FRASER RIVER ACTION PLAN

Proceedings

3rd
Research
Workshop

Feb. 20-22, 1996
Vancouver, B.C.

Canada

DOE FRAP 1996-10

Environment Canada   Environnement Canada

PROCEEDINGS

3rd RESEARCH WORKSHOP
February 20-22, 1996
Vancouver, B.C.

DOE FRAP 1996-10

Prepared by:

Janet M. Landucci and Maki Hanawa

Environment Canada
Environmental Conservation Branch
Science Division
700-1200 West 73rd Avenue
Vancouver, B.C.
V6P 6H9

December 1996

DISCLAIMER

This report was funded by Environment Canada under the Fraser River Action Plan through the Environmental Quality Technical Working Group. The views expressed herein are those of the authors and do not necessarily state or reflect the policies of Environment Canada.

Any comments regarding this report should be forwarded to:

Science Division, Research Section
Environmental Conservation Branch
Environment Canada
700-1200 West 73rd Avenue
Vancouver, B.C.
V6H 6P9

TABLE OF CONTENTS

SESSION 3: URBAN ISSUES

SESSION 4: AGRICULTURAL ISSUES

SESSION 5: BIOLOGICAL INDICATORS

SESSION 6: ESTUARY ISSUES

SUMMARY AND CONCLUSIONS

Participants

BCMOELP

Anthony Chan
BC Ministry of Environment
Sr. Environmental Protection Officer
15326-103A Avenue
Surrey, BC V3R 7A2
TEL: 604 582-5238
FAX: 604 584-9751

Don Holmes
BC Ministry of Environment
Environmental Section, Head
1259 Dalhousie Drive
Kamloops, BC V2C 5Z5
TEL: 604 327-6237
FAX: 694 828-4000
dholmes@kamloops.env.gov.bc.ca

Jim McCracken
BC Ministry of Environment
Lower Mainland, Regional Director
10334-152A Street
Surrey, BC V3R 7P8
TEL: 604 582-5365
FAX: 604 660-8926
jmccrack@surrey.env.gov.bc.ca

Dave Morrison
BC Ministry of Environment
Technical Services and Special Wastes Section
1106-1175 Douglas Street
Victoria, BC V8V 1X4
TEL: 604 387-9981
FAX: 604 953-3856
dmorrison@epdiv1.env.gov.bc.ca

Narender Nagpal
BC Ministry of Environment
Water Quality Branch
765 Broughton Street
Victoria, BC V8V 1X4
TEL: 604 387-9507
FAX: 604 356-8298
nnagpal@epdiv1.env.gov.bc.ca

John Rex
BC Ministry of Environment
Environmental Section
1011-4th Avenue, 3rd Flr.
Prince George, BC V2L 3H9
TEL: 604 565-6853
FAX: 604 565-6629
jfrex@prince.env.gov.bc.ca

DFO

Karen Hutton
Fisheries and Oceans
Habitat Management
555 W. Hastings Street
Vancouver, BC V6B 5G3
TEL: 604 666-6529
FAX: 604 666-7112
hutton%am%frdlan@mr.pac.dfo.ca

Dennis Martens
Fisheries and Oceans
Cultus Lake
Salmon Research Laboratory
4222 Columbia Valley Hwy.
Cultus Lake, BC V0X 1H0
TEL: 604 858-7117
FAX: 604 858-3757

Jennifer Nener
Fisheries and Oceans
Water Quality Coordinator
555 W. Hastings Street
Vancouver, BC V6B 5G3
TEL: 604 666-0395
FAX: 604 666-3450
nenerj@mailhost.pac.dfo.ca

Mark Yunker
Fisheries and Oceans
Institute of Ocean Sciences,
PO Box 6000
9860 West Saanich Road
Sidney, BC V8L 4B2
TEL: 604 363-6805
FAX: 604 363-6807

DOE

Vic Bartnick
Environment Canada
Environmental Conservation Branch
400-1200 West 73rd Avenue
Vancouver, BC V6P 6H9
TEL: 604 664-4007
FAX: 604 664-9126
vic.bartnick@ec.gc.ca

Myriam Beaulne
Environment Canada
Environmental Conservation Branch
400-1200 West 73rd Avenue
Vancouver, BC V6P 6H9
TEL: 604 664-4040
FAX: 604 664-9126

Don Bernard
Environment Canada
Environmental Conservation Branch
400-1200 West 73rd Avenue
Vancouver, BC V6P 6H9
TEL: 604 664-4051
FAX: 604 664-9126
don.bernard@ec.gc.ca

Al Colodey
Environment Canada
Environmental Protection Branch
224 West Esplanade
North Vancouver, BC V7M 3H7
TEL: 604 666-2883
FAX: 604 666-9107
al.colodey@ec.gc.ca

Reg Dunkley
Environment Canada
Monitoring & Systems Branch
1200 W 73rd Avenue
Vancouver, BC V6P 6H9
TEL: 604 664-9065
FAX: 604 664-9066
reg.dunkley@ec.gc.ca

Bruce Galbraith
Environment Canada
Environmental Protection Branch
224 West Esplanade
North Vancouver, BC V7M 3H7
TEL: 604 666-5265
FAX: 604 666-7294

Christine Garrett
Environment Canada
Environmental Protection Branch
224 West Esplanade
North Vancouver, BC V7M 3H7
TEL: 604 666-3332
FAX: 604 666-6800
chris.garrett@ec.gc.ca

Mike Hagen
Environment Canada
Environmental Protection Branch
224 West Esplanade
North Vancouver, BC V7M 3H7
FAX: 604 666-9107

Maki Hanawa
Environment Canada
Environmental Conservation Branch
400-1200 West 73rd Avenue
Vancouver, BC V6P 6H9
TEL: 604 664-9108
FAX: 604 664-9126

Patricia Hayes
Environment Canada
CWS
PWRC
5421 Robertson Road
Delta, BC V4K 3Y3
TEL: 604 946-8546
FAX: 604 946-7022

Kirk Johnstone
Environment Canada
Environmental Conservation Branch
400-1200 West 73rd Avenue
Vancouver, BC V6P 6H9
TEL: 604 664-9102
FAX: 604 664-9126
kirk.johnstone@ec.gc.ca

Kim Joslin
Environment Canada
Environmental Conservation Branch
224 West Esplanade
North Vancouver, BC V7M 3H7
TEL: 604 666-8010
FAX: 604 666-6756

Kay Kim
Environment Canada
Environmental Protection Branch
1200 West 73rd Avenue
Vancouver, BC V6P 6H9
TEL: 604 664-4080
FAX: 604 666-7294
kay.kim@ec.gc.ca

Janet Landucci
Environment Canada
Environmental Conservation Branch
400-1200 West 73rd Avenue
Vancouver, BC V6P 6H9
TEL: 604 664-4000
FAX: 604 664-9126
janet.landucci@ec.gc.ca

Hugh Liebscher
Environment Canada
Environmental Conservation Branch
400-1200 West 73rd Avenue
Vancouver, BC V6P 6H9
TEL: 604 664-4050
FAX: 604 664-9126
hugh.liebscher@ec.gc.ca

Rick McKelvey
Environment Canada
CWS
PWRC
5421 Robertson Road
Delta, BC V4K 3Y3
TEL: 604 946-8546
FAX: 604 946-7022
rick.mckelvey@ec.gc.ca

Bev McNaughton
Environment Canada
Monitoring and Systems Branch
224 West Esplanade
North Vancouver, BC V7M 3H7
TEL: 604 664-4055
FAX: 604 664-9176
bev.mcnaughton@ec.gc.ca

Dan Millar
Environment Canada
Environmental Conservation Branch
224 West Esplanade
North Vancouver, BC V7M 3H7
TEL: 604 666-6225
FAX: 604 666-6756
dan.millar@ec.gc.ca

Gail Moyle
Environment Canada
Environmental Conservation Branch
400-1200 West 73rd Avenue
Vancouver, BC V6P 6H9
TEL: 604 664-4073
FAX: 604 664-9126
gail.moyle@ec.gc.ca

Mike Nassichuk
Environment Canada
Environmental Protection Branch
224 West Esplanade
North Vancouver, BC V7M 3H7
TEL: 604 666-2799
FAX: 604 666-9107
mike.nassichuk@ec.gc.ca

Carolyn O'Neill
Environment Canada
Environmental Conservation Branch
P.O. Box 340
Delta, BC V4K 3Y3
TEL: 604 664-4008
FAX: 604 664-9126
carolyn.oneill@ec.gc.ca

John Pasternak
Environment Canada
Environmental Protection Branch
224 West Esplanade
North Vancouver, BC V7M 3H7
TEL: 604 666-8077
FAX: 604 666-6800
john.pasternak@ec.gc.ca

Martin Pomeroy
Environment Canada
Environmental Protection Branch
224 West Esplanade
North Vancouver, BC V7M 3H7
TEL: 604 666-5193
FAX: 604 666-9107

John Power
Environment Canada
GIS Section, Head
224 West Esplanade
North Vancouver, BC V7M 3H7
TEL: 604 666-3859
FAX: 604 666-3325

Andrea Ryan
Environment Canada
Environmental Protection Branch
224 West Esplanade
North Vancouver, BC V7M 3H7
TEL: 604 664-4001
FAX: 604 664-9176
andrea.ryan@ec.gc.ca

Patrick Shaw
Environment Canada
Environmental Conservation Branch
400-1200 West 73rd Avenue
Vancouver, BC V6P 6H9
TEL: 604 664-4071
FAX: 604 664-9126
patrick.shaw@ec.gc.ca

Frances Smart
Environment Canada
Environmental Conservation Branch
224 West Esplanade
North Vancouver, BC V7M 3H7
TEL: 604 666-3605
FAX: 604 666-6756
frances.smart@ec.gc.ca

Bruce Thomson
Environment Canada
Environmental Conservation Branch
400-1200 West 73rd Avenue
Vancouver, BC V6P 6H9
TEL: 604 664-9122
FAX: 604 664-9126
bruce.thomson@ec.gc.ca

Lisa Walls
Environment Canada
Commercial Chemicals Branch
224 West Esplanade
North Vancouver, BC V7M 3H7
TEL: 604 666-6262
FAX: 604 666-7294
lisa.walls@ec.gc.ca

Paul Whitfield
Environment Canada
Environmental Conservation Branch
224 West Esplanade
North Vancouver, BC V7M 3H7
TEL: 604 664-9238
FAX: 604 664-9195

Brian Wilson
Environment Canada
Environmental Conservation Branch
P.O. Box 340
Delta, BC V4K 3Y3
TEL: 604 664-4065
FAX: 604 664-4068

Laurie Wilson
Environment Canada
CWS
PWRC
5421 Robertson Road
Delta, BC V4K 3Y3
TEL: 604 946-8546
FAX: 604 946-7022
laurie.wilson@ec.gc.ca

Phil Wong
Environment Canada
Environmental Conservation Branch
224 West Esplanade
North Vancouver, BC V7M 3H7
TEL: 604 666-2699
FAX: 604 666-7294

Stewart Yee
Environment Canada
Regional Environmental Laboratories
4195 Marine Drive
West Vancouver, BC V7V 1N8
TEL: 604 924-2518
FAX: 604 924-2554

FBMP

Nisha Foerstner
Fraser Basin Management Program
2970-700 W. Georgia Street
Vancouver, BC V7Y 1B6
TEL: 604 660-6582
FAX: 604 660-3600
nishaf@fraserbasin.bc.ca

Greg Mallette
Fraser Basin Management Program
Lower Fraser Basin, Regional Coordinator
2970-700 West Georgia
Vancouver, BC V7Y 1B6
TEL: 604 660-6581
FAX: 604 792-7110
mallette@fraserbasin.bc.ca

FREMP
Sharon Peters
Fraser River Estuary
Management Program
Water Quality Management
Coordinator
Suite 301-960 Quayside Drive
New Westminster, BC V3M 6G2
TEL: 604-525-1047
FAX: 604 525-3005
fremp@mindlink.bc.ca

SFU
Zainal Arifin
Simon Fraser University
Dept. of Biology
Burnaby, BC V5A 1S6
TEL: 604 291-5621
FAX: 604 291-3496
arifin@sfu.ca

Joseph Pan
Simon Fraser University
Dept. of Biology
Burnaby, BC V5A 1S6
TEL: 604 291-4475
FAX: 604 291-3496

Peiwan Qiao
Simon Fraser University
Dept. of Biology
Burnaby, BC V5A 1S6
TEL: 604 291-3977
FAX: 604 691-3496
qiao@sfu.ca

Kevin Smyth
Simon Fraser University
Department of Biology
Burnaby, BC V5A 1S6
TEL: 604 291-5634
FAX: 604 291-3496
ksmyth@sfu.ca

UBC
Stelvio Bandiera
University of British Columbia
Faculty of Pharmaceutical Sciences
2146 East Mall
Vancouver, BC V6T 1X3
TEL: 604 822-3815
FAX: 604 822-3035
bandiera@unixg.ubc.ca

Kim Cheng
University of British Columbia
Dept. of Animal Science
6270 University Blvd
Vancouver, BC V6T 1Z4
TEL: 604 822-2634
FAX: 692 822-4400
kmtc@unixg.ubc.ca

Pam Dymond
University of British Columbia
Westwater Research
1933 West Mall
Vancouver, BC V6T 1W5
TEL: 604 822-4956
FAX: 604 822-5357
dymond@zoology.ubc.ca

Wayne Evans
University of British Columbia
Department of Civil Engineering
2324 Main Mall, Room 2010
Vancouver, BC V6T 1Z4
TEL: 604 822-5371
FAX: 604 822-6901

Gregg Howald
University of British Columbia
Dept. of Animal Science
208-2357 Main Mall
Vancouver, BC V6T 1Z4
TEL: 604 822-6095
FAX: 604 822-4400
ghowald@unix.ubc.ca

Tim Lissimore
University of British Columbia
Westwater Research Centre
1933 West Mall
Vancouver, BC V6T 1Z2
TEL: 604 822-5495
FAX: 604 822-5357
lissimor@zoology.ubc.ca

Bonnie Marks
University of British Columbia
Department of Civil Engineering
2324 Main Mall, Room 2010
Vancouver, BC V6T 1Z4
TEL: 604 822-5371
FAX: 604 822-6901

Karen Pettit
University of British Columbia
Dept. of Animal Science
230-2357 Main Mall
Vancouver, BC V6T 1Z4
TEL: 604 254-9615
FAX: 604 822-4400
kepettit@unix.ubc.ca

Jason Vine
University of British Columbia
Department of Civil Engineering
2324 Main Mall, Room 2010
Vancouver, BC V6T 1Z4
TEL: 604 822-5371
FAX: 604 822-6901

Hamish Wetherley
University of British Columbia
Department of Geography
6270 University Blvd.
Vancouver, BC V6T 1Z1
TEL: 604 822-6959
FAX: 604 822-6150

OTHER

Stan Bertold
Greater Vancouver Regional District
4330 Kingsway
Burnaby, BC V5H 4G8
TEL: 604 451-6007
FAX: 604 451-6019
sbertold@qc.gvrd.bc.ca

Georgina Brooks
AXYS Analytical Laboratories
Project Chemist
2045 Mills Road
Sidney, BC V8L 3S8
TEL: 604 656-0881
FAX: 604 656-4511
analytical@axys.com

Joanne Ellis
Greater Vancouver Regional District
Project Engineer
14th Floor, 4330 Kingsway
Burnaby, BC V5H 4G8
TEL: 604 436-6905
FAX: 604 436-6714
jellis@gvrd.bc.ca

Jill Fitz
AXYS Analytical Services
Laboratory Team Leader
2045 Mills Road
Sidney, BC V8L 3S8
TEL: 604 656-0881
FAX: 604 656-4511

Bob Jones
Greater Vancouver Regional District
Administrator
4330 Kingsway
Burnaby, BC V5H 4G8
TEL: 604 451-6001
FAX: 604 451-6019
bjones@gvrd.bc.ca

Joyce Moffat
University of Victoria
Centre for Environmental Health
Suite 213-9865 Saanich Road
Sidney, BC V8L 3S8
TEL: 604 656-8146
FAX: 604 656-8148
jmoffat@castle.uivc.ca

Paul Rennie
BC Cancer Agency
Director, Research Administration
600 West 10th Avenue
Vancouver, BC V5Z 4E6
TEL: 604 877-6016
FAX: 604 877-6011
prennie@unixg.ubc.ca

Speakers

DFO
Colin Levings
Fisheries and Oceans
West Vancouver Laboratory
4160 Marine Drive
West Vancouver, BC V7V 1N6
TEL: 604 666-7915
FAX: 604 666-3497

Robie MacDonald
Fisheries and Oceans
Institute of Ocean Sciences
P.O. Box 6000
Sidney, BC V8L 4B2
TEL: 604 363-6409
FAX: 604 363-6807
robie@ios.bc.ca

Derek Nishimura
Fisheries and Oceans
Coastal and Marine Habitat Science
4160 Marine Drive
West Vancouver, BC V7V 1N6
TEL: 604 666-7563
FAX: 604 666-3497
nishimurad%vanwvl@mr.pac.dfo.ca

DOE
Vivian Au
Environment Canada
Environmental Protection Branch
224 West Esplanade
North Vancouver, BC V7M 3H7
TEL: 604 666-3487
FAX: 604 666-7294
vivian.au@ec.gc.ca

Wayne Belzer
Environment Canada
Environmental Conservation Branch
700-1200 West 73rd Avenue
Vancouver, BC V6P 6H9
TEL: 604 664-9125
FAX: 604 664-9195
wayne.belzer@ec.gc.ca

Roxanne Brewer
Environment Canada
Environmental Conservation Branch
400-1200 West 73rd Avenue
Vancouver, BC V6P 6H9
TEL: 604 664-4070
FAX: 604 664-9126

George Derksen
Environment Canada
Environmental Protection Branch
224 West Esplanade
North Vancouver, BC V7M 3H7
TEL: 604 666-3220
FAX: 604 666-7294
george.derksen@ec.gc.ca

John Elliott
Environment Canada
CWS
PWRC
5421 Robertson Road
Delta, BC V4K 3Y3
TEL: 604 946-8546
FAX: 604 946-7022

Robert Elner
Environment Canada
CWS
PWRC
5421 Robertson Road
Delta, BC V4K 3Y3
TEL: 604 787-3269
FAX: 604 787-3507

Colin Gray
Environment Canada
Environmental Conservation Branch
400-1200 West 73rd Avenue
Vancouver, BC V6P 6H9
TEL: 604 664-4002
FAX: 604 664-9126
colin.gray@ec.gc.ca

Lee Harding
Environment Canada
CWS
PWRC
5421 Robertson Road
Delta, BC V4K 3Y3
TEL: 604 946-8546
FAX: 604 946-7022
lee.harding@ec.gc.ca

Bert Kooi
Environment Canada
Environmental Protection Branch
224 West Esplanade
North Vancouver, BC V7M 3H7
TEL: 604 666-2790
FAX: 604 666-7294

Fred Mah
Environment Canada
Environmental Conservation Branch
400-1200 West 73rd Avenue
Vancouver, BC V6P 6H9
TEL: 604 664-4006
FAX: 604 664-9126

Bev Raymond
Environment Canada
Environmental Conservation Branch
400-1200 West 73rd Avenue
Vancouver, BC V6P 6H9
TEL: 604 664-4053
FAX: 604 664-9126
bev.raymond@ec.gc.ca

Mark Sekela
Environment Canada
Environmental Conservation Branch
400-1200 West 73rd Avenue
Vancouver, BC V6P 6H9
TEL: 604 664-4098
FAX: 604 664-9126
mark.sekela@ec.gc.ca

Taina Tuominen
Environment Canada
Environmental Conservation Branch
400-1200 West 73rd Avenue
Vancouver, BC V6P 6H9
TEL: 604 664-4054
FAX: 604 664-9126
taina.tuominen@ec.gc.ca

Robert Vadas
Environment Canada
CWS
PWRC
5421 Robertson Road
Delta, BC V4K 1X4
TEL: 604 946-8548
FAX: 604 946-7022
bvadas@golder.com

NHRI
Kevin Cash
National Hydrology
Research Institute
11 Innovation Boulevard
Saskatoon, SK S7N 3H5
TEL: 306 975-4010
FAX: 306 975-5143
cashk@nhrisv.nhrc.sk.doe.ca

Patricia Chambers
National Hydrology
Research Institute
11 Innovation Boulevard
Saskatoon, SK S7N 3H5
TEL: 306 975-5592
FAX: 306 975-5143
chambersp@nhrisv.nhrc.sk.doe.ca

Joseph Culp
National Hydrology
Research Institute
11 Innovation Boulevard
Saskatoon, SK S7N 3H5
TEL: 306 975-5742
FAX: 306 975-5143
culpj@nhrisv.nhrc.sk.doe.ca

Fred Wrona
National Hydrology
Research Institute
Chief Ecosystem Evaluation Division
11 Innovation Boulevard
Saskatoon, SK S7N 3H5
TEL: 306 975-6099
FAX: 306 975-5143
wronaf@nhrisv.nhrc.sk.doe.ca

NWRI
Scott Kirby
National Water Research Institute
Lakes Research Branch
Box 5050, 867 Lakeshore Road
Burlington, ON L7R 4A6
TEL: 905 336-4692
FAX: 905 336-6430
kirsten.day@cciw.ca

B.G. Krishnappan
National Water Research Institute
Rivers Research Branch
Box 5050, 867 Lakeshore Road
Burlington, ON L7R 4A6
TEL: 905 336-4776
FAX: 905 336-4420
kris.krishnappan@cciw.ca

Kelly Munkittrick
National Water Research Institute
Bayfield Institution
Box 5050, 867 Lakeshore Road
Burlington, ON L7R 4A6
TEL: 905 336-4864
FAX: 905 336-6430
kelly.munkittrick@cciw.ca

Joanne Parrott
National Water Research Institute
Box 5050, 867 Lakeshore Road
Burlington, ON L7R 4A6
TEL: 905 336-4551
FAX: 905 336-6430
joanne.parrott@cciw.ca

Trefor Reynoldson
National Water Research Institute
Lakes Research Branch
Box 5050, 867 Lakeshore Road
Burlington, ON L7R 4A6
TEL: 905 336-4692
FAX: 905 336-6430
trefor.reynoldson@cciw.ca

SFU
Leah Bendell-Young
Simon Fraser University
Department of Biological Sciences
Burnaby, BC V5A 1S6
TEL: 604 291-5621
FAX: 604 291-3496
bendell@sfu.ca

Tony Farrell
Simon Fraser University
Department of Biological Sciences
Burnaby, BC V5A 1S6
TEL: 604 291-5640
FAX: 604 291-3496
anthony_farrell@sfu.ca

Frank Gobas
Simon Fraser University
Resource and Environmental Mgmt.
Burnaby, BC V5A 1S6
TEL: 604 291-5928
FAX: 604 291-4968
gobas@sfu.ca

Chris Kennedy
Simon Fraser University
Department of Biological Sciences
Burnaby, BC V5A 1S6
TEL: 604 291-5640
FAX: 604 291-3496
ckennedy@sfu.ca

Dov Lank
Simon Fraser University
Department of Biological Sciences
Burnaby, BC V5A 1S6
TEL: 604 291-3010
FAX: 604 291-3496
lank@sfu.ca

Philippa Shepherd
Simon Fraser University
Burnaby, BC V5A 1S6
TEL: 604 946-8546
FAX: 604 946-7022
shepherd@sfu.ca

Christine Thomas
Simon Fraser University
Department of Biological Sciences
Burnaby, BC V5A 1S6
TEL: 604 291-5621
FAX: 604 291-3496
christit@sfu.ca

UBC

Joseph Arvai
University of BC
Dept. of Oceanography
6270 University Blvd.
Vancouver, BC V6T 1Z1
TEL: 604 822-4198
FAX: 604 822-6091
arvai@unixg.ubc.ca

Jim Atwater
University of BC
Civil/Mechanical Engineering
2324 Main Mall, Room 2010
Vancouver, BC V6T 1Z4
TEL: 604 822-4694
FAX: 604 822-6901

Mike Church
University of BC
Dept. of Geography
6270 University Blvd.
Vancouver, BC V6T 1Z1
TEL: 604 822-6050
FAX: 604 822-6150
mchurch@geog.ubc.ca

Kathy Gordon
University of BC
Dept. of Oceanography
Rm 2521-6270 University Boulevard
Vancouver, BC V6T 1S6
TEL: 604 822-4198
FAX: 604 822-6091

Kathy Grant
University of BC
Resource Management & Envt'l Studies
Rm 436E, 2206 East Mall
Vancouver, BC V6T 1Z3
TEL: 604 822-6224
FAX: 604 822-9250
klynn@unixg.ubc.ca

Ken Hall
University of BC
Westwater Research Centre
1933 West Mall
Vancouver, BC V6T 1W5
TEL: 604 822-6474
FAX: 604 822-5357
kjhall@civil.ubc.ca

Paul Harrison
University of BC
Dept. of Oceanography
Rm 2521-6270 University Boulevard
Vancouver, BC V6T 1S6
TEL: 604 822-4198
FAX: 604 822-6091
pharrison@unixg.ubc.ca

Amie Hillaby
University of BC
Dept. of Oceanography
Rm 2521-6270 University Boulevard
Vancouver, BC V6T 1S6
TEL: 604 822-4198
FAX: 604 822-6091
amiemh@netinfo.ubc.ca

Greg Lawrence
University of BC
Civil Engineering Department
2324 Main Mall, Room 2010
Vancouver, BC V6T 1Z4
TEL: 604 822-5371
FAX: 604 822-6901
lawrence@civil.ubc.ca

J.D. McPhail
University of BC
Department of Zoology
6270 University Boulevard
Vancouver, BC V7T 1Z4
TEL: 604 822-3326
FAX: 604 822-2416
mcphail@bcu.ubc.ca

John Richardson
University of BC
Westwater Research Centre
1933 West Mall
Vancouver, BC V6T 1W5
TEL: 604 822-6586
FAX: 604 822-5357

Lauren Ross
University of BC
Dept. of Oceanography
Rm 2521-6270 University Boulevard
Vancouver, BC V6T 1S6
TEL: 604 822-4198
FAX: 604 822-6091
lross@unixg.ubc.ca

Hans Schreier
University of BC
Westwater Research Centre
1933 West Mall
Vancouver, BC V6T 1W5
TEL: 604 822-4402
FAX: 604 822-8639
hans.schreier@mtsg.ubc.ca

Kedong Yin
University of BC
Dept. of Oceanography
Rm 2521-6270 University Boulevard
Vancouver, BC V6T 1S6
TEL: 604 822-4198
FAX: 604 822-6091
kedong@unixg.ubc.ca

OTHER

Wade Gibbons
University of Waterloo
Department of Biology
Waterloo, ON N2L 3G1
TEL: 519 885-1211
FAX: 519 746-0614
wngibbons@biology.watstar.uwaterloo.ca

Don Hodgins
Seaconsult Marine Research Ltd.
8805 Osler Street
Vancouver, BC V6P 4G1
TEL: 604 266-9135
FAX: 604 266-8855

Abstract

The Fraser River Action Plan (FRAP) is a seven-year ecosystem based initiative. Initially, it was managed jointly by the Department of the Environment (DOE) and the Department of Fisheries and Ocean (DFO). DFO's primary concern is with rebuilding salmon stocks and protecting fish habitat. Environment Canada's focus is on wildlife habitat, cleaning up the ecosystem and determining the environmental quality or the health of the river as well as building the framework for a management program to ensure the basin's sustainability. DFO is delivering FRAP results in March, 1997 while DOE will complete FRAP initiatives in March, 1998.

In the quest to increase the scientific understanding of the Fraser basin, DOE's Environmental Quality Program supports a research network comprised of scientists from federal, provincial and university research communities. Ongoing research projects focus on: (1) The basin-wide assessment of pollution impact on aquatic quality; (2) The assessment of environmental impacts of specific pollution sources; (3) The chemical criteria development; and, (4) Ecosystems objectives development.

To facilitate the review and examination of the progress of each project, Environment Canada sponsors an annual workshop. In preparation for the 1996 workshop, the research partners were asked to present information summarizing their projects, justifying the research, explaining what results have been obtained to date and to contribute to the process of "planning for the delivery of results." During the workshop, discussion was encouraged in support of the development of a management perspective regarding future decisions and to identify information gaps which could direct future research activities.

The 1996 workshop was organized into six sector- and/or geographical-based sessions including: (1) Pulp Mill Effluent Issues; (2) Transport and Sedimentation of Contaminants; (3) Urban Issues; (4) Agricultural Issues; (5) Biological Indicators; and, (6) Estuary Issues. The workshop was held on February 20-22, 1996 in Vancouver and it is the material presented there, as well as any additional supporting submissions that is the subject of this report.

Acknowledgments

Environment Canada would like to acknowledge the support of C. Gray, J. Culp, G. Lawrence, K. Hall, H. Schreier, T. Tuominen and P. Harrison who acted as chairs of workshop sessions, as well as all the speakers and participants for their contribution by providing abstracts, papers and presentation summaries. The professional editing services of Roegan Lloydd of Gordon Enterprises and Rory Steiman of Rory Steiman & Associates is also gratefully acknowledged.

Opening Remarks

B. Wilson - Director, *Environmental Conservation Branch, Environment Canada*

I would like to welcome you to this, the third Environment Canada FRAP Research Workshop.

My name is Brian Wilson and, as director of the Environmental Conservation Branch in the Pacific and Yukon region, I am responsible for overseeing Environment Canada's role in the Fraser River Action Plan.

Once upon a time, I was a research scientist and because, or maybe in spite of that, I have always respected the fundamental importance of good science to the progress of a modern society. Fifteen years ago, I abandoned active research to pursue a career in management where I have learned the equally fundamental importance of: having clients for our science; making science relevant to those clients; and, using our science to change the way we think about the environment and how we make decisions that affect the environment.

From the very beginnings of FRAP, we realized that our success in delivering sustainable development in the basin would depend in large measure on our scientific understanding of the Fraser basin and how it functions under both normal and stressed conditions. As a result, the FRAP Commitment to research has been both broad in its scope and intensive in its application. Indeed, one of the legacies of FRAP will be the new knowledge of the Fraser basin that has been gained. But a far more important legacy of the FRAP Research Program will be the impact that this new knowledge and understanding will have on decision makers throughout the basin, and through them, on the long-term health of the Fraser basin environment.

We are at a critical juncture in the Fraser River Action Plan. We have five years of effort under our belts and the program has two more years to go. People are beginning to ask what we have achieved so far and what we expect to deliver in the way of results by the end of the program. Taxpayers are wanting to know what return they can expect on their substantial investment in the program. Governments are asking what relevance the program has for them and the general public is asking, "What is this thing called 'FRAP' anyway?"

Clearly, we need to do a good job of profiling the program and marketing its results. Clearly, we need to do a good job of getting our science to decision-makers in a form that is both understandable and useful to them. And clearly, we need to link our science to results — results that are meaningful, measurable and relevant to our clients.

The attendance at this year's workshop marks a departure from previous years in that only one-third of the participants are people who have been actively conducting research under the Fraser River Action Plan. The other two-thirds of the participants are people who have expressed an interest in sharing and using our new-found knowledge and understanding of the basin — in other words, our "clients."

It is, therefore, important that we find a balance over the next three days between scientific rigor and the need to make our science relevant to clients and decision-makers. It is important that we talk passionately about our research, but without so much of the jargon that is only decipherable by other scientists. It is important that we talk about the application of our research in the real world of economic and social priorities. And, it is important that we welcome and encourage the active participation of non-scientists throughout this workshop. They are, after all, both the clients of our research and the potential users of our research findings.

We began FRAP with a commitment to good science, but it was Henry Wordsworth Longfellow who said that "Great is the art of beginning, but greater is the art of ending." With five years down and two years to go, we are well into that transition between beginning and ending. It is, therefore, critical that we now begin to focus our attention on the art of ending and consider very seriously the FRAP research legacy that we want to bequeath to the basin and its decision-makers.

With that in mind, I want to wish you a very stimulating, productive and relevant workshop.

Introduction

Colin Gray - Head, Research Coordination and Application Section

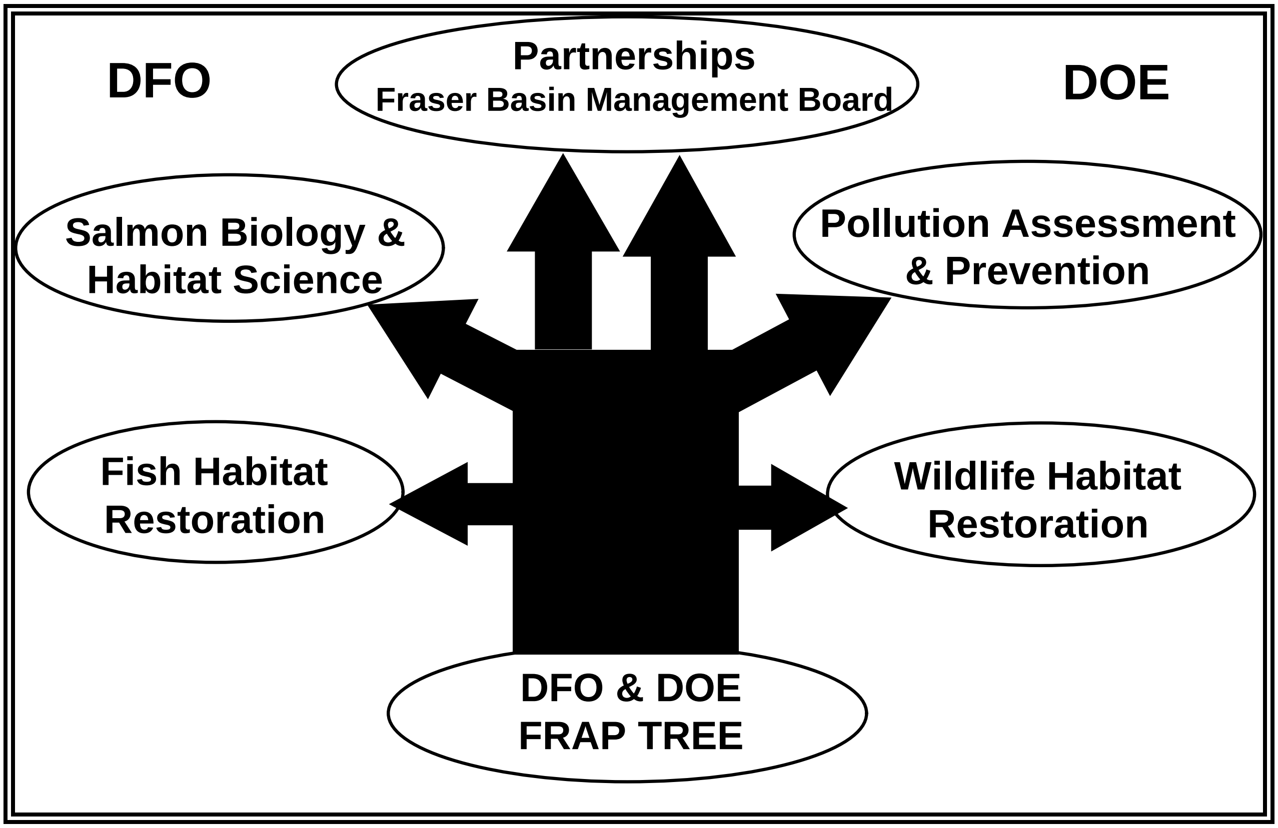
Aquatic and Atmospheric Sciences Division, Environmental Conservation Branch, Environment Canada

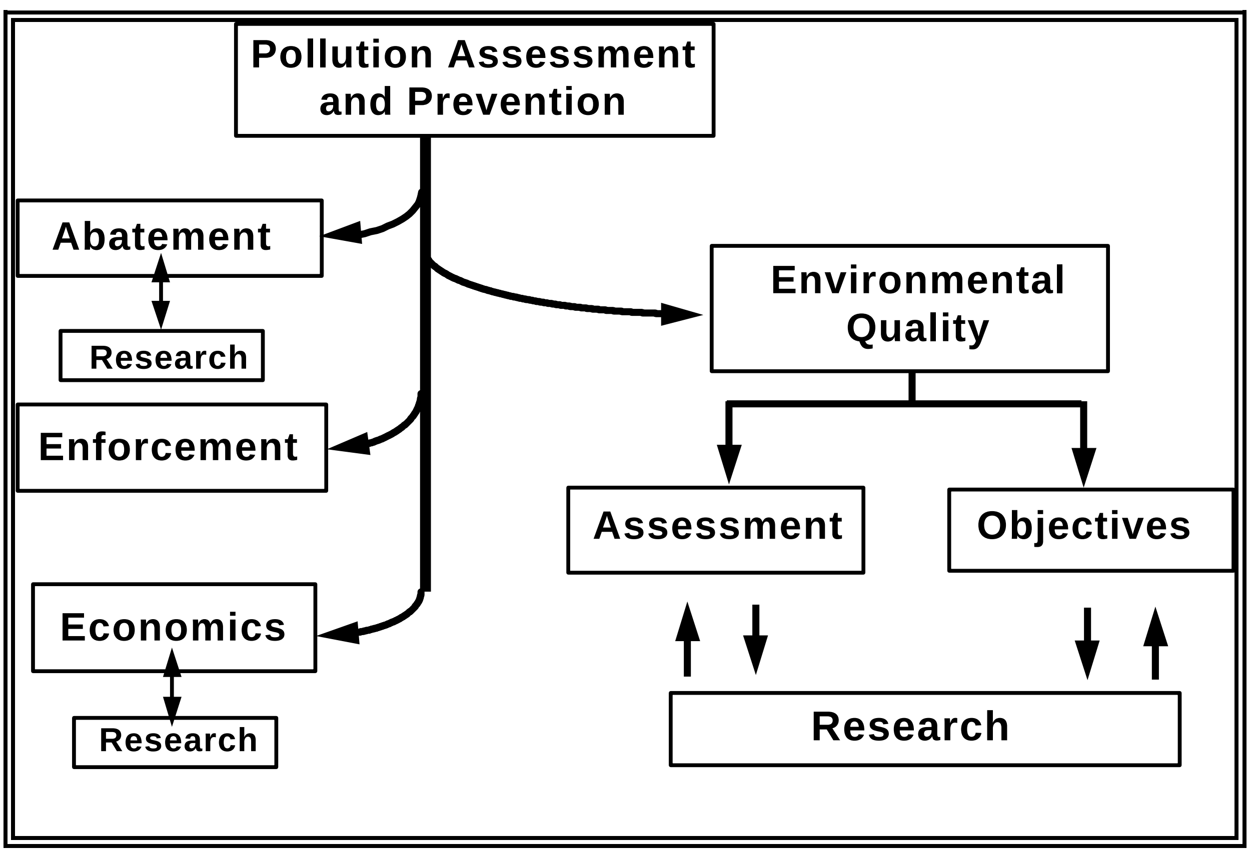
This workshop has been organized by Environment Canada's Fraser River Action Plan (FRAP) research coordination section. The projects to be presented have been integrated with four other components either jointly or independently delivered by the Department of Fisheries and Oceans (DFO) and Department of Environment (DOE) (Figure 1). While the previous two FRAP workshops have focused on work funded through the Environmental Quality Technical Work Group, this year the Pollution Abatement Technical Work Group has also contributed its research information.

