E. Lafleur. 1991. Effects of Biologically Treated Bleached Kraft Mill Effluent on Cold Water Stream Productivity in Experimental Stream Channels. *Environmental Toxicology and Chemistry* 10(8):1051-1060.

Hamilton, H.R., M.V. Thompson and L. Corkum. 1985. *Water Quality Overview of the Athabasca River Basin.* Nanuk Engineering and Development Ltd., Cochrane, Alberta.

HBT AGRA Limited. 1992. *Environmental Monitoring Studies in the Vicinity of the Peace River Pulp Division Mill at Peace River, Alberta, May 1992.* HBT AGRA Limited (formerly Monenco Consultants Ltd.).

Hodson, P.V., M. McWhirter, K. Ralph, B. Gray, D. Thivierge, J.H. Carey, G. Van Der Kraak, D.M. Whittle and M-.C. Levesque. 1992. Effects of Bleached Kraft Mill Effluent on Fish in the St. Maurice River, Quebec. *Environmental Toxicology and Chemistry* 11:1635-1651.

Hoefs, N.J. and T.P Boyle. 1992. Contribution of Fish Community Metrics to the Index of Biotic Integrity in Two Ozark Rivers. p.283-304 **In** McKenzie, D.H., D.E. Hyatt and V.J. McDonald (eds). *Ecological Indicators*. Elsevier Applied Science, London.

Hoffman, D.J., B.A. Rattner, G.A. Burton, Jr. and J. Cairns, Jr. 1995. *Handbook of Ecotoxicology*. Lewis Publishers, Boca Raton.

Hope, B.K. 1993. Ecological Considerations in the Practice of Ecotoxicology. *Environmental Toxicology and Chemistry* 12:205-206.

IEC Beak Consultants Ltd. 1985. *Peace River Basin Water Quality Review.* Prepared for Planning Division, Alberta Environment.

IVL. 1989. *The Influence of Chelating Agents on Aquatic Life.* IVL Report No. B921 (in Swedish) (cited in McCubbin and Folke 1992).

Karr, J.R. 1993. Defining and Assessing Ecological Integrity: Beyond Water Quality. *Environmental Toxicology and Chemistry* 12:1521-1531.

Karr, J.R., K.D. Fausch, P.L. Angermeier, P.R. Yant and I.J. Schlosser. 1986. *Assessing Biological Integrity in Running Waters: a Method and its Rationale*. Illinois Natural History Survey Publication 5, Champaign, IL.

Kloepper-Sams, P.J. and E. Benton. 1994. Exposure of fish to Biologically Treated Bleached-kraft Effluent. 2. Induction of Hepatic Cytochrome P4501A in Mountain Whitefish (*Prosopium williamsoni*) and Other Species. *Environmental Toxicology and Chemistry* 13(9):1483-1496.

Kloepper-Sams, P.J., S.M. Swanson, T. Marchant, R. Schryer and J.W. Owens. 1994. Exposure of Fish to Biologically Treated Bleached-Kraft Effluent. 1. Biochemical, Physiological and Pathological Assessment of Rocky Mountain Whitefish (*Prosopium williamsoni)* and Longnose Sucker (*Catastomus catostomus*). *Environmental Toxicology and Chemistry* 13(9):1469-1482.

Kosinski, R. J. 1989. Artificial Streams in Ecotoxicological Research. p297-319 **In** A. Boudou and F. Ribeyre (ed.) *Aquatic Ecotoxicology: Fundamental Concepts and Methodologies.* Volume 1. CRC Press, Inc. Boca Raton, Florida.

Kuehl, D.W., P.M. Cook, A.R. Batterman, D.B. Lothenbach and B.C. Butterworth. 1987. *Bioavailability of Polychlorinated Dibenzo-p-dioxins and Dibenzofurans from Contaminated Wisconsin River Sediment to Carp.* Chemosphere. 18:667.

Landis, W.G. and M-H Yu. 1994. *Introduction to Environmental Toxicology.* Lewis Publishers, Boca Raton.

LaPoint, T.W., J.F. Fairchild, E.E. Little, and S.E. Finger. 1989. Laboratory and Field Techniques in Ecotoxicological Research: Strengths and Limitations. p239-256 **In** A. Boudou and F. Ribeyre (eds.) *Aquatic Ecotoxicology: Fundamental Concepts and Methodologies*. Volume 2. CRC Press, Inc., Boca Raton, Florida.

Lehtinen, K.J. 1991a. Effects of BKME on Marine Communities Studied in Mesocosms. International Conference on Bleaching Kraft Pulp Mills - Technical and Environmental Issues. *Proc. National Pulp Mills Research Program*. 4-7 Feb. 1991. Melbourne, Australia (cited in McCubbin and Folke 1992).

Lehtinen, K.J. 1991b. Inhibitory and Stimulatory Responses in Fish Exposed to Bleached Kraft Mill Effluent. International Conference on Bleaching Kraft Pulp Mills - Technical and Environmental Issues. *Proc. National Pulp Mills Research Program.* 4-7 Feb. 1991. Melbourne, Australia (cited in McCubbin and Folke 1992).

Lehtinen, K.J., M. Notini, J. Mattson and L. Landner. 1988. Disappearance of Bladder-Wrack (*Fucus vesiculosus*) in the Baltic Sea: Relation to Pulp Mill Chlorate. *Ambio* 17(6):387-393.

Lindstrom-Seppa, P., S. Huuskonen, M. Pesonen, P. Muona and O. Hanninen. 1992. Unbleached Pulp Mill Effluents Affect Cytochrome p-450 Monooxygenase Enzyme Activities. *Marine Environ. Res.* 34:157-161 (cited in Carey *et al.*, 1993).

Long, E.R. and P.M. Chapman. 1985. A Sediment Quality Triad: Measures of Sediment Contamination, Toxicity and Infaunal Community Composition in Puget Sound. *Marine Pollution Bulletin*. 16:405-415.

Malins, D.C. and G. K. Ostrander. 1994. *Aquatic Toxicology Molecular, Biochemical, and Cellular Perspectives*. Lewis Publishers, Boca Raton.

Margalef, J.L. 1958. Information Theory in Ecology. *General Systems* 3:36-71.

Martel, P.H., T.G. Kovacs, B.L. O'Connor and R.H. Voss. 1993. *A Survey of Pulp and Paper Mill Effluents for their Potential to Induce Mixed Function Oxidase Enzyme Activity in Fish.* Proc. 79th Annual Meeting, Canadian Pulp and Paper Association, Technical Section: A165-A177.

McCarthy, J.F. 1990. Concluding Remarks: Implementation of a Biomarker-based Environmental Monitoring program. p429-439 **In** J.F. McCarthy and L.R. Shugart (eds.) *Biomarkers of Environmental Contamination*. Lewis Publishers, Boca Raton, Florida.

McCubbin, N. and J. Folke. 1992. *Review of Literature on Characteristics of Effluent from Pulp and Paper Mills in Northern River Basins of Alberta, B.C. and Northwest Territories.* Report prepared for the Northern River Basins Study. N. McCubbin Consultants Inc.

McLeay, D. and Associates Ltd. 1987. *Aquatic Toxicity of Pulp and Paper Mill Effluent: A Review*. Prepared for Environment Canada, Fisheries and Oceans Canada, Canada Pulp and Paper Association, and Ontario Ministry of Environment. Environment Canada. Report EPA 4/PF/1. 191pp.

McMaster, M.E., G.J. Van Der Kraak, C.B. Portt, K.R. Munkittrick, P.K. Sibley, I.R. Smith and D.G. Dixon. 1992. Changes in Hepatic Mixed-function Oxygenase (MFO) Activity, Plasma Steroid Levels and Age at Maturity of a White Sucker (*Catostomus commersoni*) Population Exposed to Bleached Kraft Pulp Mill Effluent. *Aquatic Toxicology* 21:199-218.

Mehrle, P.M., D.R. Buckler, E.E. Little, L.M. Smith, J.D. Petty, P.H. Peterman, D.L. Stalling, G.M. De Graeve, J.J. Coyle and W.J. Adams. 1988. Toxicity and Bioconcentration of 2,3,7,8-tetrachloro-dibenzodioxin and 2,3,7,8-tetrachlorodibenzofuran in Rainbow Trout. *Environmental Toxicology and Chemistry* 7(1):47-62.

Microbics Corp. 1991. *Mutatox™ Test Procedure.* Microbics Corp., Carlsbad, California.

Monenco Consultants Ltd. 1990a. *Environmental Monitoring Studies in the Vicinity of the Peace River Pulp Company Mill at Peace River, Alberta, July, 1989.* Prepared for Daishowa Canada Co. Ltd. Monenco Consultants Ltd., Calgary, Alberta.

Monenco Consultants Ltd. 1990b. *Environmental Monitoring Studies in the Vicinity of the Peace River Pulp Company Mill at Peace River, Alberta, September 1989.* Prepared for Daishowa Canada Co. Ltd. Monenco Consultants Ltd., Calgary,

Monenco Consultants Ltd. 1990c. *Fish Tissue and Sediment Studies in the Vicinity of the Peace River Pulp Division Mill at Peace River, Alberta, 29 September - 01 October 1989.* Prepared for Daishowa Canada Co. Ltd., Monenco Consultants Ltd., Calgary, Alberta.

Monenco Consultants Ltd. 1990d. *Environmental Monitoring Studies in the Vicinity of the Peace River Pulp Mill at Peace River, Alberta, April, 1990.* Prepared for Daishowa Canada Co. Ltd., Monenco Consultants Ltd., Calgary, Alberta.

Monenco Consultants Ltd. 1991. *Environmental Monitoring Studies in the Vicinity of the Peace River Pulp Mill at Peace River, Alberta, September, 1990.* Prepared for Daishowa Canada Co. Ltd., Monenco Consultants Ltd., Calgary, Alberta.

Monenco Consultants Ltd. 1992a. *Environmental Monitoring Studies on the Vicinity of the Peace River Pulp Division Mill at Peace River, Alberta, April, 1991.* Prepared for Daishowa Canada Co. Ltd. Monenco Consultants Ltd., Calgary, Alberta.