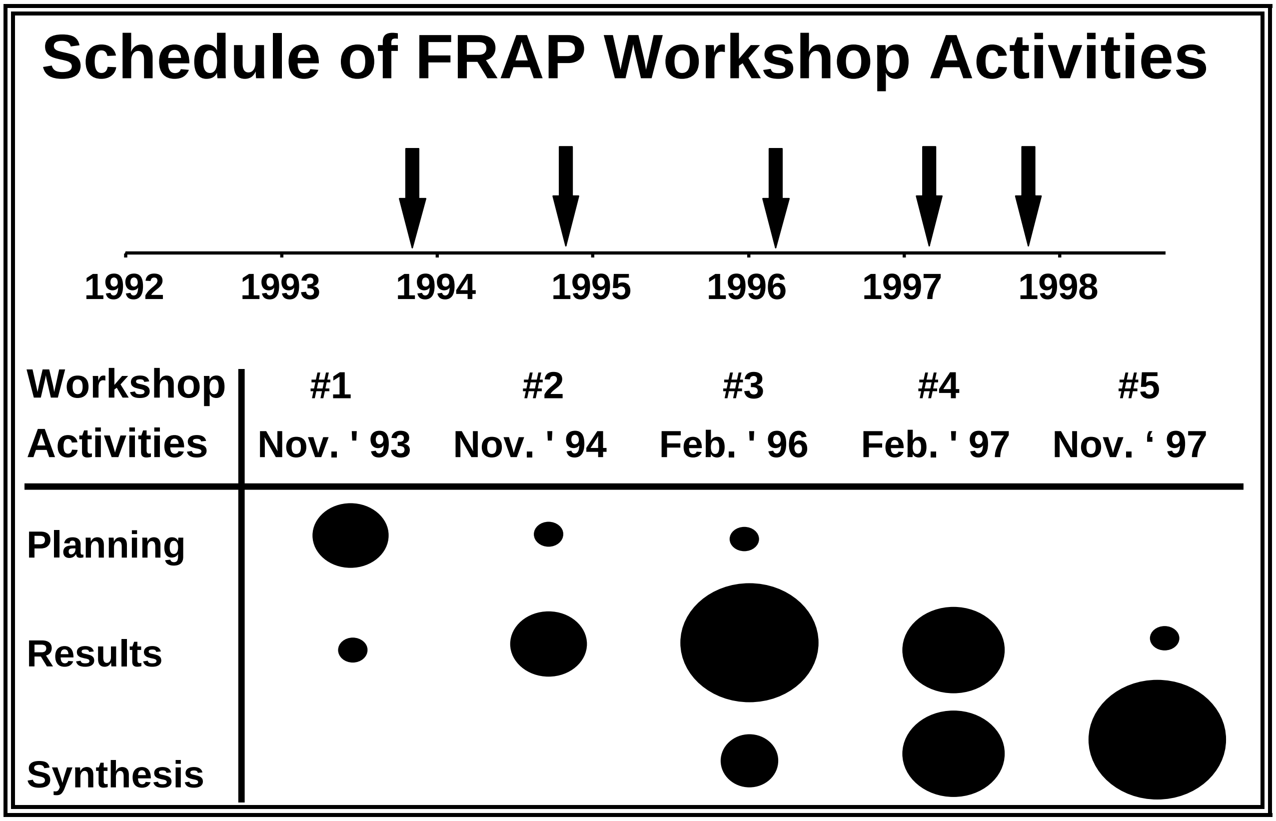
The various FRAP projects are organized based on the nature of the issues that they address: those which are ecosystem oriented, or those which relate to contaminant behaviour or pollutant sources. This workshop features five presentation and discussion sessions which focus on the following areas: (1) pulp mills; (2) transport and sedimentation of contaminants; (3) urban runoff; (4) agricultural runoff; (5) biological indicators; and, (6) estuaries.

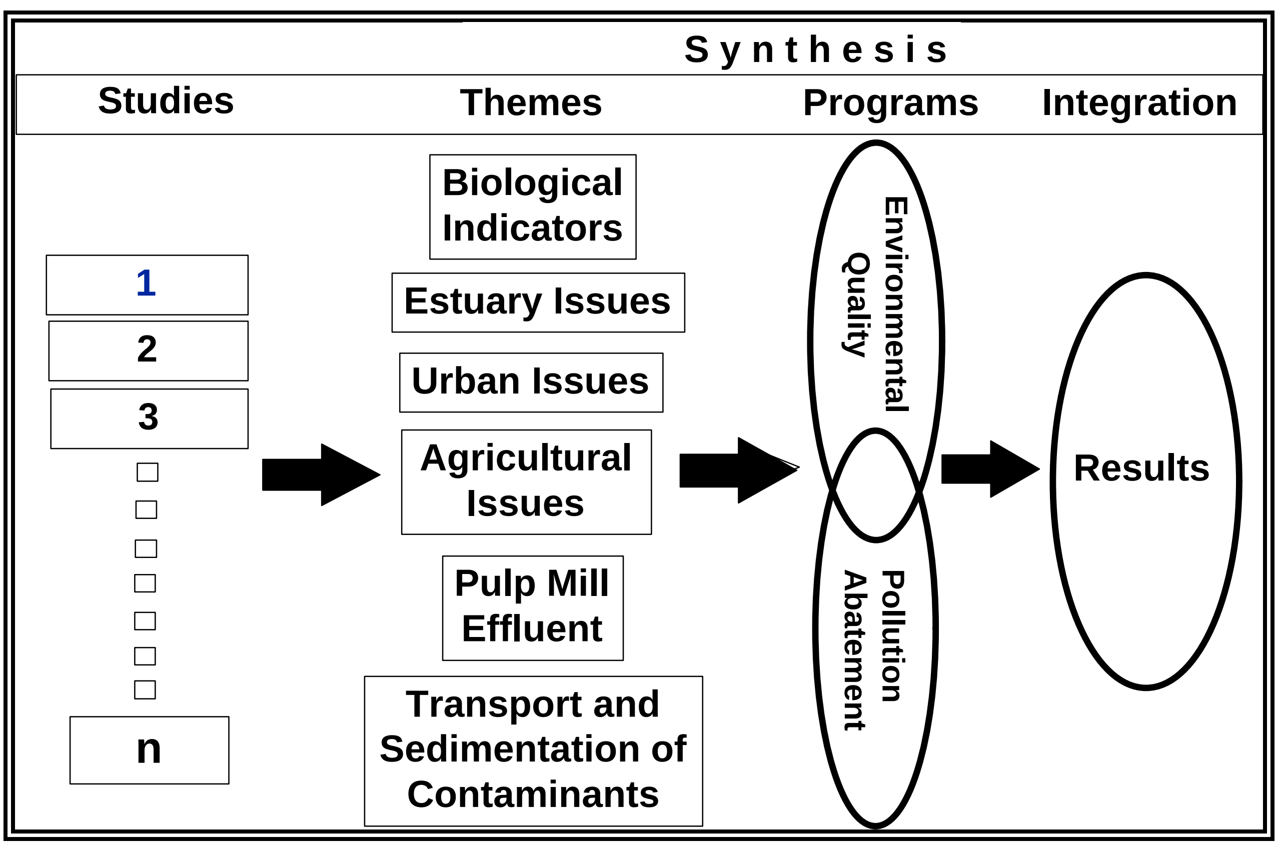
As FRAP progressively develops, so will the objectives of its workshops. In the beginning, the focus was primarily on descriptions and discussions of both planning issues and preliminary results. The present workshop is significant as it will begin, through a number of summary sessions, the shift from results to the process of information integration. In the future, two anticipated workshops will have a stronger emphasis on scientific synthesis in order to generate conclusions on the state of the Fraser River. They will also likely address the issues of enforcement and economics (Figure 2), and consider what specific management decisions and regulatory actions are required to abate and/or prevent pollution.

The third FRAP workshop, therefore, has three main goals. First, to measure the progress of each project or program. Secondly, to begin the integration and synthesis of the generated knowledge and finally, to plan how best to organize and deliver the information to governments, industries and stakeholder groups who have long-term interests or responsibilities in sustaining the aquatic ecosystem of the Fraser River.


DFO
Partnerships
Fraser Basin Management Board
DOE
Salmon Biology & Habitat Science
Pollution Assessment & Prevention
Fish Habitat Restoration
Wildlife Habitat Restoration
DFO & DOE FRAP TREE


Pollution Assessment and Prevention
Abatement
Research
Enforcement
Economics
Research
Environmental Quality
Assessment
Objectives
Research


Schedule of FRAP Workshop Activities
1992
1993
1994
1995
1996
1997
1998
Workshop Activities
#1 Nov. ' 93
#2 Nov. ' 94
#3 Feb. ' 96
#4 Feb. ' 97
#5 Nov. ‘ 97
Planning
Results
Synthesis


Synthesis
Studies
Themes
Programs
Integration
1
2
3
n
Biological Indicators
Estuary Issues
Urban Issues
Agricultural Issues
Pulp Mill Effluent
Transport and Sedimentation of Contaminants
Environmental Quality
Pollution Abatement
Results

The Northern River Basin Study Experience

F. Wrona, Chief, Ecosystem Evaluation Division

National Hydrology Research Institute

Scientific Credibility — Public Faith

- External scientific peer review
  — scientific editorial process
- Science advisory committee
  — arms-length committee to oversee science program/reviews
- Public science forums
  — “open” question/answer process
  — public accountability

Data Issues

- Database standardization: archiving/management
- Biological sample archiving/custodianship
- Samples inventory
- GIS products-standardization

Science Management
Public/Stakeholder Expectations

Linking Science to Basin Management

The Northern River Basin Study
Science Synthesis

Putting It All Together

- Allow sufficient budgets for data analyses/scientific support
- Time is never on your side — set final year for synthesis
- Consider management contracts; be prepared for conflicting priorities
- Establish reporting standards; graphics, wordprocessing and databases

NRBS Products

- Eight science component groups
- 160 technical reports
- Databases, GIS
- 13 scientific synthesis reports: ~140 scientific recommendations
- Final product — study board report to ministers-24 recommendations

NRBS Science Components

- Nutrients
- Contaminants
- Food chain
- Drinking water
- Aquatic uses
- Hydrology
- Traditional knowledge
- Synthesis/modeling

Study Board; Science Advisory Committee; Treaty 8 Env. Comm.; Human Health Comm.

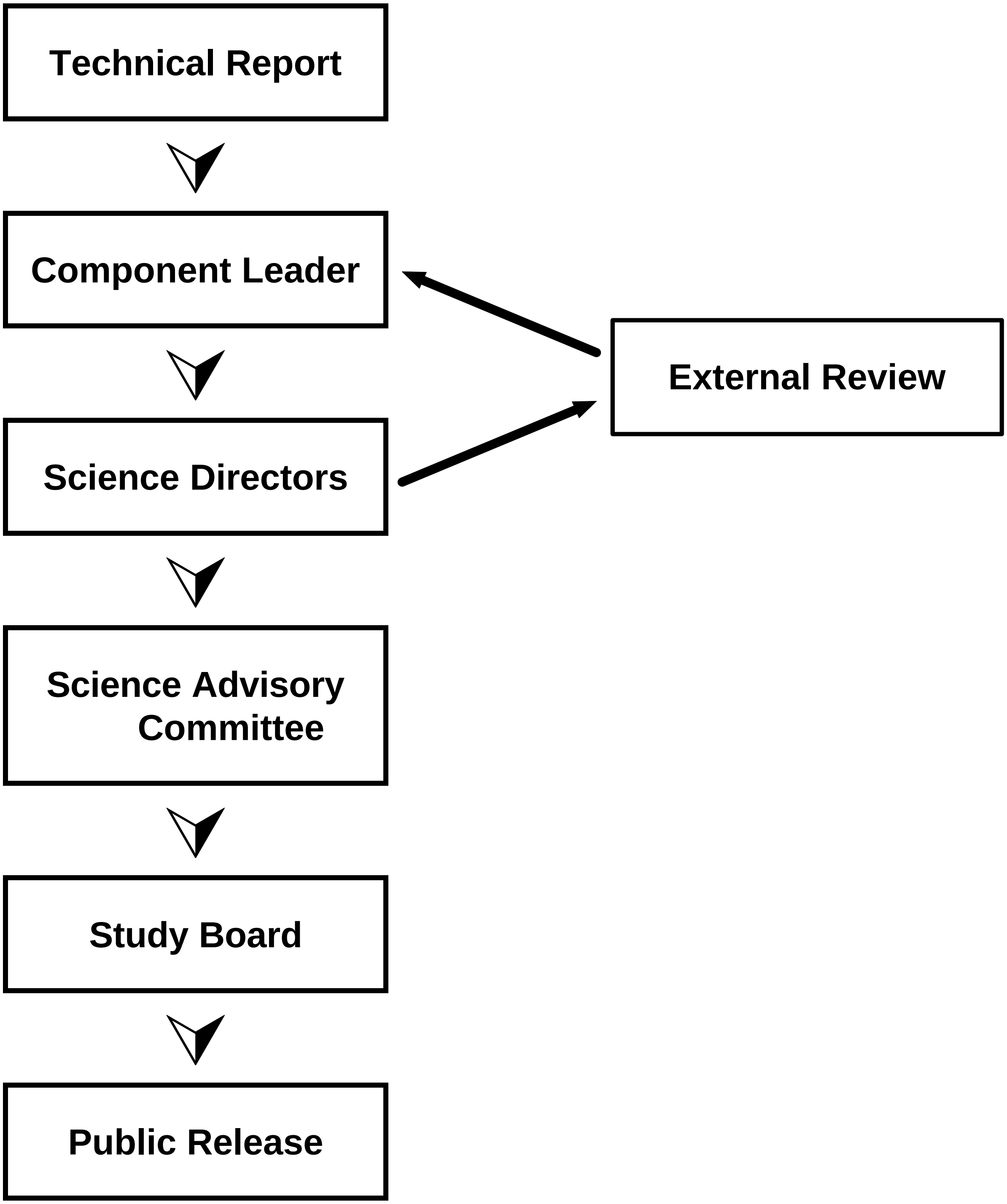
Challenges

- Defining themes/levels for integration — clear understanding of scientific objectives vs. stakeholder expectations
- <u>Securing</u> expertise to lead writing/integration
- Team building — integration often “up-hill” battle
- Multi-disciplinary approach — easier said than done

NRBS Status

- Building recommendations: Dec-March
- Reconciliation-public consultations: Feb-March
- Preparing announcement — ministerial briefs, speeches, ...
- Final report: March 31, 1996
- Decommissioning June, 1996
- <u>Reporting is behind schedule</u>

NRBS Review Process



SESSION 1

PULP MILL EFFLUENT ISSUES

Industrial Discharges, Fraser River Pollution Abatement Program

V. Au

Environment Canada

Program Overview

The Industrial Discharges section of the Fraser River Pollution Abatement Office (FPAO) has conducted numerous projects over the last six years to meet the objectives of the Fraser River Action Plan (FRAP). Included in this program were the development of two databases, pollution prevention guidelines and best management practices, and although not discussed here, numerous wastewater characterization and toxicity studies. In particular, the objectives of the Industrial Discharges program have been to:

1. reduce the release of persistent toxic substances entering the waters of the Fraser River basin pursuant to the Canadian Environmental Protection Act (CEPA) and identified as priority from inventories and environmental data to the extent allowed by best practicable technology;
2. develop and maintain an inventory of major pollution sources and loadings to the basin; and,
3. reduce environmentally disruptive industrial effluent discharges by 30% to meet environmental quality objectives.

In order to identify and analyze industrial pollution sources and meet the first objective, wastewater characterization methods were developed for industrial effluents. These methods and supporting documents were used in a series of wastewater characterization studies conducted prior to 1994.

To meet the second objective listed above, two databases, Envirodat and the Fraser River Pollution Point Source Inventory (FRPSI) were developed. Both of these databases are geo-referenced and data are available upon request.

Envirodat, the national environmental database, is currently used as the data storage and retrieval system for monitoring data on industrial, and potentially municipal, wastewater discharges in the Fraser River basin. In addition, Envirodat is a relational database containing laboratory and field results for a host of chemical, physical and biological variables, as well as sample location descriptions, geographic coordinates, sample collection dates and methods.

Data were collected from waste management permit compliance monitoring reports, wastewater characterization studies and water quality monitoring reports. Until May 1995, wastewater monitoring data was entered, by cooperative education students, directly into Envirodat using Oracle/Vax. However, this method was slow and cumbersome, and mistakes were difficult to correct. Therefore, a user-friendly data entry interface, WWDAT, was developed in Microsoft Access. WWDAT is now used as a front-end data entry system to enter monitoring data into Envirodat via PC. WWDAT has several improved capabilities, such as quality assurance checks and simplified error correction. Data entered in WWDAT is compiled in Envirodat-formatted files which are subsequently uploaded to Envirodat in a batch operation.

Envirodat can be queried and produce reports for user-specified sites, time periods and parameters in text files. WWDAT also has reporting capabilities to produce daily, monthly or annual summary reports. To date, Envirodat is estimated to contain over 130,000 monitoring data.

Conclusions

A graphical summary of pulp mill effluent data for pulp production, TSS and BOD loadings are presented in Figures 1 to 14 (Figures 9 and 10 excluded by author). Production, TSS and BOD loading appeared to have fluctuated over a span of five to six years. The overall trend of these select parameters over time were unclear and required further analysis.

A preliminary assessment of mill effluent data using best fit lines are presented in Figures 15 to 17.

CANADIAN FOREST PRODUCTS LTD. (P.G.)

Figure 1 - TSS 8 BOD Loading vs. Month

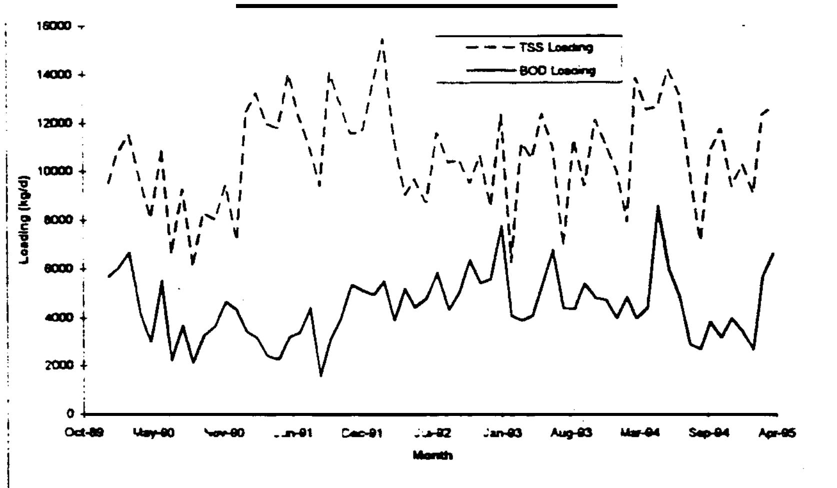
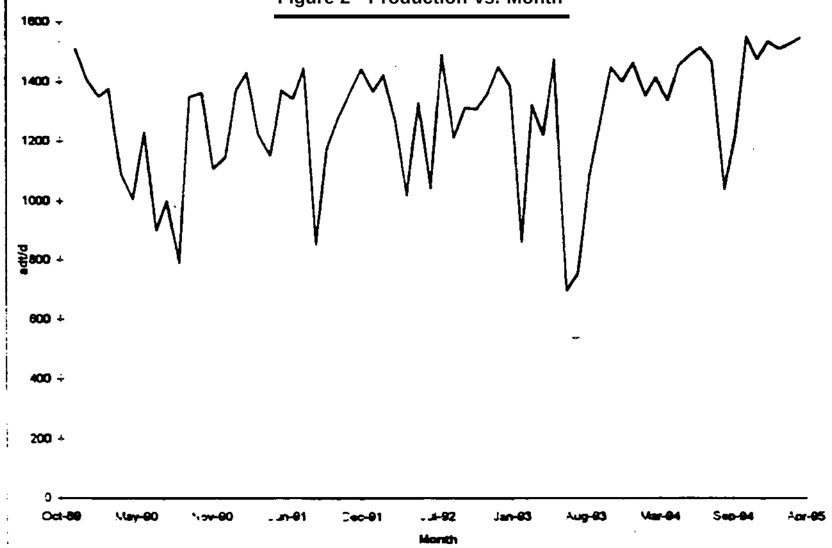


Figure 2 - Production vs. Month



CARIBOO PULP & PAPER COMPANY

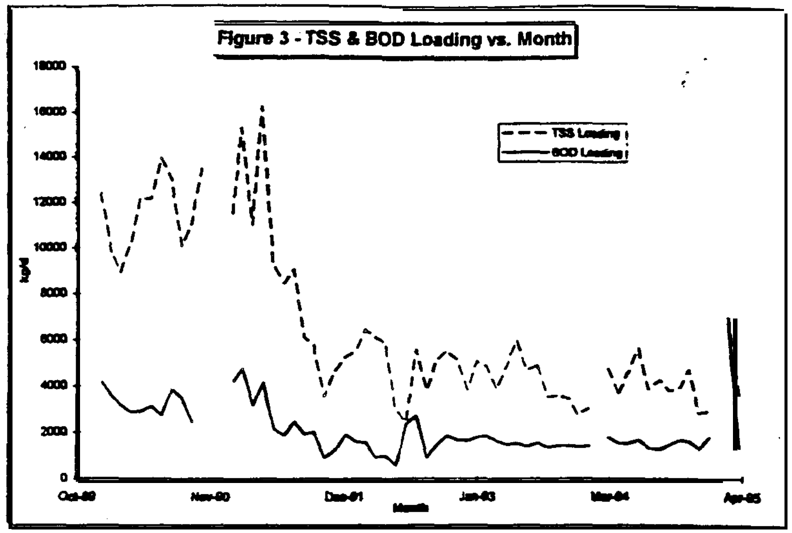


Figure 3 - TSS & BOD Loading vs. Month

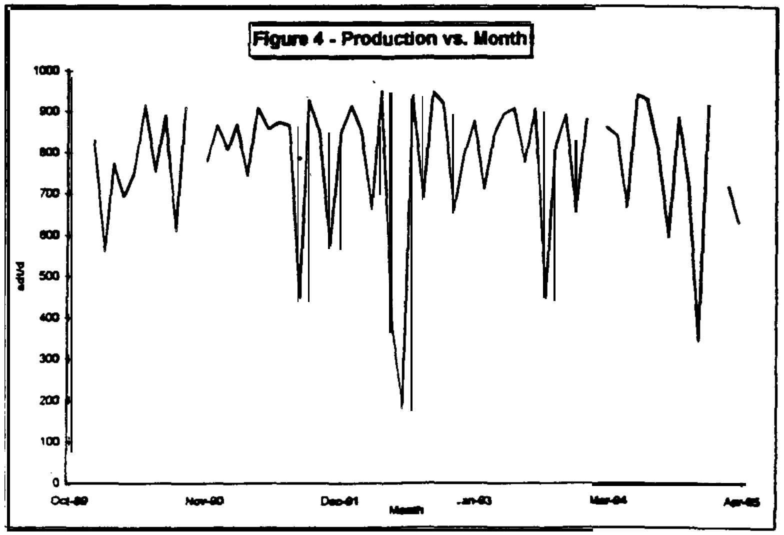


Figure 4 - Production vs. Month

CROWN PACKAGING LTD.

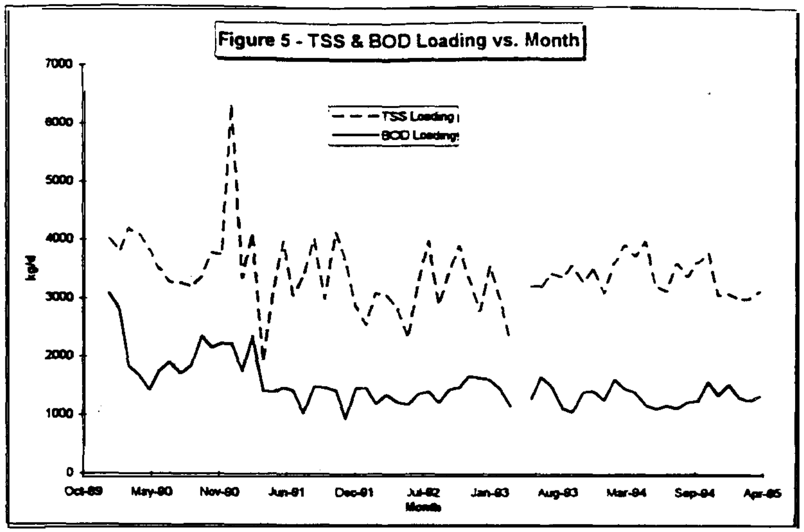


Figure 5 - TSS & BOD Loading vs. Month

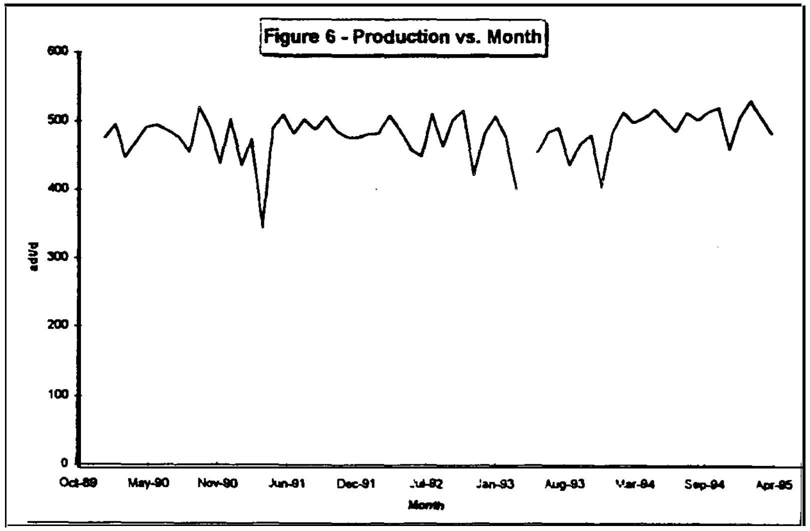
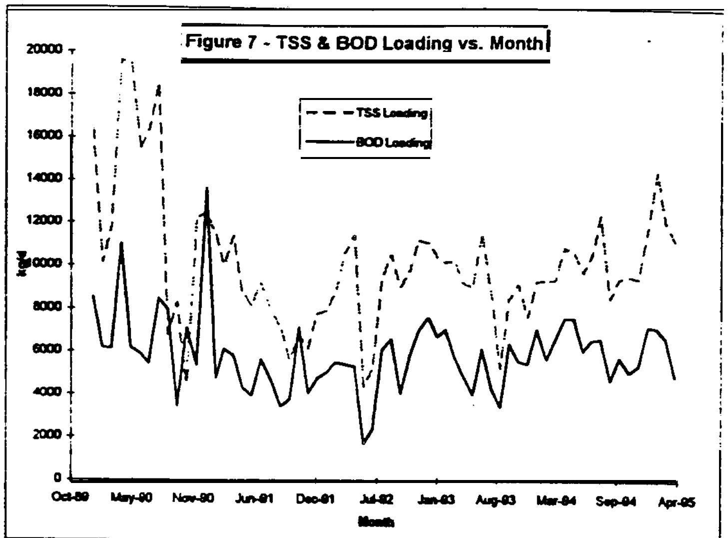
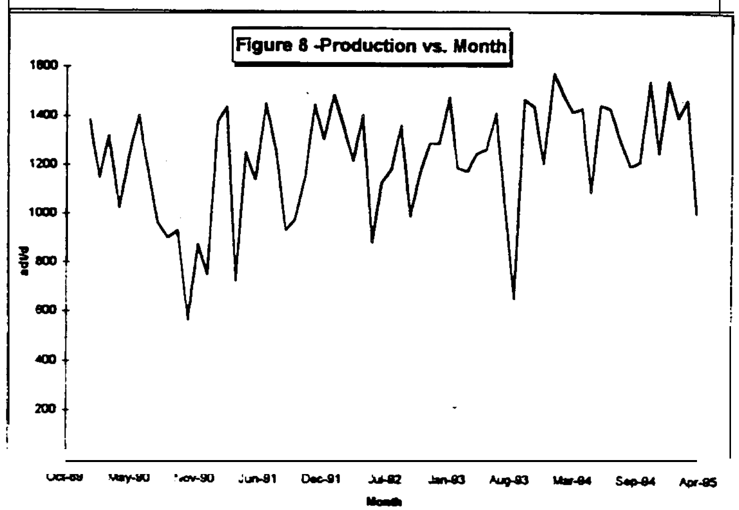


Figure 6 - Production vs. Month

NORTHWOOD PULP & TIMBER LTD.





(Figures 9 and 10 excluded by author)

SCOTT PAPER LTD.

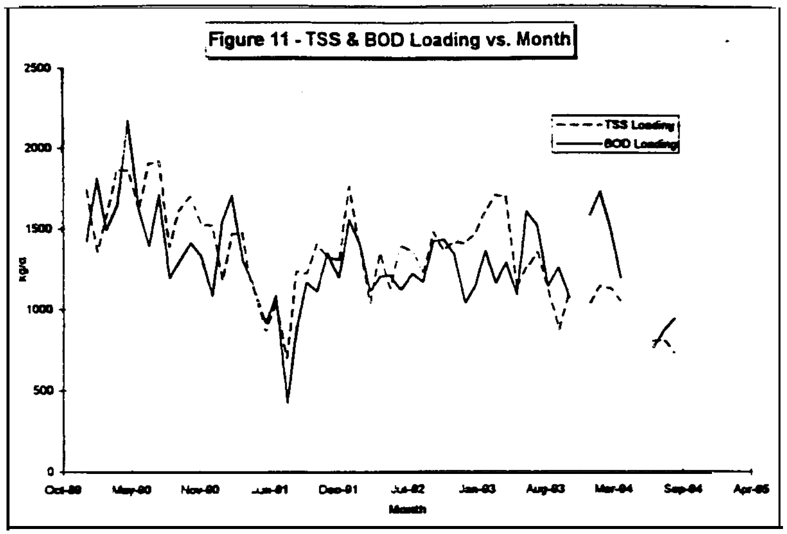


Figure 11 - TSS & BOD Loading vs. Month

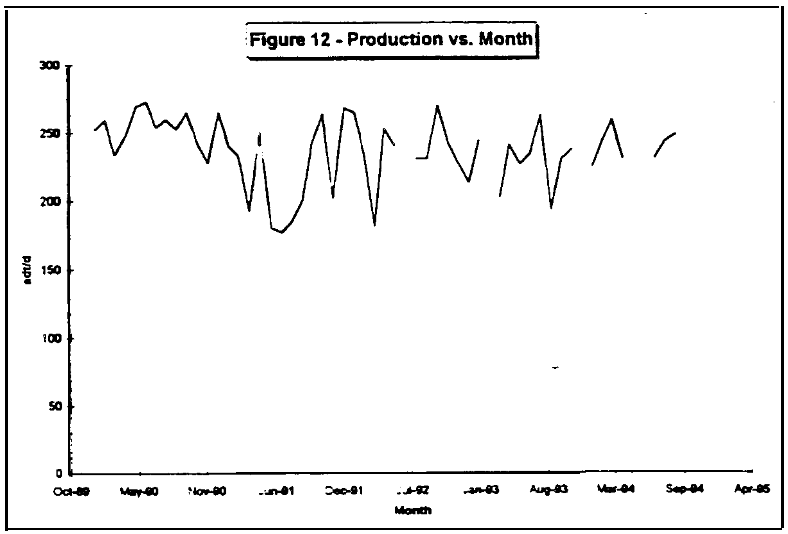


Figure 12 - Production vs. Month

WEYERHAEUSER (Kamloops Pulp Div.)

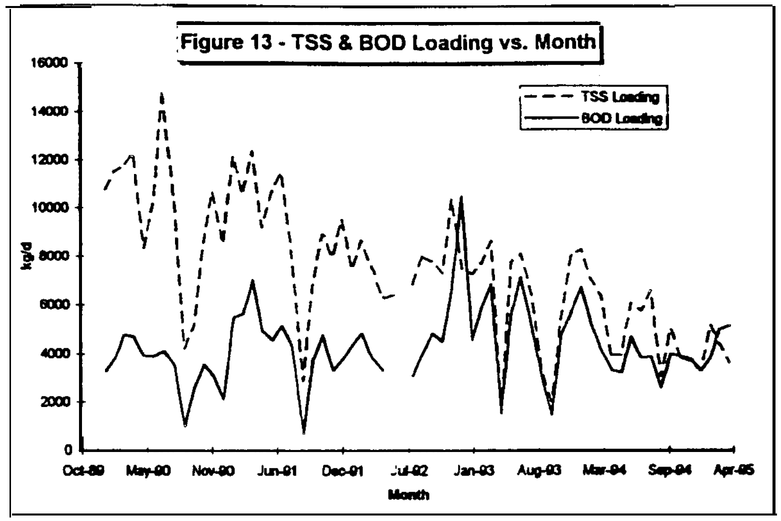


Figure 13 - TSS & BOD Loading vs. Month

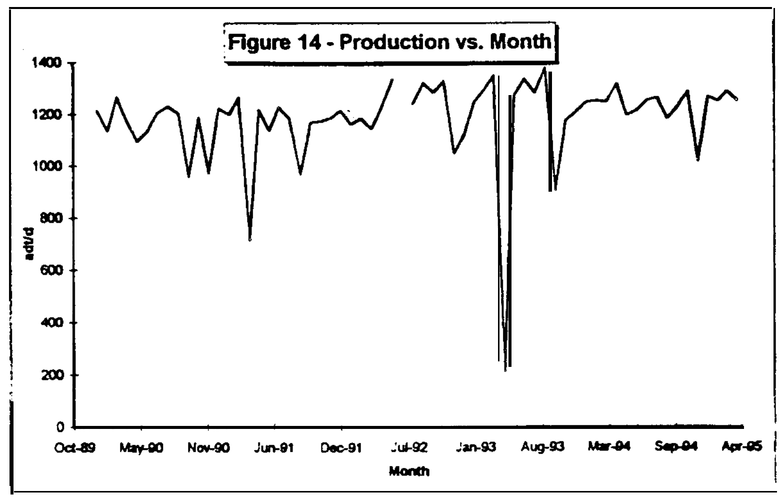


Figure 14 - Production vs. Month

Figure 16 - BOD Loading Trend vs. Month at 7 Mills

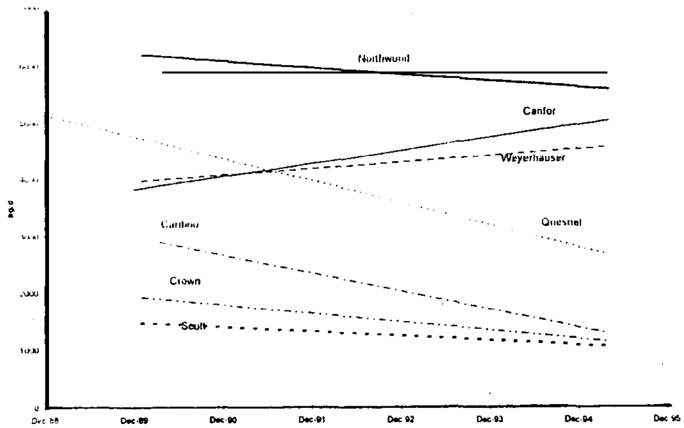


Figure 15 - TSS Loading Trends at 7 Mills vs. Month

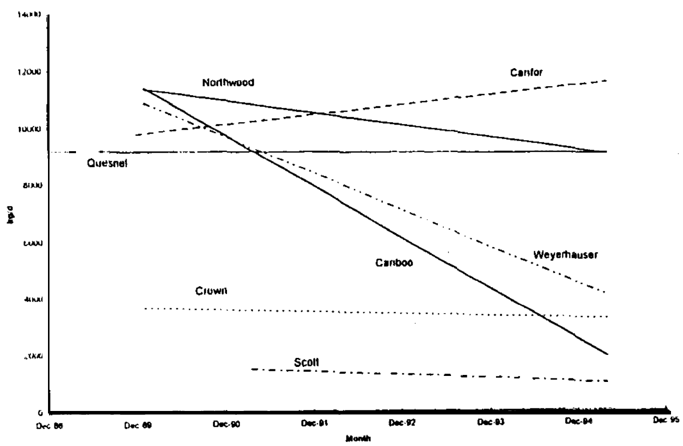
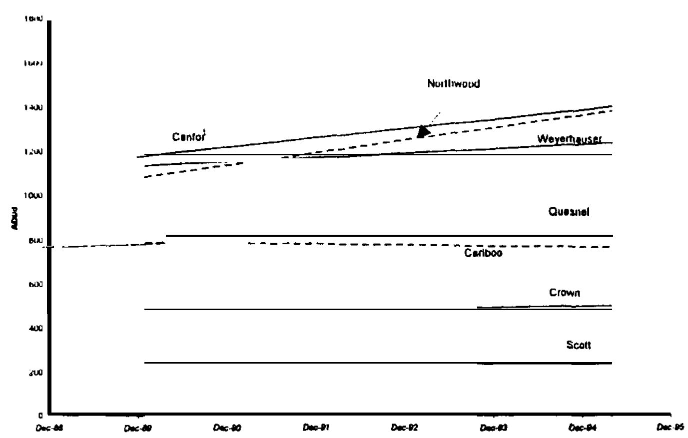


Figure 17 - Production Trend vs. Month at 7 Mills



TSS and BOD loadings appeared to have decreased in five of the seven mills while production increased or remained relatively constant in all seven mills. Additional analysis of pulp mill effluent data are presented in the table below:

Table 1 - Pulp Mill Parameter % Changes from 1989 to 1995

Mill Name	% Reduction - BOD Loading	% Reduction - TSS Loading	% Increase - Production
Canadian Forest Products	-30	-18	15
Cariboo Pulp and Paper	48	84	-4
Crown Packaging	42	12	6
Northwood Pulp and Timber	10	21	28
Quesnel River Pulp Co.	48	2	10
Scott Paper Ltd.	+29	42	-10
Weyerhauser (Kamloops)	-13	63	4

A preliminary assessment of pulp mill effluent data retrieved from Envirodat indicated there may have been a reduction of up to 30% in TSS and a 20% reduction in BOD from December 1988 to November 1995. Concurrently, there may have been an increase in pulp production of up to 7% in the mills for the same time span.

Envirodat and WWDAT will be used to estimate the pollutant load from industrial discharges for the period of 1990 to 1998. As most waste management program permit holders, with the exception of the pulp and paper industry, are only required to monitor BOD, TSS and flow, quantitative assessment of temporal trends will only be performed for relatively few parameters (i.e., flow, BOD, TSS, production, dioxins and furans). Data stored in Envirodat can be used by decision makers and researchers to make more informed choices in the management of the Fraser River basin.

Efforts are currently being made to link Envirodat with Arcview, a geographic information system (GIS), to produce a tool which will be able to locate point source discharges and their associated loadings. The resulting tool will be able to demonstrate temporal loading changes and the geographic differences in pollutant loadings throughout the Fraser River basin. Concurrently, efforts are being made to collect more industrial effluent monitoring data from provincial government regional offices to provide a more complete view of industrial pollutant loadings to the Fraser River.

The Fraser River Point Source Inventory is an inventory of all municipal and industrial point source effluent discharges authorized under Waste Management Permit within the Fraser basin. FRPSI includes information on the discharge name, location, Standard Industrial Classification (SIC) code, wastewater treatment type, authorized flow rates, concentration and toxicity limits.

Data for FRPSI were obtained from B.C. Ministry of Environment, Land and Parks (MOELP) databases as well as the Federal Facilities Environmental Activities Database (FFEAD). Permit listings were compiled for each MOELP regional office and missing data were photocopied and entered manually. Data were divided geographically into four regions and 13 sub-basins of the Fraser basin in order to provide a more meaningful geographic estimation of pollutant loadings.

Data summaries can be generated by region, sub-basin, key parameters and major SIC codes. It should be noted that results from FRPSI are not actual pollutant loadings but the maximum allowable loadings as defined in provincial waste permits.

FRPSI is linked to the MapInfo GIS software which allows the sites to be displayed on 1:250,000 scale digitized maps of the Fraser basin. The database is updated continually as Permit Amendments and new Permits are referred to the Pollution Abatement Division. Date-stamped copies of the data files are archived to allow future comparisons of permitted discharges. FRPSI is programmed in FoxPro for DOS and a diskette containing a non-editable version is mailed on request to interested parties.

To address the last objective, namely the reduction of environmentally disruptive industrial effluent discharges by 30% to meet environmental quality objectives, a number of pollution prevention (P2) and best management practices (BMP) were developed. Initially, a reference workbook, complete with planning worksheets, was developed to provide engineering consultants with guidance to develop industrial sector-specific guides for the preparation of pollution prevention guides. The industrial sector-specific guides are designed to provide background information on manufacturing processes, waste characteristics and to recommend pollution prevention techniques. Completed P2 guides were distributed to industry with the suggestion that they be used as a tool by individual companies to develop facility-specific pollution prevention plans.

A number of industrial sectors were identified in British Columbia for which pollution prevention guidelines could be developed. They were:

- Sawmill
- Wood Preservation
- Auto Recycling
- Foundry
- Sand & Gravel
- Metal Smelter
- Scrap Metal
- Cement
- Dry Bulk Terminal
- Shipyard
- Petroleum Terminal
- Chlor-alkali
- Sodium Chlorate
- Chemical
- Sugar
- Ready-Mix
- Fish Processing
- Meat Processing
- Fruit and Vegetable Processing
- Feed Mill
- Abattoir
- Dairy
- Winery
- Brewery

The following guides have been produced as a part of the Fraser River Action Plan Industrial Discharges Program:

1. Ready Mix Concrete Industry - Environmental Code of Practice;
2. Guide for Best Management Practices for B.C. Dry Bulk Terminals;
3. A Practical Manual of Waste Treatment for Small Metal Finishing Operators;
4. A Review of Stormwater Management Practices at Petroleum Product Bulk Terminals;
5. Guide for Best Management Practices for Process Water Management at Fish Processing Plants in British Columbia;
6. Technical Guide for the Development of Pollution Prevention Plans for Fish Processing Operations in the Lower Fraser Basin;
7. Reference Workbook: Pollution Prevention Plans;
8. Best Management Practices for Ship and Boat Building and Repair Industry in B.C.; and,
9. Best Management Practices for Marina and Small Boatyards in B.C.

The following are guides which are under final review:

1. Technical Guide for the Development of Pollution Prevention Plans for the Fruit and Vegetable Operations in the Lower Fraser Basin;
2. Guide for Stormwater Best Management Practices for Selected Industrial Sectors in the Lower Fraser Basin;

3. Technical Guide for the Development of Pollution Prevention Plans for Ready Mix Concrete Operations; and,
4. Technical Guide for the Development of Pollution Prevention Plans for the Automotive Recycling Industry in B.C.

Lastly, the following is a list of guides under development and expected to be completed by April 1996:

1. Technical Guide for the Development of Pollution Prevention Plans for the Dairy Operations in the Lower Fraser Basin;
2. Technical Guide for the Development of Pollution Prevention Plans for the Asphalt Operations in the Lower Fraser Basin;
3. Technical Guide for the Development of Pollution Prevention Plans for the Foundry Operations in the Lower Fraser Basin; and,
4. Technical Guide for the Development of Pollution Prevention Plans for the Brewery and Winery Operations in the Lower Fraser Basin.

In the absence of an industrial sector-specific guide, the pollution prevention reference workbook may also be used to provide a generic basis for the development of facility pollution prevention plans.

In summary, FPAO has analyzed pollution sources, developed pollution abatement tools and methods to evaluate the progress of pollution mitigative measures on the Fraser River. The next step in the Industrial Discharges program is to facilitate pollution abatement actions.

In order to facilitate pollution abatement actions the Industrial Discharges program is aiming to build better relationships with industry and other governments or government departments. Through stronger relationships with industry and the private sector a better understanding of industry interests, coupled with government initiatives, will lead to an increased willingness to implement pollution abatement actions. An additional incentive to industry, as well as other governments, to implement pollution curtailing measures is the FRAP Cost-Sharing Agreement. Under the agreement, FRAP is willing to fund up to 50%, to a maximum of $35,000, of pollution prevention project costs. Projects that will be considered for cost-sharing must be implemented and applicable to more than one site in the Fraser basin. Pollution abatement projects may include the implementation of pollution prevention plans, best available technologies, and technical education programs with a focus on pollution prevention.

Efforts to maintain and build relationships with industry should be encouraged following the end of FRAP. A strong relationship with continuing technical advice will keep the pollution prevention initiative active in years to come. Furthermore, information stored in Envirodat as well as FRPSI should be maintained to track pollutant loadings to the Fraser and will also provide valuable data in future decision-making processes.

Role of Particles in the Accumulation by Fish of Chemicals from Pulp Mill Effluents

J.L. Parrott[1], B.G. Krishnappan[1] and P.V. Hodson[2]

[1]*National Water Research Institute*
[2]*Department of Biology, Queens University*

Abstract

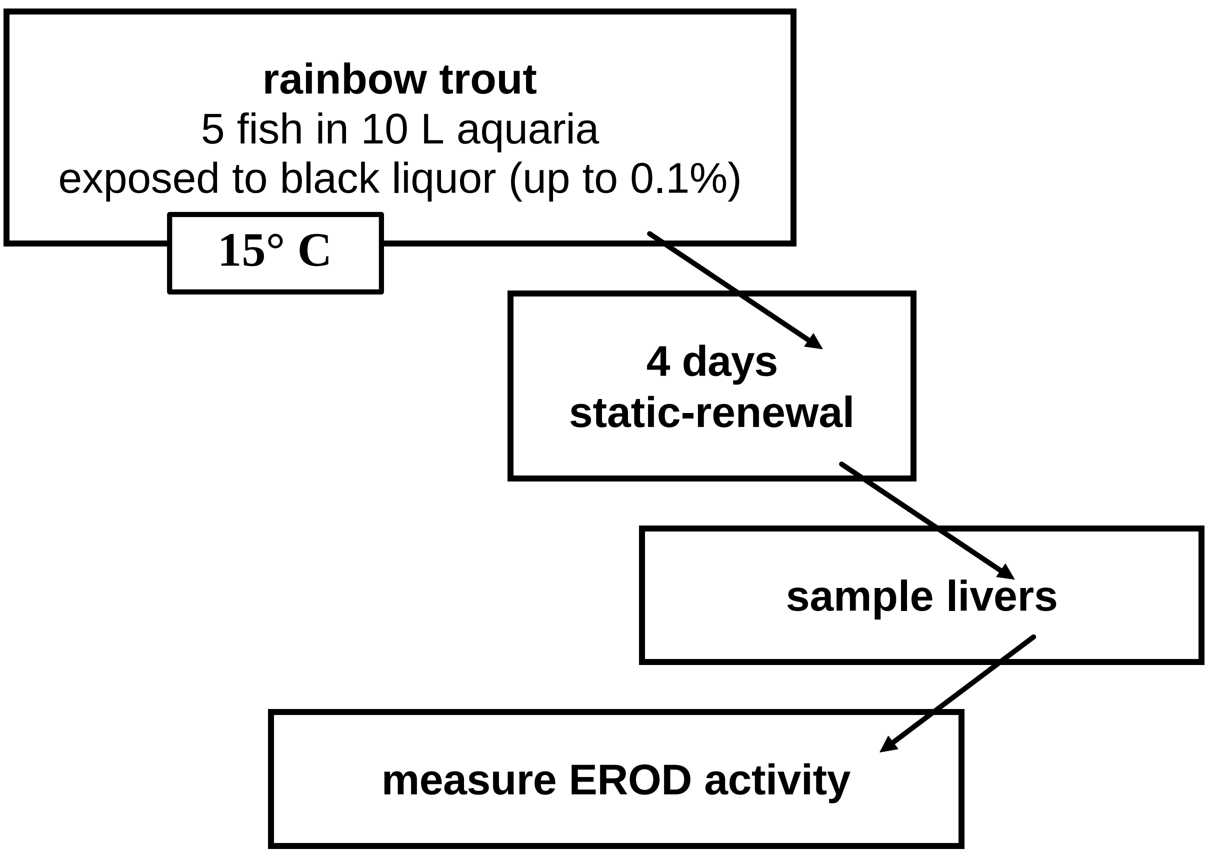
Fish exposed to the spent cooking liquors from Kraft pulping (black liquor) demonstrated a linear increase in liver mixed function oxygenase (MFO) activity (MFO induction). The interaction between chemical accumulation by fish and the presence of particles in water was evaluated by bioassays of MFO induction with trout exposed to black liquor in aquaria, stirred carboys, or in a large rotating flume that controlled bed shear stress and hence, the number and size of particles. The extent of MFO induction should reflect the influence of particles on chemical accumulation by fish. The null hypothesis was that particles would not reduce chemical availability. Preliminary experiments with fish exposed in both the flume and in aquaria showed that fish could survive in the flume if eddies were created to reduce swimming effort. However, MFO induction in the presence of black liquor was much lower than expected based on parallel aquaria studies. High temperatures and exercise appeared to reduce MFO induction caused by exposure to black liquor, so temperature controls were installed in the flume to maintain 15°C, but the 'flume effect' persisted, suggesting some chemical adsorption to the walls of the flume, or influence of exercise on fish MFO. Particles added to stirred aquaria (carboys) caused a reduction in MFO induction by black liquor, which did not support the null hypothesis. These experiments were preliminary and designed primarily to evaluate the best methods for testing fish in the flume. Fish exposures are continuing using six newly constructed, stainless steel, linear flow channels. When built, these channels will be used to test current speed effects on MFO. We will study the effects of particle concentrations and sources on MFO induction by black liquor, using sediments from Nechako, Thompson and Main rivers.

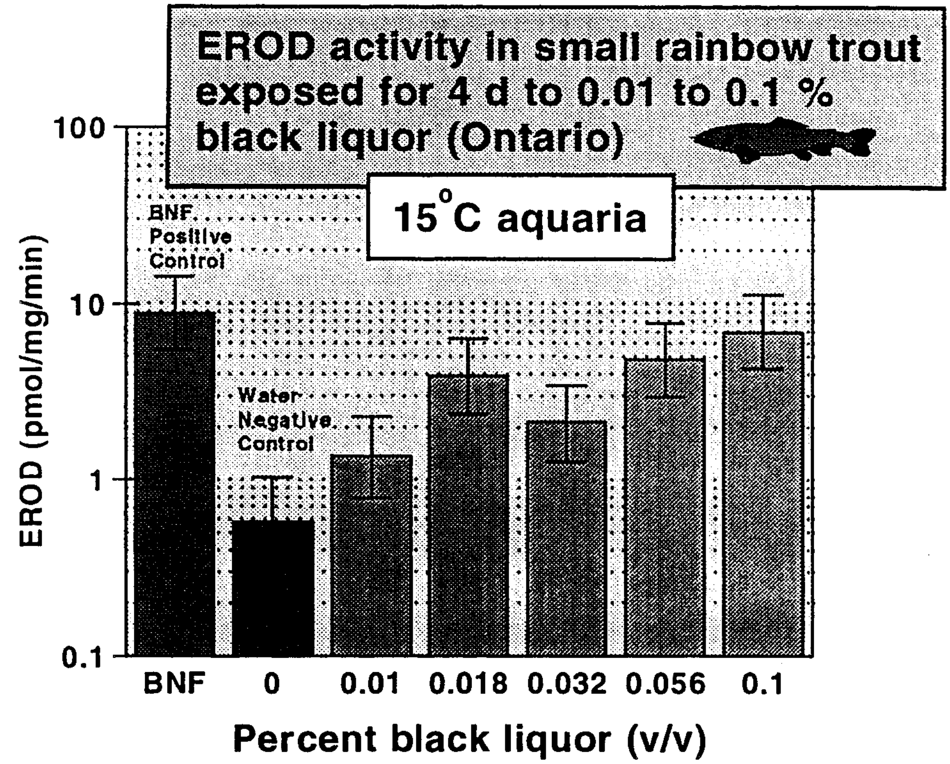
Fish MFO

- wild fish have elevated MFO downstream of pulp mills
- in lab, fish MFO induced by pulp mill effluents, black liquor

Do suspended particles affect fish accumulation of MFO inducers from pulp mill effluents?

- concentrations of particles
- types of particles/sediments





Fish Exposures to MFO Inducers and Particles

- rotating flume at NWRI
- changing speed of rotation creates different shear stress
- produces different size spectra of particles in suspension

modify for fish exposure up to 0.121 N/m^2 30 cm/sec, 20°C

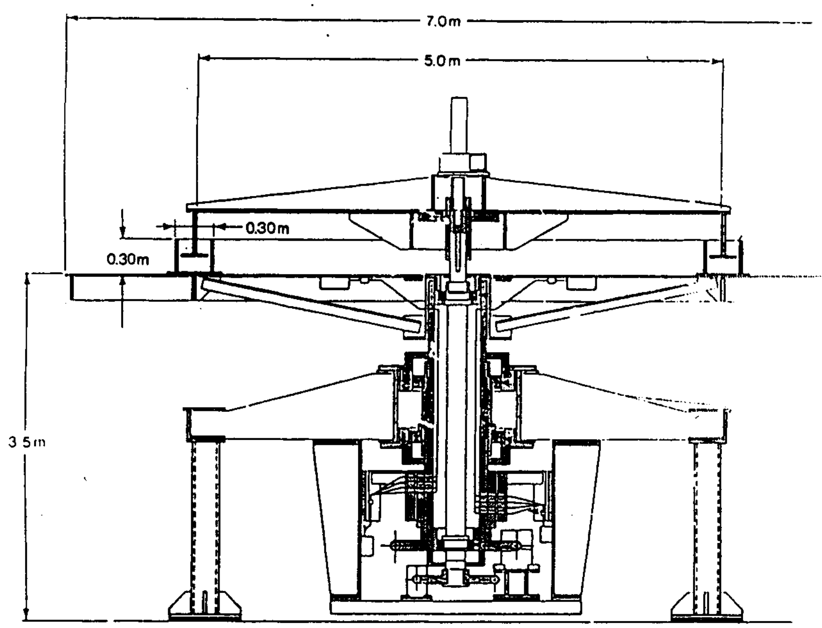


Figure 1: A sectional view of NWRI's rotating circular flume

Flume

Strong temperature effect

- control temperature of flume water (15°C)

Increase black liquor concentration

0.1% black liquor, 15°C, 4 d - 2.5-fold induction

induction lower than expected (should be 10-fold)

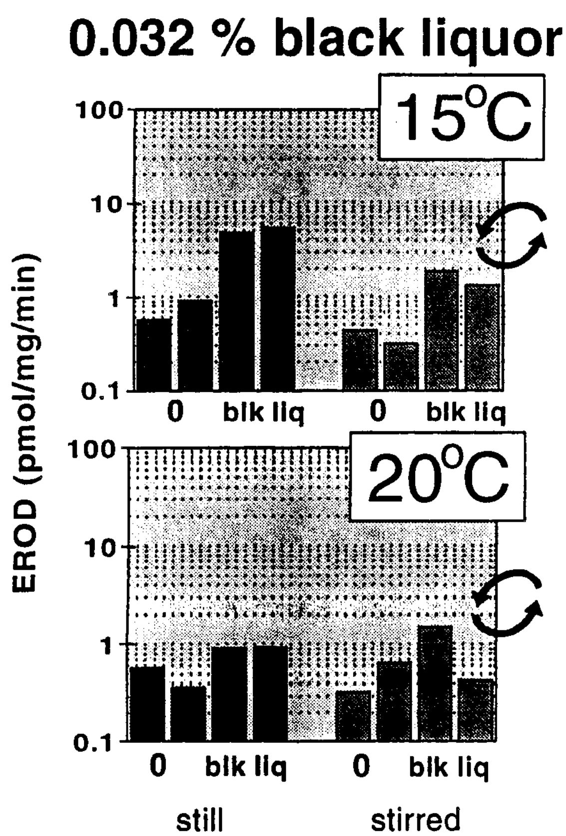
Investigate exercise effects ...

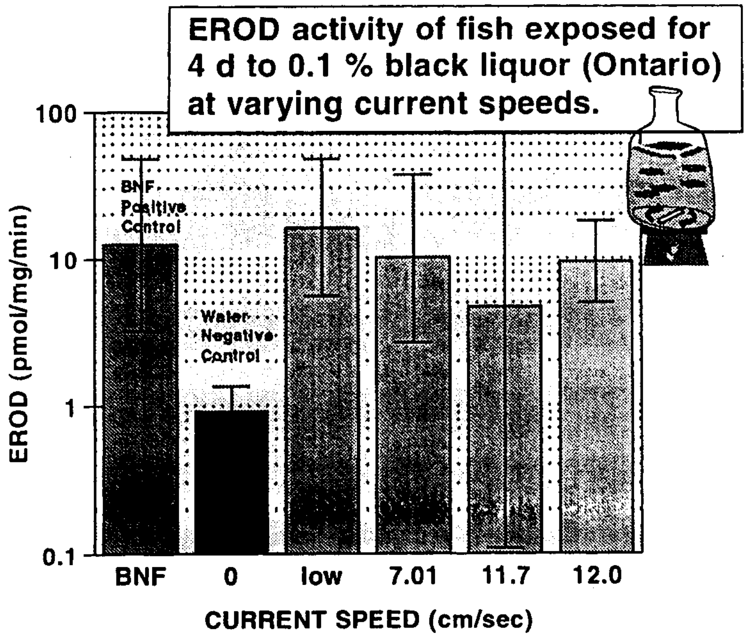
Fish Exposed for 4 d in Stirred Glass Carboys

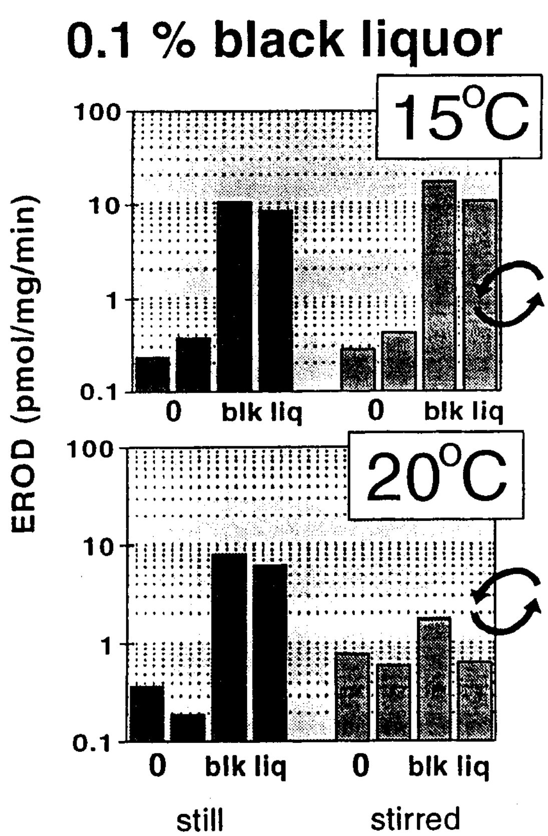
- five small 1-2 g rainbow trout
- 10 L solution
- 15° C or 20° C

Stir speed controls current (0 to 15 cm/sec)

- current is averaged




EROD activity of fish exposed for 4 d to 0.1 % black liquor (Ontario) at varying current speeds.
EROD (pmol/mg/min)
100
10
1
0.1
BNF Positive Control
Water Negative Control
BNF
0
low
7.01
11.7
12.0
CURRENT SPEED (cm/sec)


0.1 % black liquor
15°C
20°C
EROD (pmol/mg/min)
100
10
1
0.1
0
blk liq
0
blk liq
still
stirred

Exercise Effects - Carboys

Not consistent

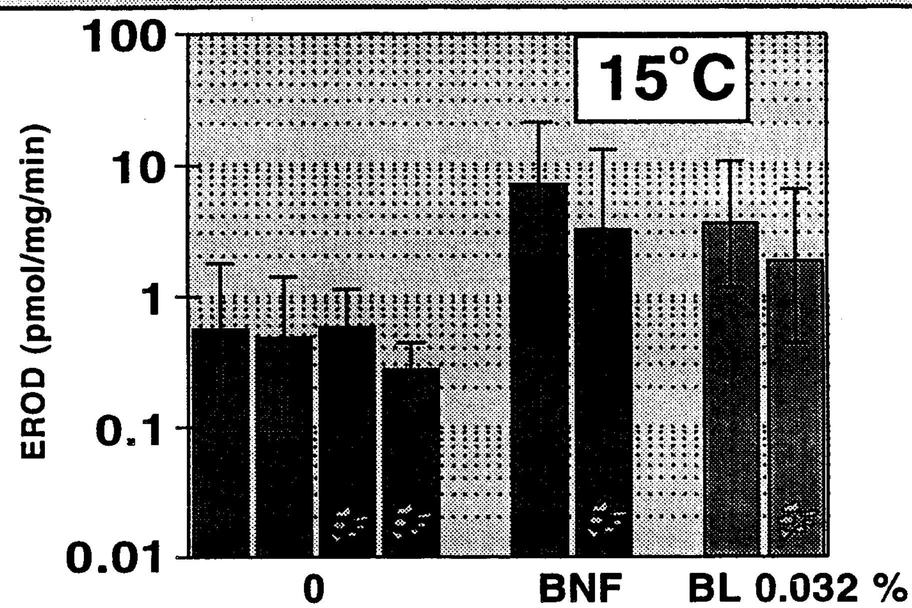
Carboy current speed varies with position

Maximum speed is less than half of flume current

Need better setup for fish exposures

- linear flow
- replicate chambers

EROD activity in small rainbow trout exposed for 4 d to 0.032 % black liquor or BNF with or without 40 mg/L Fraser R. sediments.



FRAP - Role of Particles in the Accumulation by Fish of Chemicals from Pulp Mill Effluents

1995

- in rotating flume or stirred glass carbuoys, fish MFO induced by black liquor
- addition of particles (40 mg/L unsieved wet Prince George sediments) slightly reduced MFO induction by BNF and black liquor

But

- MFO affected by temperature
- MFO affected by exercise - current needed to keep particles suspended
- only 1 rotating flume for exposures - slowed experiments

FRAP - Role of Particles in the Accumulation by Fish of Chemicals from Pulp Mill Effluents

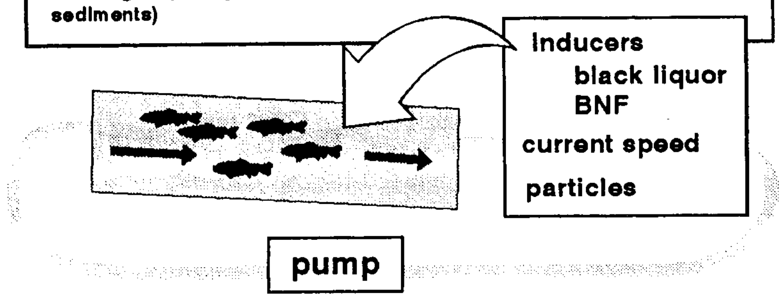
1996

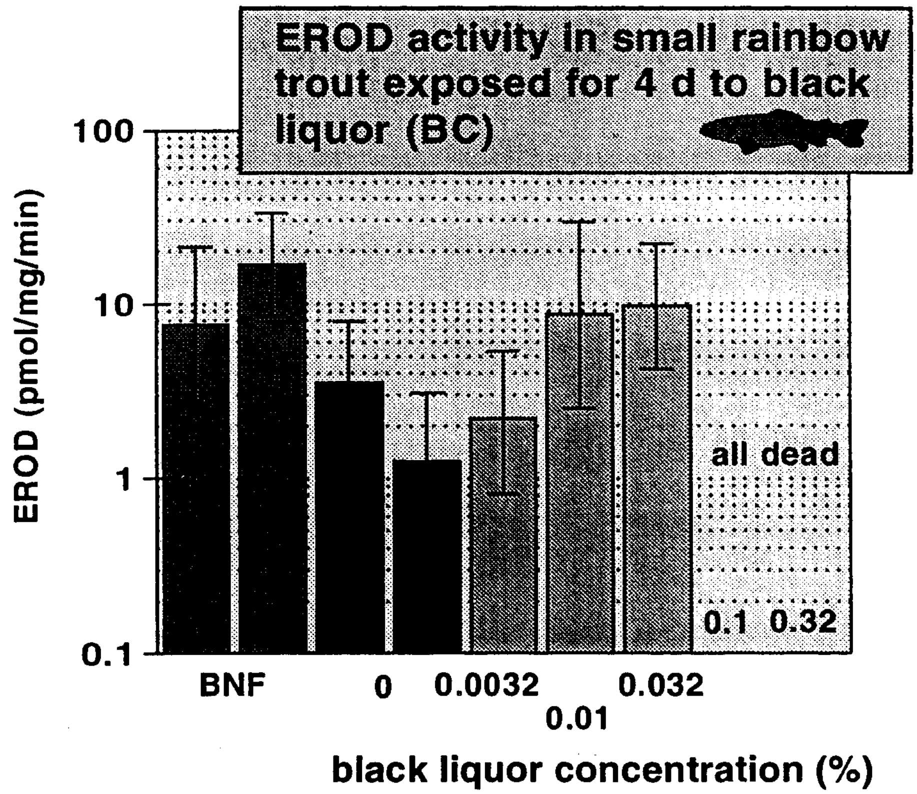
Building 6 stainless steel flow channels 1 m long to expose fish to particles / inducers at various current speeds

Current speed effects - test induction by black liquor or positive control compound B-naphthoflavone (BNF) at various current speeds

Particle effects - test induction by black liquor and pulp mill effluents with different concentrations of particles added

Nature of Particles - test induction by black liquor with particles of differing clay / organic contents (from Nechako, Thompson and Main R. sediments)




EROD activity in small rainbow trout exposed for 4 d to black liquor (BC)
100
10
1
0.1
EROD (pmol/mg/min)
all dead
0.1 0.32
BNF
0
0.0032
0.01
0.032
black liquor concentration (%)

Response of Peamouth chub (*Mylocheilus caurinus*) to BKME exposure in the upper Fraser River, B.C.

W.N. Gibbons[1], K.R. Munkittrick[2] and W.D. Taylor[1]

[1]*Department of Biology, University of Waterloo*
[2]*Great Lakes Laboratory for Fisheries and Aquatic Sciences*

As part of the Environmental Quality component of the Fraser River Action Plan (FRAP), effort was initiated to study the effects of pulp and paper effluents on the upper Fraser River. One of the elements of study included monitoring the effects of pulp mill effluent on resident fish populations of the upper Fraser River. The emphasis of this project was to evaluate the suitability of small fish species as “sentinels” for monitoring effluent-related effects in river environments.

The upper Fraser River was selected as the study area because pulp mills contribute a substantial proportion of the industrial effluent discharged into this section of the river: three Kraft mills (two discharges - referred to as mill A and B) near Prince George, plus a TMP/CTMP mill (mill C) and a Kraft mill (mill D) near Quesnel. For the purposes of the field research, the study area was confined to the receiving waters of pulp mills at Prince George to focus the initial monitoring program on effluent from Kraft mill processes. A sentinel species was selected based on limited mobility, abundance and capture efficiency. Fish responses were defined according to measurements describing body and organ metrics, reproductive parameters, age estimates, mixed function oxygenase activity (MFO; EROD activity) and sex steroid levels. The project consisted of three components: 1) field surveys conducted during fall 1993 and spring 1994; 2) laboratory exposure to mill effluent; and 3) an on-site field exposure test conducted in the fall of 1994.

The fall 1993 pilot survey was conducted to allow sentinel species selection and initiate monitoring of a resident sentinel fish species exposed to mill effluent. Capture success of most of the potential sentinel fish species (e.g., cyprinids, cottids) were low. Of the potential species, peamouth chub (*Mylochelius caurinus*) was the most abundant and widely distributed species captured. Moderate success was achieved in catching live peamouth chub by beach seining, although overnight sets of 40 mm mesh gillnets also proved successful and less labour intensive.

Instream concentrations of conductivity were used to track the approximate delineation of the downstream mill effluent to ensure that sampling sites were located in areas influenced by effluent. The exact location of sampling sites within the reference and exposure zones were dictated by capture success of peamouth chub at a particular spot. Despite moderate success in the reference zone, capture success of mature peamouth chub in both near-field zones was poor. Limited sample sizes made it difficult to compare responses between reference and exposed fish; however, preliminary results did not suggest dramatic changes in whole organism parameters. Hepatic MFO activity in exposed immature chub was induced relative to reference fish and remained induced for a considerable distance downstream (30 km). In the absence of previous knowledge, it was sometimes difficult to confidently identify mature and immature individuals. Subsequent analyses indicated that many of the chub collected were of borderline size and age of maturity, and that the fully mature peamouth were not sampled effectively. This was especially true for the near-field zones where sites of suitable habitat for sampling were limited relative to the reference zone.

Increased concentrations of conductivity, chloride, sodium and sulphate downstream of both mill A and B diffusers indicated that the sites of intensive fish collections were exposed to effluent. As well, EROD induction in immature chub from the near-field and far-field sites also indicated effluent exposure. Instream concentrations of AOX and chlorinated phenolics were not above detection limits.

A second field survey was conducted the following spring (1994) in an effort to capture greater numbers of sexually mature male and female chub. Beach seining, gillnetting, electrofishing, setlining and trap netting techniques were all used to improve the capture success of mature peamouth chub. The greatest numbers of peamouth were caught in eddy pools along the margins of the river using sinking, monofilament gillnets (50 mm mesh). Despite substantial sampling effort, numbers of mature male/female fish captured in the exposure zones were again limited. Capture success was strongly hindered by high, turbid water levels and large amounts of suspended debris which fouled the gillnets.

Conclusions

Overall, there were few differences in whole organism and physiological parameters between fish collected from the reference and near-field zones. Limited sample sizes for mature male and female fish made it difficult to confidently compare characteristics between zones. However, a graphical approach comparing the spatial position of individual near-field fish relative to the 95% confidence ellipse of reference fish did not show substantial deviations in the parameters of exposed chub. As in the fall survey, immature peamouth chub from the near-field zones had induced EROD activity (1.5- to 4.1-fold) relative to reference fish, indicating exposure to mill effluent. No steroid hormone differences (circulating levels or *in vitro* production) were observed between reference and exposed fish. Comparisons between spring and fall reference fish indicated that sexually mature fish collected in the spring were significantly larger and older than fish collected during the fall survey. These results further supported the hypothesis that chub collected during the fall were probably borderline in terms of size and age of maturity.

As in the fall, instream concentrations of conductivity, chloride, sodium and suphate were predictably higher downstream of the mill diffusers during the spring survey. Chloride data indicated that effluent concentrations were approximately 0.08-0.6% downstream of mill A and approximately 0.03-0.4% downstream of mill B. The chemistry data, along with MFO data, indicated that the fish sampled during the spring survey were exposed to mill effluent.

Concurrent to the field surveys, laboratory effluent exposure tests were conducted to determine whether effluents from the Fraser River mills (Prince George and Quesnel mills) were capable of inducing MFO activity in exposed rainbow trout. Fish were exposed to 100% effluent for a total of four days. Hepatic EROD activity in exposed trout were induced 6.7-fold with mill A effluent, 8-fold with mill B effluent, 14.5-fold with mill C effluent and 3.1-fold with mill D effluent relative to reference fish.

Similar exposure tests were conducted in the field at the mill A site using peamouth chub from the reference zone. Male and female chub were exposed to river water (collected upstream of diffuser) or 50% whole effluent from mill A for five days. After the exposure period MFO activity and circulating levels of testosterone were measured. Unfortunately, problems related to fish survival occurred (fungal infection) affecting the sample size, exposure time and power of the test. No differences were observed in EROD activity or plasma concentrations of testosterone between exposed and reference fish. Confidence in the results were influenced by high within-treatment variability and reduced exposure time. However, the on-site test represented a useful approach for assessing the potential of effluents to affect resident fish species, especially in situations where the capture success of exposed fish is poor.

Despite the limited field data, there was evidence which suggested that effluent from mills A and B were capable of eliciting physiological responses in laboratory and resident fish species (immature chub). However, the success of using peamouth chub for monitoring the upper Fraser River is uncertain. First, peamouth chub is larger than many cyprinid/cottid species and its capacity for large-scale movement is unknown. Although likely to be less mobile relative to larger species such as mountain whitefish or squawfish, the degree of mobility of peamouth chub needs to be assessed. Second, the success of using peamouth chub as a sentinel monitoring species is strongly influenced by the ability to capture mature chub within the near-field zones. Unless capture success improves, use of peamouth chub as a sentinel species will be restricted to far-field zones, or mills located further downstream of Prince George where peamouth chub are more abundant.

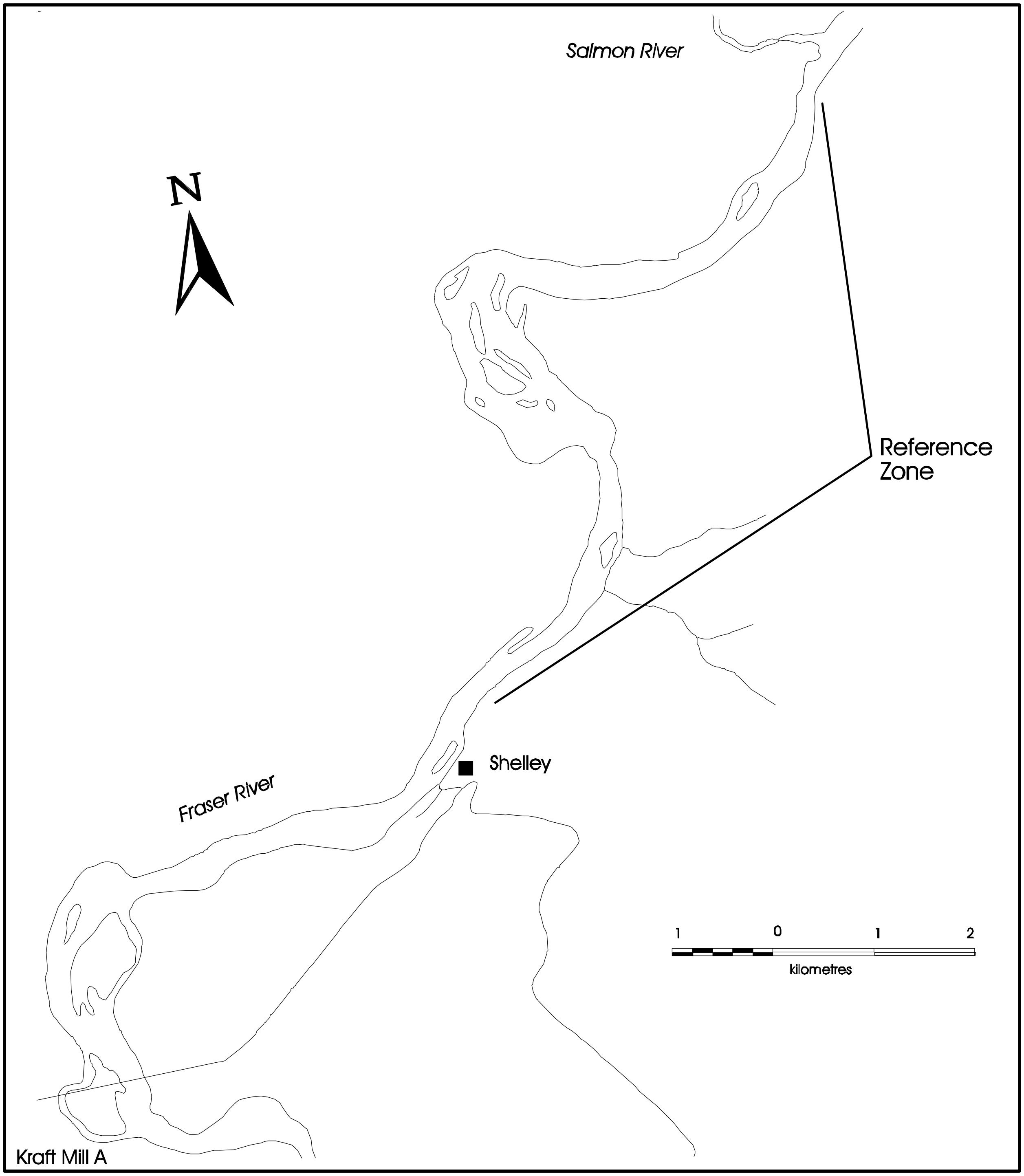


Figure 1: Location of the designated reference zone for collecting fish during the field surveys on the upper Fraser River, Prince George, B.C.