Monenco Consultants Ltd. 1992b. *Environmental Monitoring Studies in the Vicinity of the Peace River Pulp Division Mill at Peace River, Alberta, October, 1991.* Prepared for Daishowa Canada Co. Ltd. Monenco Consultants Ltd., Calgary, Alberta.

Munkittrick, K.R. and D.G. Dixon. 1989a. Use of White Sucker (Catostomus commersoni) Populations to Assess the Health of Aquatic Ecosystems Exposed to Low-level Contaminant Stress. *Canadian Journal of Fisheries and Aquatic Sciences* 46:1455-1462.

Munkittrick, K.R. and D.G. Dixon. 1989b. A Holistic Approach to Ecosystem Health Assessment Using Fish Population Characteristics. *Hydrobiology* 188/189:123-135.

Munkittrick, K.R., C.B. Portt, G.J. Van Der Kraak, I.R. Smith and D.A. Rokosh. 1991. Impact of Bleached Kraft Mill Effluent on Population Characteristics, Liver MFO Activity, and Serum Steroid Levels of a Lake Superior White Sucker (*Catostomus commersoni*) Population. *Canadian Journal of Fisheries and Aquatic Sciences.* 48:1371-1380.

Munkittrick, K.R., G.J. Van Der Kraak, M.E. McMaster and C.B. Portt. 1992a. Response of Hepatic MFO Activity and Plasma Sex Steroids to Secondary Treatment of Bleached Kraft Pulp Mill Effluent and Mill Shutdown. *Environmental Toxicology and Chemistry* 11(11):1427-1439.

Munkittrick, K.R., M.E. McMaster, C.B. Portt, G.J. Van Der Kraak, I.R. Smith and D.G. Dixon. 1992b. Changes in Maturity, Plasma, Sex Steroid Levels, Hepatic Mixed Function Oxygenase Activity and the Presence of External Lesions in Lake Whitefish (*Coregonus cliperaformis*) Exposed to Bleached Kraft Mill Effluent. *Canadian Journal of Fisheries and Aquatic Sciences* 49(8):1560-1569.

Munkittrick, K.R., M.R.v.d. Heuvel, D.A. Metner, W.L. Lockhart and J.J. Stegeman. 1993. Interlaboratory Comparison and Optimization of Hepatic Microsomal Ethoxyresorufin o-

Deethylase Activity in White Sucker (Catostomus commersoni) Exposed to Bleached Kraft Pulp Mill Effluent. *Environmental Toxicology and Chemistry* 12:1273-1282.

Munkittrick, K.R., G.J. Van Der Kraak, M.E. McMaster, C.B. Portt, M.R.v.d. Heuvel and M.R. Servos. 1994. Survey of Receiving-Water Environmental Impacts Associated with Discharges from Pulp Mills. 2. Gonad Size, Liver Size, Hepatic EROD Activity and Plasma Sex Steroid Levels in White Sucker. *Environmental Toxicology and Chemistry* 13(7):1089-1101.

National Council for Air and Stream Improvement (NCASI). 1989. *Effects of Biologically Stabilized Bleach Kraft Mill Effluents on Cold Water Stream Productivity as Determined in Experimental Stream Channels.* 5th Progress Report. National Council of the Paper Industry for Air and Stream Improvement, Inc., New York. Technical Bulletin 566 (cited in Expert Panel 1994).

National Research Council (NRC). 1987. Committee on Biological Markers. *Environmental Health Perspectives*. 74:3-9.

Newman, M.C. 1995. *Quantitative Methods in Aquatic Ecotoxicology*. Advances in Trace Substances Series. Lewis Publishers, Boca Raton.

Noton, L.R. 1989. *The Peace and Athabasca River Systems: A Synopsis of Alberta Environment's Monitoring Programs and the Water Quality Effects of Existing Pulp Mill Effluents.* Environmental Quality Monitoring Branch, Environmental Assessment Division, Alberta Environment, Edmonton. 11pp.

Noton, L.R. 1990a. *Limnological Aspects of the Peace and Athabasca Rivers.* Environmental Quality Monitoring Branch, Environmental Assessment Division, Alberta Environment, Edmonton.

Noton L.R. 1990b. *Aspects of Nitrogen and Phosphorus in the Athabasca River System.* Environmental Quality Monitoring Branch, Environmental Assessment Division, Environmental Protection Services, Alberta Environment.

Noton, L.R. 1992a. *Water Quality in the Wapiti-Smoky River System Under Low-Flow Conditions 1987-1991: A Synopsis of Government Surveys and Monitoring*. Environmental Quality Monitoring Branch, Environmental Assessment Division, Alberta Environment, Edmonton.

Noton, L.R. 1992b. *Water Quality in the Wapiti-Smoky River System Under Low-Flow Conditions 1987-1991: A Synopsis of Government Surveys and Monitoring: Supplement.* Environmental Quality Monitoring Branch, Environmental Assessment Division, Alberta Environment, Edmonton.

Noton, L.R. and R.D. Shaw. 1989. *Winter Water Quality in the Athabasca River System, 1988-1989.* Environmental Quality Monitoring Branch, Environmental Assessment Division, Environmental Protection Services, Alberta Environment, Edmonton.

Noton, L.R., A.M. Anderson, T.B. Reynoldson and J. Kostler. 1989. *Water Quality in the Wapiti-Smoky River System Downstream of the Procter & Gamble Pulp Mill, 1983.* Environmental Quality Monitoring Branch, Alberta Environment, Edmonton.

O'Connor, B.I., T.G. Kovacs and R.H. Voss. 1992. The Effect of Wood Species Composition on the Toxicity of Simulated Mechanical Pulping Effluents. *Environmental Toxicology and Chemistry*. 11:1259-1270.

Oikari, A., B. Holmbolm, E. Anas, M. Millunpalo, G. Kruzynski and M. Castren. 1985. Ecotoxicological Aspects of Pulp and Paper Mill Effluents Discharged to an Inland Water system: Distribution in Water and Toxicant Residues and Physiological Effects in Caged Fish (*Salmo gairdneri*). *Aquatic Toxicology* 6:219-239.

Paetkau, P. and F. Bishop. 1971. *Biological Survey: Wapiti River 1970-1971*. Pollution Report No.2. Alberta Fish and Wildlife Division, Fisheries Section. 28pp.

Pascoe, D. and R.W. Edwards. 1989. Single Species Toxicity Tests. p93-126 **In** A. Boudou and F. Ribeyre (eds.) *Aquatic Ecotoxicology: Fundamental Concepts and Methodologies*. Volume 2. CRC Press, Inc., Boca Raton, Florida.

Peakall, D.B. 1992. *Animal Biomarkers as Pollution Indicators*. Chapman & Hall, London.

Ramade, F. 1987. *Ecotoxicology*. John Wiley & Sons, Toronto.

Rand, G.M. and S.R. Petrocelli. 1985. *Fundamentals of Aquatic Toxicology*. Hemisphere Publishing Co., Washington.

Rapport, D.J. 1992. Evolution of Indicators of Ecosystem Health. P121-134 **In** McKenzie, D.H., D.E. Hyatt and V.J. McDonald (eds). *Ecological Indicators*. Elsevier Applied Science, London.

Ravera, O. 1989. Enclosure Methodologies. p249-296 **In** A. Boudou and F. Ribeyre (eds.) *Aquatic Ecotoxicology: Fundamental Concepts and Methodologies*. Volume 1. CRC Press, Inc., Boca Raton, Florida.

Reice, S.R. and M. Wohlenberg. 1993. Monitoring Freshwater Benthic Macroinvertebrates and Benthic Processes: Measures for the Assessment of Ecosystem Health. P287-305 **In** Rosenberg, D.M. and V.H. Resh (eds) *Freshwater Biomonitoring and Benthic Macroinvertebrates*. Chapman & Hall, New York.

Robinson, R.D., J.H. Carey, K.R. Solomon, I.R. Smith, M.R. Servos and K.R. Munkittrick. 1994. Survey of Receiving-Water Environmental Impacts Associated with Discharges from Pulp Mills. 1. Mill Characteristics, Receiving-Water Chemical Profiles and Lab Toxicity Tests. *Environmental Toxicology and Chemistry* 13:1075-1088.

Rosenberg, D.M. and V.H. Resh. 1993. Introduction to Freshwater Biomonitoring and Benthic Macroinvertebrates. p.1-9 **In** Rosenberg, D.M. and V.H. Resh (eds) *Freshwater Biomonitoring and Benthic Macroinvertebrates*. Chapman & Hall, New York.

Schindler, D.W. 1987. Detecting Ecosystem Responses to Anthropogenic Stress. *Canadian Journal of Fisheries and Aquatic Sciences* 44 (Suppl. 1):6-25.

Seager, J., I. Milne and M. Crane. 1992. The Application of In Situ Bioassays as Ecological Indicators for Assessing River Water Quality. P243-259 **In** McKenzie, D.H., D.E. Hyatt and V.J. McDonald (eds). *Ecological Indicators*. Elsevier Applied Science, London.

SENTAR Consultants Ltd. (SENTAR). 1992a. *Benthic Invertebrate Monitoring Study on the Athabasca River, Whitecourt, Alberta, 1991.* Prepared for Millar Western (Whitecourt) Pulp Ltd. SENTAR Consultants Ltd., Calgary, Alberta.

SENTAR Consultants Ltd. (SENTAR). 1992b. *A Benthic Invertebrate Monitoring Study on the Athabasca River, Whitecourt, Alberta*. Prepared for Millar Western (Whitecourt) Pulp Ltd. SENTAR Consultants Ltd., Calgary.

SENTAR Consultants Ltd. (SENTAR). 1993a. *Nutrient Loading on the Athabasca, Peace and Slave Rivers - Synthesis Report. Project 2511-B1.* Prepared for Northern River Basins Study.

SENTAR Consultants Ltd. (SENTAR). 1993b. *Nutrient Loading on the Athabasca, Peace and Slave Rivers - Annotated Bibliography. Project 2511-B1.* Prepared for Northern River Basins Study.

SENTAR Consultants Ltd. 1993c. *Wapiti/Smoky River Ecosystem Study.* Prepared for Weyerhaeuser Canada, Grande Prairie, Alberta. 158pp + appendices.

SENTAR Consultants Ltd. (SENTAR). 1994. *A Baseline Aquatic Monitoring Study on the Athabasca River Between the Town of Athabasca and Grand Rapids, 1991-1993.* Volume 1. Main Report. Prepared for Alberta-Pacific Fort Industries Inc., Boyle Alberta. SENTAR Consultants Ltd., Calgary.

Servos, M.R., M. Ferguson, J. Parrott and K. Munkittrick. 1992. EROD Induction in Caged and Feral Fish Downstream of a Modernized Bleached Kraft Mill. Society of Environmental Toxicology and Chemistry, 13th Annual Meeting, Cincinnati, Ohio. Abstract No.494.

Servos, M.R., S.Y. Huestis, D.M. Whittle, G.J. Van Der Kraak and K.R. Munkittrick. 1994. Survey of Receiving-Water Environmental Impacts Associated with Discharges from Pulp Mills. 3. Polychlorinated Dioxins and Furans in Muscle and Liver of White Sucker (*Catostomus commersoni*). *Environmental Toxicology and Chemistry*. 13(7):1103-1115.

Shannon, C.E. and W. Weaver. 1949. *The Mathematical Theory of Communication*. University of Illinois Press, Urbana, IL. (as cited in Cairns and Pratt 1993).

Sergy, G.A. and R.G. Ruggles. 1975. Toxicity of Wastewater Discharges and Their Effects on Receiving Waters at Northwest Pulp and Power Co. Ltd., Hinton, Alberta. Surveillance Report. EPS 5-NW-75-1, Water Pollution Control Section, Environmental Protection Service, Environment Canada. 40 pp.

Shaw, R.D. and L.R. Noton. 1989. *A Preliminary Assessment of the Impact of Existing Pulp Mills on the Peace River.* Environmental Quality Monitoring Branch, Alberta Environment.

Shaw, R.D., L.R. Noton, A.M. Anderson and G.W. Guenther. 1990. *Water Quality of the Peace River in Alberta*. W-9020. Alberta Environment, Edmonton, Alberta.

Sheehan, P.J. 1984. Effects on individuals and populations p23 **In** Sheehan, P.J., D.R. Miller, G.C. Butler and P. Bourdeau (eds.) *Effects of Pollutants at the Ecosystem Level.* John Wiley & Sons, Chichester.

Smith I.R., C. Portt and D.A. Rokosh. 1991. Hepatic Mixed Function Oxidases are Induced in Populations of White Sucker, *Catostomus comersoni*, from Areas of Lake Superior and the St. Mary's River. *Journal of Great Lakes Research* 17:382-393.

Södergren, A. and L. Okla. 1988. Simulation of Interfacial Mechanisms with Dialysis Membranes to Study Uptake and Elimination of Persistent Pollutants in Aquatic Organisms. *Verh. Internat. Verein. Limnol.* 23:1633-1638.

Södergren, A. 1991. Solvent-Filled Dialysis Membranes Mimic Bioaccumulation of Pollutants in Aquatic Environments. p.129-135 **In** R.A. Baker (ed.) *Organic Substances and Sediments in Water*. Lewis Publishers Inc. Boca Raton.

Södergren, A. (ed). 1989. *Biological Effects of Bleached Pulp Mill Effluents.* Final Report from the Environment/Cellulose I Project. Bratts Trykeri AB, Jonjoping.

Spitsbergen, J.M., J.M. Kleeman and R.E. Peterson. 1988a. Morphologic Lesions and Acute Toxicity in Rainbow Trout (*Salmo gairdneri*) Treated with 2,3,7,8-tetrachlorodibenzo-p-dioxin. *Journal of Toxicology Environmental Health* 23:333.

Spitsbergen, J.M., J.M. Kleeman and R.E. Peterson. 1988b. 2,3,7,8-tetrachlorodibenzo-p-dioxin Toxicity in Yellow Perch (*Perca flavescens*). *Journal of Toxicology Environmental Health* 23:359.

Sprague, J.B., N. Bonsor and N. McCubbin. 1991. *Effluents from Non-Kraft Pulp and Paper Mills in Ontario.* Prepared for the Technical Advisory Committee, Pulp and Paper Sector of MISA, Ministry of the Environment, Toronto, Ontario.

Suter, G.W.II. 1993. *Ecological Risk Assessment.* Lewis Publishers, Boca Raton.

Swanson, S.M., R. Schryer, R. Shelast, P.J. Kloepper-Sams and J.W. Owens. 1994. Exposure of Fish to Biologically Treated Bleached-Kraft Mill Effluent. 3. Fish Habitat and Population Assessment. *Environmental Toxicology and Chemistry* 13(9):1497-1507.

Taub, F.F.B. 1989. Standardized Aquatic Microcosm: Development and Testing. p47-92 **In** A. Boudou and F. Ribeyre (eds.) *Aquatic Ecotoxicology: Fundamental Concepts and Methodologies.* Volume 2. CRC Press, Inc., Boca Raton, Florida.

Terrestrial and Aquatic Environmental Managers (TAEM) Ltd. 1989. *Biological and Water Quality Survey of the Athabasca River, 1989.* TAEM Ltd., Saskatoon, Saskatchewan.

Terrestrial and Aquatic Environmental Managers (TAEM) Ltd. 1990. *An Historical Review of the Biological and Water Quality Surveys of the Wapiti River, 1970-1988.* TAEM Ltd., Saskatoon, Saskatchewan.

Terrestrial and Aquatic Environmental Managers (TAEM) Ltd. 1991a. *Biological and Water Quality Surveys of the Wapiti River, October 1990 and April 1991.* TAEM Ltd., Saskatoon, Saskatchewan.

Terrestrial and Aquatic Environmental Managers (TAEM) Ltd. 1991b. *Biological and Water Quality Survey of the Athabasca River 1990.* TAEM Ltd., Saskatoon, Saskatchewan.

Terrestrial and Aquatic Environmental Managers (TAEM) Ltd. 1991c. *Biological and Water Quality Survey of the Athabasca River, April 1991.* TAEM Ltd., Saskatoon, Saskatchewan.

Terrestrial and Aquatic Environmental Managers (TAEM) Ltd. 1992a. *Benthic Macroinvertebrate and Water Quality Survey of the Wapiti River, January 1992.* TAEM Ltd., Saskatoon, Saskatchewan.

Terrestrial and Aquatic Environmental Managers (TAEM) Ltd. 1992b. *Biological and Water Quality Survey of the Athabasca River, April 1992.* TAEM Ltd., Saskatoon, Saskatchewan.

Thomann, R.V., J.P. Connolly and T.F. Parkerton. 1992. An Equilibrium Model of Organic Chemical Accumulation in Aquatic Food Webs and Sediment Interaction. *Environmental Toxicology and Chemistry* 11(5):615-630.

United States Environmental Protection Agency (U.S. EPA). 1991. *Technical Support Document for Water Quality-based Toxins Control.* Office of Water (EN-336) EPA/505/2-90-001, PB91-127415. 145pp.

Van Den Heuvel, M.R., M.R. Servos, K.R. Munkittrick, C.B. Portt, G.J. Van Der Kraak, M.R. McMaster and D.G. Dixon. 1994. Survey of Receiving Water Environmental Impacts Associated with Discharges from Pulp Mills. IV. Bioassay-Derived 2,3,7,8-tetrachlorodibenzo-*p*-dioxin Toxic Equivalent Concentration in Relation to Biochemical Indicators in White Sucker. *Environmental Toxicology and Chemistry* 13(7):1117-1126.

von Westernhagen. 1988. Sublethal Effects of Pollutants on Fish Eggs and Larvae. P.253-356. **In** W.S. Hoar and D.J. Randall (eds.) *Fish Physiology: Volume XI - the Physiology of Developing Fish. Part A. Eggs and Larvae.* Academic Press, Inc. New York. 546pp.

Wallace, R.R. and P.J. McCart. 1984. *The Fish and Fisheries of the Athabasca River Basin, Their Status and Environmental Requirements.* Prepared for Planning Division, Alberta Environment. Dominion Ecological Consulting Ltd. March 31, 1984.

Western Research. 1989. *Environmental Impact Assessment for the Proposed Alberta Energy Company Ltd. Bleached Chemi-Thermo-Mechanical Pulp Mill, Slave Lake, Alberta.*

APPENDIX A

TERMS OF REFERENCE

SCHEDULE A - TERMS OF REFERENCE

Project 2112-B1: Effluent Characterization, Contaminants in Aquatic Ecosystems and Ecotoxicity of Pulp Mill Effluents

I. Introduction

These Terms of Reference have been developed in support of three projects, which to a certain extent, deal with the ecotoxicity of liquid contaminants released into the aquatic environment by municipalities and industries or that already exist in the ambient aquatic environment. All of the projects will involve compiling and synthesizing existing information on contaminants and their ecotoxicological effects. This background information will be vital to the development of a comprehensive ecotoxicity strategy and aquatic ecosystem risk assessment for the Northern River Basins Study.

Proposals will be judged based on the following criteria:

1. the expertise assigned to the project;

2. the work that can be completed on the project before March 31st, 1993;

3. total cost; and,

4. when the entire project will be completed.

II. Effluent Characterization - Municipal and Non-Pulp Mill Industry Sources

1. Objective

The purposes of this project include the following:

1) to identify the location, treatment technology, types of wastes (ie., liquid, solid, gas) and waste disposal methods of all licensed effluent dischargers in the Peace, Athabasca and Slave river basins: and,

2) to compile and synthesize existing information from government and industry sources on the nature of liquid effluents (ie., nutrients, pathogens, contaminants, toxic compounds, compounds that cause taste and odour problems in fish and water, etc.) from municipal and non-pulp mill industries that are being discharged into the Peace, Athabasca and Slave rivers and their major tributaries.