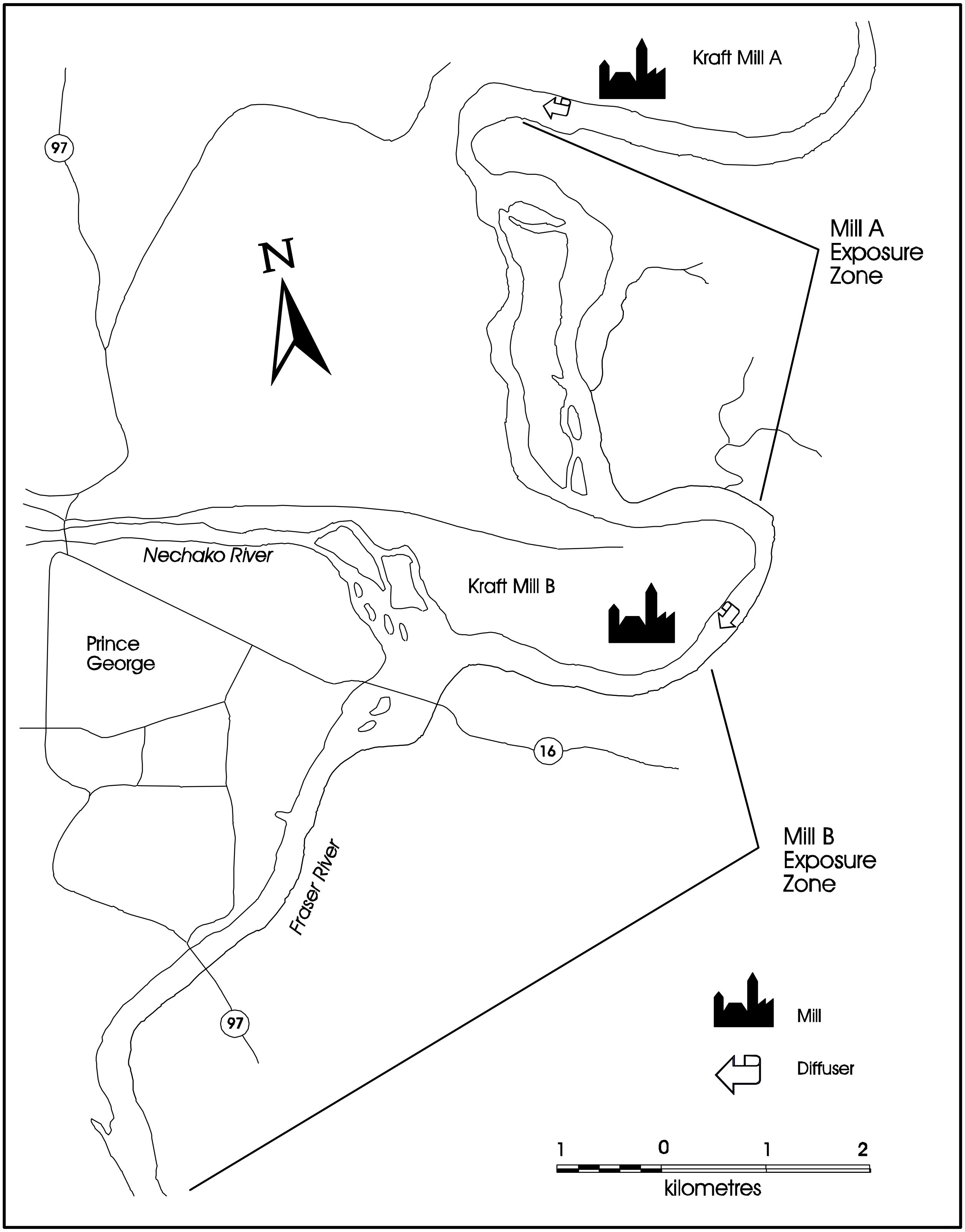


Figure 2: Location mill A and B near-field zones for collecting fish during the field surveys on the upper Fraser River, Prince George, B.C.

Response Parameters

- **whole organism measurements:**
  - — size-at-age
  - — mean age
  - — condition
  - — liver weight
  - — gonad weight
  - — fecundity
  - — egg size
- **physiological measurements**
  - — hepatic MFO induction (EROD)
  - — circulating and *in vitro* sex steroid levels

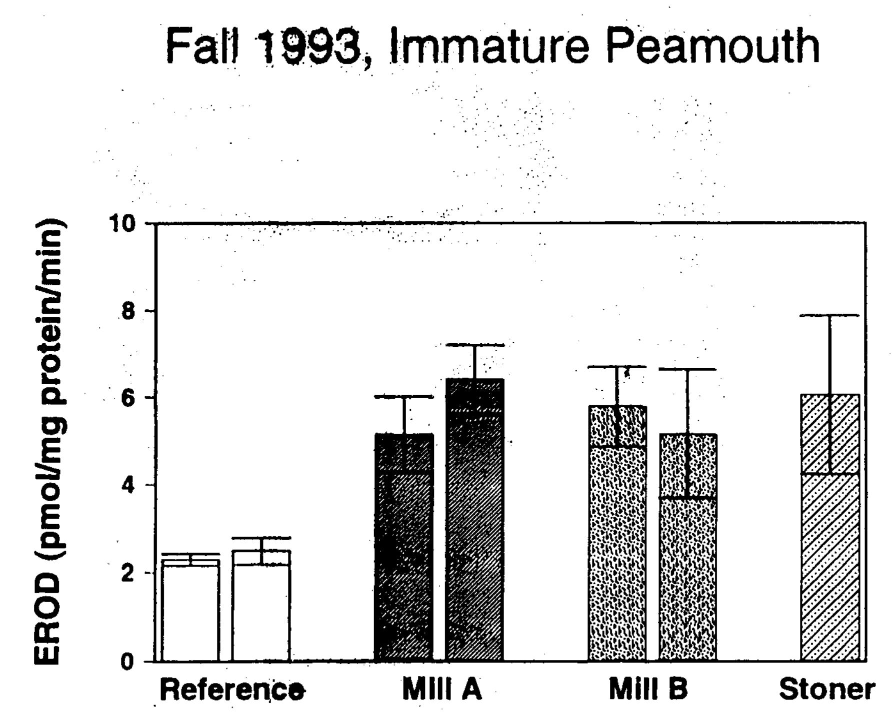
Pilot Survey

- **possible sentinel species included:**
  - longnose dace
  - leopard dace
  - peamouth chub
  - redside shiner
  - prickly sculpin
  - slimy sculpin
- **final selection based on abundance and capture efficiency**
- **sampling gear included: electrofisher, beach seine, minnow traps and gillnets**

Catch Record (>90 Sites), Fall, 1993

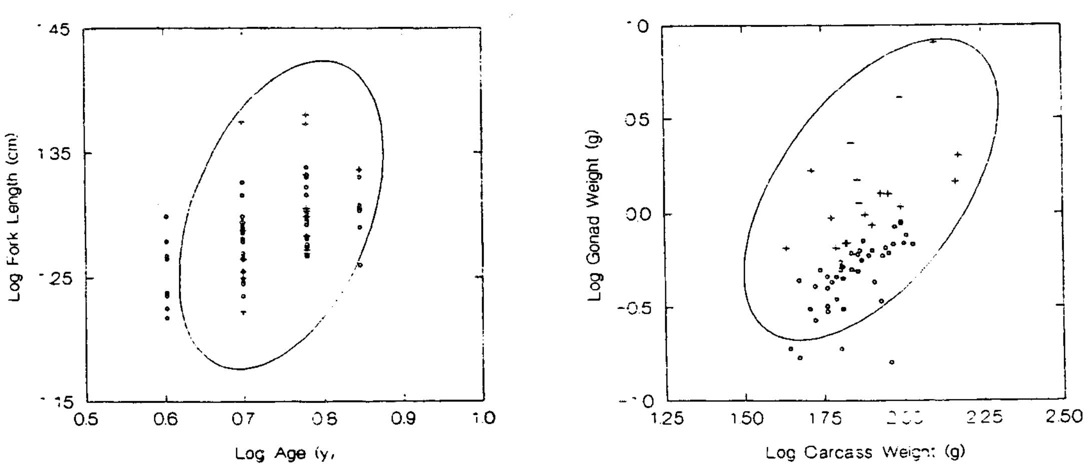
Species	Total Number Caught
salmon sp.[1]	1,004
mountain whitefish	482
Dolly Varden	10
northern squawfish	59
longnose sucker	5
largescale sucker	6
white sucker	10
bridgelip sucker [2]	33
burbot	5
peamouth chub	176
redside shiner [2]	78
longnose dace	3
leopard dace	5
sculpin sp.	5

[1]mostly chinook (juvenile); [2]mostly young-of-the-year

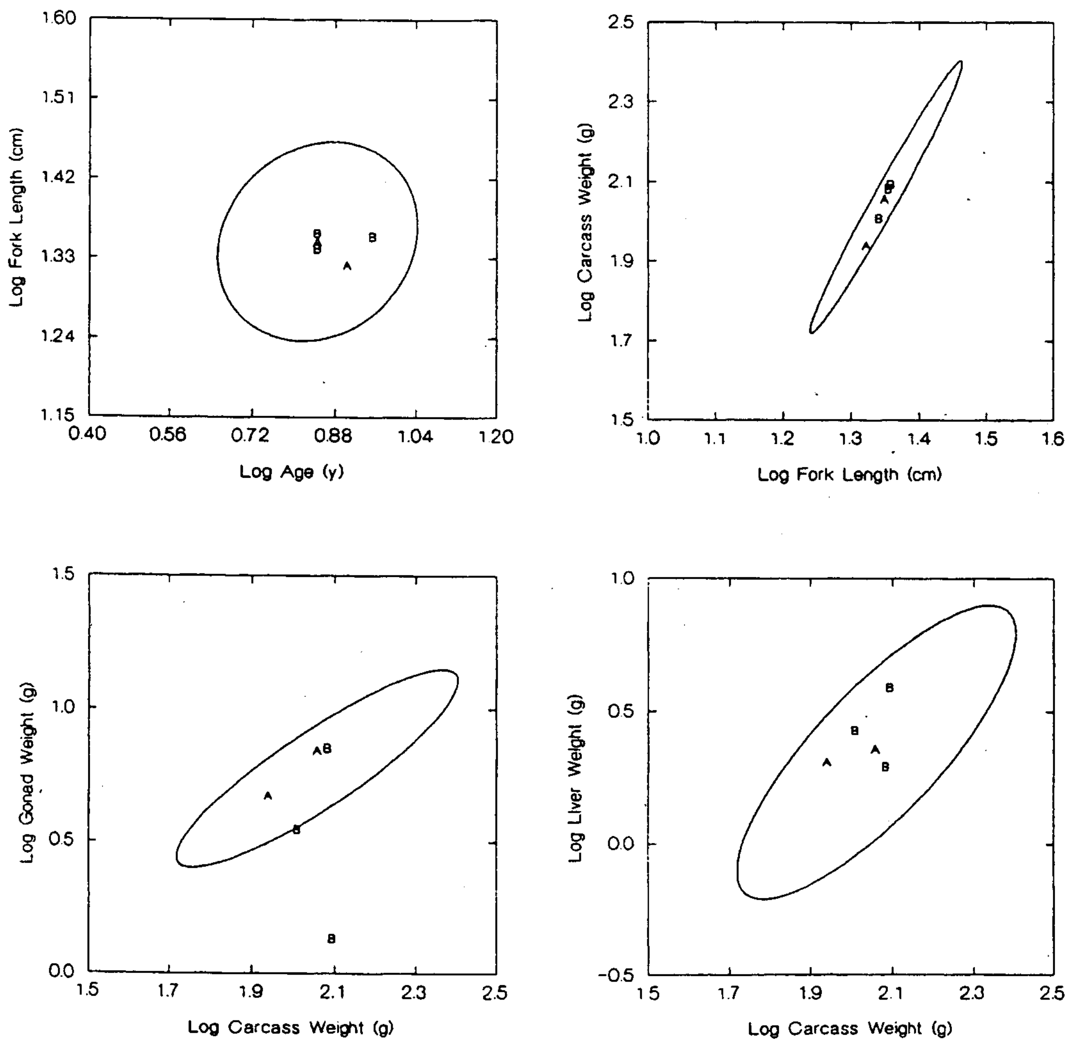


Mature vs. Immature

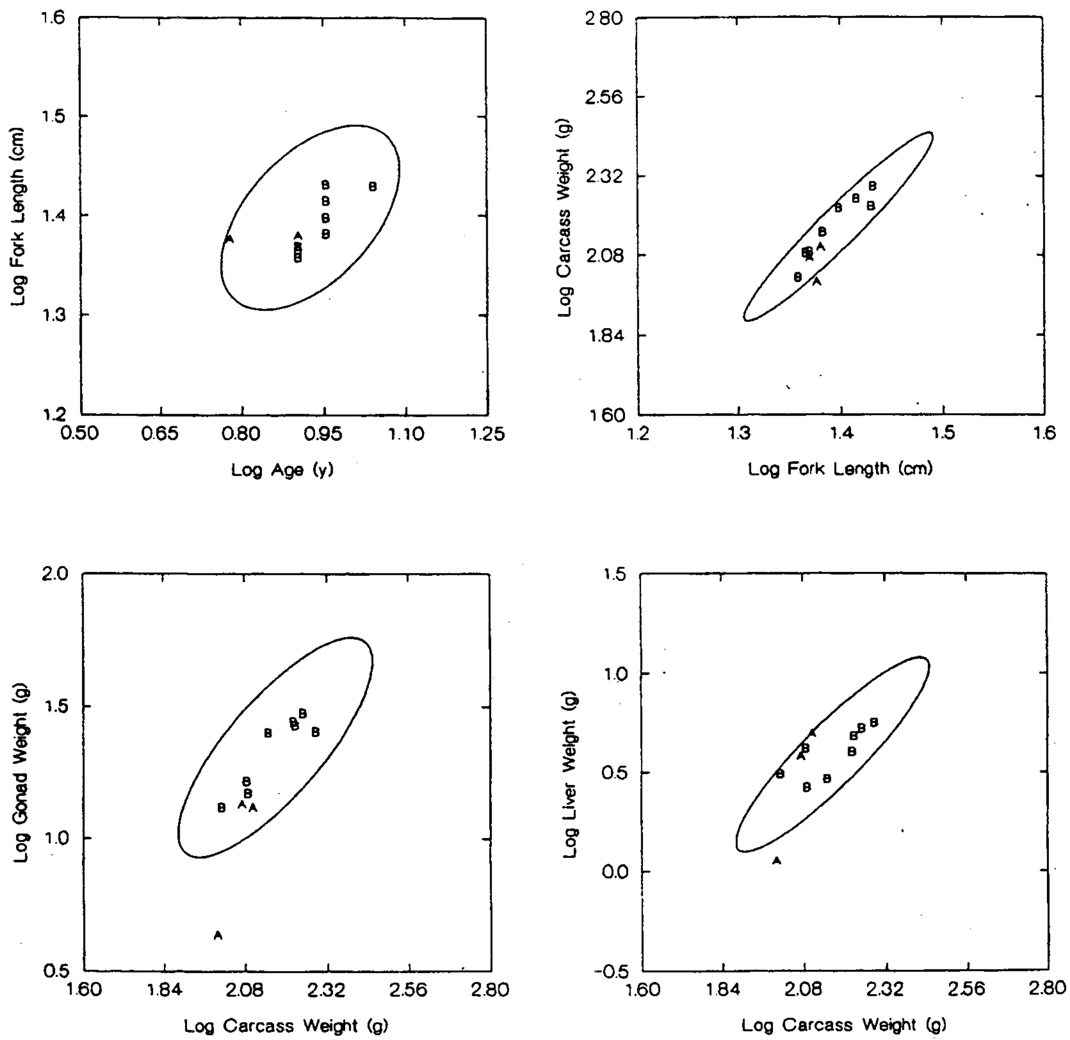
- based on reference data, individuals were considered mature when the GSI > 1%
- sometimes difficult to confidently identify mature and immature individuals due to limited gonadal development
- ages of mature and immature chub from the reference zone overlapped
- also plotted fork length vs. age and gonad weight vs. carcass weight to investigate possible overlap



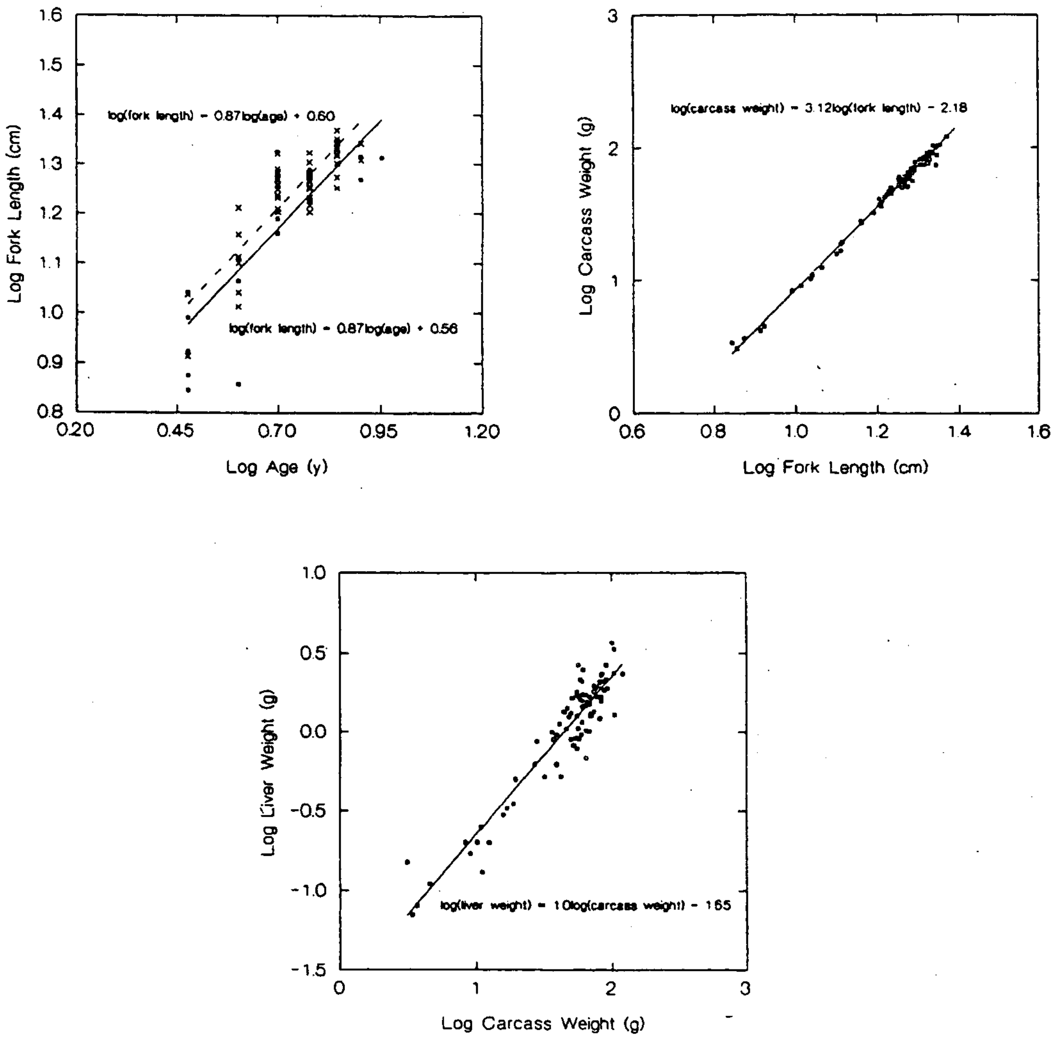
Bivariate plots of size-at-age and gonad weight showing the spatial positioning of "mature" and immature peamouth chub collected from the reference zone during the fall 1993 survey, Fraser River, BC. The ellipse defines the 95 % confidence region around mature male/female fish (+). Immature fish are shown by an open circle (°).



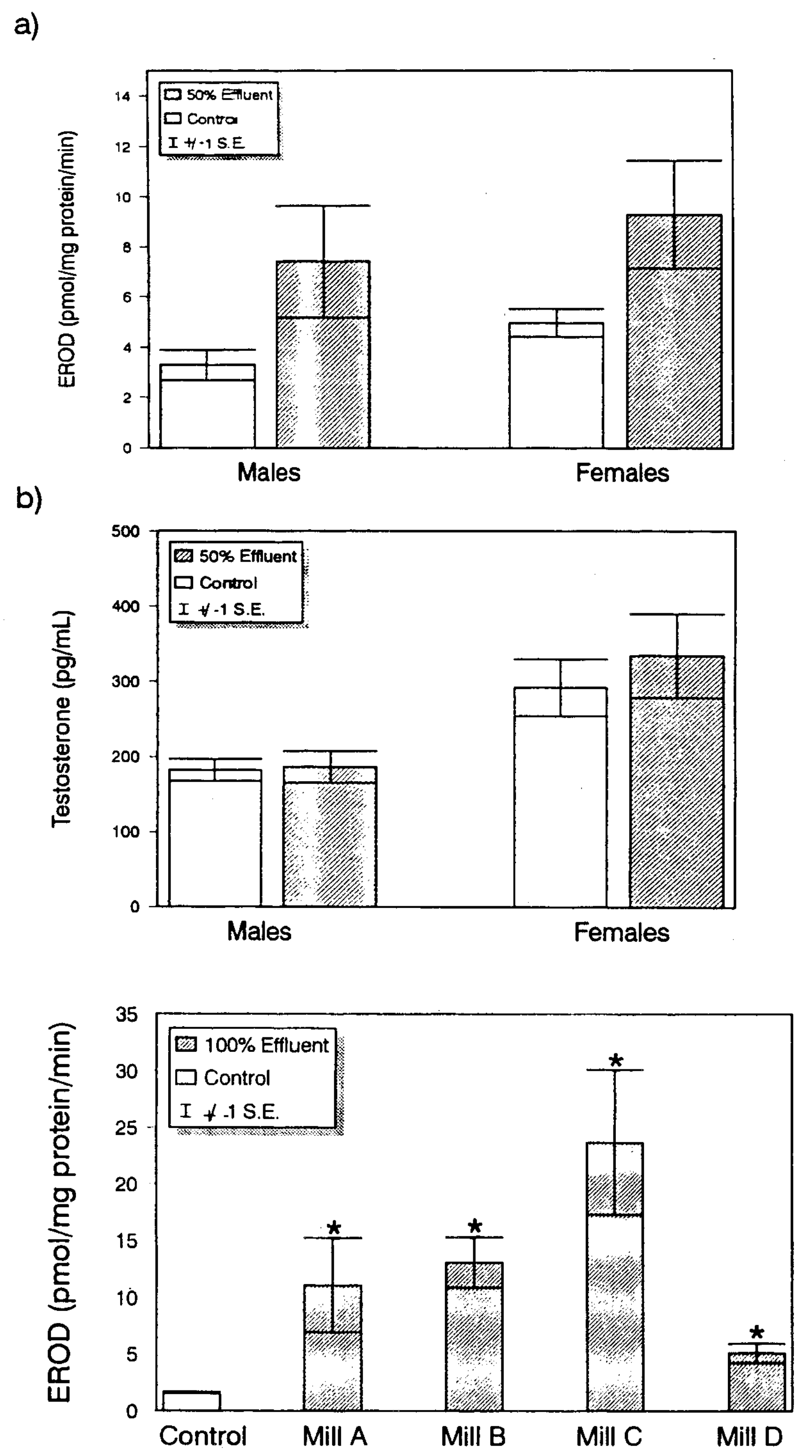
Bivariate plots of size-at-age, condition, gonad weight, and liver weight for male peamouth chub, Fraser River, BC., spring 1994. The ellipse defines the 95 % confidence region around reference male fish. Mill A and B near-field fish are depicted by the letter A and B, respectively.



Bivariate plots of size-at-age, condition, gonad weight, and liver weight for female peamouth chub, Fraser River, BC., spring 1994. The ellipse defines the 95 % confidence region around reference female fish. Mill A and B near-field fish are depicted by the letter A and B, respectively.



Bivariate plots of size-at-age, condition and liver weight for immature peamouth chub, Fraser River, BC., spring 1994. For size-at-age, separate regression lines are shown for the reference zone (solid line) and pooled near-field zones (dashed line).


a)
EROD (pmol/mg protein/min)
0
2
4
6
8
10
12
14
50% Effluent
Control
+/-1 S.E.
Males
Females
b)
Testosterone (pg/mL)
0
100
200
300
400
500
50% Effluent
Control
+/-1 S.E.
Males
Females
EROD (pmol/mg protein/min)
0
5
10
15
20
25
30
35
100% Effluent
Control
+/-1 S.E.
*
*
*
*
Control
Mill A
Mill B
Mill C
Mill D

General Synopsis

- several potential sentinel species occur in the upper Fraser; few were found in sufficient abundance and distribution
- by virtue of capture success, peamouth chub represented the best species for monitoring
- although mature chub were collected from the reference zone, limited numbers were collected from either near-field zone
- despite substantial effort, capture success in the near-field zones appeared hampered by a lack of suitable sampling habitat
- regardless of the limited field data, there was evidence which suggested that effluent from mills A and B were capable of eliciting physiological responses in laboratory and resident fish species (immature chub)

How Results Affect Future Management

- near-field evaluations of fish responses have been difficult in the Fraser River

- need to continue to try to develop near-field evaluation techniques for sites where there are dramatic seasonal changes in flow and differences in habitat

- the success of using peamouth chub for monitoring the upper Fraser River is uncertain:

  1. larger than many cyprinid/cottid species and its capacity for large-scale movement is unknown
  2. inability to capture chub in near-field zones restricts use of this species to far-field zones, or mills located further downstream of Prince George where peamouth chub are more abundant

- although there are problems associated with peamouth chub for monitoring the near-field zones, use of small fish species for monitoring has been successful in other studies:

  lake chub - Athabasca River near Whitecourt, Alberta
  spoonhead sculpin - Athabasca River near Hinton, Alberta
  trout-perch - Moose River system, Ontario

- general approach should be considered a viable alternative to monitoring large, mobile fish species

Organochlorine and Trace Metal Contaminants in Mink (*Mustela vison*) and Otter (*Lutra canadensis*) in the Columbia and Fraser River Systems — Progress Report

L. Harding,[1] C. Stevens[2] and J. Elliott[1]

[1] *Environment Canada*
[2]*Faculty of Medicine, University of British Columbia*

Introduction

Mink (*Mustela vison*) and river otter (*Lutra canadensis*) are good indicators of contaminant uptake from aquatic food webs because they are resident, largely piscivorous, and at or near the top of the food chain (Moul and Nichol, 1994). Mink and otter suffer reproductive failure and other forms of toxicity at the low parts per million levels of polychlorinated biphenyls (see reviews by Leonards *et al.,* 1994; Smit *et al.*, 1994 and Elliott *et al.*, 1996). In this study, otter and mink were collected during 1995 in the upper and lower Fraser River and the Kootenay and Columbia River systems; in the last, collections were coordinated with those of the U.S. Fish and Wildlife Service from the U.S.-Canada border downstream to the mouth of the Columbia. Chemical analysis of liver tissues was combined with biological measurements and pathological examination of various tissues and organs. The purpose of this study was to repeat collections of mink and otter on these systems that were made in 1991 (Elliott *et al.,* 1996) again during 1995 to determine if there has been a reduction in organochlorine contaminants following improved regulation of pulp mill effluents in British Columbia.

Methods

Study Design

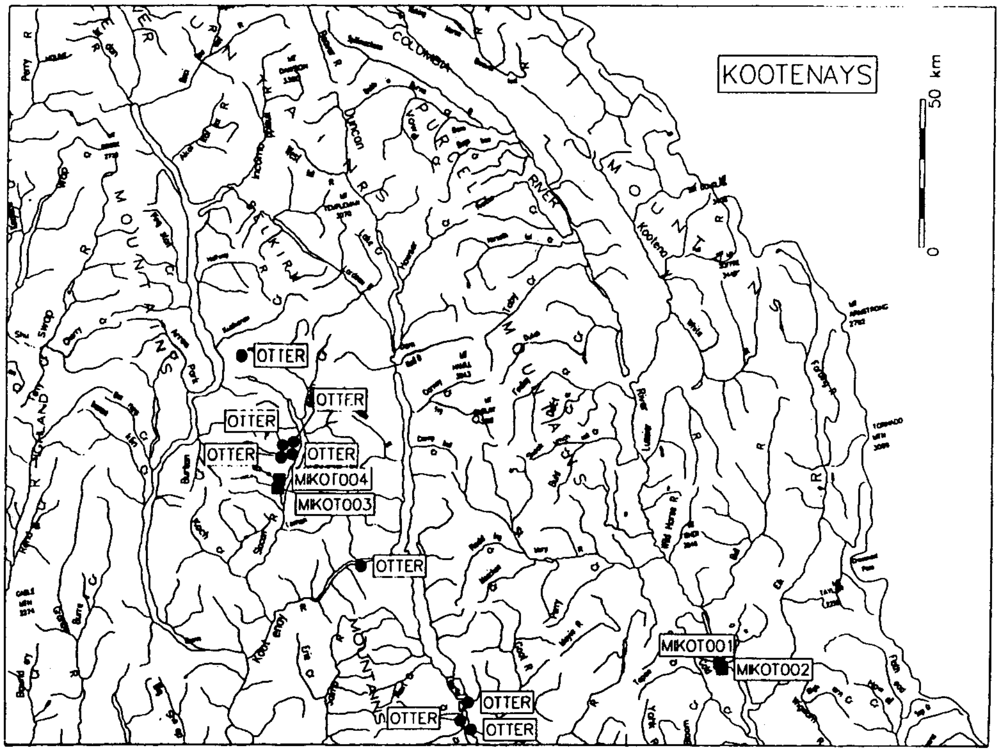
The sampling design was based on detailed analysis for chlorinated organics of composites of livers from six to 10 individuals from each species at each location and individual analyses of the same specimens for metals, pesticides and total PCBs. Five locations were sampled (see maps): Upper Fraser, Lower Fraser, Upper Columbia (above Arrow Lakes), Kootenay system and Lower Columbia (below Hugh Keenlyside Dam). A preliminary sample of six mink was selected in March, 1995 to be analyzed individually to assess variability.

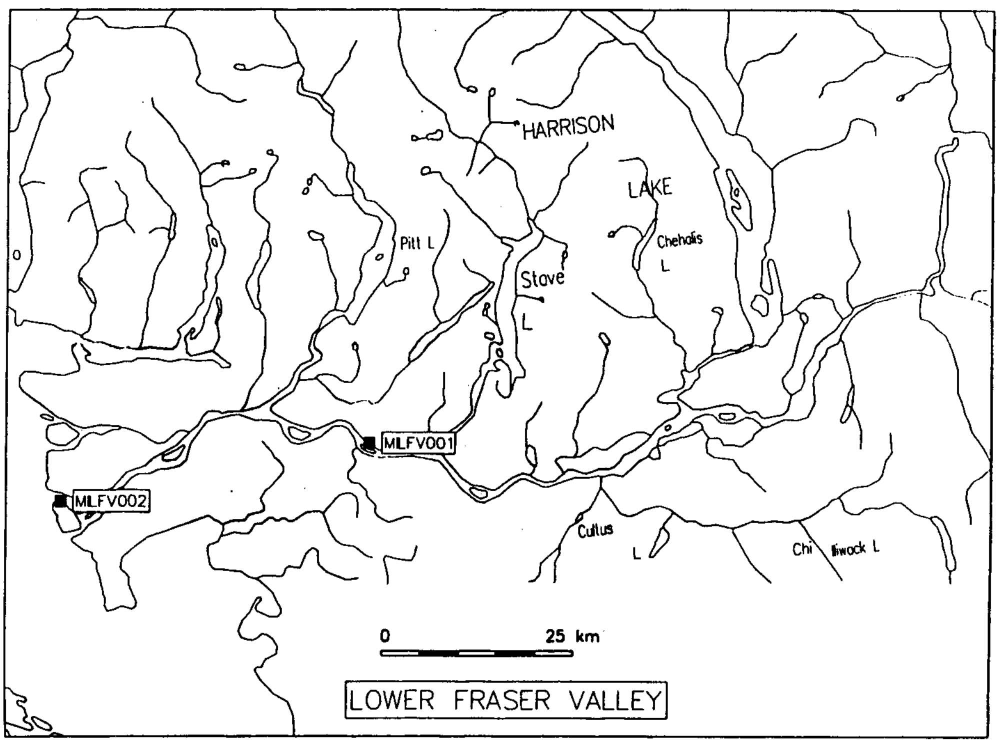
Collections

With the assistance of regional wildlife biologists of the B.C. Wildlife Branch, specimens were obtained fresh from registered trappers, tagged, wrapped in aluminum foil, placed in a plastic bag and frozen. A standard sample collection protocol was distributed to each trapper participating in the program. Each carcass was tagged with information on the trapper, the specimen, the location and the date trapped. Carcasses were shipped by air freight to Vancouver, or picked up and driven directly to the laboratory. As of February 6, 1996, 32 otter and 20 mink had been collected, as well as five marten (*Martes americana*) as a terrestrial analogue of the mink. Each specimen was sexed, measured and weighed and the head removed for aging by dental cementum annuli.

Analysis

During March, 1995, six mink were taken to the North Vancouver Environment Canada laboratory for dissection. The liver and kidneys were excised from each animal with a stainless steel knife and forceps (washed with hexane between dissections), weighed and placed in separate, hexane-washed, heat-treated jars. Femurs from each were placed in plastic bags and archived at -40°C. Kidney samples were submitted for trace metal analysis by ICP, low level cadmium and lead by flameless AA, and mercury by AAS. Liver samples were submitted to Zenon Environmental Laboratories Ltd. for dioxin/furan (low


KOOTENAYS
50 km
0
OTTER
OTTER
OTTER
OTTER
OTTER
MIKOT004
MIKOT003
OTTER
MIKOT001
MIKOT002
OTTER
OTTER
OTTER
COLUMBIA
RIVER
Duncan
Kootenay


HARRISON
LAKE
Chehalis
L
Pitt L
Stove
L
MLFV001
MLFV002
Cultus
L
Chilliwack L
0
25 km
LOWER FRASER VALLEY

resolution GC/MS), organochlorines and coplanar PCBs. Mink collected subsequently have been stored frozen for later examination and analysis.

The 32 otters were weighed and external measurements (total length, tail length) were taken. The baculum was excised and measured with an electronic micrometer (length and width) and archived frozen. One each upper and lower canine were collected for aging. Samples were then dissected as follows: From each animal, selected organs were excised with a stainless steel knife and forceps (washed with hexane between dissections), weighed and examined by a veterinary pathologist according to a protocol developed by the U.S. Biological Survey for a related study in the lower Columbia River. Livers were divided into three portions and placed in separate hexane-washed, heat-treated jars. One subsample from each liver was delivered to Zenon Environmental Laboratories (Bumaby, B.C.) for trace organic analysis of composite samples, and two to the Environment Canada Pacific Environmental Science Centre (PESC) for heavy metals and trace organics analysis of individual samples. Composite analyses by Zenon were: 12 otter from the Kootenay system, one from the lower Columbia River, six from the lower Fraser River (these were further divided into two composites of three otter each), seven from the upper Columbia (these were further divided into two composites of three and four otter, respectively), and six from the upper Fraser River.

Quality Contol

One of the six mink liver samples was split and submitted as a blind duplicate (labeled as a separate sample) to Zenon. Zenon met standard QA/QC requirements of provincial contracts including analysis of certified reference samples, blanks, a laboratory duplicate and internal standard samples. One reference sample was supplied by B.C. Environment and one by the National Wildlife Research Centre, Environment Canada, Ottawa. Two of the kidney samples submitted to the Pacific Environmental Science Centre were homogenized and split for replicate analyses, and a standard QA blend reference material was analyzed in triplicate.

For otter livers, three of the PESC samples for metals were homogenized and replicated, and three standard reference samples (DOLT - 2 liver) were included in the batch. With the batch submitted to Zenon, QA/QC procedures, as for the mink samples submitted earlier, were followed.

Preliminary Results

Chemical

Chemical analytical results for the six mink (two from the Kootenay River, two from the Slocan River [tributary to the Kootenay] and two from the lower Fraser River) have been received.

Metals in kidney were higher (about 1 - 6 µg/g dry wt.) in the Kootenay system (including Slocan) than in the lower Fraser Valley (<1µg/g). Lead and mercury were not significantly different between the two systems; mercury was about 1 - 6 µg/g in both.

Organic analysis results by Zenon were blank-corrected (not corrected for surrogate recoveries) and reported as µg/g wet weight except for coplanar PCBs which were reported as ng/g wet weight. Neither dioxin nor furan were detected (low-res MS). Other chlorinated organics and pesticides were low (generally lower than 0.1µg/g) or not detected, although somewhat different patterns were seen in lower Fraser vs. Kootenay system mink. PCB 18, 28, 33, 44, 118, 153, 105, 138, 182/l 87, 180, 170 and 194 were detected in mink livers from both areas. PCB 70/76, 101, 87, 110 and 149 were detected in the Kootenay system but not the lower Fraser, while PCB 156 was found in the Lower Fraser Valley mink but not in those from the Kootenay system. Within the Kootenay system, PCB 28, 33, 22, 183 and 128 were found in Slocan River mink, while mink from the Kootenay River below the Skookumchuk pulp mill had PCB 52,70/76, 66/95, 56/60, 101, 87, 110, 149 and 146. Overall levels in total (sum of congener-specific) PCBs between the lower Fraser Valley and the Kootenay system were not different.