2. Requirements

1) <u>Identification of Effluent Sources</u>

Compile existing information from government and industry sources pertaining to the location, treatment technology, types of wastes (ie., liquid, solid, gas) and waste disposal methods of all licensed effluent dischargers in the Alberta and Northwest Territories portions of the Peace, Athabasca and Slave river basins. This information is to be compiled in a geo-referenced (to facilitate GIS utilization of the data), electronic database (dBase IV format).

2) <u>Non-Pulp Mill Industry and Municipal Effluent Characterization</u>

a) Based on 1, above, identify those licensed dischargers that release liquid effluents into the Peace, Athabasca and Slave rivers and their major tributaries. From government and industry sources, assemble comprehensive historical data pertaining to the nature and ecotoxicity of these effluents as well as the treatment technology employed.

b) From the above, select one effluent source and enter all relevant data into a prototype geo-referenced (to facilitate GIS utilization of the data), electronic database (dBase IV format), and prepare tables, graphs and statistics of the data. The prototype database is then to be reviewed by the Project Liaison Officer and others associated with the NRBS for its consistency with other NRBS databases and ease of use. The database is to include comprehensive data on nutrients (N, P, C, BOD, etc.), contaminants (metals, organics, sulphides, compounds that cause taste and odour problems, etc.) and pathogens (microbiology) associated with liquid effluent discharges, as well as the results of toxicological tests of these effluents. The database is also to include comprehensive information on the types of treatment systems employed and the physical nature of the discharges (ie., the volume, timing, duration, loading and concentrations of discharges).

c) Review the prototype database with the Project Liaison Officer and modify the format of the database as directed by the Project Liaison Officer. Utilizing the agreed to format, enter all remaining data for all municipal and non-pulp mill effluent sources and prepare appropriate tables, graphs and statistics.

d) Prepare a concise technical report on the database system including a guide for users, dictionary and any other pertinent specifications of the electronic database submission.

3) Synthesis Report

a) Based on the data compiled in 2, above, as well as other information sources, prepare a comprehensive synthesis report discussing the nature of liquid effluents from non-pulp mill and municipal sources and the impacts or potential impacts of these effluents on the aquatic ecosystems of the northern rivers. The report should be similar in style and content, with the exception that it will contain greater discussion on ecotoxicity, to McCubbin and Folke (1992).

b) The synthesis report is to include the following:

- information on the location of non-pulp mill industry and municipal effluent sources in the Study Area and relative to pulp mill effluent sources (include 1:250,000 or greater maps);
- a discussion on the chemistry, ecotoxicology and microbiology of discharges, including a statistical summary of the parameters discussed;
- a discussion of the physical nature of liquid effluent discharges (ie., timing, duration, quantities, loading and concentration of discharges), including a statistical summary of the parameters discussed;
- a discussion of the impacts or potential impacts of non-pulp mill industry and municipal liquid effluent discharges on the aquatic environment;
- a discussion of the Quality Assurance/Quality Control measures imposed on data from various sources;
- to the extent possible, a discussion of licensing requirements for non-pulp mill industry and municipal discharges and compliance with these requirements (regulations);
- identification of information gaps and recommendations as to how information gaps can be resolved; and,
- an assessment of the relative importance of various non-pulp mill industry and municipal liquid effluents with respect to contaminant, pathogen (microbe) and nutrient loading in the Study Area.

c) The data, included in the databases compiled in 1 and 2, above, are to be included as hardcopy appendices to the synthesis report. Reference to these appendices should be made in the main body of the report.

3. Reporting Requirements

1) Submit the initial database format, compiling effluent data from a single source, by a date to be decided upon by the Project Liaison Officer and Scientific Staff in consultation with the contractor.

2) Submit ten copies of the draft technical report for the electronic database and ten copies of the draft synthesis report to the Project Liaison Officer by a date to be decided upon by the Project Liaison Officer and Scientific Staff in consultation with the contractor. Also submit the "draft" electronic database on non-pulp mill industry and municipal effluent characterization and the "draft" electronic database on licensed effluent discharges in the northern river basins along with the draft technical report for the electronic database and the draft synthesis report.

3) Submit final reports of the technical report for the electronic database and the synthesis report to the Project Liaison Officer three weeks after the receipt of the review comments on the draft reports. Five cerlox bound copies and two camera-ready original of each final report are to be submitted to the Project Liaison Officer. Electronic copies, in Word Perfect 5.1 format, of each report are also to be submitted on a 5 1/4 or 3 1/2 inch floppy disk to the Project Liaison Officer. The synthesis report is to include an executive summary.

4) Specific data contained within tables, figures and appendices of the final synthesis report must be placed in a dBase IV file on a 5 1/4 or 3 1/2 inch floppy disk and submitted to the Project Liaison Officer along with the final report.

5) Submit the final electronic databases to the Project Liaison Officer three weeks after receipt of the reviewed databases.

III. Contaminants in Aquatic Ecosystems - Annotated Bibliography and Synthesis Report

1. Objective

The purpose of this project is to prepare an annotated bibliography and expert synthesis report on contaminants found in the ambient aquatic environment of the northern rivers and their potential impacts and ecotoxicological effects on the aquatic ecosystem.

2. Requirements

1. Annotated Bibliography

Prepare an annotated bibliography of databases (indicate whether the database exists in hardcopy or electronic format), government and non-government reports, journal reports, book chapters, student theses, etc. pertaining to chemical and microbial contaminants existing in the aquatic environment (water, sediment, biota) and potential impacts and ecotoxicological effects of these contaminants to aquatic ecosystems. Factors such as loading persistence, bioaccumulation and toxicity should be used as search criteria. Discussion is to be presented regarding the adequacy of Quality Assurance/Quality Control measures imposed on data.

2. Synthesis Report

a) Prepare an expert synthesis report from the information and data assembled in 1, above, on contaminants (chemical and microbial) found in the aquatic environment (water, sediment, biota) of the northern rivers and their potential impacts and ecotoxicological effects.

b) The report is to include the following:

- a comparison of the findings to present trends in effluent quality/quantity in the study area;
- summary statistics about the types and levels of contaminants present;
- a discussion of the ecotoxicological significance, including significance to human health, of contaminants and their concentrations;
- an assessment of the significance of the presence, concentration and distribution of contaminants found in the aquatic environment;
- a discussion of the presence, concentration and distribution of contaminants in the aquatic environment with respect to water quality guidelines and objectives;
- a discussion of information gaps regarding potential toxic effects of contaminants in the study area, including parameters requiring monitoring, etc.; and,
- a discussion of the Quality Assurance/Quality Control measures imposed on data considered in this report.

3. Reporting Requirements

1) Submit ten copies of the draft annotated bibliography and ten copies of the draft synthesis report by a date to be decided upon by the Project Liaison Officer and Scientific Staff in consultation with the contractor.

2) Three weeks after the receipt of review comments on the draft annotated bibliography and draft synthesis report, submit five cerlox bound copies and two camera-ready originals of each final report to the Project Liaison Officer. The synthesis report is to include an executive summary.

3) An electronic copy, in Word Perfect 5.1 format, of both the annotated bibliography and synthesis report are to be submitted to the Project Liaison Officer on 5 1/4 or 3 1/2 inch floppy disk along with the final reports.

4) Specific data contained within tables, figures and appendices of the final annotated bibliography and synthesis report must be placed in dBase IV files and submitted to the Project Liaison Officer at the same time as the final reports.

IV. Ecotoxicity of Pulp Mill Effluents

1. Objective

The purpose of this project is to prepare an annotated bibliography and expert synthesis report pertaining to the acute and chronic toxic effects of pulp mill effluents discharged into the northern rivers.

2. Requirements

1. Annotated Bibliography

Prepare an annotated bibliography of databases (indicate whether the database exist in hardcopy or electronic form), government and non-government reports, journal reports, book chapters, student theses, etc. pertaining to the ecotoxicity of pulp mill effluents. This is to include information specific to the northern rivers, as well as major review papers on pulp mill effluent toxicity.

2. Synthesis Report

a) Prepare an expert synthesis report from the data and information assembled in 1 above, on the ecotoxicity of pulp mill effluents in the Study Area.

b) The report is to include the following:

- consideration of both actual toxicity and the volume of effluent discharges (ie., the "load" of toxicity);
- a comparison of the findings to present trends in effluent quality/quantity in the study area;
- a discussion of the ecotoxicological significance, including significance to human health, of pulp mill effluents and their concentrations; and
- a discussion of information gaps regarding the potential toxic effects of pulp mill effluents in the study area, including recommendations for further monitoring and study, etc.

3. Reporting Requirements

1) Submit ten copies of the draft annotated bibliography and ten copies of the draft synthesis report to the Project Liaison Officer by a date decided upon by the Project Liaison Officer and Scientific Staff in consultation with the contractor.

2) Three weeks after the receipt of review comments on the draft annotated bibliography and draft synthesis report, submit five cerlox bound copies and two camera-ready originals of each final report to the Project Liaison Officer. The synthesis report is to include an executive summary.

3) An electronic copy, in Word Perfect 5.1 format, of both the annotated bibliography and synthesis report are to be submitted to the Project Liaison Officer on 5 1/4 or 3 1/2 inch floppy disk along with the final reports.

4) Specific data contained within tables, figures and appendices of the final annotated bibliography and synthesis report must be placed in dBase IV files and submitted to the Project Liaison Officer at the same time as the final reports.

V. Literature Cited

McCubbin, N. and J. Folke. 1992 (November). Review of literature on characteristics of pulp and paper mills in northern river basins of Alberta, BC and Northwest Territories. Prepared for: Northern River Basins Study. Prepared by: N. McCubbin Consultants Inc.