Coplanar PCBs 77 and 126 were found in mink from below the Skookumchuk mill and in the lower Fraser Valley (where they were slightly higher), but not in Slocan River mink.

Pesticides found in both the Kootenay system and the lower Fraser Valley were heptachlor epoxide, hexachlorobenzene and oxychlordane. In addition, DDE, dieldrin and endosulfan II were found in the lower Fraser Valley.

Quality Control and Variation

PESC analyses of heavy metals included two replicates and two standard reference samples. Most of the two sets of replicates analyzed by ICP were acceptable (40% variation), but the graphite furnace gave a couple of odd results. In a Kootenay mink kidney, the GF reported no detectable cadmium, but the ICP result was 3.8 µg/g; likewise, one of the replicates reported no cadmium by GF, whereas its mate had 6.3 µg/g by GF, and 7.8 µg/g by ICP. These results were discussed with the analyst, and no reason for the discrepancies were discovered. If the ICP result was the more accurate (if not as precise), then the cadmium levels based on GF may be underestimated. All other samples were consistent between the GF and ICP results, between the two pairs of replicates.

A whole liver sample split (not homogenized) during sample preparation and submitted to Zenon as a separate sample was almost identical to its mate, although a number of individual PCB congeners varied by up to about 50% at the ppb level. An internal laboratory duplicate analysis varied about the same. The blanks were blank and the reference materials were within accepted limits of the certified values.

Biological

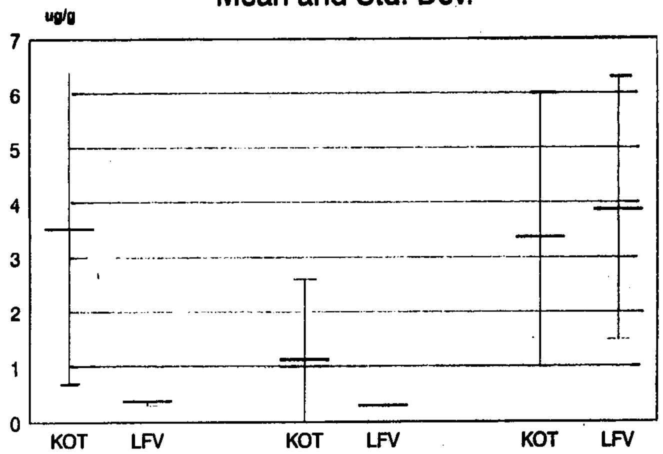
Few gross abnormalities were observed in the various otter examined, and most specimens were healthy and fat, although some had no fat. Fish bones and scales were seen in several stomachs. A few parasites (nematodes) were seen in one individual. One female had an enlarged spleen and no fat. A male had a missing kidney and an undescended testis. Another had no testes. Total body length was weakly correlated with weight, but baculum length in males was not correlated with total body length, as would have been expected. Except as noted, and testes were present in all males, except where the trapper was incautious with the knife during skinning. No other obvious signs of reproductive impairment were observed in males or females. One female had two fetuses. When chemical analytical results are received, the organ measurements will be compared with contaminant levels.

Conclusions

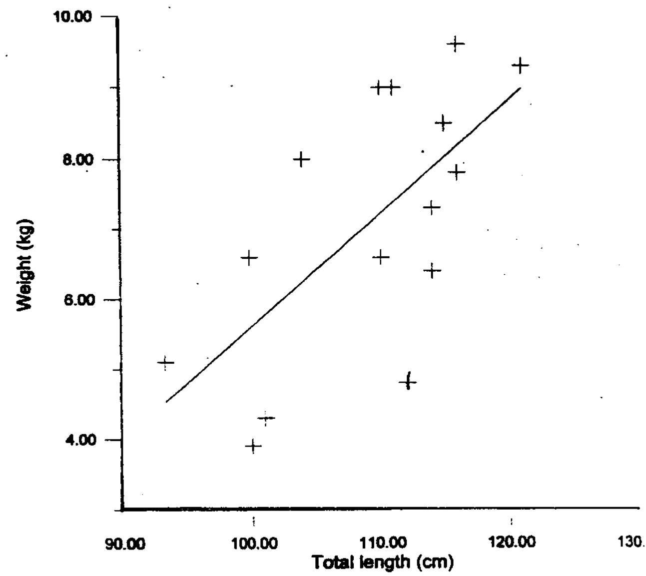
These mustelids are relatively healthy and uncontaminated, but not free of environmental contaminants that have become widely distributed. Mink from the Columbia River system had a greater variety of PCB congeners, and those from the lower Fraser Valley had a greater variety of pesticide residues.

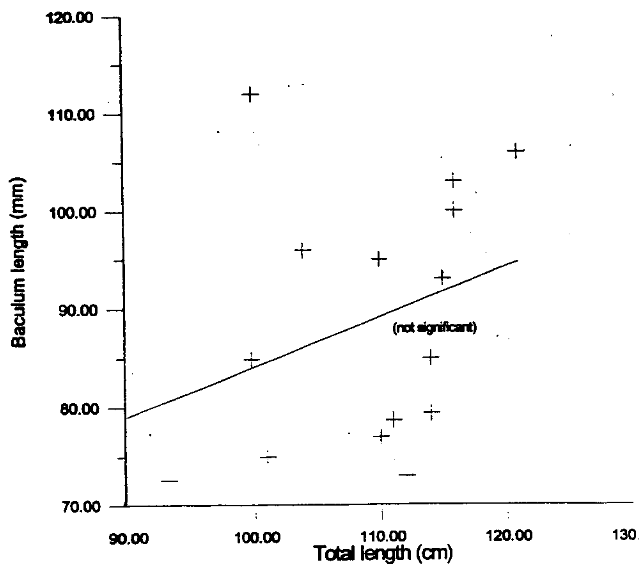
Heavy Metals in Mink Kidneys

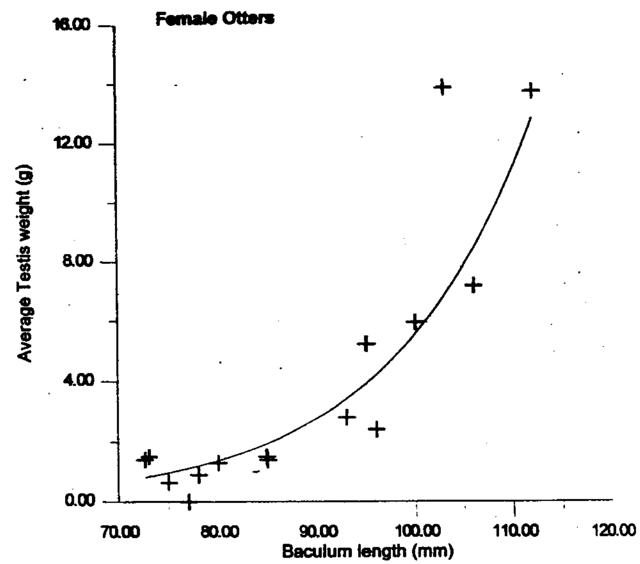
Mean and Std. Dev.



KOT=Kootenay, n=4; LFV=Lower Fraser Valley, n=2







Testis weight and baculum length in river otters

Effects of Pulp Mill Effluent on Benthic Communities in the Upper Fraser and Lower Thompson River Systems

J.M. Culp, K.J. Cash and R.B. Lowell

National Hydrology Research Institute

Experimentation using field-based artificial streams provides a promising, complimentary approach to biomonitoring assessments because artificial streams provide control over relevant environmental variables and true replication of treatments.

We have used large and small artificial stream systems, based in the field, to examine the effect of treated bleached Kraft pulp mill effluent (BKME) on the benthos of the Fraser and Thompson rivers. Under natural regimes of temperature, water chemistry and insolation, these artificial streams provide current velocities and substrata to food chains or food webs that are representative of those in the study river. With these tools, we have shown that BKME treatments increased algal biomass and invertebrate density in the Fraser River. While BKME treatments did not change diatom species richness or diatom species diversity, insect familial richness in the Fraser River was reduced by exposure to 1% and 3% BKME.

In the Thompson River, BKME stimulated mayfly growth above that which could be accounted for by fertilization of their algal food supply. In contrast, moulting frequency was inhibited at high BKME concentrations. Results from the Thompson River artificial stream experiments also indicated that increased algal biomass and abundances of benthic invertebrates downstream of BKME outfalls were induced by nutrient enrichment from the effluent. Our experimental results helped to explain long-term (20-year) patterns in invertebrate community structure in the Thompson River and provided the opportunity to examine the effect on environmental assessments of using different sampling frequencies (one to three per year) for environmental effects monitoring (EEM) programs.

Conclusions

In summary, the integration of field monitoring data with results from artificial stream experiments provides a means of understanding the mechanisms of stressor effects over a continuum ranging from single stressor effects on specific taxa to the effects of multiple stressors on communities and ecosystems.

Modelling the Fate of Contaminant Discharges in the Fraser River Basin

F.A.P.C. Gobas

School of Resource and Environmental Management
Simon Fraser University

Abstract

The objective of this project was to develop and test a simulation model of the environmental and ecological fate of organic chemical discharges in the Fraser-Thompson River basin. The main purpose of this model was to:

1. assess and verify the impacts of discharge of contaminants in the Fraser River from single and multiple sources and the resulting concentrations of these substances in water, sediments, benthic invertebrates and fish throughout the Fraser River basin as a function of time and during different seasons in the year;
2. determine whether existing contaminant loadings from point and non-point sources will meet environmental quality guidelines and standards and human consumption guidelines within the Fraser-Thompson River basin;
3. recommend targets for remediation on a whole-basin basis;
4. aid in the interpretation of data collected in monitoring programs;
5. establish guidelines with regards to the experimental design of contaminant and environmental effects monitoring (EEM) programs within the basin;
6. assess the time response of the contaminant concentrations throughout the Fraser River basin to changes in contaminant emissions under various loading scenarios; and,
7. identify data gaps and targets for research.

Summary

- We developed and tested a novel and truly time-dependent food chain bioaccumulation model, which, as far as we know, is the first truly time-dependent food chain bioaccumulation model for contaminants. In contrast to our earlier model, this new model is able to simulate the effect of seasonal and life-time changes in organism weight, lipid content and diet composition of fish and benthic invertebrate species. Each generation or age-class of organisms is now treated independently. This makes it possible to:
  - (i) stimulate changes in chemical concentrations that occur seasonally and throughout the life-span of the organisms;
  - (ii) compare contaminant levels between age-classes since several generations coexist at one time; and,
  - (iii) represent inter-generational transfer of contaminants between adults and their respective off-spring.
- We compiled new data regarding the growth rates, changes in lipid content and age-dependent feeding behaviour for Rocky Mountain whitefish, rainbow trout and large-scale sucker in the Fraser and Thompson rivers and in Kamloops Lake. These data are used to build the food chain bioaccumulation model.
- A new algorithm for simulating dietary uptake is included in the bioaccumulation model based on studies described in Gobas *et al.*, 1993.
- Emission records of 2,3,7,8-tetrachlorodibenzo-p-dioxin and 2,3,7,8-tetrachlorodibenzofuran from five pulp and paper mills were compiled. Effluent concentrations were multiplied by the reported average

pulp and paper mill effluent discharge rate to derive contaminant loadings in units of grams per day. These loadings were used to conduct model simulations.

- Reported concentrations of 2,3,7,8-tetrachlorodibenzo-p-dioxin and 2,3,7,8-tetrachlorodibenzofuran in water, sediments and fish of the Fraser and Thompson rivers for the period of 1989 to 1993 were compiled. These data were used to verify model predictions and to derive model uncertainty.
- An initial model verification was conducted by comparing available observed and predicted concentrations for the time period from 1989 to 1993. The results were compiled and are graphically illustrated in Figures 1 and 2.

  Figure 1 illustrates the agreement between observed and predicted concentrations of TCDF in the organic carbon of sediments at various locations in the Fraser and Thompson rivers. The quality of agreement between observed and predicted TCDF concentrations in river bed sediments can be expressed by the mean ratio of the observed and predicted concentrations of TCDF in the sediments, which is 1.33, suggesting the model slightly under-predicts the observed concentrations. The 95% confidence limits of the model predictions range by a factor of 1.7 of the mean, suggesting that 95% of the observed sediment concentrations are approximately within a factor of 1.7 of the predicted concentrations. The uncertainty introduced in the model due to year-to-year variability in monthly river flow rates, river compartment widths and depths, concentration in suspended sediments, organic carbon content of suspended sediments and water temperature is represented in Figure 1 by the error bars which are 95% confidence limits of the mean derived through Monte Carlo Simulation. The 95% confidence limits range between a factor of 1.0 to 2.3 of the mean among the various compartments in the Fraser River and between a factor of 2.2 to 4.5 in the Thompson River. This means that year-to-year variability in the above mentioned model parameters is expected to cause variations in TCDF concentrations in the sediments that range between a factor of 2.0 to 4.5 depending on the location in the rivers. With the exception of the TCDF concentration observed in the Fraser River estuary (i.e., Compartment 18), all observed TCDF concentrations in the sediments of the Fraser and Thompson rivers are within the 95% confidence limits of the predicted concentrations. The higher TCDF concentration in the Fraser River estuary may be explained by local sources of TCDF, which are ignored in this study, as the Fraser River estuary is located in a highly industrialized part of Vancouver.

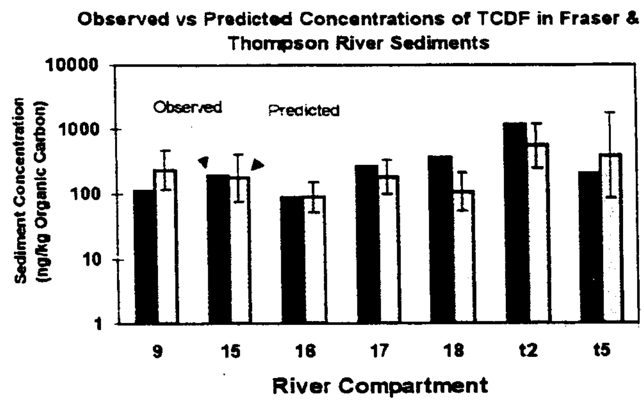


Figure 1: Observed and predicted concentrations of TCDF in Fraser and Thompson river sediment.

The ability of the model to predict concentrations of dioxins and furans in Rocky Mountain whitefish is illustrated in Figure 2. This figure illustrates that there is a reasonable agreement between observed and predicted concentrations.

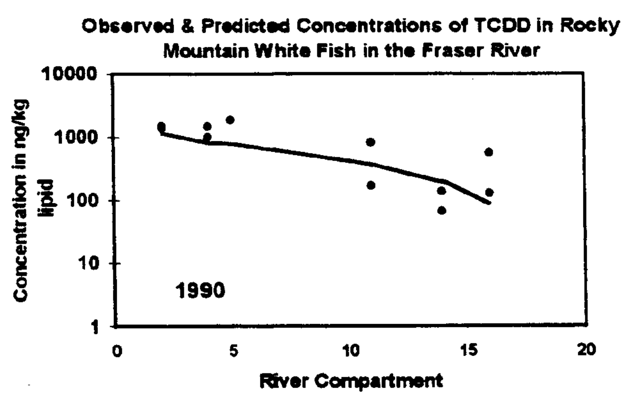


Figure 2: Observed and predicted concentrations of TCDD in Fraser and Thompson river Rocky Mountain whitefish.

- Monte Carlo simulations were conducted to investigate the impact of uncertainty in model input parameters on predicted concentration in water and sediment, but not on the concentrations in fish and other biota.
- The uncertainty of the model prediction was expressed in terms of 95% confidence limits. These limits of the predicted concentrations contain 95% of the observed concentrations.
- We have incorporated a sediment transport model for fine sediment, developed by Dr. B.G. Krishnappan. We are currently parameterizing this model for the Fraser River with the help of Dr. M. Church.

Chlorophenol Effects on the Early Development and Growth of White Sturgeon

B. Bennett and A.P. Farrell

Biological Sciences
Simon Fraser University

Objective

To quantify specific effects of selected chlorinated guaiacol, catechol, and vanillin compounds on early development stages of white sturgeon under controlled conditions of exposure in a laboratory setting.

Rationale

White sturgeon are regarded as a valued component of the Fraser River ecosystem. Sturgeon have been lost from other large river systems through anthropogenic impacts. There is no toxicological information on the sensitivity of juvenile sturgeon to components of pulp mill effluents. There is insufficient information to determine whether or not juvenile sturgeon might act as a sentinel species for the Fraser River.

Approach

The large quantity of fertilized eggs that are required for toxicity testing cannot be obtained in B.C. We, therefore, had to secure a supplier and transportation method to bring fertilized eggs rapidly from California to B.C. since hatching is completed in about one week.

There are no published methods for toxicity testing with juvenile sturgeon. We, therefore, developed our own testing techniques through trial and error, and based on advice from others.

The selection of test chemicals, made by Environment Canada, was intended to reflect chemicals of concern in the Fraser River. The test chemicals in 1994 were 5-monochlorovanillin, 4-chlorocatechol and 3,4,5,6-tetrachloroguaiacol. The test chemicals in 1995 were 6-monochlorovanillin, 4,5-dichlorocatechol and 4,5-tetrachloroguaiacol. In addition, the anti-sapstain, DDAC, was tested in both years and pentachlorophenol was tested as a reference chemical in 1995.

Conclusions

1. We were successful in transporting, hatching and rearing several thousand eggs during the two-year period. The transplant permit required that all fish were killed upon completion of the experiments.
2. In contrast to our experience with salmonid eggs, sturgeon eggs and larvae are very sensitive to environmental changes and handling, which can both lead to mass mortality. The transition from feeding larvae to feeding fry invariably is associated with a high mortality.
3. Toxicity testing with eggs was deemed unsuccessful due to variability in the results. In part, the problem may relate to eggs clumping even after the de-adhesion process.
4. The toxicity testing with larvae and fry was more successful. Estimates for LC_0, LC_{50} and LC_{100} are presented in Table 1. We have greater confidence in the 1995/96 results because methods were refined by the second year of testing. Nonetheless, there is good agreement between the test results in 1994 and 1995 for DDAC.
5. The data for 1995 show a clear and substantial decrease in sensitivity towards the test chemicals with increasing development age. Larvae were one to two orders of magnitude more sensitive than the feeding fry.

6. The acute toxic range for larvae to chlorinated phenols was typically between 10 ppb and 100 ppb. Larvae were more sensitive to DDAC.
7. The acute toxic range for feeding fry to chlorinated phenols was typically between 1 ppm and 10 ppm. Feeding fry were more sensitive to DDAC.
8. There are no comparative data for the toxicity of the chlorinated phenolic test chemicals for other fish larvae.
9. Sturgeon fry have a similar acute toxicity to 3,4,5,6-tetrachloroguaiacol and 4-chlorocatechol as found in previous studies with juvenile bleak and pink salmon, and are at least five times more sensitive to pentachlorophenol compared with a variety of other fish.
10. Sturgeon fry and larvae are considerably more sensitive (100 - 1,000 times) to DDAC compared with the other juvenile fish we have tested.
11. Studies of growth rates following sublethal exposures were unsuccessful. The post-exposure death rate was progressive for controls and for exposed fish (Figure 1). However, there was a marked pulse of mortality after each handling to measure body mass. Interestingly, some of the survivors of test chemical exposure shower excessive mortality following handling. These observations point to, but provide no conclusive evidence, multiple stresses being a particular threat to juvenile sturgeon.

Recommendations

1. A source of white sturgeon eggs in B.C. needs to be established.
2. A standardized rearing and testing protocol needs to be established. We have only begun to understand all the possible variables. Focus should be placed on acute toxicity testing of larvae and feeding fry, since these life stages appear to be viable options. However, we do not feel that testing with sturgeon eggs will produce consistent or reliable data. A different protocol to the one we used, possibly involving less handling of the fish, will be needed before successful studies of juvenile growth are practical.
3. Relevant environmental chemical concentrations and the rate of chemical degradation must be obtained in order to evaluate the consequences of exposure. A chemical transportation/fate model might be useful here.
4. Information on the biology of white sturgeon is needed in order to determine where juveniles reside and, therefore, what the actual chemical exposure might be.

Table 1: Acute Toxicity Results

1994

3,4,5,6 TETRACHLOROGUAIACOL (ppm)

	LC_0	LC_{50}	LC_{100}
LARVAE	1	1.0-10	10
FRY	1	1.0-10	10

5, MONOCHLOROVANILLIN (ppm)

	LC_0	LC_{50}	LC_{100}
LARVAE	1	1.0-10	10
FRY	0.5	0.5-5	5

DIDECYL-DIMETHYL-AMMONIUM-CHLORIDE(ppm)

	LC_0	LC_{50}	LC_{100}
LARVAE	<0.00001	0.001	0.0001
FRY	<0.00001	0.001-0.01	0.01

1995

4,5 DICHLOROGUAIACOL (ppm)

	LC_0	LC_{50}	LC_{100}
LARVAE	<0.001	0.001-0.01	0.01
FRY	0.1-1.0	0.1-10	10

6, MONOCHLOROVANILLIN (ppm)

	LC_0	LC_{50}	LC_{100}
LARVAE	<0.001	<0.001	0.001
FRY	<1	<1	10

DIDECYL-DIMETHYL-AMMONIUM-CHLORIDE(ppm)

	LC_0	LC_{50}	LC_{100}
LARVAE	<0.00005	<0.00005	0.00005
FRY	0.00001	0.001-0.01	0.01

4,5 DICHLOROCATECHOL (ppm)

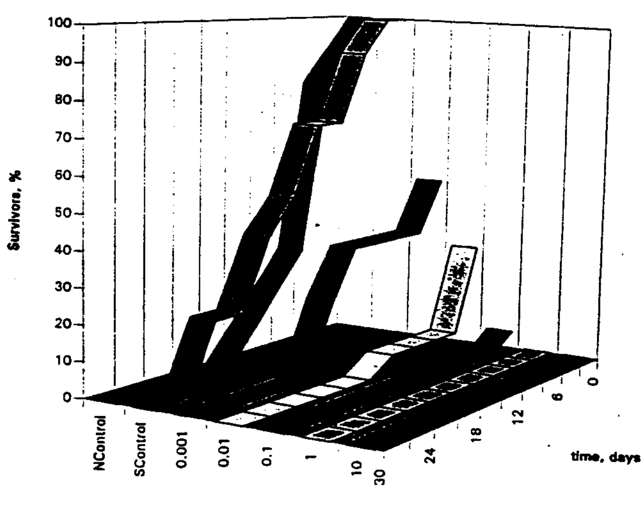
	LC_0	LC_{50}	LC_{100}
LARVAE	<0.001	0.01*	0.1
FRY	0.01	0.51*	10

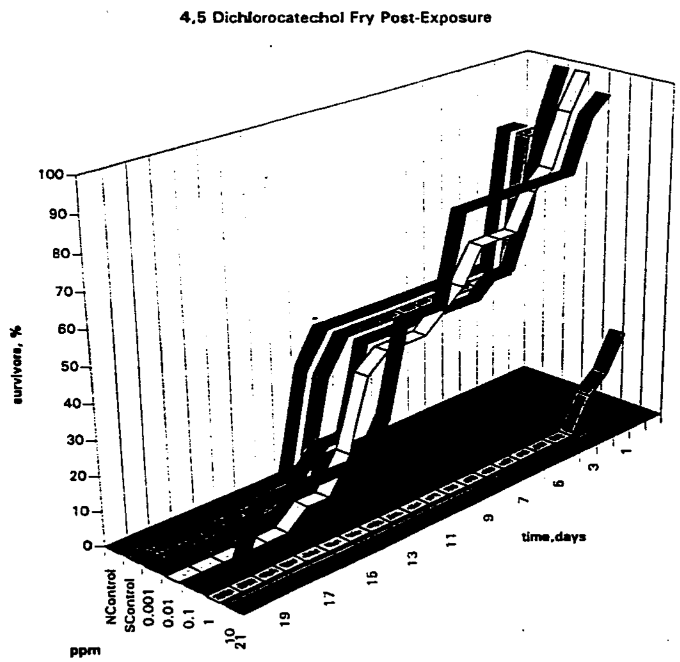
PENTACHLOROPHENOL (ppm)

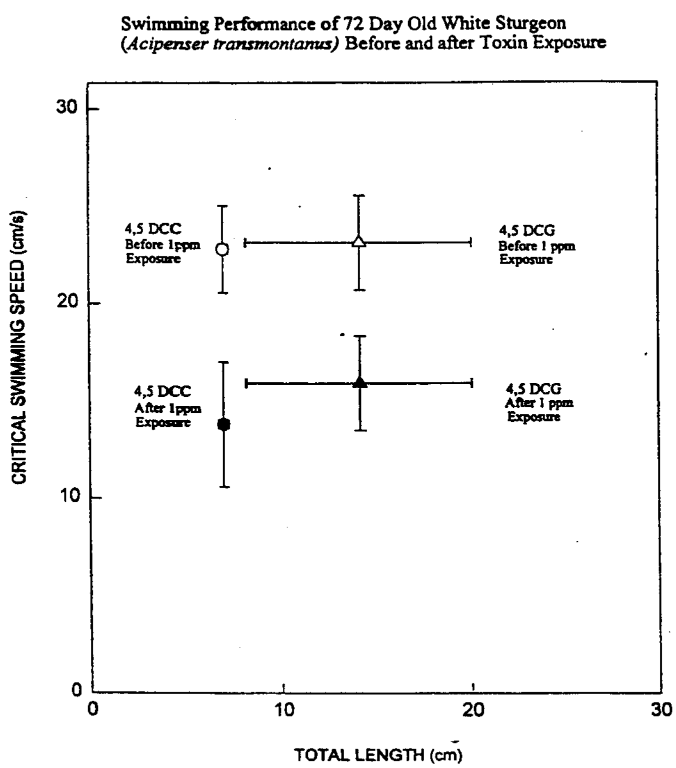
	LC_0	LC_{50}	LC_{100}
FRY	0.01	0.01-0.5	0.5

* = probit analyses, 95% confidence limits
nc & sc 1995 = 100% survivors
nc 1994 larvae and fry = 100% survivors
sc 1994 larvae = 0 survivors
sc 1994 fry = 100 % survivors, except 90% DDAC

4,5 Dichlorocatechol Larvae Post-Exposure




4,5 Dichlorocatechol Fry Post-Exposure
survivors, %
100
90
80
70
60
50
40
30
20
10
0
NControl
SControl
0.001
0.01
0.1
1
10
ppm
21
19
17
15
13
11
9
7
5
3
1
time,days


Swimming Performance of 72 Day Old White Sturgeon
(Acipenser transmontanus) Before and after Toxin Exposure
CRITICAL SWIMMING SPEED (cm/s)
30
20
10
0
4,5 DCC
Before 1ppm
Exposure
4,5 DCG
Before 1 ppm
Exposure
4,5 DCC
After 1ppm
Exposure
4,5 DCG
After 1 ppm
Exposure
0
10
20
30
TOTAL LENGTH (cm)

SESSION 2

TRANSPORT AND SEDIMENTATION OF CONTAMINANTS

Contaminants in Wastewater Biosolids (Suspended Solids)

G. Derksen

Environment Canada

A limited number of wastewater biosolids have been collected from various industrial (pulp mills) and municipal discharges (sewage treatment plants, combined sewer overflows) in order to characterize suspended solids-associated contaminants (Table 1). The solids were separated from the main effluent discharge using a continuous-flow centrifuge operating at 4 L/min.

In cases where whole effluent samples were also collected on the same day that centrifuge samples were collected (e.g., PAHs), the solids had a greater number of compounds (Table 2).

Conclusions

The results for dioxins/furans are shown in Figures 1 and 2, PAHs in Figures 3 and 4, coplanar PCBs in Figure 5 and chlorinated pesticides in Figure 6. For one municipal sample, the centrifuge was passed through a XAD-2 resin column; both the centrifuged solids and eluted column were analyzed for PAHs. The results clearly demonstrated the association of higher 1ogKow compounds with the solids (Figure 7).

TABLE 1: BIOSOLIDS SAMPLE (1993-1995) AND METHOD SUMMARY

Sample	Date		Dioxin & Furan	PAH	Aroclor	PCB Congeners	Co-planar	Chlorinated Pesticide	Chlorinated Pesticide	Chlorinated Phenolics
						ortho		non & med polar	highly polar	
NWood	Nov 04/93		HRGC/HRMS	HRGC/MS	HRGC/MS	HRGC/MS	HRGC/HRMS			HRGC/MS
	Oct 25/94		HRGC/HRMS	HRGC/MS	HRGC/MS	HRGC/HRMS	HRGC/HRMS			HRGC/MS
CFOR	Nov 05/93		HRGC/HRMS	HRGC/MS	HRGC/MS	HRGC/MS	HRGC/HRMS			HRGC/MS
	Nov 23/93		HRGC/HRMS	HRGC/MS	HRGC/MS	HRGC/MS	HRGC/HRMS			HRGC/MS
	Oct 24/94									HRGC/MS
QRP	Nov 01/93		HRGC/HRMS	HRGC/MS	HRGC/MS	HRGC/MS	HRGC/HRMS			HRGC/MS
CBOO	Nov 02/93		HRGC/HRMS	HRGC/MS	HRGC/MS	HRGC/MS	HRGC/HRMS			HRGC/MS
Weyer	Nov 08/93		HRGC/HRMS	HRGC/MS	HRGC/MS	HRGC/MS	HRGC/HRMS			HRGC/MS
PG STP	Nov 03/93		HRGC/HRMS	HRGC/MS	HRGC/MS	HRGC/MS	HRGC/HRMS	HRGC/MS	HRGC/ECD	HRGC/MS
AI STP	Mar 03/94		HRGC/HRMS	HRGC/MS	HRGC/MS	HRGC/MS	HRGC/HRMS	HRGC/MS	HRGC/ECD	HRGC/MS
	Aug 22/95		HRGC/HRMS	HRGC/MS	HRGC/MS	HRGC/MS	HRGC/HRMS	HRGC/MS	HRGC/ECD	HRGC/MS
	Nov 21/95		HRGC/HRMS	HRGC/MS	HRGC/MS	HRGC/MS	HRGC/HRMS	HRGC/MS	HRGC/ECD	HRGC/MS
LI STP	May 12/94		HRGC/HRMS	HRGC/MS	HRGC/MS	HRGC/MS/ECD	HRGC/HRMS	HRGC/MS	HRGC/ECD	HRGC/MS
CI CSO	Mar 22/93		HRGC/HRMS	HRGC/MS						
	Apr 06/94		HRGC/HRMS	HRGC/MS	HRGC/MS	HRGC/MS/ECD	HRGC/HRMS	HRGC/MS	HRGC/ECD	HRGC/MS

Table 2: COMPARISON OF NUMBER OF PAH COMPOUNDS IDENTIFIED FOR WHOLE EFFLUENT AND CENTRIFUGE SOLIDS

WASTEWATER	WHOLE EFFLUENT	SUSPENDED SOLIDS
Pulpmill	0	7
Pulpmill	4	11
CSO	3	15
CSO	8	17