APPENDIX B

ALBERTA ENVIRONMENTAL PROTECTION TOXICITY DATABASE

Table B.1: Alberta Newsprint Company Final Effluent

Date (M/D/Y)	*Daphnia Magna*	Rainbow Trout I	Rainbow Trout II	Date (M/D/Y)	*Daphnia Magna*	Rainbow Trout I	Rainbow Trout II	Date (M/D/Y)	*Daphnia Magna*	Rainbow Trout I	Rainbow Trout II
7/31/90		1		1/13/93	1			3/14/94	1		
8/19/90	1	1		2/2/93	1	1	1	3/21/94	1		
9/17/90	1	1		2/8/93	1			3/28/94	1		
10/15/90	1	1		2/15/93	1			4/4/94	1	1	1
11/12/90	1	1		2/22/93	1			4/11/94	1		
12/3/90	1	1		3/2/93		1	1	4/18/94	1		
1/7/91	1	1		4/5/93		1	1	4/25/94	1		
2/12/91	1	1		5/5/93		1	1	5/4/94	1	1	1
3/11/91	1	1		6/7/93		1	1	5/9/94	1		
4/15/91	1	1		7/5/93		1	1	5/16/94	1		
5/6/91	1	1		8/3/93		1	1	5/24/94	1		
6/10/91	1	1		9/7/93			1	5/30/94	1		
7/2/91	1	1		9/8/93		1		6/6/94	1	1	1
8/7/91	1	1		10/4/93	1	1	1	6/13/94	1		
9/9/91	1	1	0	10/12/93	1			6/20/94	1		
9/19/91	1	1	1	10/18/93	1			6/27/94	1		
10/7/91	1	1	1	10/25/93	1			7/4/94	1	1	1
11/4/91	1	1	1	11/2/93	1	1	1	7/11/94	1		
12/10/91	1	1	1	11/8/93	1			7/18/94	1		
1/14/92	1	1	1	11/15/93	1			7/25/94	1		
2/4/92		1	1	11/22/93	1			8/2/94	1	1	1
3/2/92	1	1	1	11/29/93	1			8/8/94	1		
4/6/92	0	1	1	12/6/93	1	1	1	8/15/94	1		
6/8/92	1	1	1	12/13/93	1			8/22/94	1		
7/6/92		1	1	12/20/93	1			8/29/94	1		
8/10/92	1	1	1	12/29/93	1			9/6/94	1	1	1
9/8/92	1	1	1	1/4/94	1	1	1	9/12/94	1	1	1
10/5/92	1	1	1	1/10/94	1			9/19/94	1	1	1
11/2/92		1	1	1/18/94	1			9/26/94	1	1	1
12/7/92	1	1	1	1/24/94	1			10/3/94	1	1	1
12/14/92	1			1/31/94	1			10/11/94	1		
12/21/92	1			2/7/94	1	1	1	10/17/94	1		
12/29/92	1			2/14/94	1			10/24/94	1		
1/4/93	0	1		2/23/94	1			10/31/94	1		
1/11/93	1			2/28/94	1			11/1/94			
1/12/93	1		1	3/7/94	1	1	1				

Notes: 1 = Pass
0 = Fail

Table B.2: Alberta-Pacific Forest Industries Inc. Final Effluent

Date (M/D/Y)	*Daphnia Magna* (% Survival)	Fish Bioassay (% Survival)	Date (M/D/Y)	*Daphnia Magna* (% Survival)	Fish Bioassay (% Survival)	Date (M/D/Y)	*Daphnia Magna* (% Survival)	Fish Bioassay (% Survival)
8/16/93		100	12/29/93	100		6/27/94	100	
8/30/93	0		1/4/94	100		7/4/94	100	100
9/3/93	100	100	1/6/94		100	7/11/94	100	
9/6/93	100		1/12/94	100		7/18/94	100	
9/9/93	90		1/19/94	100		7/25/94	100	
9/12/93	100		1/24/94	100		8/2/94	100	100
9/15/93	100		2/1/94	100		8/8/94	100	
9/20/93	100		2/7/94	100	100	8/15/94	100	
9/22/93	100		2/15/94	100		8/22/94	100	
9/28/93	100		3/2/94		100	8/29/94	100	
10/7/93	100		4/5/94	100	100	9/6/94	100	100
10/12/93	100	90	4/11/94	100		9/12/94	100	
10/19/93	100		4/18/94	100		9/19/94	100	
11/2/93	100		4/25/94	100		9/26/94	90	
11/9/93		100	5/3/94	100	100	10/3/94	100	100
11/15/93	100		5/9/94	100		10/11/94	90	
11/17/93	100		5/16/94	100		10/17/94	100	
11/21/93	100		5/23/94	100		10/24/94	100	
12/7/93	100	100	6/6/94	100	100	10/31/94	100	
12/13/93	100		6/13/94	100		11/1/94		
12/20/93	100		6/21/94	100				

Table B.3: Daishowa-Marubeni International Ltd. Final Effluent

Date (M/D/Y)	*Daphnia Magna*	Rainbow Trout	Date (M/D/Y)	*Daphnia Magna*	Rainbow Trout	Date (M/D/Y)	*Daphnia Magna*	Rainbow Trout
7/29/90	1	0	1/14/93	1		1/13/94	1	
8/9/90		1	1/18/93		1	1/20/94	1	
8/15/90		1	1/20/93	1		1/24/94	1	1
8/21/90	1	1	1/27/93	1		2/3/94	1	
9/24/90	1	1	2/3/93	1		2/10/94	1	
10/1/90	1	1	2/10/93	1		2/14/94	1	1
10/12/90	1		2/16/93	1	1	2/25/94	1	
11/5/90	1		2/24/93	1		3/3/94	1	
11/6/90		1	3/15/93		1	3/10/94	1	
12/3/90	1	1	4/7/93	1		3/14/94	1	1
1/5/91	1	1	4/12/93	1	1	3/24/94	1	
2/4/91	1	1	4/21/93	1		3/31/94	1	
3/11/91	1	1	4/29/93	1		4/7/94	1	
4/8/91	1	1	5/6/93	1		4/11/94	1	1
5/14/91	1	1	5/13/93	1		4/21/94	1	
6/5/91		1	5/17/93	1	1	4/28/94	1	
6/24/91	1		5/27/93	1		5/5/94	1	
7/3/91		1	6/3/93	1		5/12/94	1	
7/9/91	1		6/10/93	1		5/16/94	1	1
8/19/91	1	1	6/14/93	1	1	5/26/94	1	
9/4/91	1	0	6/24/93	1		6/2/94	1	
9/9/91		1	7/12/93		1	6/9/94	1	
9/12/91	1	1	8/5/93	1		6/13/94	1	1
9/17/91		1	8/12/93	1		6/23/94	1	
9/23/91		1	8/16/93	1	1	6/29/94	1	
10/25/91	1	1	8/26/93	1		7/7/94	1	
11/5/91	1	1	9/2/93	1		7/11/94	1	1
12/30/91	1	1	9/9/93	1		7/21/94	1	
1/21/92	1	1	9/13/93	1	1	7/28/94	1	
2/26/92	1	1	9/23/93	1		8/4/94	1	
3/4/92	1	1	10/2/93	-100		8/11/94	1	
3/20/92		1	10/7/93	-100		8/15/94	1	1
4/29/92	1	1	10/14/93	-100		8/25/94	1	
5/19/92	1	1	10/18/93	-100	1	9/1/94	1	
6/2/92	1	1	10/26/93	-100		9/8/94	1	
7/8/92	1	1	11/1/93	1		9/15/94	1	
8/19/92	1	1	11/9/93	1		9/19/94		1
9/1/92	1	1	11/15/93	1	1	9/22/94	1	
10/1/92	1	1	11/25/93	1		9/29/94	1	
11/4/92		1	12/1/93	1		10/6/94	1	
12/1/92	1		12/9/93	1		10/13/94	1	
12/9/92	1		12/13/93	1	1	10/20/94	1	
12/15/92	1	1	12/20/93	1		10/24/94		1
12/23/92	1		12/29/93	1		10/27/94	1	
1/6/93	1		1/6/94	1		11/1/94		

Notes: 1 = Pass
0 = Fail
-100 = ____________________

Table B.4: Millar Western Pulp (Whitecourt) Ltd. Final Effluent

Date (M/D/Y)	Rainbow Trout	Date (M/D/Y)	Rainbow Trout	Date (M/D/Y)	Rainbow Trout	Date (M/D/Y)	Rainbow Trout
1/31/89	0	5/30/90	0	9/9/91	1	6/8/93	1
2/20/89	1	6/18/90	0	10/21/91	1	7/6/93	1
3/6/89	0	6/22/90	0	11/7/91	1	8/10/93	1
3/28/89	1	6/26/90	0	12/3/91	1	9/13/93	-100
6/26/89	0	7/4/90	1	1/8/92	1	10/18/93	1
7/11/89	0	7/9/90	1	2/3/92	1	11/16/93	1
7/20/89	0	7/16/90	1	3/9/92	1	12/6/93	0
8/1/89	0	7/24/90	1	4/6/92	1	12/9/93	0
8/28/89	1	8/28/90	1	5/11/92	1	12/13/93	1
9/18/89	0	9/6/90	1	6/8/92	1	12/20/93	1
9/26/89	0	10/25/90	1	7/6/92	1	12/30/93	1
10/27/89	0	11/28/90	0	8/10/92	1	2/22/94	1
11/8/89	0	11/29/90	1	9/8/92	1	3/28/94	1
12/18/89	0	12/12/90	1	10/26/92	1	4/18/94	1
12/27/89	0	1/8/91	0	11/16/92	1	5/9/94	1
1/3/90	0	1/21/91	1	11/30/92	1	6/23/94	1
1/12/90	1	2/22/91	1	12/7/92	1	8/22/94	1
1/19/90	1	3/18/91	1	1/12/93	1	9/20/94	1
1/26/90	1	4/15/91	1	2/8/93	1	10/17/94	1
2/26/90	1	5/23/91	1	2/20/93	1	10/26/94	1
3/27/90	0	6/20/91	1	3/3/93	1	11/1/94	
4/5/90	1	7/22/91	1	5/3/93	1		