Fig. 1 : BIOSOLIDS DIOXIN AND FURAN LEVELS

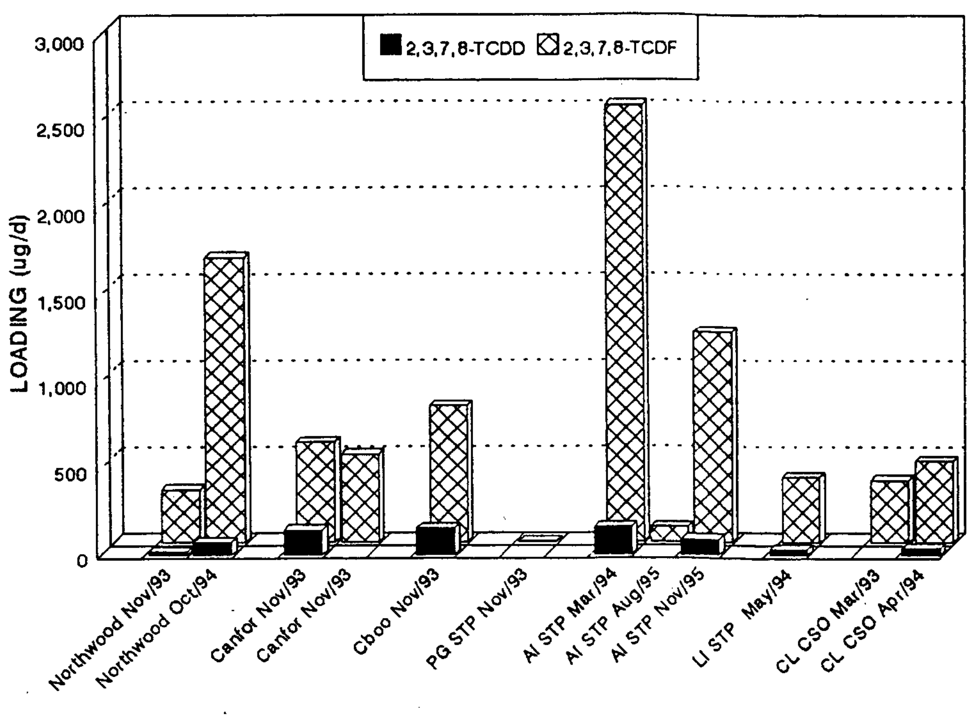


Fig. 2 : BIOSOLIDS DIOXIN AND FURAN LEVELS

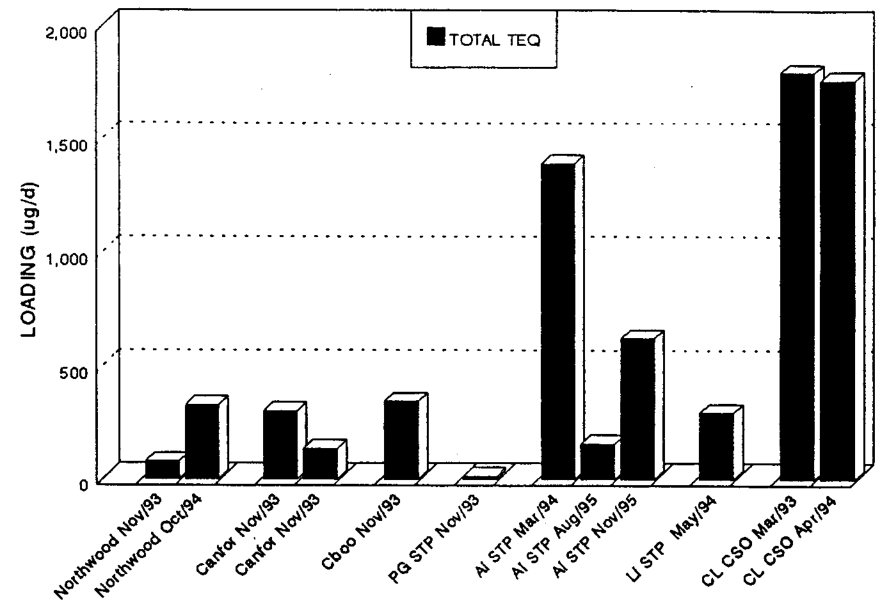


Fig. 3 : BIOSOLIDS PAH LEVELS

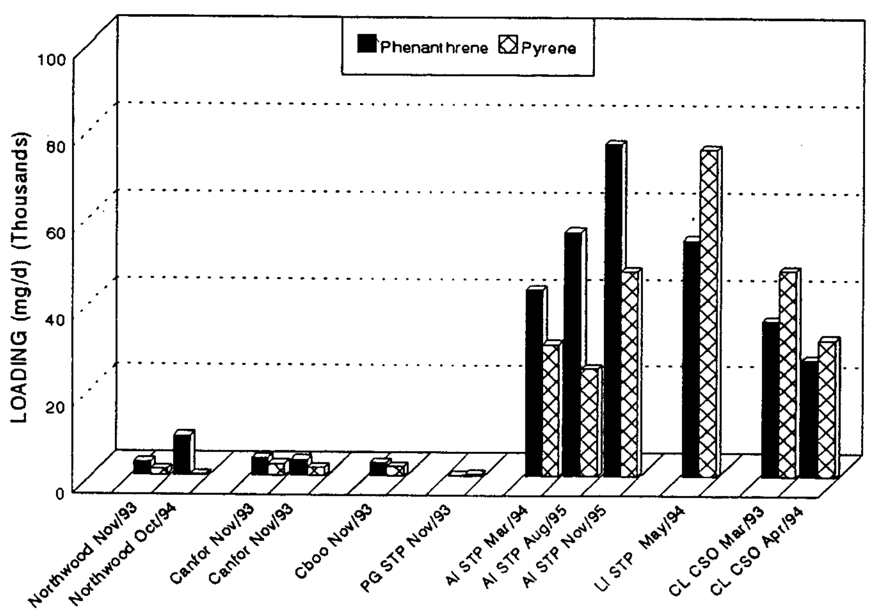


Fig. 4 : BIOSOLIDS PAH LEVELS

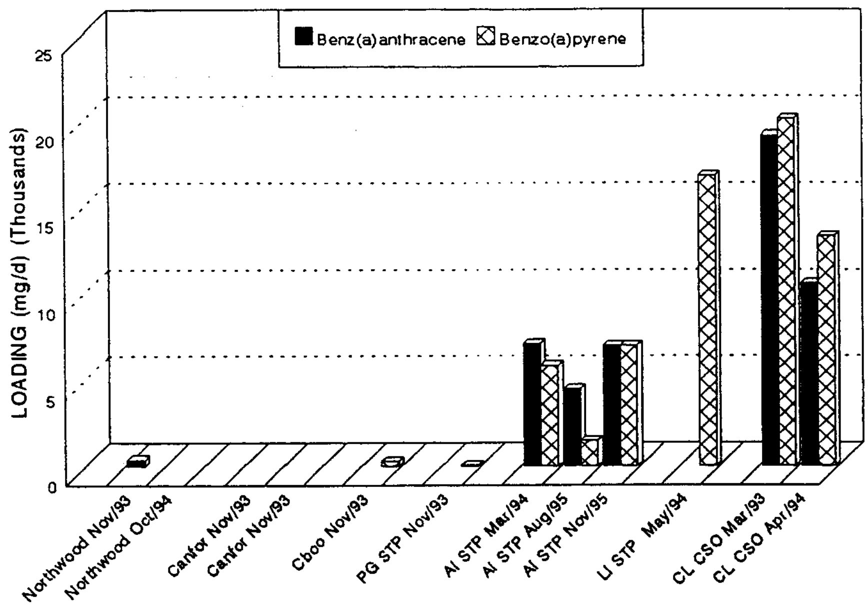


Fig. 5 : BIOSOLIDS CO-PLANAR PCB

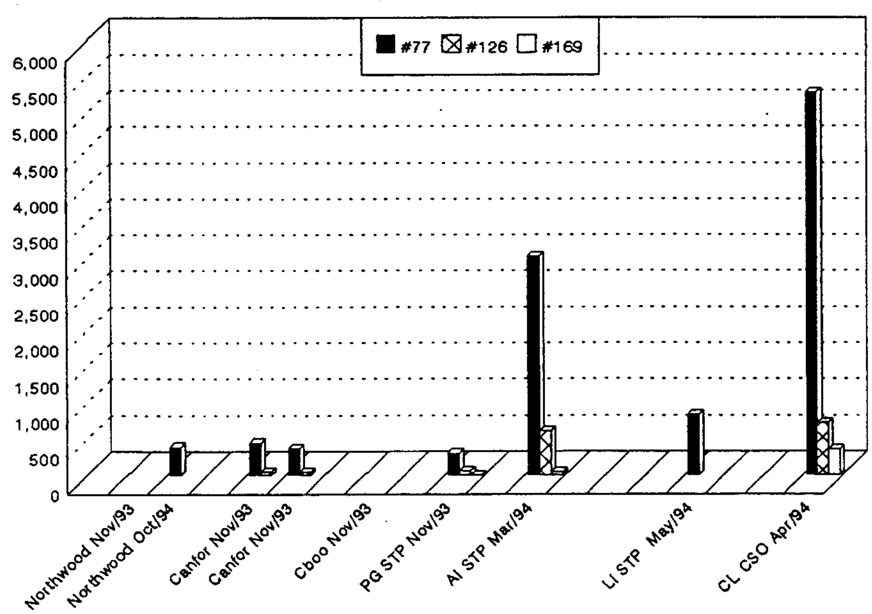


Fig. 6 : BIOSOLIDS CHLORINATED PESTICIDES

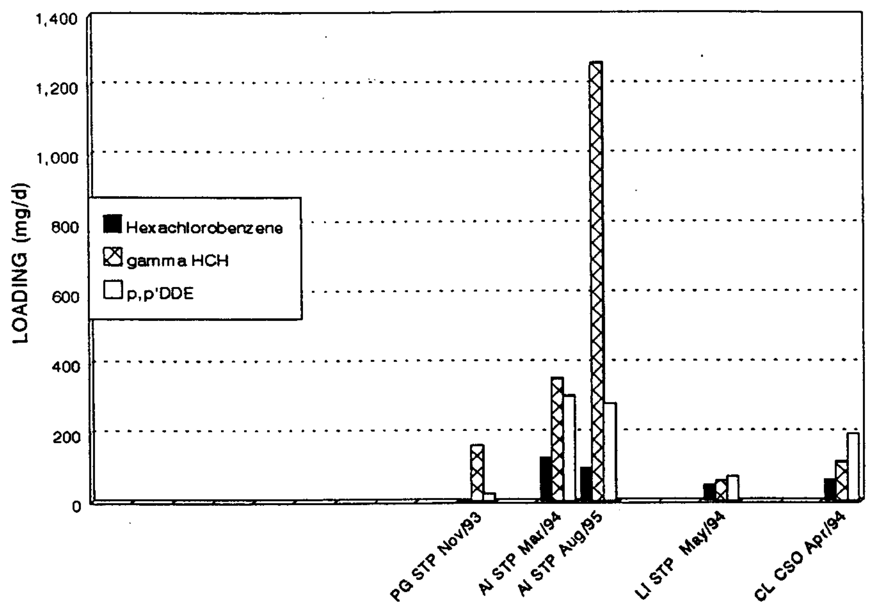
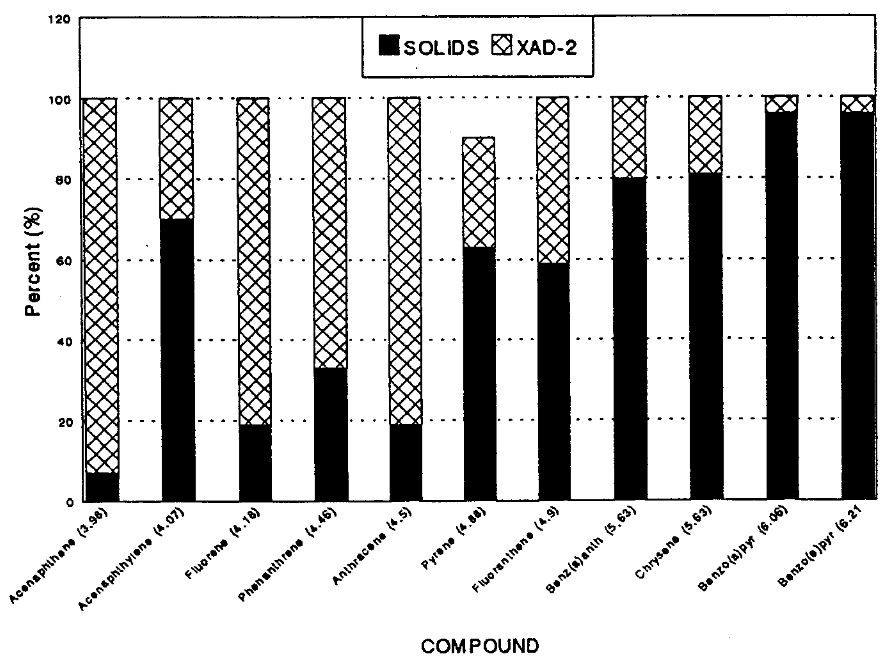


Fig. 7: PAH PARTITIONING



Effluent Dispersion from the Landsdowne Road Wastewater Treatment Centre, Prince George

D. Hodgins

Seaconsult Marine Research Ltd.

Summary

On October 13, 1993, an effluent plume delineation study was carried out at the Prince George Landsdowne Road Wastewater Treatment Centre to evaluate performance of the outfall in terms of dilution rate and distribution of the effluent down-river.

A fluorescent red dye was added to the effluent stream to act as a measurable tracer of the effluent which allowed mapping of the plume from the diffuser to 12 km downstream. During the survey, the Fraser River discharge at Prince George was approximately 400 m^3/s which was roughly 1,000 times the Lansdowne outfall discharge. Surveying with an *in situ* fluorometer successfully traced the dye effluent to concentrations of less than 0.05% with positional accuracy of +/-5 m in the horizontal.

Initial dilution was rapid from 100% effluent concentration in the diffuser to 0.65% or less within 250 m of the outfall and vertical mixing was complete at 1 km. Beyond about 8 km no concentrations were observed anywhere in the river that exceeded 0.1% effluent. North of the 8-km section, there was no observed contact with the eastern shore.

Lateral mixing appeared to be inhibited by current shear zones separating the central, fast-moving core of the river (which contained most of the freshly discharged effluent) and relatively quiescent areas along some sections of the shorelines. Because mixing across the shear zones is slow, effluent in the quiescent waters will tend to be of older origin (i.e., discharged earlier) than effluent in the main river core.

The diffuser discharged effluent in two persistent jets that were separated by roughly 10 m. This characteristic appears to be indicative of the diffuser performance. No leaks were detected.

The Wastewater Plume Delineation Study for the Glenbrook CSO, New Westminster

D. Hodgins

Seaconsult Marine Research Ltd.

Summary

A wastewater plume delineation study for the Glenbrook combined sewer overflow (CSO) was conducted in February 1995 to assist in setting priorities for contaminant monitoring in the Fraser River estuary. The work was undertaken as part of the component of the Fraser River Action Plan concerned with identifying contaminants entering the Fraser River. The Glenbrook CSO discharges into Sapperton Channel at New Westminster, B.C. The wastewater plume was measured in the receiving water using a rhodamine dye tracer and a towed *in situ* fluorometer. Two injections of dye were made over two days for different stages of the tide. The dye plume was also observed on February 17 using the CASI multispectral imager flown on a small airplane. Three separate images were obtained.

The surveying methods were successful in accurately delineating the plume, particularly the areas of shore contact and the cross-channel width and depth of the plume. Estimates of secondary dilution were obtained. In general, it was found that the plume was confined to the north shore of the river, forming a narrow streak less than 100 - 150 m in width downstream of the outfall. The highest concentrations were observed next to the shore and the plume remained in continuous contact with the shore from the outfall to the North Arm of the estuary. The plume was carried upstream on the flood tide for a distance of 2,600 m, near the end of Sapperton Channel. The plume width was approximately 150 m wide in Sapperton Channel. Mixing was found to be most effective within 300 m of the outfall, producing a minimum dilution of about 60:1. Dilutions of 100:1 were observed at a distance of 850 m on ebb flows, and reached approximately 400:1 at the junction to the North Arm. Vertical mixing was found to be rapid, producing nearly-uniform concentrations over the water column within 200 m of the outfall.

Transport and Sedimentation of Fine Grain Sediments

M. Church, M. Hassan and H. Wetherley

Department of Geography
University of British Columbia

In this project, the Water Survey of Canada (WSC) historical archive of suspended sediment observations along Fraser River was analyzed to determine the regime of fine sediment transport in the river. This is by far the most extensive collection of sediment transport observations available in the basin, but it has limitations which must be understood. Most significantly, it consists of observations of clastic sediment coarser than about one micron. Very fine sediment is not included, and organic particles are not separated, identified or analyzed. Grain size distribution data are available for most higher flows, so that sediment ratings are accessible for selected sub-ranges.

We constructed the data set of all primary observations from WSC field notes using different (and statistically more rigorous) methods than were originally used by WSC. Our results were not systematically different than those originally reported, however. We constructed sediment rating surveys by size range and by year for all stations. In our current work, we are seeking to determine whether the individual ratings are distinct, or reflect a common underlying relation of sediment concentration in the water column to flow variates. The outcome of this exercise will be the key result of our analysis: if the relations are distinct from year to year, there is no alternative to continued monitoring if natural suspended sediment concentrations are required to be known.

The principal explanatory flow variates are current discharge and discharge 10 days prior. The latter variate reflects synoptic effects on sediment pickup processes along the channel margins. The rating curves are not simple. Commonly, they exhibit anticlockwise hysteresis (higher sediment concentration on the rising limb), which is common in rivers with supply-limited transport.

Stations available for analysis over many years between 1966 and the present include Hansard, upstream from Prince George; Marguerite Ferry, south of Quesnel; Hope, at the south end of Fraser Canyon; and Agassiz and Mission City within the Lower Mainland. These stations conveniently divide reaches with important contaminant sources and ones with potentially significant impact reaches, but they do not provide a high resolution within the Fraser and Thompson rivers.

Conclusions

Monitoring data of the type represented by WSC records can be incorporated into a model for the prediction of water quality along the river by setting a suspended sediment value at some known site (e.g., Hansard) and propagating suspended sediment downstream in a hydraulic model that includes sediment pickup and deposition. Two sorts of corrections are possible. At downstream stations, a new value can be introduced. Otherwise, knowledge of the location of major sources and sinks of fine sediment along the river can guide estimates of sediment recruitment rate between known stations. Knowledge of significant bank sources is available and sediment exchange with the bed can be computed (See Krishnappan, Engel and Stephens).

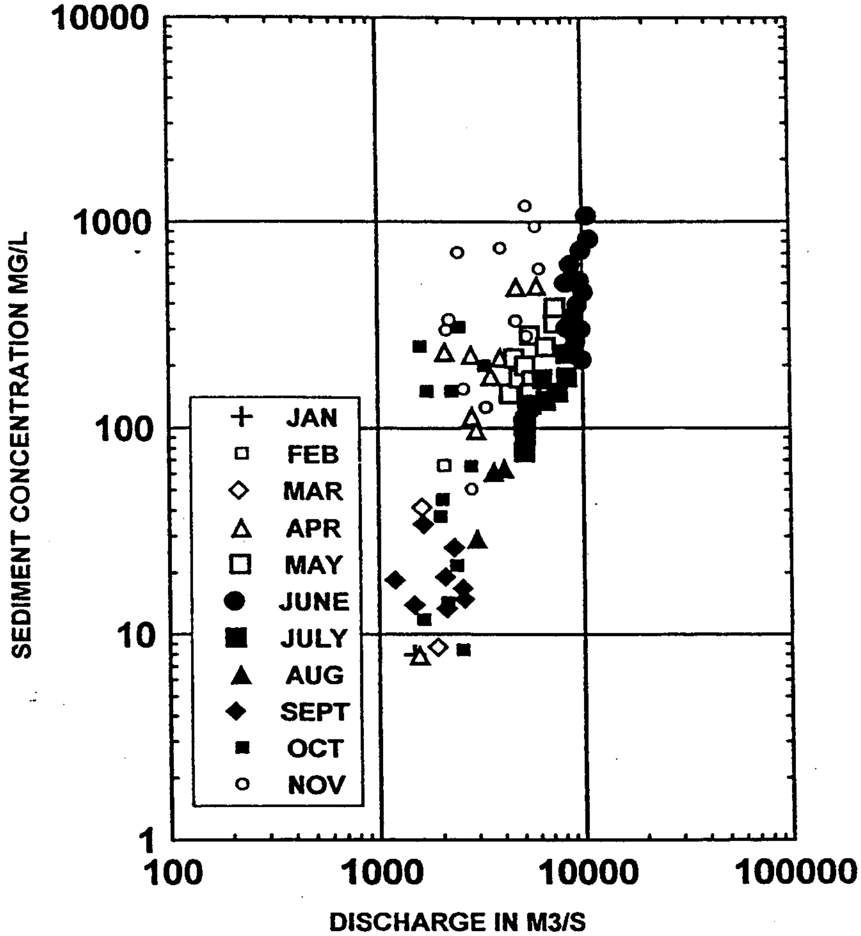


Figure 1. Sediment rating at Mission for 1990, based on all observations and all grain sizes.

Survey of Contaminants in Bed Sediment in the Fraser River Basin

M. Sekela, R. Brewer, C. Baldazzi, G. Moyle and T. Tuominen

Environment Canada

The objective of this program was to develop an indicator of contaminant stress in the Fraser River basin that could be used with other indicators developed through the Fraser River Action Plan to determine the current health of the basin ecosystem.

Bed sediment samples were collected from 14 reaches in the Fraser River basin. Four samples were collected per reach in order to characterize each reach. In the fall of 1994, samples were collected from the following 12 reaches: Fraser River - McBride to Prince George; Fraser River - Prince George to Quesnel; Fraser River - Quesnel to Lytton; Fraser River - Lytton to Chilliwack; Stuart River; Nechako River; Quesnel River; Chilcotin River; North Thompson River; South Thompson River; Thompson River and Harrison River. These reaches were resampled in the fall of 1995 as well as two additional reaches, the Fraser River - Main Arm and the Fraser River - North Arm. All samples were collected using a minimum of five Ekman grabs and will be analyzed for trace inorganic and organic contaminants.

Initial results from the 1994 samples indicated that the majority of the contaminants analyzed were below detection. However, PAHs and the higher chlorinated dioxins and furans (hexa, hepta and octa congeners) were detectable at all sites, 2,3,7,8-T4CDD was detectable at one site on the Thompson River and PCBs were elevated at one site on the South Thompson River. Interpretation of the 1994 data is continuing while the chemical analyses of the samples collected in 1995 has not been completed.

Program Objectives:

1) to develop an indicator of ecosystem stress in the Fraser River basin based on levels of persistent bioaccumulative toxic substances; and,
2) to determine the current level of persistent bioaccumulative toxic substances in Fraser River basin bed sediments.

Chemical Analyses:

Dioxins/Furans	Resin/Fatty Acids
PCBs	Nonylphenol
Chlorophenolics	Trace Metals
PAHs	Total Organic Carbon
Pesticides	Particle Size

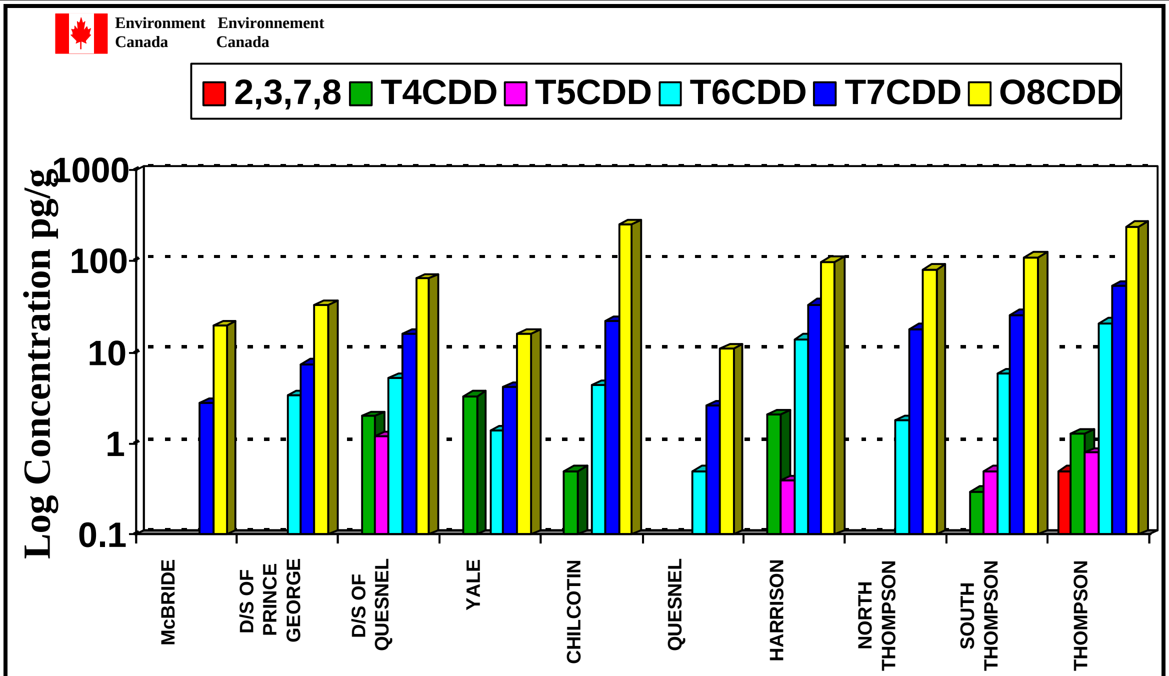
Project Deliverables:

⇒ provide new knowledge for environmental quality assessments and objectives

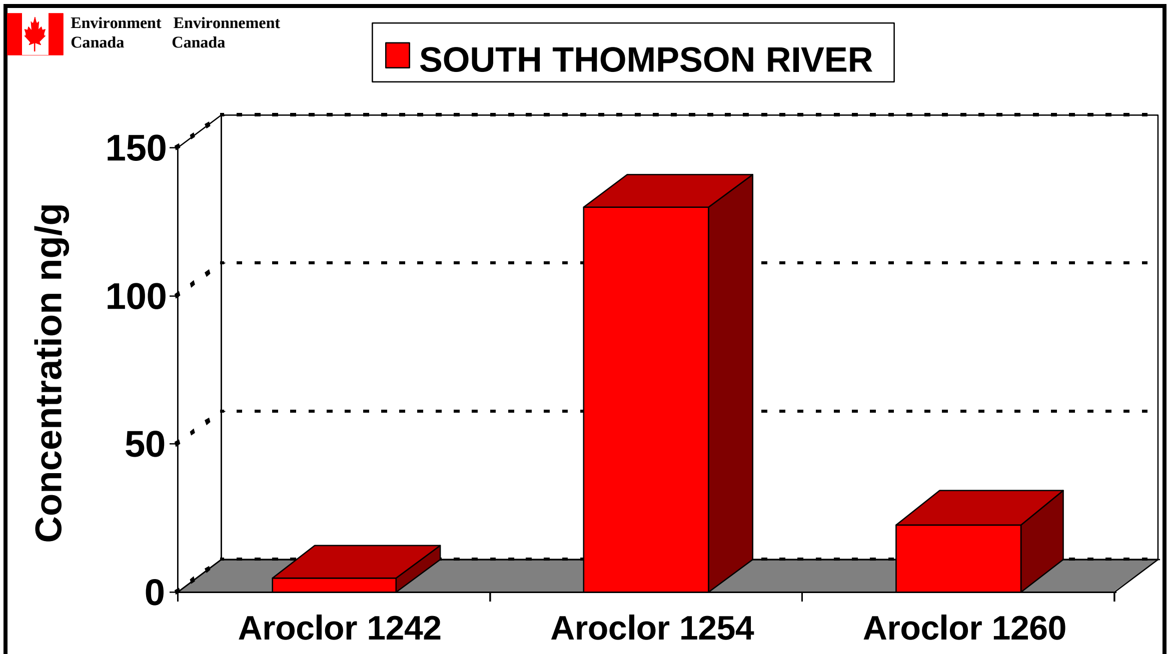
⇒ report on the condition of the basin

⇒ assess contamination from major pollution sources

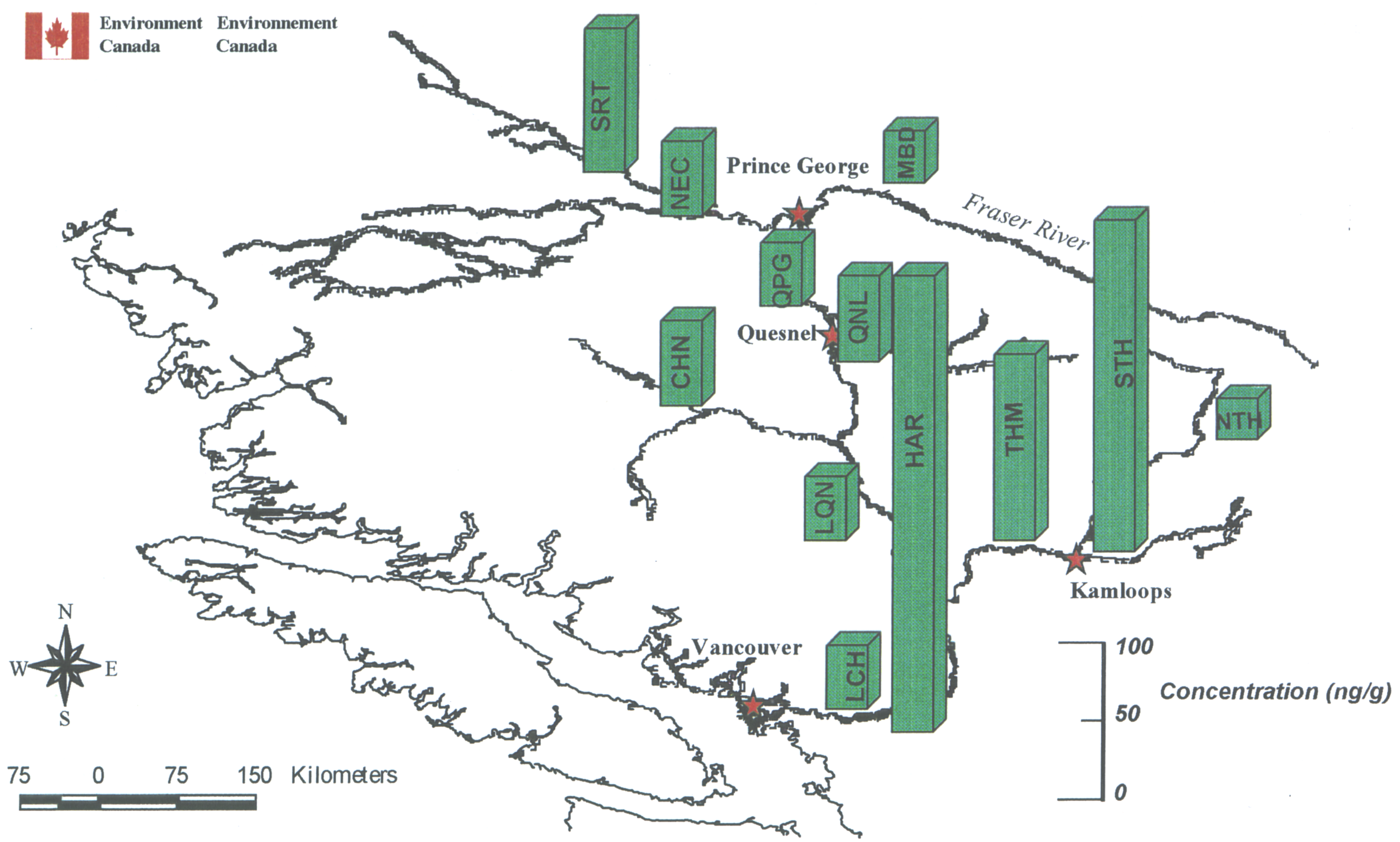
⇒ assess the effectiveness of selected pollution abatement measures



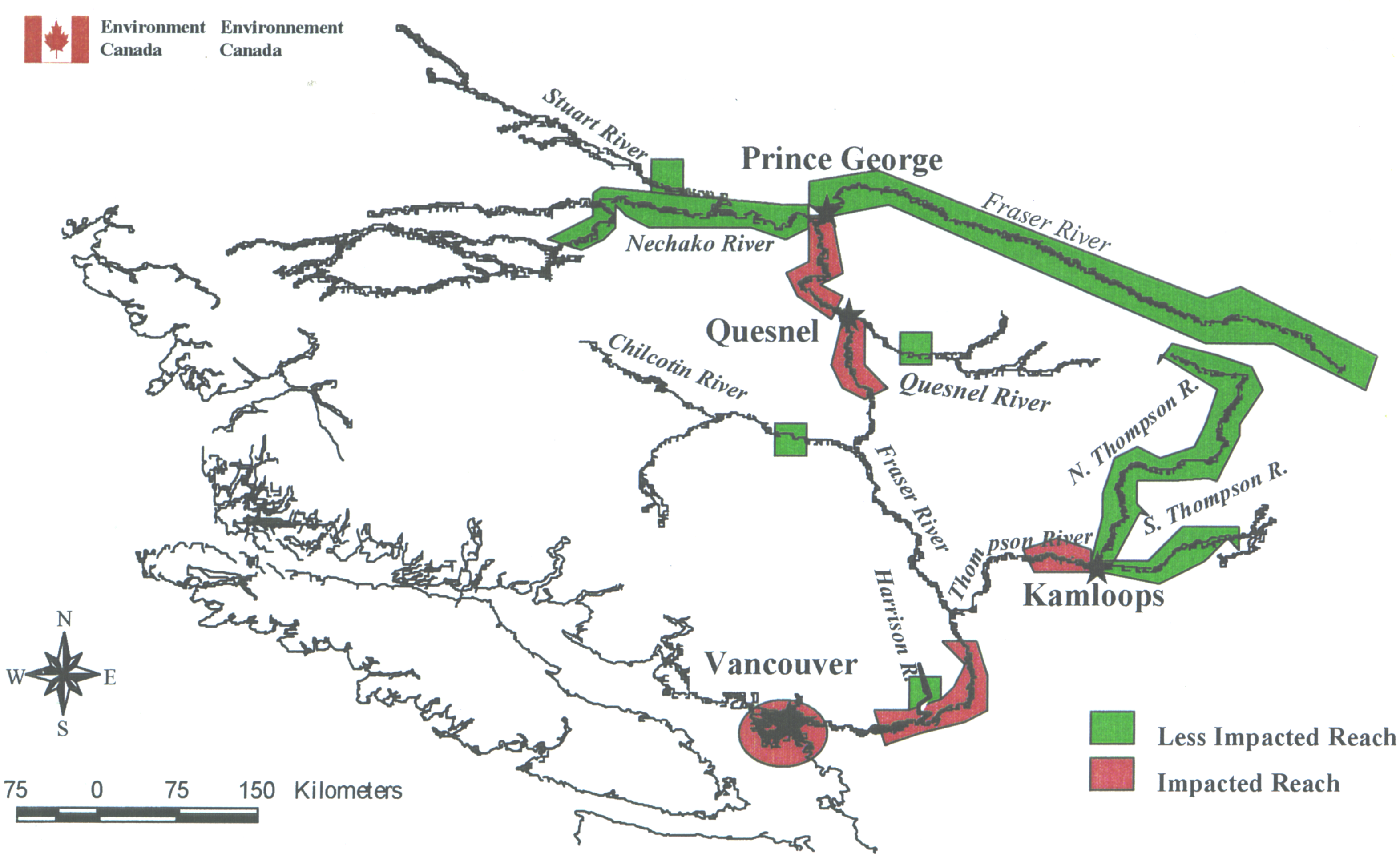
DIOXIN CONCENTRATIONS IN BED SEDIMENTS FROM THE FRASER RIVER BASIN



PCB AROCLOR CONCENTRATIONS IN BED SEDIMENTS FROM THE SOUTH THOMPSON RIVER



TOTAL PAH CONCENTRATIONS IN FRASER RIVER BASIN BED SEDIMENTS



BED SEDIMENT SAMPLING REACHES LOCATED IN THE FRASER RIVER BASIN

Survey of Contaminants in Suspended Sediment and Water in the Fraser River Basin

M. Sekela, R. Brewer, C. Baldazzi, G. Moyle and T. Tuominen

Environment Canada

Abstract

Concentrations of trace organic contaminants (dioxins, furans, chlorophenolics, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, pesticides, fatty acids and resin acids) were measured in suspended sediments and/or water samples collected upstream and downstream of six pulp mills located in the Fraser River basin. Sampling was conducted under fall low-flow conditions over three consecutive years (1992 - 1994) and under winter base-flow conditions in February 1993. Concentrations of contaminants in both sediment and water were used to calculate log K_{oc} values for dioxins, furans, chlorophenolics and polycyclic aromatic hydrocarbons.

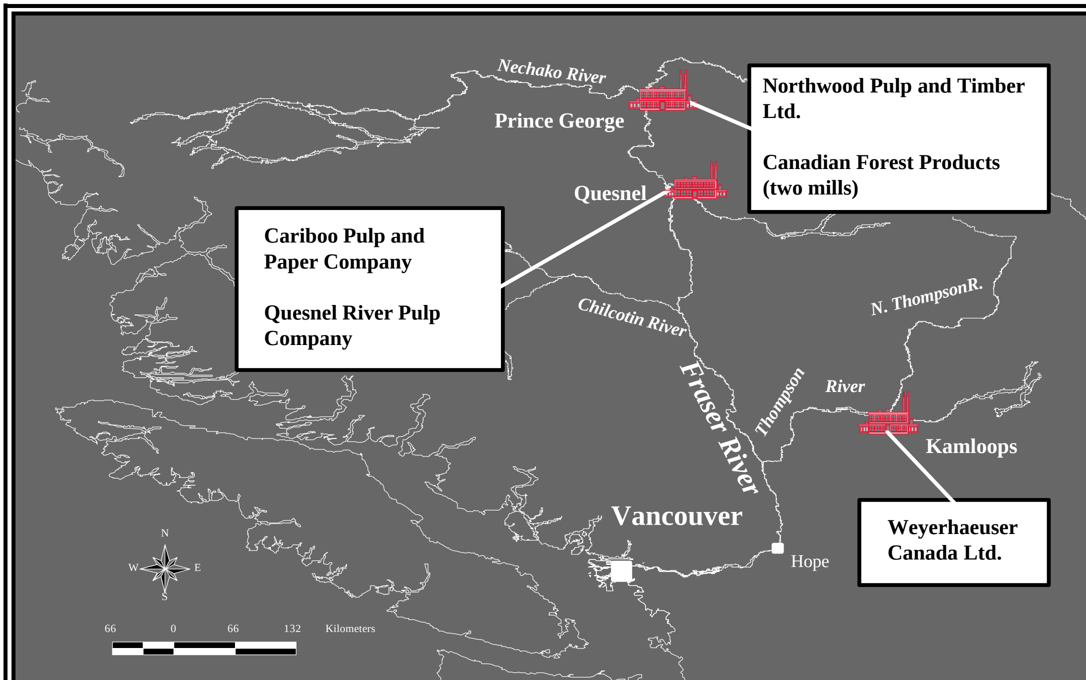
Results indicated that:

1. dioxins, furans, chlorophenolics, polycyclic aromatic hydrocarbons, fatty acids and resin acids, measured in suspended sediments, were found in higher concentrations downstream of pulp and paper mills than at reference sites upstream of the mills;
2. these contaminants were generally found in higher concentrations during winter base-flow periods than under fall low-flow conditions;
3. concentrations of 2,3,7,8-T4CDD and 2,3,7,8-T4CDF in suspended sediments have decreased from levels measured in 1990 prior to implementation of pulp mill abatement measures;
4. phase partitioning of polycyclic aromatic hydrocarbons between sediment and water was highly variable and appeared to be influenced by site-specific environmental conditions; and,
5. none of the organic contaminants exceeded existing federal guidelines or provincial water quality criteria for the protection of aquatic life. However, guidelines or criteria currently do not exist for many organic contaminants which were measured at elevated levels downstream of the mills.