Notes: 1 = Pass
0 = Fail
-100 = ____________________

Table B.5: Slave Lake Pulp Corporation Final Effluent

Date (M/D/Y)	*Daphnia Magna*	Rainbow Trout	Date (M/D/Y)	*Daphnia Magna*	Rainbow Trout	Date (M/D/Y)	*Daphnia Magna*	Rainbow Trout
12/28/90	1	1	3/3/93	1		1/6/94	1	
1/9/91		1	3/9/93		1	1/11/94	1	
2/6/91		1	3/10/93	1		1/19/94	1	
3/11/91		1	3/17/93	1		1/26/94	1	
3/12/91	1		3/24/93	1		2/2/94	1	1
4/29/91	1	1	3/31/93	1		2/10/94	1	
5/28/91	0	0	4/5/93		1	2/15/94	1	
6/3/91		0	5/2/93		1	2/22/94	0	
6/10/91		1	5/3/93	1		2/25/94	1	1
6/17/91		1	5/10/93	1		2/28/94	1	
6/27/91		0	5/11/93	0		3/1/94	1	
7/3/91		1	5/12/93	0		3/8/94	1	
7/4/91	1		5/17/93	1		3/15/94	1	1
8/1/91		1	5/18/93	1		3/22/94	1	
8/8/91		1	5/19/93	1		3/29/94	1	
9/5/91	1	1	5/27/93	1		4/5/94	1	
10/2/91	1	1	6/8/93		1	4/12/94	0	
11/6/91	1	1	6/14/93		1	4/16/94	1	0
12/12/91		1	7/7/93	0	1	4/18/94	1	
1/15/92		1	7/13/93	0		4/19/94	1	
2/29/92		0	7/14/93	1		4/21/94	1	1
3/13/92		0	7/15/93	1		4/22/94		1
3/19/92		0	7/20/93	1		4/29/94		1
3/20/92		0	7/21/93	1		5/2/94	1	1
3/25/92		0	7/22/93	1		5/12/94	1	
3/26/92		1	7/27/93	1		5/17/94	1	
3/27/92		1	8/4/93	1		5/25/94	1	
3/31/92		0	8/11/93	1		5/30/94	1	
4/1/92		1	8/16/93	1	1	6/7/94	1	1
4/3/92		1	8/25/93	1		6/17/94	1	
4/6/92		1	9/1/93	1		6/20/94	1	
7/9/92		0	9/7/93	1		7/1/94	1	
8/8/92		1	9/13/93	1	1	7/4/94	1	1
9/10/92	1	1	9/21/93	1		7/11/94	1	
10/6/92		1	9/29/93	1		7/19/94	1	
10/7/92	1		10/5/93	1		7/25/94	1	
10/15/92		1	10/14/93	1	1	8/2/94	1	
10/19/92		1	10/19/93	0		8/8/94	1	
10/28/92		1	10/22/93	1	1	8/18/94	1	
11/3/92		1	10/26/93	1		8/22/94	1	1
12/7/92		1	10/27/93	0		8/29/94	1	
1/6/93	1	1	10/28/93	1		9/6/94	1	
1/13/93	1		11/2/93	1		9/12/94	1	
1/20/93	1	1	11/10/93	1		9/19/94	1	1
1/27/93	1		11/17/93	1	1	9/29/94	1	
2/3/93	1		11/25/93	1		10/3/94	1	1
2/10/93	1		12/1/93	1		10/11/94	1	
2/16/93	0		12/7/93	1	1	10/17/94	1	
2/21/93	1	1	12/15/93	1		10/27/94	1	
2/24/93	1		12/20/93	1		11/1/94		
2/25/93	1		1/4/94	1	1			

Notes: 1 = Pass
0 = Fail

Table B.6: Weldwood of Canada Limited Final Effluent

Date (M/D/Y)	*Daphnia magna*	Rainbow Trout	Date (M/D/Y)	*Daphnia magna*	Rainbow Trout	Date (M/D/Y)	*Daphnia magna*	Rainbow Trout
1/12/89		0	10/6/92	1	1	1/4/94	1	1
1/16/89		0	11/3/92	1	1	1/11/94	1	
1/17/89		1	12/8/92	1	1	1/18/94	1	
1/25/89		0	1/6/93	1	1	1/25/94	1	
1/26/89		1	2/2/93	1	1	2/1/94	1	
1/27/89		1	2/11/93	1		2/8/94	1	1
5/16/89		1	2/16/93	1		2/15/94	1	
7/31/89		1	2/23/93	1		2/22/94	1	
10/30/89		1	3/2/93		1	3/1/94	1	1
1/15/90		1	3/9/93		1	3/8/94	1	
2/26/90		1	3/16/93		1	3/15/94	1	
3/19/90		1	3/23/93		1	3/22/94	1	
4/2/90		1	3/30/93		1	3/29/94	1	
5/2/90		1	4/6/93		1	4/5/94	1	1
6/5/90		1	5/4/93		1	4/12/94	1	
7/3/90		1	5/7/93	1		4/19/94	1	
8/22/90	1	1	5/11/93	1		4/26/94	1	
9/3/90	1		5/14/93	1		5/3/94	1	
9/4/90		1	5/18/93	1		5/10/94	1	
10/2/90	1	1	5/25/93	1		5/17/94	1	
11/6/90	1	1	6/8/93		1	5/24/94	1	
12/5/90		1	7/6/93		1	5/31/94	1	
1/8/91	1	1	8/3/93	1	1	6/7/94	1	1
2/5/91	1	1	8/10/93	1		6/14/94	1	
3/5/91	1	1	8/17/93	1		6/21/94	1	
4/2/91	1	1	8/24/93	1		6/28/94	1	
5/6/91	1	1	8/31/93	1		7/5/94	-100	-100
6/4/91	1	1	9/6/93		1	7/12/94	-100	
7/3/91	1	1	9/7/93	1		7/19/94	-100	
8/6/91	1	1	9/14/93	1		7/26/94	-100	
9/3/91	1	1	9/21/93	1		8/2/94	1	1
10/1/91	1	1	9/28/93	1		8/9/94	1	
11/5/91	1	1	10/5/93	1	1	8/16/94	1	
12/2/91		1	10/12/93	1		8/23/94	1	
12/3/91	1		10/19/93	1		8/30/94	1	
1/6/92	1	1	10/26/93	1		9/6/94	1	1
2/11/92		1	11/2/93	1	1	9/13/94	1	
2/12/92	1		11/9/93	1		9/20/94	1	
3/3/92	1	1	11/16/93	1		9/27/94	1	
4/7/92	1	1	11/23/93	1		10/4/94	1	1
5/19/92	1	1	11/30/93	1		10/11/94	1	
6/2/92	1	1	12/7/93	1	1	10/18/94	1	
7/7/92	1	1	12/14/93	1		10/25/94	1	
8/4/92	1	1	12/23/93	1		11/1/94		
9/1/92	1	1	12/28/93	1				

Notes: 1 = Pass
0 = Fail
-100 = ___________

Table B.7: Weyerhaeuser Canada Ltd. Final Effluent

Date (M/D/Y)	*Daphnia Magna*	Rainbow Trout	Date (M/D/Y)	*Daphnia Magna*	Rainbow Trout	Date (M/D/Y)	*Daphnia Magna*	Rainbow Trout	Date (M/D/Y)	*Daphnia Magna*	Rainbow Trout	Date (M/D/Y)	*Daphnia Magna*	Rainbow Trout
3/15/89		0	1/5/92	1	0	2/18/92		1	1/26/93	0		1/19/94	1	
4/6/89		1	1/6/92		0	2/19/92		1	1/27/93	0		1/26/94	1	
8/17/89		1	1/7/92	1	1	2/20/92		1	1/31/93	0		2/2/94	1	1
9/21/89		1	1/8/92	1	0	2/21/92		1	2/3/93		1	2/9/94	1	
12/5/89		1	1/9/92	1	0	2/22/92		1	2/10/93		1	2/16/94	1	
2/23/90		1	1/10/92		0	2/23/92		1	2/24/93		1	2/25/94	1	
3/19/90		1	1/11/92	1	1	2/24/92	1	1	3/3/93	1		3/2/94	1	1
4/17/90		1	1/12/92		1	2/25/92		1	3/10/93	1		3/9/94	1	
5/15/90		1	1/13/92		1	2/26/92		1	3/17/93	1		3/16/94	1	
6/14/90		1	1/14/92		1	2/27/92		1	3/22/93	1	1	3/23/94	1	
7/13/90		0	1/15/92		1	2/28/92		1	3/31/93	1		3/30/94	1	
7/18/90		1	1/16/92		1	2/29/92		1	4/4/93		1	4/6/94	1	1
7/25/90		1	1/17/92	1	1	3/1/92		1	5/13/93		1	4/13/94	1	
7/31/90		1	1/18/92		1	3/2/92	1	1	6/9/93		1	4/20/94	1	
8/9/90		1	1/19/92		1	3/3/92		1	7/7/93		1	4/27/94	1	
9/24/90		1	1/20/92	1	0	3/4/92		1	7/14/93		1	5/4/94	1	1
9/30/90	1		1/21/92		1	3/5/92		1	8/4/93	1		5/11/94	1	
10/30/90	1		1/22/92		1	3/6/92		1	8/8/93		1	5/18/94	1	
10/31/90		1	1/24/92		1	3/9/92	1	1	8/11/93	1		5/25/94	1	
11/6/90	1	1	1/26/92		1	3/11/92		1	8/18/93	1		6/1/94	1	1
12/4/90	1	0	1/27/92		1	3/13/92		1	8/25/93	1		6/10/94	1	
12/14/90		1	1/28/92		1	3/16/92	1	1	9/1/93	-100		6/15/94	1	
12/29/90		1	1/29/92		1	3/18/92		1	9/8/93	-100	1	6/22/94	1	
1/4/91		1	1/30/92		1	3/20/92		1	9/15/93	-100		6/29/94	1	
1/8/91	1	1	1/31/92		1	3/23/92	1		9/22/93	-100		7/6/94	1	1
2/5/91	1	1	2/1/92		1	4/2/92	1	1	9/29/93	-100		7/14/94	1	1
3/5/91	1	1	2/2/92		1	5/5/92	1	1	10/6/93	1	1	7/19/94	1	
4/2/91	1	1	2/3/92		1	6/2/92	1	1	10/13/93	1		7/27/94	1	
5/7/91	1	1	2/4/92		1	7/15/92	1	1	10/20/93	1	1	8/3/94	1	1
6/4/91	1	1	2/5/92	1	1	8/6/92	1	1	10/27/93	1		8/10/94	1	
7/3/91	1	1	2/6/92		1	9/9/92	1	1	11/3/93	1	1	8/17/94	1	
8/7/91	1	1	2/7/92		1	10/7/92	1	1	11/4/93	1	1	8/24/94	1	
9/3/91	1	1	2/8/92		1	11/4/92	1	1	11/9/93	1		8/31/94	1	
10/1/91	1	1	2/9/92		1	12/2/92	1	1	11/15/93	1		9/7/94	1	1
11/3/91	1	1	2/10/92		1	12/16/92	1		11/24/93	1		9/14/94	1	
12/3/91	1	0	2/11/92	1	1	12/22/92	1		12/1/93	1	1	9/21/94	1	
12/10/91		0	2/12/92		1	1/7/93	1	1	12/8/93	1		9/28/94	1	
12/16/91		1	2/13/92		1	1/13/93	1		12/15/93	1		10/5/94	1	1
1/1/92		0	2/14/92		1	1/20/93	1		12/22/93	1		10/12/94	1	
1/2/92	1	0	2/15/92	1	1	1/22/93	0		12/29/93	1		10/19/94	1	
1/3/92		0	2/16/92		1	1/24/93	0		1/5/94	1	1	10/26/94	1	
1/4/92		0	2/17/92	1	1	1/25/93	0		1/12/94	1		11/1/94		