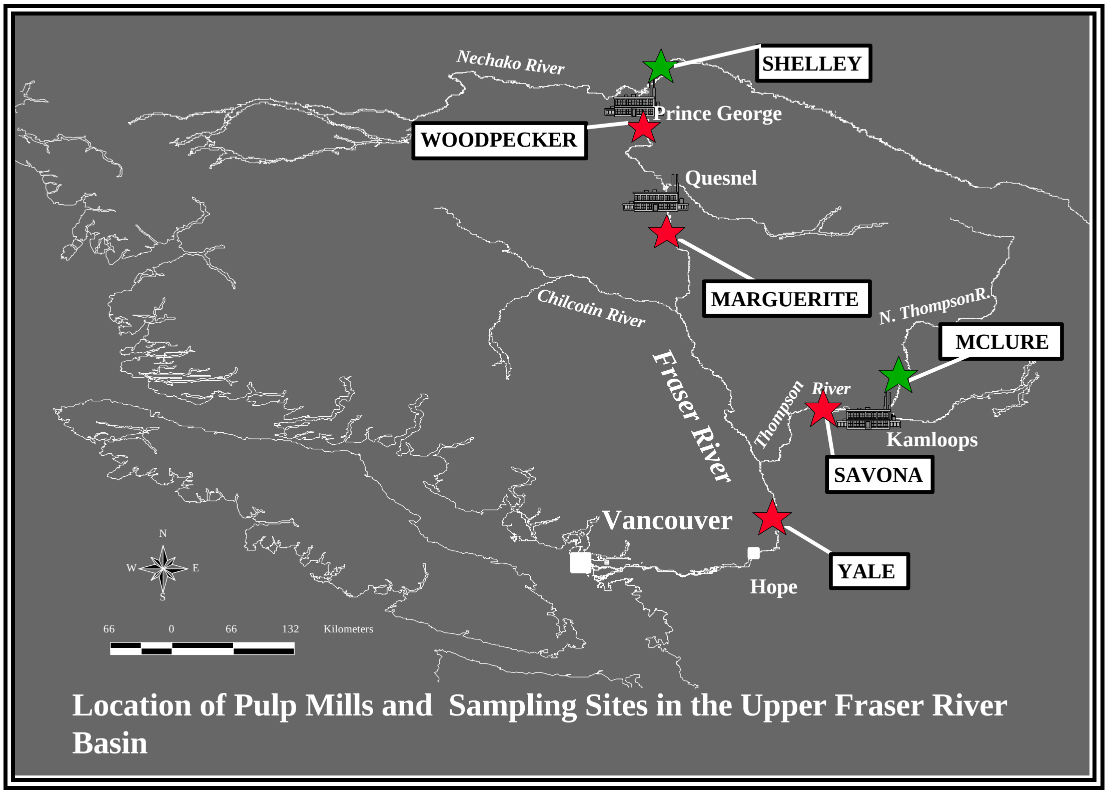
Study Objectives

- **To determine the geographical distribution and concentration of chlorinated organic contaminants and PAHs in Fraser River Basin suspended sediment and water during different flow conditions**

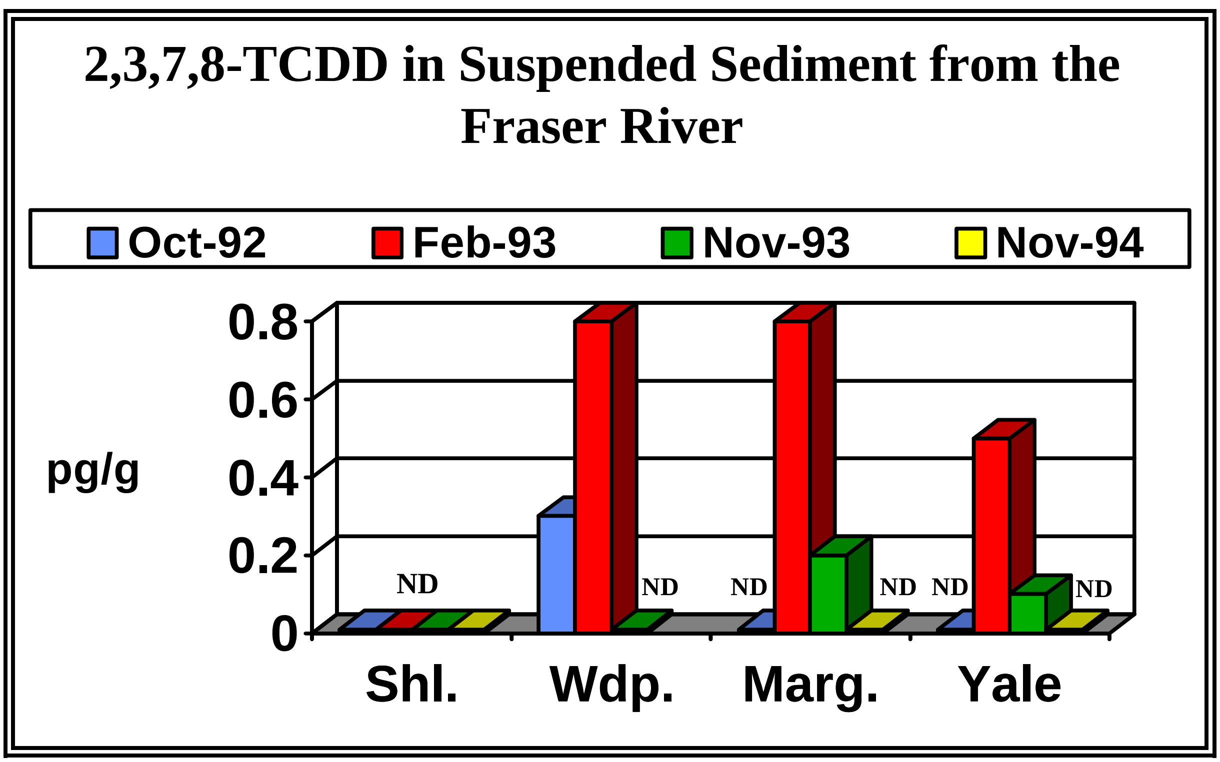
- **To determine what effect pulp mill abatement measures, introduced in 1991, have had on levels of 2,3,7,8-TCDD and 2,3,7,8 -TCDF in suspended sediment from the Fraser River Basin**



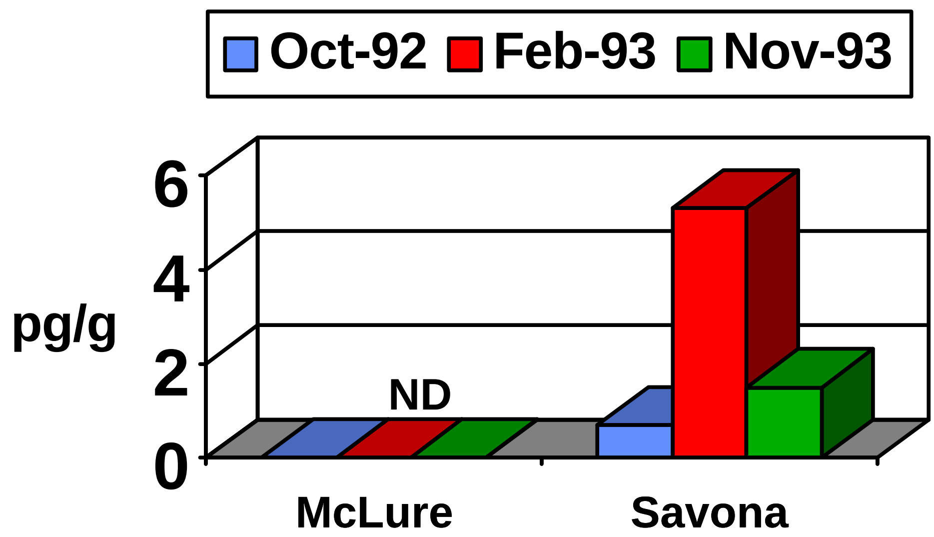
Location of Pulp and/or Paper Mills in the Upper Fraser River Basin



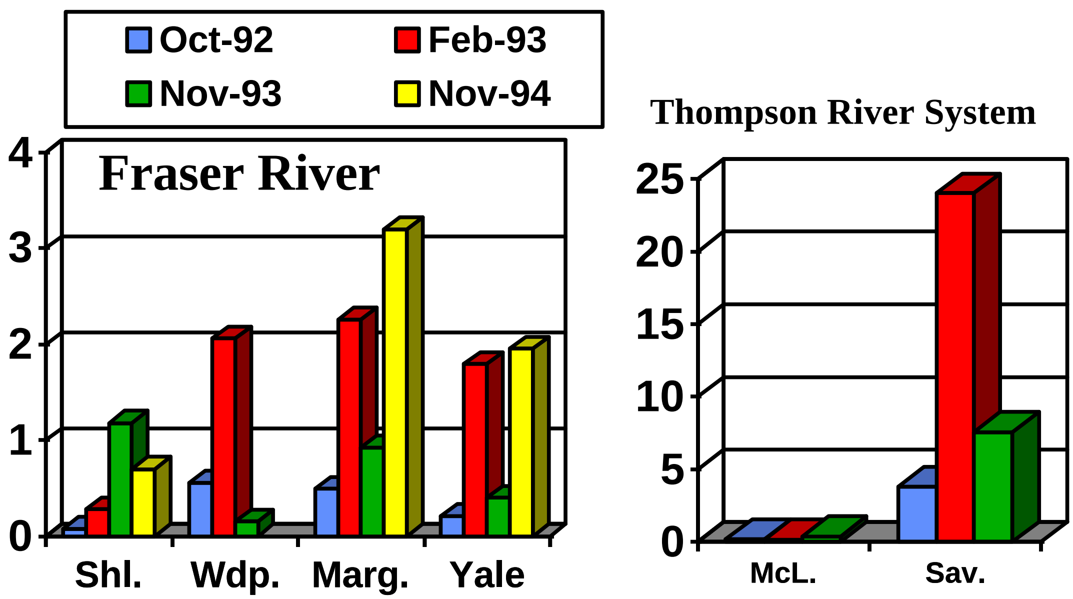
Location of Pulp Mills and Sampling Sites in the Upper Fraser River Basin

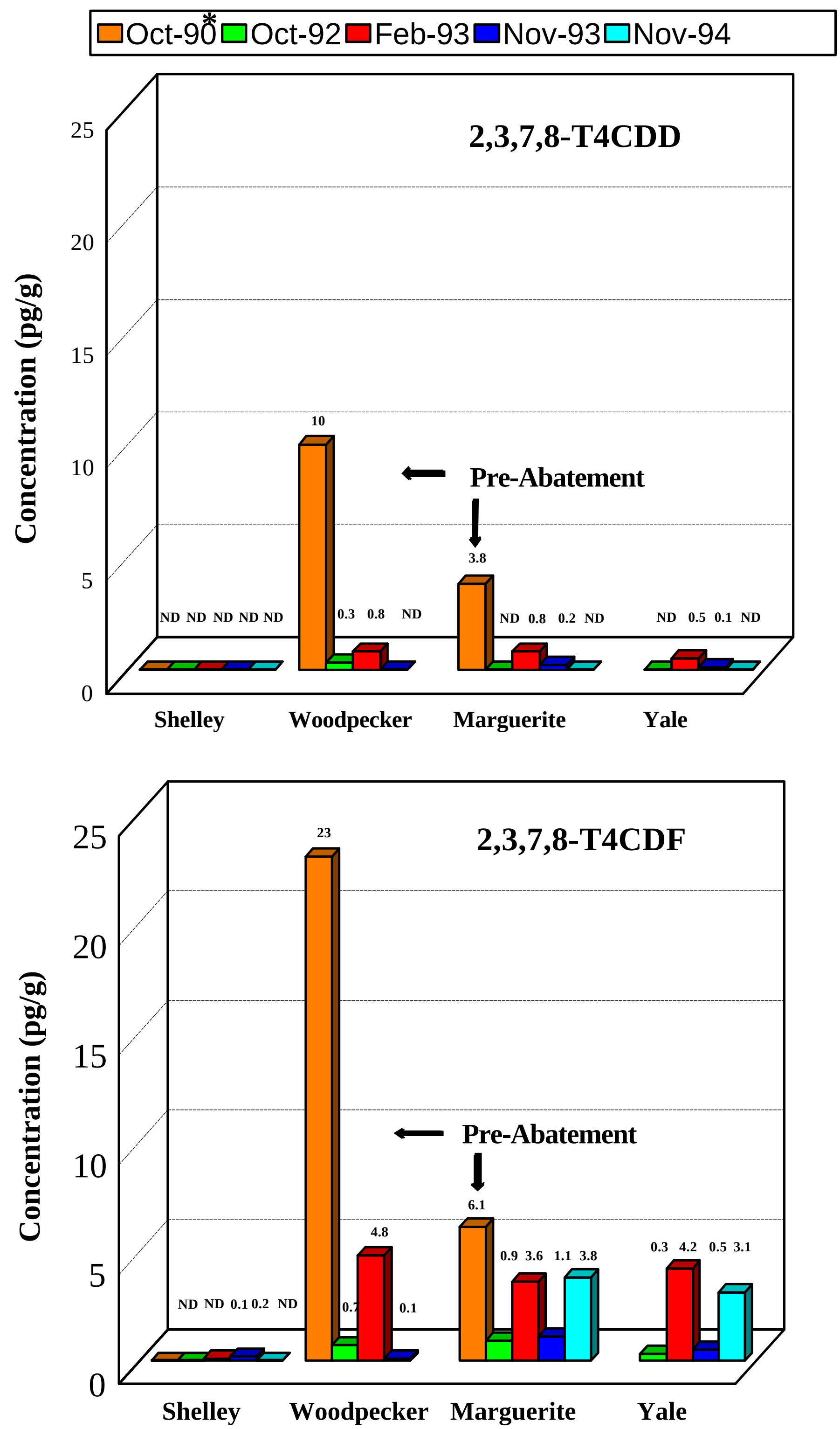


2,3,7,8-TCDD in Suspended Sediment from the Thompson River System



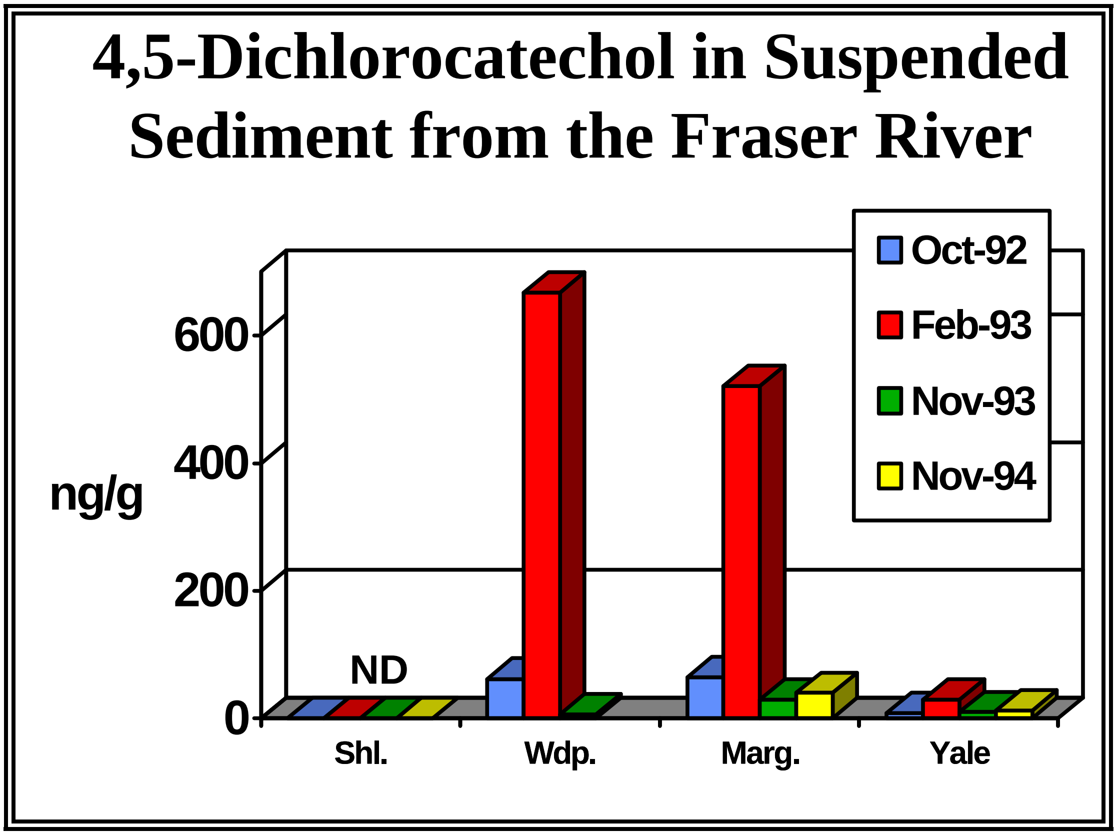
Dioxin and Furan Toxicity Equivalents (pg/g) in Suspended Sediment from the Fraser River Basin

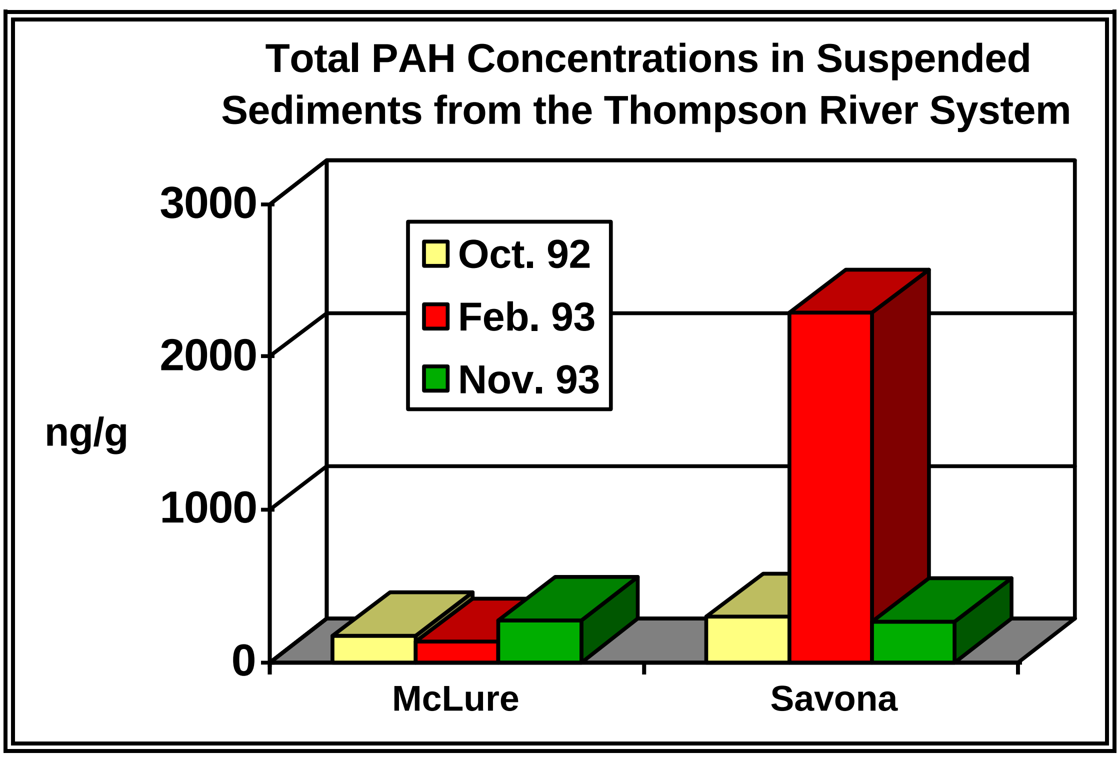




*** October 1990 data provided by George Derksen, Environment Canada**

Pre- and Post- Abatement Levels of 2,3,7,8-TCDD and 2,3,7,8-TCDF in Suspended Sediments from the Fraser River


4,5-Dichlorocatechol in Suspended Sediment from the Fraser River
ng/g
600
400
200
0
ND
Oct-92
Feb-93
Nov-93
Nov-94
Shl.
Wdp.
Marg.
Yale


Total PAH Concentrations in Suspended Sediments from the Thompson River System
ng/g
3000
2000
1000
0
Oct. 92
Feb. 93
Nov. 93
McLure
Savona

Other Contaminants Measured in Suspended Sediments

Resin Acids - **total resin acids were up to 125 times greater downstream of Fraser River pulp mills than at the reference site**

Fatty Acids - **total fatty acids were up to 4 times greater downstream of Fraser River pulp mills than at the reference site**

Pesticides - **trace levels (< 0.5 ng/g) of alpha-hexachlorocyclohexane and hexachlorobenzene were detected at all Fraser River sites**

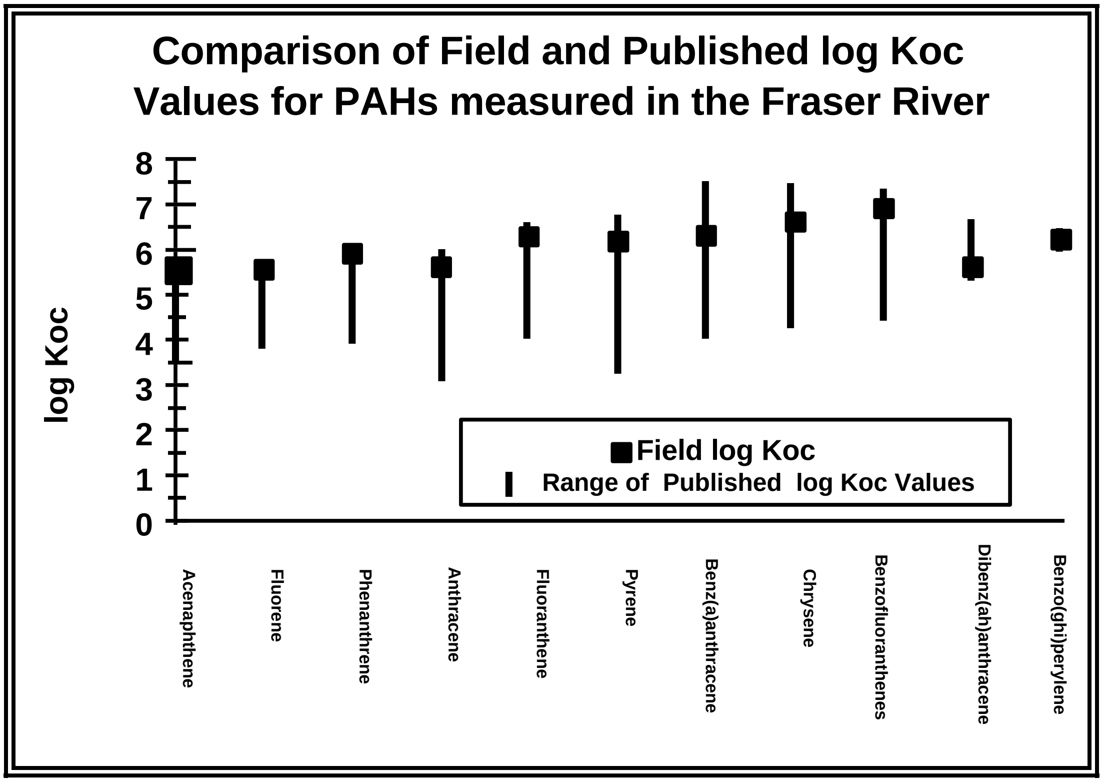
PCBs - **PCB congeners were detected in similar concentrations (< 1 ng/g) at all Fraser River sites**

Summary of Results of Contaminants Measured in River Water

- chlorophenolics and some resin and fatty acids were detected in higher concentrations downstream of pulp and paper mill relative to reference sites

- considerably fewer contaminants were detected in river water than in suspended sediments, as a result of both the hydrophobic nature of some of the contaminants and the higher detection limits in water samples

- none of the contaminants measured exceeded water quality guidelines or criteria for the protection of aquatic life

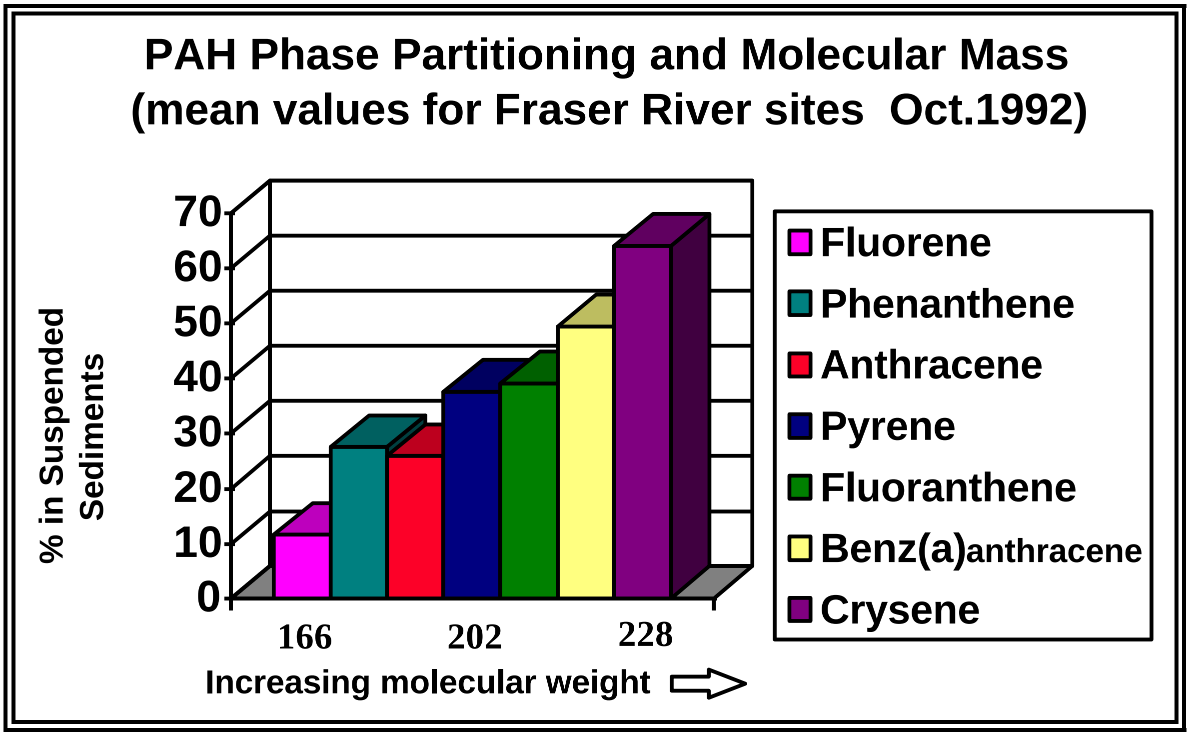


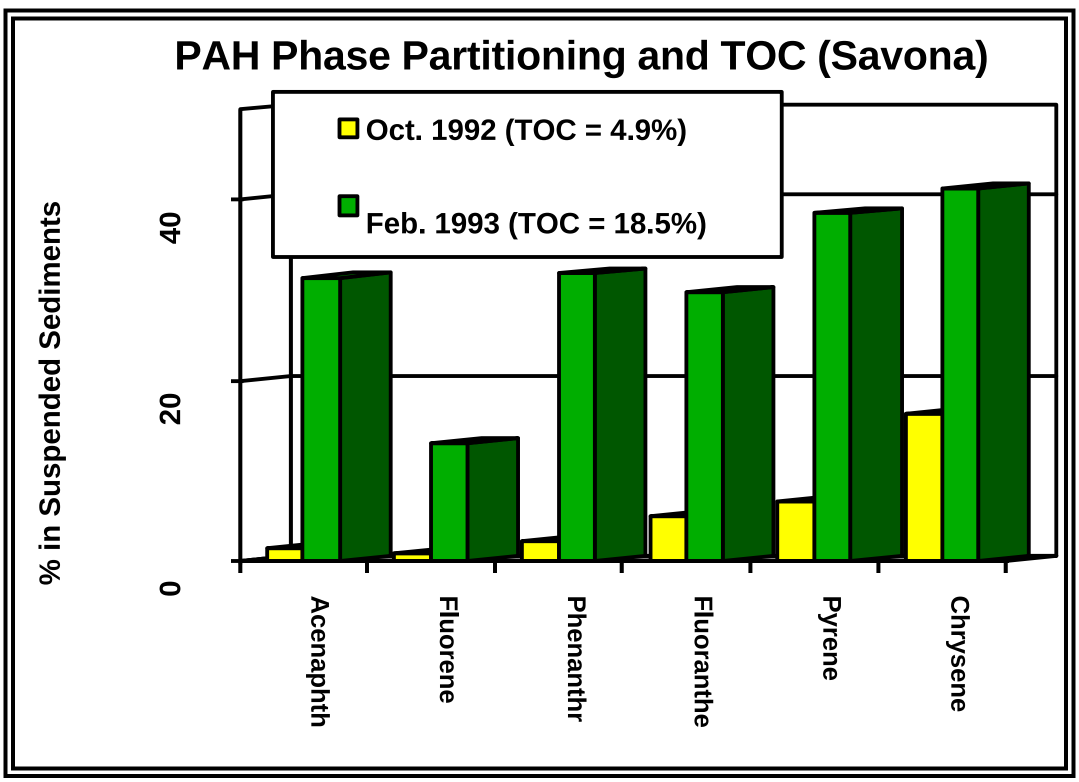
Factors Influencing PAH Phase Partitioning

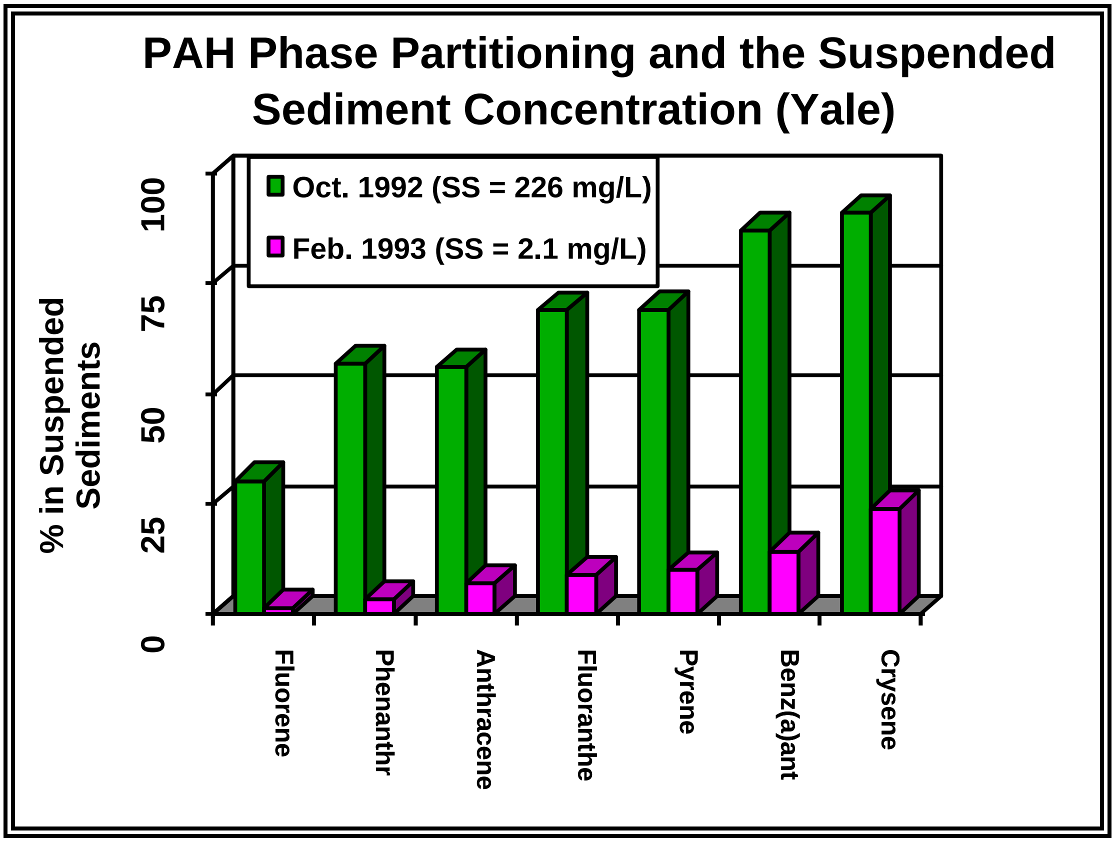
1. **Molecular Mass**

2. **Sediment Organic Carbon Content**

3. **Suspended Sediment Concentration**


PAH Phase Partitioning and Molecular Mass
(mean values for Fraser River sites Oct.1992)
% in Suspended Sediments
70
60
50
40
30
20
10
0
166
202
228
Increasing molecular weight
Fluorene
Phenanthene
Anthracene
Pyrene
Fluoranthene
Benz(a)anthracene
Crysene


PAH Phase Partitioning and TOC (Savona)
Oct. 1992 (TOC = 4.9%)
Feb. 1993 (TOC = 18.5%)
% in Suspended Sediments
40
20
0
Acenaphth
Fluorene
Phenanthr
Fluoranthe
Pyrene
Chrysene



Conclusions

1. Suspended sediments are a good indicator of contaminant levels in the aquatic environment, especially for those contaminants which are found at low concentrations in river water.

2. Although tetra-chlorinated dioxin and furan levels have decreased since 1990, chlorinated pulp mill contaminants are still detectable in the receiving environment.

3. Pulp mill contaminants and PAHs are higher in concentration during winter base flow conditions.

4. Site specific environmental factors such as the TOC and suspended sediment concentration appear to affect the phase partitioning of PAHs.

Information Gaps

1. **Toxicological implications of contaminants associated with suspended sediments**

2. **Guidelines/criteria for contaminants associated with suspended sediments**

3. **Site specific objectives for the Fraser River**

4. **Tributary input information**

5. **More data on contaminant phase partitioning under variable field conditions**

In-River Flocculation Processes and the Transport of Suspended Sediment

B.G. Krishnappan, P. Engel and R. Stephens

National Water Research Institute

Abstract

The objective of this FRAP project was to study the transport processes of suspended sediments of the Fraser and Thompson river systems and to determine the transport functions that are needed to model the sediment and contaminant transport both in the near-field and far-field regions.

The work carried out under this project so far consisted of field surveys and laboratory investigations. In the field surveys, the size distributions of the suspended sediment were measured using an immersible laser particle size analyzer that was assembled at the National Water Research Institute and were compared with the size distribution of the primary particles. From these comparisons, one can determine the extent of flocculation of the suspended sediment in different reaches of the river systems. The results showed that the sediment in the mainstem Fraser, upstream of the Northwood pulp mill was not flocculated while the sediment in the downstream reach was. The flocculation of the sediment in the downstream reach was attributed to the presence of pulp mill effluents.

The size distribution data also showed that the flow conditions in the river played a major role in determining size of flocs. The role of the hydrodynamics on the flocculation process was investigated in the laboratory using the rotating circular flume of the National Water Research Institute. The flume experiments shed new light on the transport characteristics of the fine sediments of the Fraser and Thompson river systems and allowed formulation of a new sediment transport algorithm that can be incorporated in the far-field food chain and bio-accumulation model and the near-field plume interaction model that are being developed for the Fraser River Action Plan.

The present study extends only up to Mission and does not include the estuary region. The sediment behaviour in the estuary could be very different from that observed in the present study because of the saltwater intrusion and the tidal effects. These effects have to be quantified in order to extend the models into the estuary regions.

Near-Field Transport and Fate of Pulp Mill Effluents

G. Lawrence, B. Marks, W. Evans, J. Vine and L. Gomm

Department of Civil Engineering
University of British Columbia

We are working on three sub-models of the transport and fate of effluent discharges into the Fraser River.

1. Bonnie Marks is investigating the initial dilution of effluent from the point of discharge to the point at which the effluent is mixed throughout the depth. In this region, the initial momentum and buoyancy of the effluent are important. Bonnie has found existing numerical models of this region inadequate, and is performing laboratory experiments to improve our understanding and modeling capability. Results obtained from the experiments will include the concentration distribution across the plume at the end of the initial mixing zone for different seasonal conditions; this will be used as an input for the second sub-model.
2. Wayne Evans has found that existing flocculation/particle aggregation theory is not capable of explaining an aggregation phenomenon noted by field researchers as a result of the discharge of pulp mill effluents into a sediment-laden river. In view of this, previously obtained field and experimental data have been analyzed and simple experiments in jars and settling columns conducted to see if aggregation is indicated. The addition of pulp mill effluents to sediment-laden waters resulted in a turbidity reduction almost instantaneously in the jar tests. It was found that the most significant effect occurred when the effluent and river water were added to one another in equal quantities. Whether this indicates an increase in aggregate sizes is still unknown. Reliable aggregate size measurements cannot be completed at UBC.

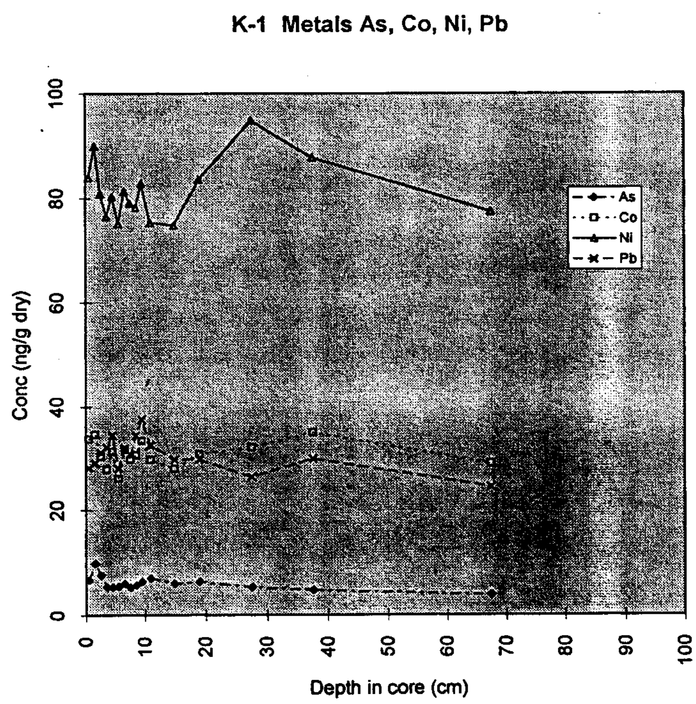
   More recent settling tests, completed in a settling column, indicated that the settlability of illite (a primary component of the <63 μm sediment fraction in the Fraser River water column) is enhanced by the addition of pulp mill effluents. The median settling velocity of the solids in one instance increased by as much as seven times on addition of pulp mill effluents. The rate of settling in the first hour of tests was also dramatically increased by the addition of pulp mill effluents. Completion of settling tests at different effluent/biosolid concentrations have suggested that biosolids are critical to the enhancement of settlability of suspended solids. Settling tests are now being conducted using Fraser River sediment, and effluent from the Northwood pulp mill at Prince George.
3. Jason Vine has developed a particle tracking model that will take the results of the above studies and track the movement and settling of particles as they are advected downstream. A computer simulation has been developed to model mid-field dispersion of pollutant in a river. The simulation currently employs the “Random Walk” method to predict dispersion of massless “tracer” particles, with the intent of calculating downstream dilution. The model can be extended to incorporate sediment and/or biosolids if the dynamic properties of the material (such as the fall velocity and drag coefficient) can be specified. The model attempts to account for dispersion due to longitudinal shear, secondary currents in bends, and turbulent diffusion. Experiments in the laboratory have been used to confirm some of the mechanisms (vertical velocity profiles and turbulence intensities). Comparison with digital air photo data shows good agreement with the predicted results.

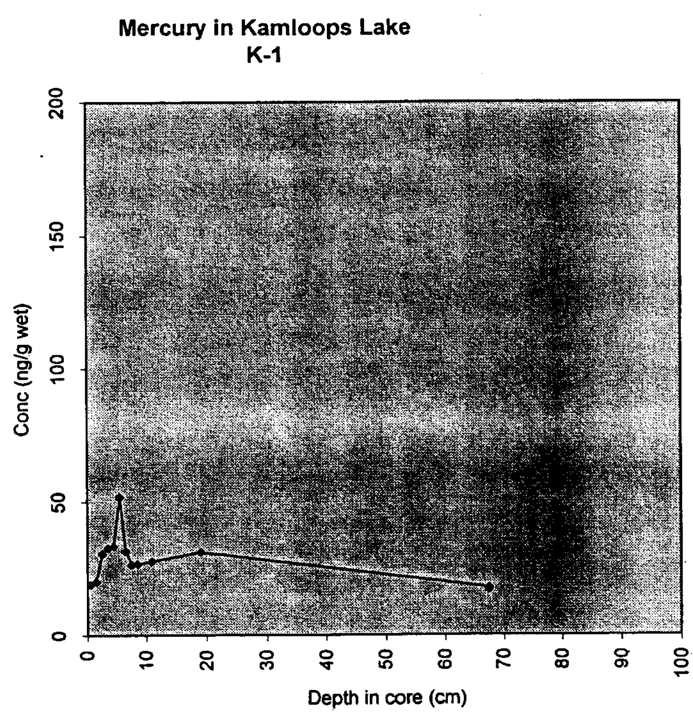
Assessment of Atmospheric Inputs of Heavy Metals and Persistent Organic Compounds to the Upper Drainage Basin

R. Macdonald

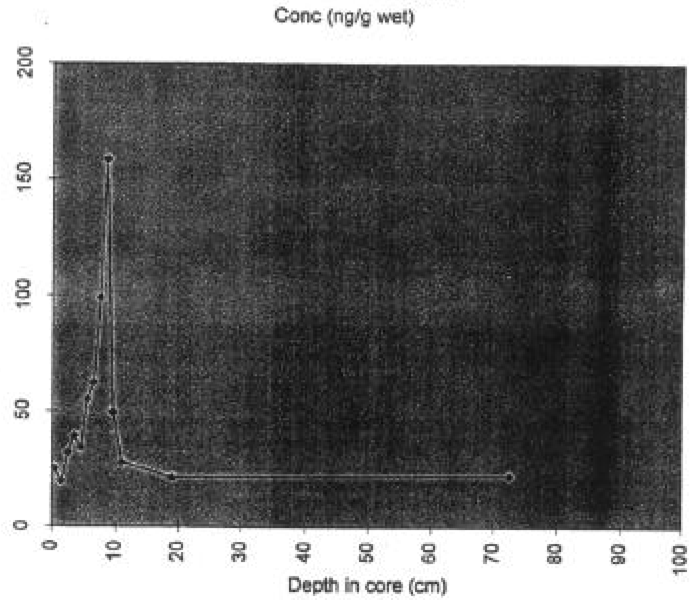
Institute of Ocean Sciences

To make a reconnaissance of contaminant distributions and trends in the drainage basin, sediment cores were collected from six lakes in the Fraser System (Moose, Stuart, Chilko, Kamloops, Horizon and Nicola). These cores have been dated using 210Pb and analyzed for a suite of contaminants. For the most part, the lake sediment core data suggested that atmospheric contaminant inputs have been very low. In particular, we saw little record of PCB inputs to Moose Lake where PCBs were earlier found elevated in fish. We saw a strong record of DDT entering into Nicola Lake and, less so, into Horizon Lake. The metals analyses showed expected increase in Pb concentration in the upper layers of many of the cores, and for Stuart Lake we found clear evidence of local Hg contamination. The PAH data suggested enhanced modern fluxes of combustion products to Nicola and Harrison lakes. Preliminary dioxin and furan data from Kamloops Lake showed some extremely high concentrations which, for the most part, can be ascribed to pulp mill inputs.