Notes: 1 = Pass 0 = Fail -100 = ____________

APPENDIX C

ECOTOXICITY OF PULP MILL EFFLUENTS ANNOTATED BIBLIOGRAPHY

Appendix C: Annotated Bibliography

This Appendix is provided on the disk bound as the last page of this report; it contains an annotated bibliography on ecotoxicity of pulp mill effluents. Data entry and coding responses to the database is described in NRBS Project Report No. 78.

The disk comprising this Appendix contains three files, using 113,780 bytes.

1. INSTALL.BAT; being 72 bytes in size.
2. PR78.EXE; being 113,222 bytes in size.
3. DISCLAIM.TXT; being 486 bytes in size.

To install the database copy the three files on this disk to a directory on your hard drive and type install.bat. The result will be 13 files totalling 746,015 bytes. To use the files with the extensions .DBF, .FRM, .FRG, .FRO and .PRF requires d-Base IV.

There is no warranty expressed or implied for the use of this database; the Northern River Basins Study does not guarantee the accuracy of the data. The NRBS does not assume any liability for actions or consequences resulting from the use of the data; individuals using this data do so entirely at their own risk. The NRBS will not update the data except as deemed necessary for its own purpose.

Prepared for:
Northern River Basins Study

Prepared by
SENTAR Consultants Ltd.

ECOTOXICITY OF PULP MILL EFFLUENTS
ANNOTATED BIBLIOGRAPHY

FEBRUARY 1994

REPORT SUMMARY

This document is an annotated bibliography of government and industrial reports and databases pertaining the ecotoxicity of effluents from the pulp mills located on the Peace, Athabasca and Slave rivers in Alberta and the Northwest Territories. Key journal articles pertaining to the ecotoxicity of pulp mill effluents have been included because of their relevance even though the articles may refer to studies outside of northern Alberta.

ACKNOWLEDGEMENTS

SENTAR would like to acknowledge the assistance of the NRBS and the co-operation of Alberta Environmental Protection, Environment Canada and the pulp mills. In particular, we would like to thank Dr. Fred Wrona, Dr. Patricia Chambers and Greg Wagner who made the majority of the documents available to us through this and earlier contracts.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

1.1 OBJECTIVE

In January 1993, SENTAR Consultants Ltd. (SENTAR) was authorized by the Northern River Basins Study (NRBS) to compile and review water quality and related data pertaining to the ecotoxicity of pulp mill effluents. The project consists of three parts: data collection, a synthesis report, and an annotated bibliography.

The objective of the annotated bibliography is to identify and annotate the available databases, government and industry reports, journal papers, and other sources of information on instream pulp mill contaminant concentrations and loading, effluent sources, and the effects of pulp mill effluents on aquatic biota within the three northern rivers of the study.

1.2 SCOPE

The study area includes the Peace, Athabasca and Slave rivers within Alberta and the Northwest Territories (Figure 1 Northern River Basins Study Area). The study includes major tributaries to the three rivers; for example, the evaluation of the Peace River will include the Wapiti River-Smoky River system. The Lesser Slave River is a major tributary to the Athabasca River.

The annotated bibliography pertaining to the ecotoxicity of pulp mill effluents is similar to two other annotated bibliographies prepared for the NRBS on related topics, including nutrient and contaminants in the aquatic ecosystems.

The bibliography was completed on dBase IV. By using this database, topics can be searched electronically by key words. To assist users, SENTAR Consultants Ltd. has supplied the ecotoxicity of pulp mill effluents bibliography in both printed version and electronic disc. The other bibliographies have been prepared in the same format on dBase IV.

References pertaining to relevant studies conducted within the NRBS study area have been annotated (Appendix A). In some cases, these reports listed secondary sources of information which have also been included in this bibliography (Appendix B), but have not been annotated. These un-annotated references were included to give the reader the original sources of information used in the preparation of the annotated reports. Also included in this document are the annotations of major review papers dealing with the ecotoxicity of pulp mill effluents. Emphasis was placed on research which has made a significant contribution to the development of present-day knowledge and techniques for monitoring the effects of pulp and paper mill effluents.

SENTAR

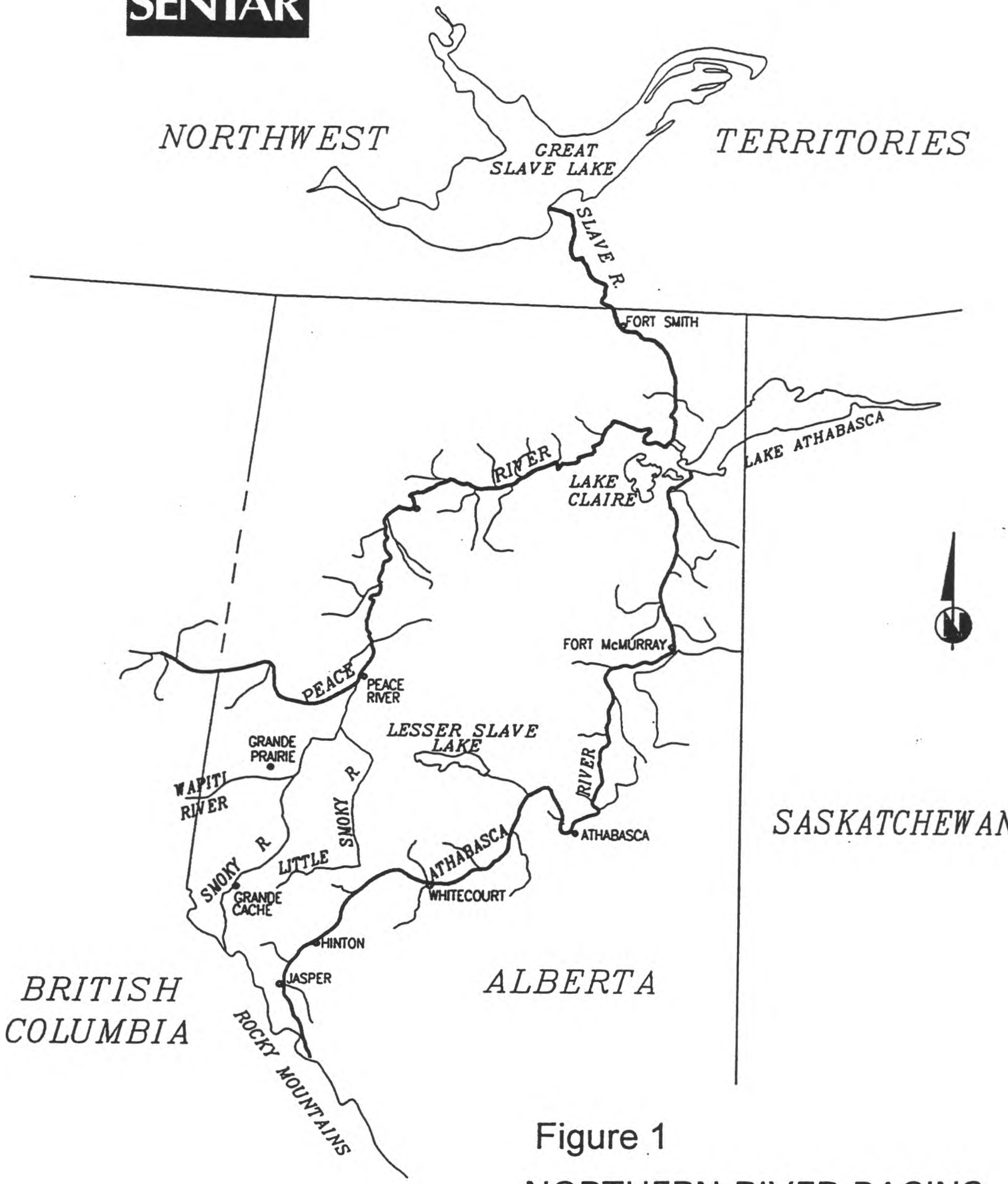


Figure 1

NORTHERN RIVER BASINS STUDY AREA

2.0 USER'S INFORMATION

2.1 ORGANIZATION

The annotated bibliography is arranged alphabetically by author, then by date of publication. As much information as possible was included in each bibliography to provide users with several options when searching for a report or group of related reports.

The annotated bibliography is organized as follows:

AUTHOR	The name of author(s) or organizations who prepared the report.
DATE	The year in which the report was published.
DUP_DATE	A lower-case letter identifying the report from other reports published by the same author in the same year.
TITLE	The report title.
OTHER1	The name of client(s) for whom the report was prepared.
PUBLISHER	The name of the publisher or the name of the journal/publication, the volume number and the pages.
OTHER2	Additional information such as project number, detailed date, report length and appendices.
ANNOTATION	A note explaining the contents of the report. When the annotation is not original, the source of the annotation is cited.
KEY	Key word fields identifying the topics covered.

This annotated bibliography is comprised of reports pertaining to pulp mills for the Northern River Basins Study area and major review papers on the ecotoxicity of pulp mill effluents; it is a subset of a larger bibliography. For this reason, the duplicate dates (e.g. Smith 1991a, 1991c) listed for the same author and year may not be consecutive if a report with the same author and year (e.g. Smith 1991b) pertains to another topic (e.g. contaminants) within the larger bibliography.

2.2 KEY WORD FIELDS

2.2.1 Summary of Key Word Field Names

Five general categories of information were identified. Key word fields were defined for each of these five information categories (Table 1 Information Categories and Key Word Field Names). Ten "key word" fields have been created. Each field contains one or more key words.

Table 1: Information Categories and Key Word Field Names

INFORMATION TYPE	FIELD NAME
1. Location	
(a) Waterbody/Basin	KEY_WATER
(b) Geographic Descriptors	KEY_GEOG
2. Physical, Chemical and Toxicological Parameters	KEY_PARAM
3. Biota	
(a) Animals	KEY_ANIMAL
(b) Plants	KEY_PLANT
(c) Microbes	KEY_MCROBE
4. Sampling Media	KEY_MEDIA
5. Miscellaneous	KEY_MISC1 KEY_MISC2 KEY_MISC3

2.3 EXPLANATION OF KEY WORD FIELDS

2.3.1 Waterbody/Basin

Key Word Field: KEY_WATER
Key Words:

ATHABASCA	MACKAY	PEMBINA
BEAVER	MACKENZIE	RED DEER
BOW	MCLEOD	SLAVE
CLEARWATER	MUSKEG	SMOKY
FRASER	NORTH SASKATCHEWAN	SOUTH SASKATCHEWAN
HARTLEY	OLDMAN	STEEPBANK
LAKE SUPERIOR	PEACE	THOMPSON
LESSER SLAVE	PEACE-ATHABASCA	WAPITI

Words entered into this field define the water body(s) referred to in a document. Zero to many waterbodies may be listed. All of the main rivers in the Northern River Basins and their tributaries are eligible for this field. In cases where waterbodies outside of the Northern River Basins are discussed, they are also listed. The key words do not indicate waterbody type; that is, they do not designate if the waterbody is a river, lake, reservoir, etc. These designations are found in the miscellaneous key word field(s).

Some of the key words in this field appear to be redundant. For example, both "Athabasca" and "Peace-Athabasca" are used. This is done to accommodate searching strategies. For example, "Athabasca" is listed to capture documents on the Athabasca River, or on the Athabasca Basin. "Peace-Athabasca" is listed to capture documents pertaining to the Peace-Athabasca Delta.

2.3.2 Geographic Descriptors

Key Word Field: KEY_GEOG
Key Words:

ALBERTA	EMBARRASS	ONTARIO
ATHABASCA	FORT CHIPEWYAN	OREGON
BENNETT DAM	FORT MCMURRAY	PEACE RIVER
BRITISH COLUMBIA	GRANDE PRAIRIE	SLAVE LAKE
CANADA	HINTON	WHITECOURT
	NORTHWEST TERRITORIES	

In some cases, it is useful to describe the location of the study in geographic terms other than the name of a waterbody/basin. This field defines political boundaries and specific locations (e.g. municipalities).

2.3.3 Physical, Chemical and Toxicological Parameters

Key Word Field: KEY_PARAM
Key Words:

CHLORINATED ORGANIC(S)	NUTRIENT(S)	OXYGEN DEMAND
EXTENSIVE	ORGANIC(S)	PHYSICAL PARAMETER(S)
METAL(S)	OXYGEN	TOXIC
NON-METAL INORGANIC(S)		

The terms listed in Table 2 Information Categories and Key Words in "Key_Parameter" Field were chosen to categorize different types of parameters, including those specifically related to contaminants.

Table 2: Information Categories and Key Words in "Key_Parameter" Field

KEY WORD	WATER QUALITY PARAMETERS
Chlorinated Organics:	- dioxins - furans - chlorinated phenols - other
Extensive:	- broad spectrum survey - more than two categories
Metals:	- all metals
Non-Metal Inorganics:	- major ions - halides - arsenic, etc.
Nutrients:	- nitrogen - phosphorous
Organics:	- non-chlorinated organics - petroleum (e.g. oil)
Oxygen:	- dissolved oxygen
Oxygen Demand:	- biochemical oxygen demand (BOD) - chemical oxygen demand (COD) - sediment oxygen demand (SOD)
Physical Parameters:	- temperature - alkalinity - hardness - pH - conductivity - odour - colour - total suspended solids (filterable residue) - total dissolved solids (non-filterable residue)
Toxic:	- toxicity of contaminants

2.3.4 Animals

Key Word Field: KEY_ANIMAL

Key Words:

FAUNA	VERTEBRATE
INVERTEBRATE	

This field indicates whether a document contains information about invertebrates, vertebrates or fauna in general. The term "fauna" is a generic term for those documents that are not specific about the animal(s) that are being discussed. Because these terms are so broad, further identification of the animal may be found in the miscellaneous key word field. For example, if a document refers to a study on the effects of contaminants on fish, the key word for this field will be vertebrates. And, in the KEY_MISC field, "fish" will be listed. (Note: the ANNOTATION field may also contain the term "fish").

2.3.5 Plants

Key Word Field: KEY_PLANT

Key Words:

ALGAE	FLORA
CHLOROPHYLL	MACROPHYTE

This field indicates whether a document contains information about plants. The same principles apply for this field, as for the KEY_ANIMAL field.

2.3.6 Microbes

Key Word Field: KEY_MCROBE

Key Words:

BACTERIA	MICROBE
FUNGI	

This field indicates whether a document contains information about microscopic biota: bacteria (total coliform, fecal coliform, fecal streptococci), fungi or viruses.

2.3.7 Sampling Media

Key Word Field: KEY_MEDIA

Key Words:

BIOTA	SEDIMENT
EFFLUENT	WATER

The type of sample that has been analyzed is identified by these key words.

2.3.8 Miscellaneous

Key Word Fields: KEY_MISC1, KEY_MISC2, KEY_MISC3
Key Words:

ALBERTA-PACIFIC	FOOD CHAIN	OIL
ANNUAL REPORT	FOREST HARVESTING	OIL SANDS
ANC	FURANS	ORGANOCHLORINE
BASELINE	GENERAL REFERENCES	POLLUTION
BASIN	GEOLOGY	PROCTER & GAMBLE
BENTHOS	HINTON	PULP MILL
BIBLIOGRAPHY	HUMAN HEALTH	REPRODUCTION
BIOACCUMULATION	HYDROLOGY	RIVER
CONTAMINANT	IMPACT	SALMONID
DAISHOWA	INDUSTRY	SAMPLING
DATABASE	INVENTORY	SEWAGE TREATMENT
DELTA	INVESTIGATION	SLAVE LAKE
DIOXINS	LAKE	SPILL
ECOLOGY	LICENCE	STUDIES
ECOSYSTEM	METHODS	SUNCOR
EFFLUENT	MILLAR WESTERN	SURVEY
EIA	MINING	SYNCRUDE
EXPERIMENT	MODEL	WATER QUALITY
FATE	MONITORING	WATER RESOURCES
FISH	NAQUADAT	WATER USE
	NUTRIENT	WELDWOOD

The key words used to compile the annotated bibliography relating to pulp mills were not placed in specific key word fields because the key words relating to this topic were too numerous. Creating key word fields for each relevant key word would have increased the level of complexity of the bibliography beyond a practical level. Instead, the selection of appropriate key words was left in the miscellaneous key word fields. This will allow the searcher to select the most relevant search criteria, depending on the topic in question. As the field name suggests, these key words are miscellaneous terms that help to describe a document and/or to refine the definition of a key word from another field. For example, if a document describes a study about the levels of oils in a river, and the key word "ORGANICS" is listed in KEY_PARAM1, then to narrow the description of the document further, "OIL" would be listed in KEY_MISC1.

2.4 dBase FILE INFORMATION

The annotated bibliography was designed using dBase IV. The database file name is PULPMILL.dbf and is accompanied with a file named PULPMILL.dbt. The .dbt extension refers to data contained in the memo field. The .dbt file must accompany the .dbf file.

Indices created during the use of the database will have an .mdx extension. When backing up files or transferring to other disks, it is important that all .dbf, .dbt and .mdx files are copied. When performing a search, the words selected must be in uppercase. It is advisable to use a "wild card" extension when searching key words that may or may not be pluralized (Example: INVERTEBRATE*, METAL*). Often, a field may have several key words. When searching for one key word in a list of several, place the key word in quotation marks preceded by a "$" sign (e.g. $"WORD"). This tells dBase that the character string being searched is imbedded. Multiple key words and multiple fields can be searched at the same time. Several key words can be searched in one field, as long as each key word is on a separate line. Put each word on a separate row (one beneath the other) in the Query definition screen. By doing this, dBase will search for records containing any or all of the key words. The above rules apply (e.g. uppercase, $ and quotation marks for imbedded strings, and separate lines for each key word). The following example illustrates this:

KEY_XX	**KEY_YY**	**KEY_ZZ**
$"WORD1"		
$"WORD2"		
	$"WORD3"	
	$"WORD4"	
		"WORD5"

The "WORD5" example shown above illustrates a case where only one key word would be found in that field, as opposed to a list of key words.

3.0 ANNOTATED BIBLIOGRAPHY

The annotated bibliography which follows in Appendix A consists of "166" annotated references from government and industry reports, scientific papers and other print sources. References cited in the reports have been retained in Appendix B. The major databases containing data on the ecotoxicity of pulp mill effluents can be found in Appendix C. A copy of the terms of reference have been included in Appendix D.

APPENDIX A

ANNOTATED BIBLIOGRAPHY FROM PRINTED (HARD COPY) SOURCES

APPENDIX B

REFERENCES CITED FROM ANNOTATED BIBLIOGRAPHIES

APPENDIX C

ANNOTATED BIBLIOGRAPHY OF MAJOR DATABASES

3 1510 00173 042 4

APPENDIX D

TERMS OF REFERENCE