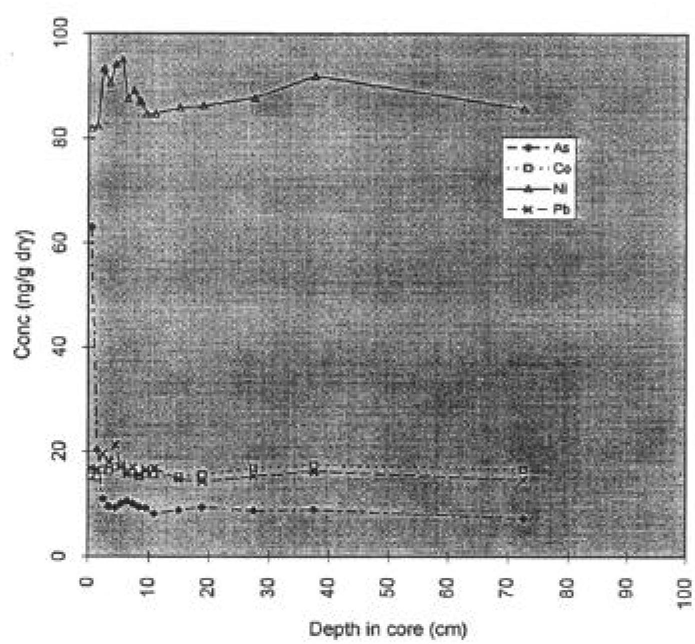

K-1 Metals As, Co, Ni, Pb
Conc (ng/g dry)
0
20
40
60
80
100
As
Co
Ni
Pb
0
10
20
30
40
50
60
70
80
90
100
Depth in core (cm)

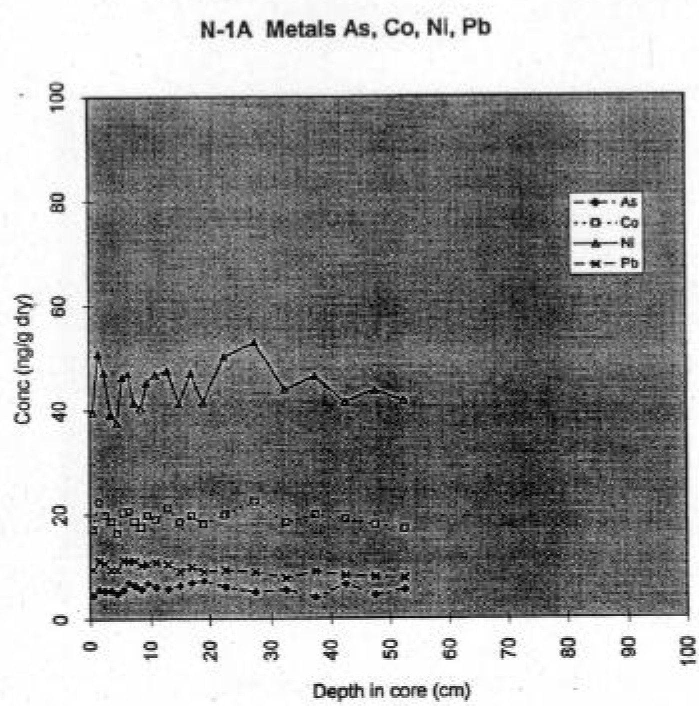

Mercury in Kamloops Lake
K-1
Conc (ng/g wet)
0
50
100
150
200
0
10
20
30
40
50
60
70
80
90
100
Depth in core (cm)

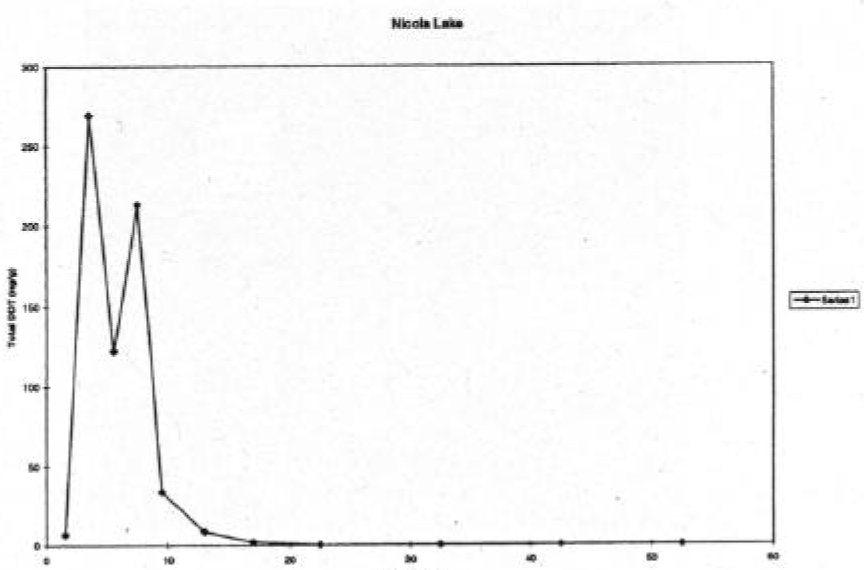
Mercury in Stuart Lake S-1
by Fluor. Amalgam



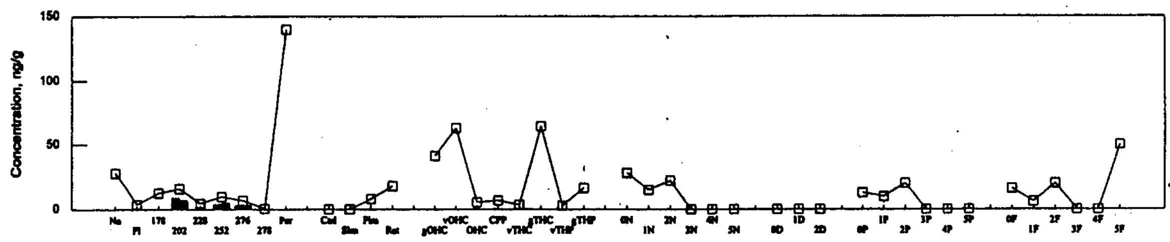
S-1 Metals As, Co, Ni, Pb



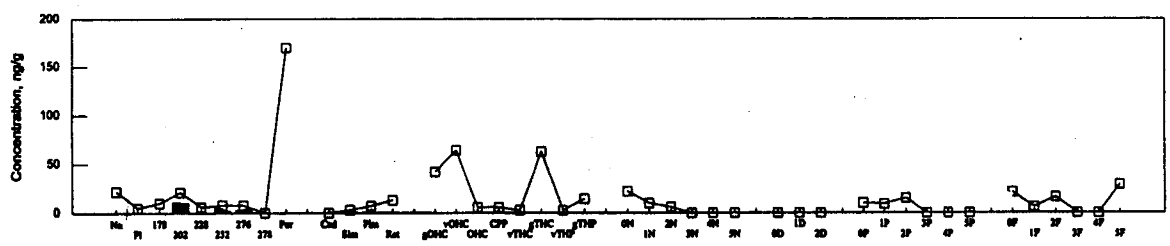

N-1A Metals As, Co, Ni, Pb
Conc (ng/g dry)
0
20
40
60
80
100
As
Co
Ni
Pb
0
10
20
30
40
50
60
70
80
90
100
Depth in core (cm)


Nicola Lake
300
250
200
150
100
50
0
Series1

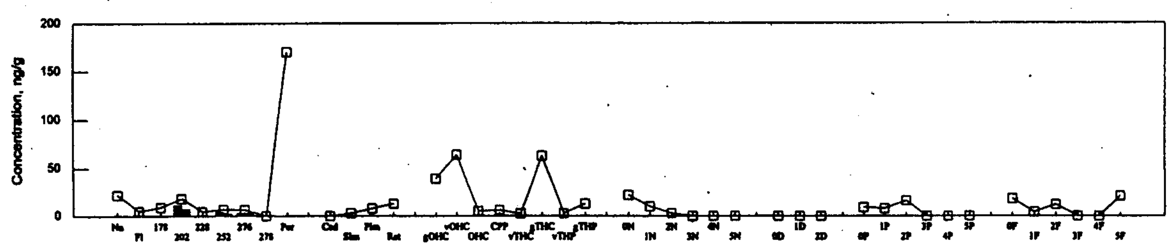
Nicola Lake -- 0-1 cm



Nicola Lake -- 2-3 cm



Nicola Lake -- 4-5 cm



6 Lakes Project

Findings (so far . . .)

- lakes are generally pretty clean
- PCBs and other OCs — mostly ND, with a few very low values
- DDTs (+ chlordane) show up as records especially in Nicola Lake
- Pb has records reflecting anthropogenic inputs to several lakes
- PAHs show trends reflecting enhanced inputs from wood burning (Nicola, Harrison)
- Hg in Stuart Lake reflects operations at Pinchi Lake
- Dioxins and furans in Kamloops Lake

SESSION 3

URBAN ISSUES

Status of Urban Programs in Pollution Abatement

B. Kooi

Environment Canada

Studies in the past have identified urban runoff as a major contributor to the degradation of many urban streams and rivers. Long-term characterization of urban runoff is difficult due to inconsistent water quality resulting from rainfall and site specificity. As part of the Fraser River Action Plan, Environment Canada, under Fraser Pollution Abatement (FPA), has been given the task of developing strategies to reduce contaminant loadings from urban runoff. The required tasks included an inventory of non-point sources, assessment of some non-point sources, development of Best Management Practices (BMPs) or Codes of Practice and, finally, measure of success.

A. Inventory and Assessment

Urban Runoff Quantification and Contaminants Loading

This study was a planning level assessment of surface water contaminant loadings to the Fraser River basin and Burrard Inlet from urban runoff sources. The report in general summarized the information within the Lower Fraser as it contains approximately 91% of the population. The study summarized the loadings of 20 different contaminants to the Fraser River basin and Burrard Inlet (Table 1). The loading estimates were average concentrations of typical urban runoff contaminants. The numerical values assigned were the average level of contamination reported in the literature. Although the contaminants levels were determined from the literature, they may assist agencies to determine a starting point from which the success of abatement activities may be measured.

Impact of Land Uses on Stormwater Quality in the Brunette River System

The intent of this study was to determine the impact of different land uses on surface water quality and compare contaminant levels to what was reported in the literature. A second phase of this project was to develop a Best Management Practice for Urban Watersheds. [Ken Hall of UBC outlines and presents the research efforts on this watershed later in this report.]

Combined Sewer Overflow Inventory

This was an inventory of all the CSOs discharging within the Fraser River basin for population centres greater than 10,000. The inventory concluded that all CSOs were located within the Lower Fraser and Burrard Inlet. The total number of CSOs found was 53 (New Westminister-5; Burnaby-13; Vancouver-35). The Fraser River accounts for 20 CSO discharges and approximately 17% of the total discharge CSO volume.

Additional work on this project included an inventory of industrial waste discharges under Greater Vancouver Regional District (GVRD) permit flowing to the wastewater collection systems within the GVRD. The study found approximately 79 permitted discharges with volumes ranging from <13 m^3/d to <12,000 m^3/d.

Characterization of Glenbrook Combined Sewer Overflow

In a joint project with the GVRD, the Glenbrook combined sewer overflow was studied to determine potential contaminant loadings from CSOs to the Fraser River. The sampling program included storm runoff and in-line sediment sampling. This work will assist in the development of future monitoring and environmental assessment work. The collected wastewater samples were analyzed for a wide array of general parameters, non-organic compounds, organic compounds and metals. A comprehensive list of contaminants was developed due to the lack of historical water quality for combined sewer overflows in the region.

Table 1: Estimated Annual Contaminant Loadings from Urban Runoff

Parameters	Fraser River Basin-totals	Lower Region	Thompson Region	Middle Region	Upper Region
TSS (tonnes)	62,781.80	54,583.60	1,689.40	913.2	5,595.60
BOD (tonnes)	4,520.30	3,930	121.6	65.8	402.9
COD (tonnes)	35,147.80	30,556.80	946.1	511.4	3,133.50
Ammonia (kg)	75,338	65,500	2,027	1,096	6,715
Nitrate/Nitrite (kg)	351,578	305,668	9,461	5,114	31,335
Total Nitrogen (kg)	878,946	764,170	23,652	12,785	78,339
Total Phosphorus (kg)	175,789	152,834	4,730	2,557	15,668
Lead (kg)	75,338	65,500	2,027	1,096	6,715
Copper (kg)	17,579	15,283	473	256	1,567
Zinc (kg)	75,338	65,500	2,027	1,096	6,715
Chromium (kg)	5,023	4,367	135	73	448
Cadmium (kg)	4,018	3,493	108	58	358
Nickel (kg)	12,556	10,917	338	183	1,119
Arsenic (kg)	6,529	5,677	176	95	582
Phenols (kg)	6,529	5,677	176	95	582
Oil and Grease (kg)	2,511,273	2,183,344	67,576	36,528	223,825
Total Hydrocarbons (kg)	2,009,018	1,746,675	54,061	29,223	179,060
PAH (kg)	502	437	13.5	7.3	44.8
Fecal Coliforms (billion)	60,270,554	52,400,252	1,621,831	876,680	5,371,792

Objectives for this project were:

1. monitor the quality and quantity of CSOs over several rain events;
2. assess the toxicity of CSO discharges;
3. characterize one sludge sample from sediment deposits on the bottom of the combined sewer overflow pipe;
4. compare measured contaminant concentrations to the CSO water quality estimates developed in the GVRD's Stage 1 Liquid Waste Management Plan (LWMP) Report;
5. identify key contaminants within the CSOs which would be appropriate for initial dilution zone and receiving water assessment studies; and,

6. refine CSO sampling procedures and protocols and provide recommendations for future CSO characterization within the GVRD.

Some of the results were as follows:

1. The average concentration of general constituents, heavy metals and selected organic compounds were either similar or less than the estimates developed as part of the GVRD Stage 1 Liquid Waste Management Plan (LWMP) (Table 2);
2. Levels of cadmium, chromium, lead and nickel were well below the Stage 1 LWMP estimates. With respect to lead, the lower levels detected were likely due to the banning of leaded gasoline several years ago;
3. PCBs were not detected in any wastewater samples. The levels of dioxins and furans detected in the wastewater sampled for events 1 and 2 (1994) were considered low and similar to those levels detected during the Clark Drive and Westridge CSO studies;
4. Twenty-six organic compounds were detected in the 1994 CSO wastewater samples and four were common to both sampling events. The compounds included: benzo(a)pyrene and pyrene (high molecular weight PAHs), methylnaphthalenes and dioxins;
5. Twenty-six organic compounds were detected in the 1995 CSO wastewater samples and ten were common to all sampling events. The compounds included:
   a) benzo(b)fluroanthene
   b) fluroanthene
   c) methylnapthalenes
   d) dimethylnapthalenes
   e) trimethylnapthalenes
   f) methylpheneanthrenes
   g) dimethylpheneanthrenes
   h) chloroform (halogenated VOC)
   i) toluenes (meta and para)
   j) xylenes (meta and para)
6. The CSOs exhibited concentrations of suspended solids, BOD and nutrients (ammonia and phosphorus) four to fourteen times below typical GVRD domestic sewage levels indicating relative rates of stormwater dilution.
7. Toxicity was evident for some samples for the Microtox and *Ceriodaphnia* tests. There were no measured toxic effects for the rainbow trout bioassay and the algal growth inhibition tests.

Stormwater Discharge Inventory

This inventory attempted to locate all large stormwater discharges on the Fraser River from the mouth of the Fraser River to Kanaka Creek including a photo record and visual observations of the surrounding area. A total of 252 stormwater discharges were found at this time. In conjunction with the inventory, the consultant was asked to expand an environmental sensitivity index developed by the Capital Regional District in Victoria for its stormwater discharge inventory around the foreshore. A high index value would indicate an environmental impact by the stormwater discharge on one of the following:

1. endangered or protected habitat such as a bird sanctuary;
2. spawning or rearing habitat of commercially or recreationally utilized fish species; and,
3. primary contact water activities such as swimming, windsurfing.

The findings of the report suggested that 16% of the stormwater discharges have potential for environmental impacts affecting human or animal health.

Table 2: Estimated Combined Sewer Overflow Concentration

Contaminants	***Cpw (Ave.)***	***Cpd (Ave.)***	***Calculated Co. (Range)***	***Reference 1 (mean)***	***Reference 2 (range)***	***Estimated Values***
BOD	46	142	15-66	54	51-76	60
COD	121	322	57-162	ND	107-190	110
Fecal Coliform (MPN/100 mL)	ND	ND	ND	ND	$3600\text{-}7.8 \times 10^{3}$	4.0×10^{5}
pH	7	7.2	6.9-7.0	ND	ND	7
Oil and Grease	16	34	6.0-17.0	ND	ND	11
Nitrogen: Ammonia	6	12	2.7-6.4	ND	ND	4
Kjeldahl	13	25	6.3-13.8	ND	ND	10
Nitrate/Nitrite	<2	<2	ND	ND	ND	ND
Total						14
Total Phosphorus	2.6	4	1.82-2.7	ND	ND	2
Metals and Inorganics:						
Aluminum	1.3	1	1.3-1.5	ND	3.0-6.22	1.4
Arsenic	<0.02	<0.02	ND	ND	0.0067-0.011	0.01
Cadmium (µg/L)	2	2.1	2	13	2-5.7	4
Chromium	<0.05	<0.05	ND	0.064	0.024-0.1	0.03
Copper	0.1	0.17	0.06-0.1	0.111	0.05-0.06	0.08
Iron	1.5	1.36	1.5-1.6	ND	2.4-5.2	2
Lead	0.06	0.036	0.06-0.07	0.322	0.1-0.24	0.09
Manganese	0.06	0.07	0.05-0.06	ND	0.062-0.2	0.05
Mercury (µg/L)	<0.5	<0.5-0.5	ND	<0.1	0.0.57	0.1
Nickel	<0.05	<0.05	ND	0.081	0.027-0.08	0.04
Zinc	0.11	0.12	0.0-0.11	0.43	0.13-0.29	0.1

(Cont.)

Table 2: (Cont.)
Estimated Combined Sewer Overflow Concentration

Contaminants	*Cpw (Ave.)*	*Cpd (Ave.)*	*Calculated Co. (Range)*	*Reference 1 (mean)*	*Reference 2 (range)*	*Estimated Values*
Halogenated Aliphatics						
Chloroform	ND	ND	ND	0.001	0.0022-0.006	0.002
Monocyclic Aromatics						
Phenol (grab sample)	0.03	0.04	0.02-0.03	0.001	0.0013-0.003	0.01
Pthalate esters:						
Di-octyl Phthalate	ND	ND	ND	0.019	0.002-0.038	0.02
Polycyclic Aromatics						
Naphthalene	ND	ND	ND	ND	0.0003-0.0095	0.005

All values are for total form and are in mg/L, except where noted

Reference:1: Crawford, 1984; Combined Sewer Overflow Toxic Pollutant Study

2: Metro Toxicant Program, 1984, 4B. Collection System Evaluation

ND=no data available

Parameter Values Used for Calculations

Co: Combined Sewer Overflow Concentrations (Calculated)

Cpw: Wet Day Composite Concentration (values in table)

Cpd: Ave. Dry Day Composite Concentation (values in table)

Golf Course Inventory

Since golf courses are presently being built in great numbers, especially in the Lower Fraser, it has become a focus of some environmental concerns. This may be due in part to their high profile and intense land management. The environmental concerns are related to surface water and groundwater quality and wildlife protection. This project was intended to inventory golf courses within the Fraser River basin including a further inventory of chemical use including fertilizers, herbicides and pesticides. Questionnaires were mailed out to the 76 golf courses located in the Fraser River Basin and approximately 44 (or 58%) responded.

The project required site assessments of five golf courses, three in the Lower Mainland and two in the northern region. In general, the golf courses practice sound environmental protection practices. However, elevated levels of some metals such as copper, zinc, arsenic, lead, chromium and cadmium were found (Tables 3 and 4). The highest levels were found in sediment samples. Sources of the contamination were not determined at this time as the main thrust of the project was the Environmental Codes of Practice developed in conjunction with the inventory information.

Car and Truck Wash Inventory

The focus of the study was to determine current practices in the industry including wash processes, chemical use, water use, wastewater pre-treatment, wastewater discharge, etc. Furthermore, the project was to determine if existing facilities generally discharged to sewer, storm drain or waterways. The study found a small percentage of the operations discharging to storm drains or waterways. In addition to the inventory, site investigations were conducted at six sites. All sites discharged to the GVRD sewer system. Analyses indicated only a few parameters exceeded the GVRD sewer use bylaw limits. The exceedances included BOD, SS, oil and grease, and iron.

Several suggested improvements at vehicle wash facilities were indicated:

1. new operations should plan for appropriate pollution prevention and treatment facilities;
2. ensure existing pollution prevention and treatment facilities are functioning properly;
3. ensure sanitary sewer discharge of vehicle washwater wherever possible;
4. upgrade any existing treatment facilities if necessary; and,
5. limit on-site activities suitable for the type of pollution treatment presently existing.

Aerial Reconnaissance of the Fraser River

This project was intended to give an historical record of the present foreshore development along the Fraser River. The video record includes the Fraser River to McBride and some of the major tributaries such as the Thompson, Nechako, Stuart and the Chilcotin rivers. Some of the video data was GIS-referenced and is presently formatted under MapInfo. The flying was done during low-flow periods to assist the Department of Fisheries and Oceans to determine the location of sandbars and good fish habitat or any potential impacts on fisheries habitat.

Table 3: Golf Course Contaminant Concentrations at Site A Compared with Existing Guidelines and Criteria

Site A	Water					Sediment			
	Background Pond 6	Canadian Water Quality Guidelines	B.C. Water Quality Guidelines	Rain Event Pond 2	Rain Event Pond 6	Units	B.C. Sediment Quality Criteria	Pond 2	Pond 6
Total Metals									
arsenic(mg/L)	0.0007	0.05	0.05	0.0008	0.0007	mg/dry kg	6.0	3.9	7.0
cadmium(mg/L)	<0.0002	0.0002	0.0002	<0.0002	<0.0002	mg/dry kg	0.6	0.2	0.2
chromium(mg/L)	0.002	0.002	0.002	0.001	<0.001	mg/dry kg	26.0	31.2	37.0
copper(mg/L)	0.013	0.002	0.0076	0.009	0.006	mg/dry kg	16.0	25.3	79.9
lead(mg/L)	0.001	0.001	0.043	<0.001	<0.001	mg/dry kg	31.0	5.5	9.1
zinc(mg/L)	0.01	0.03	0.03	0.005	<0.005	mg/dry kg	120.0	91.0	158.0

(Cont.)

Table 3: (Cont.)
Golf Course Contaminant Concentrations at Site A Compared with Existing Guidelines and Criteria

Site A	Water					Sediment			
	Background Pond 6	Canadian Water Quality Guidelines	B.C. Water Quality Guidelines	Rain Event Pond 2	Rain Event Pond 6	Units	B.C. Sediment Quality Criteria	Pond 2	Pond 6
Dissolved Metals									
arsenic(mg/L)	0.0003	n/a	n/a	0.0006	0.0003				
cadmium(mg/L)	<0.0002	n/a	n/a	<0.0002	<0.0002				
chromium(mg/L)	<0.001	n/a	n/a	<0.001	<0.001				
copper(mg/L)	0.007	n/a	n/a	0.006	0.005				
lead(mg/L)	<0.001	n/a	n/a	<0.001	<0.001				
zinc(mg/L)	<0.005	n/a	n/a	<0.005	<0.005				

[box] meets or exceeds existing criteria

Table 4: Golf Course Contaminant Concentrations at Site E Compared with Existing Guidelines and Criteria

Site E	Water					Sediment			
	Background Pond 1	Canadian Water Quality Guidelines	B.C. Water Quality Guideline	Rain Event Pond 1	Rain Event Pond 2	Units	B.C. Sediment Quality Criteria	Pond 1	Pond 2
Total Metals									
arsenic (mg/L)	0.0012	0.05	0.05	0.001	0.0005	mg/dry kg	6.0	9.6	9.9
cadmium (mg/L)	<0.0002	0.0002	0.0002	<0.0002	<0.0002	mg/dry kg	0.6	<0.1	<0.1
chromium (mg/L)	<0.001	0.002	0.002	<0.001	<0.001	mg/dry kg	26.0	22.7	22.3
copper (mg/L)	0.002	0.002	0.0076	0.002	0.004	mg/dry kg	16.0	56.0	49.0
lead (mg/L)	<0.001	0.001	0.043	0.004	<0.001	mg/dry kg	31.0	10.1	9,3
zinc (mg/L)	<0.005	0.03	0.03	<0.005	<0.005	mg/dry kg	120.0	477.0	304.0
Dissolved Metals									
arsenic (mg/L)	0.001	n/a	n/a	0.0009	0.0004				
cadmium (mg/L)	<0.0002	n/a	n/a	<0.0002	<0.0002				
chromium (mg/L)	<0.001	n/a	n/a	<0.001	<0.001				
copper (mg/L)	0.002	n/a	n/a	0.002	0.003				
lead (mg/L)	<0.001	n/a	n/a	0.001	<0.001				
zinc (mg/L)	<0.005	n/a	n/a	<0.005	<0.005				

[boxed] meets or exceeds existing criteria

B. Environmental Codes of Practice

Commercial Car and Truck Wash Best Management Practices

The BMPs refer to suggested "state of the art" practices which could be implemented on a daily basis to assist the operator complying with local sewer use restrictions and the protection of the environment. The BMP guidelines could help the operator to:

1. reduce water use and wastewater discharges;
2. reduce wastewater pollutants;
3. reduce accidental or uncontrolled discharges;
4. reduce health and safety claims; and,
5. reduce upsets at private or municipal wastewater treatment plants.

However, not all of the recommendations in this manual may be applicable or economically feasible and some operator judgment is required in their implementation.

The manual addresses seven areas in which BMPs may be applied:

1. materials management - for example, the use of reusable or recyclable materials can lead to materials cost savings and a reduction in waste generation, thereby reducing disposal costs;
2. good housekeeping - for example, chemicals should be stored in containers which are difficult to overturn and will not leak or corrode;
3. spill control measures - for example, a well managed chemical storage area and good housekeeping practices will help minimize the occurrence of spills. Spill control measures, however, should still be in place so that, in the event of a spill, potential harmful consequences may be minimized;
4. maintenance - for example, regular inspections will help identify potential trouble spots, keep equipment in peak operating condition and thus, help avoid equipment failure and chemical spills;
5. education - owners, managers and staff should be kept informed of new developments in management practices and pollution prevention through trade associations meetings, publications or government workshops;
6. record keeping - for example, records should be kept on materials inventory, maintenance, waste disposal and employee training; and,
7. solid waste disposal - bottom sludge from the oil/water separators may be contaminated and should be removed and disposed of by an approved commercial tank cleaning company.

As a second part to the BMP, recommended practices were summarized for mobile vehicle washes and charity washes.

Mobile vehicle wash operations are recommended to abide by the local sewer use bylaws. This may entail collecting all wastewater generated for the transportation to a site where it can undergo pre-treatment. Depending upon the municipality, the operator may be allowed to collect the washwater for discharging directly to the sanitary system at an approved location. The wastewater may be captured by:

1. routing to a depression;
2. containing it with portable plastic berms;
3. sealing catch basins with rubber gaskets; and,
4. using a portable containment device under vehicles.

As for the charity washes, the wastewater should be directed to the sanitary sewer for treatment. If this is not possible, then the following could be suggested:

1. only wash vehicle bodies; do not wash undercarriages or engines;
2. use water only; do not use detergents, solvents, heavy degreasers or high alkaline or acidic agents;
3. do not wash heavily soiled, greasy or oily surfaces;
4. use a flow control device on the water hoses;
5. wash vehicles on grassy or gravel areas with sufficient soaking capacity; and,
6. if washing on pavement, wash cars next to the storm drain.

Golf Course Environmental Codes of Practice

To complement the inventory and site assessment work on golf courses, an Environmental Code of Practice was also developed to assist golf superintendents to enhance any current BMPs they now practice.

Many aspects of environmentally responsible management are already being practiced by many golf course superintendents under the designation of the Integrated Pest Management Program (IPM). However, it is important to recognize that the full advantages of the Integrated Pest Management Program cannot be fully realized until there is a full buy-in, written commitment and regular monitoring and recording of progress.

An environmental management plan also goes beyond IPM. While IPM forms an essential component of a management plan, management plans are also intended to address other golf course practices which can potentially impact the environment, for example, stormwater management, pesticide and fertilizer storage, equipment washing and composting.

What IPM and an environmental management plan have in common is the employment of methods described as Best Management Practices (BMPs). BMPs are methods of operation and management which help to prevent or reduce pollution, in this case, water pollution.

The intent of this manual was to increase awareness of BMPs and provide a strategy for the development of management plans (protection of surface water quality). The manual is not exhaustive and it is duly recognized that management decisions will require consideration of numerous factors, often of a very specific nature. This manual was therefore only intended as a guide to the superintendent, to be used in conjunction with good educational background and experience.

Impact of Land Uses on Stormwater Quality

In conjunction with the Brunette River data reports on stormwater quality, the intent of this project was also to develop a Best Management Practices for urban runoff. The BMP is to be transferable to other watersheds within the Fraser River basin. A report is due for release March 31, 1996.

Nitrogen and Phosphorus in the Upper Fraser River in Relation to Point- and Diffuse-Source Loadings

P.A. Chambers and T.D. French

National Hydrology Research Institute

Water quality studies on the Fraser River have focused largely on contaminants and their effect on fisheries and primary production, particularly in the reach between the town of Hope and the estuary. By comparison, few studies have addressed water quality issues in the upper reaches of the Fraser River. The objective of this study was to evaluate trends in nitrogen (N) and phosphorus (P) chemistry in the Fraser River from the headwaters to Hope. Anthropogenic nutrient loading to the Fraser River upstream of Hope was found to be highly regionalized with loading being minimal to the reach extending from the headwaters to Hansard, greatest between Hansard and Marguerite ($16x10^4$ m^3/d from indirect pulp mill discharge; $1x10^4$ m^3/d from direct and $2.5x10^4$ m^3/d from indirect sewage discharge).

Total P export increased from an average of 7 tonnes/yr near the headwaters (Red Pass) to 10,337 tonnes/yr at Hope, with 85% of the TP export at Hope occurring during the high flow season and only 15% during low flows. N export also increased from an average of 113 tonnes/yr near the headwaters to 13,217 tonnes/yr at Hope. Anthropogenic sources contributed 13% (11% from pulp mills and 2% from municipalities) and 5% (4% from pulp mills and 1% from municipalities) of the total P load at Marguerite during low and high flow seasons, respectively. The anthropogenic contribution to total P export at Hope was 12% and 3% over the same flow regime, whereas anthropogenic contributions were negligible upstream of Prince George.

Conclusions

While anthropogenic sources contribute only a small fraction of the nutrient load in the upper Fraser River (<7% annually), the high proportion of bioavailable forms of N and P in effluents compared to natural sources can result in ecological changes downstream of effluent outfalls during periods of low discharge.

AIM

- **To evaluate trends in nutrient chemistry in the Fraser River from its headwaters to the town of Hope.**

WHY?

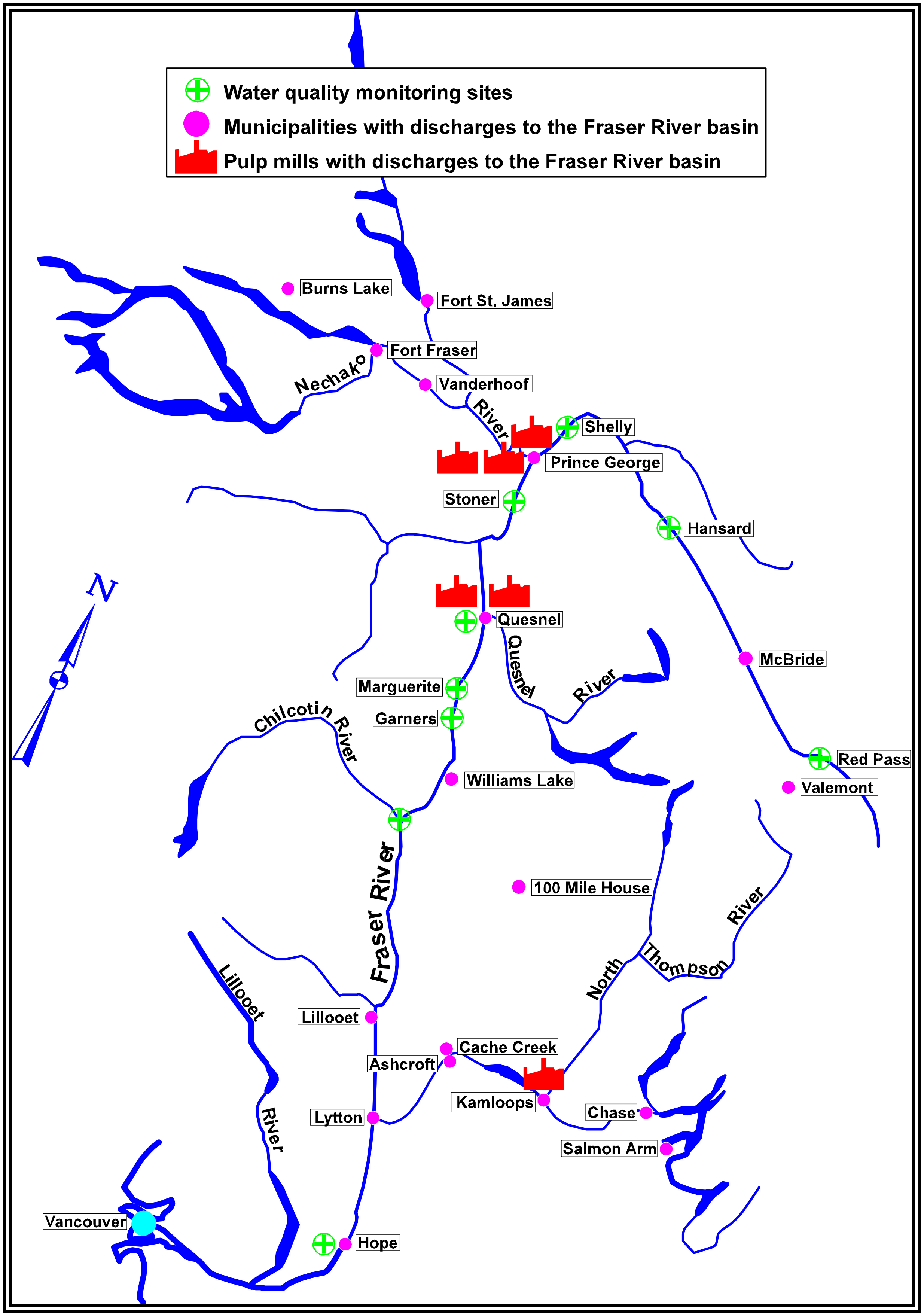
- **Most water quality studies on the Fraser River have focused on contaminants and fisheries aspects, particularly for the lower Fraser.**
- **Improvements in pulp mill technology have reduced BOD and toxicity concerns, however nutrients are still a major issue.**

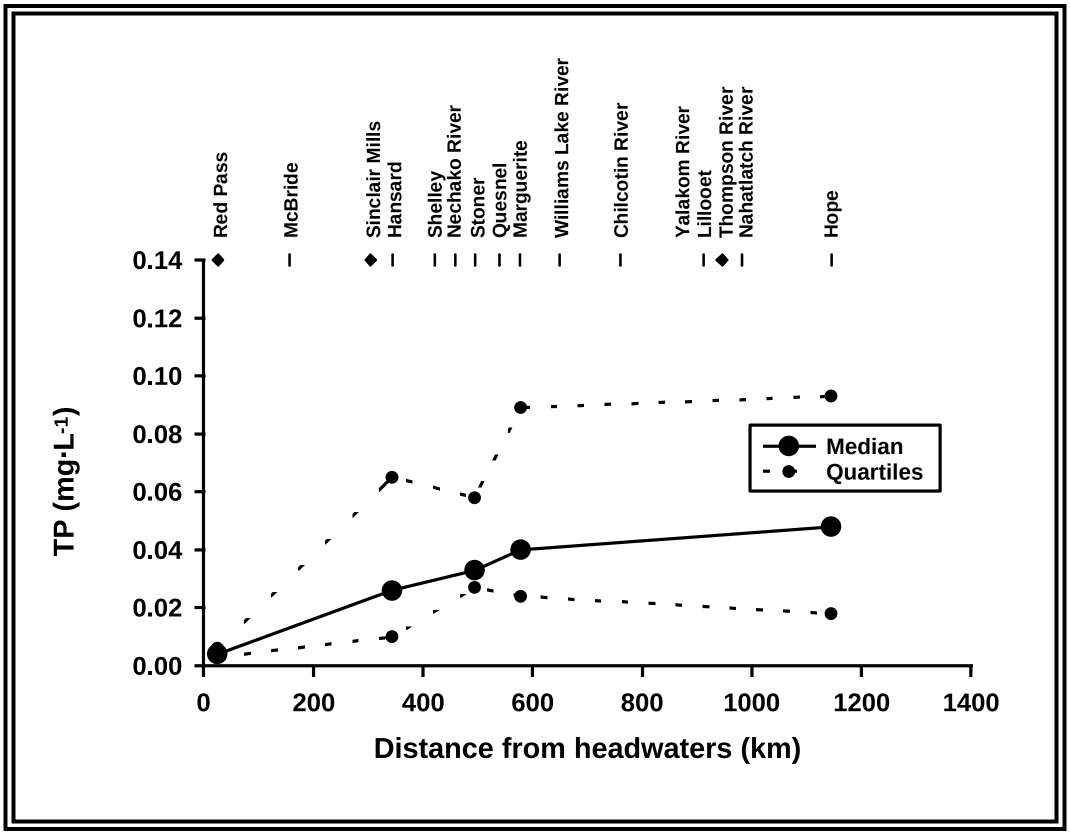
APPROACH

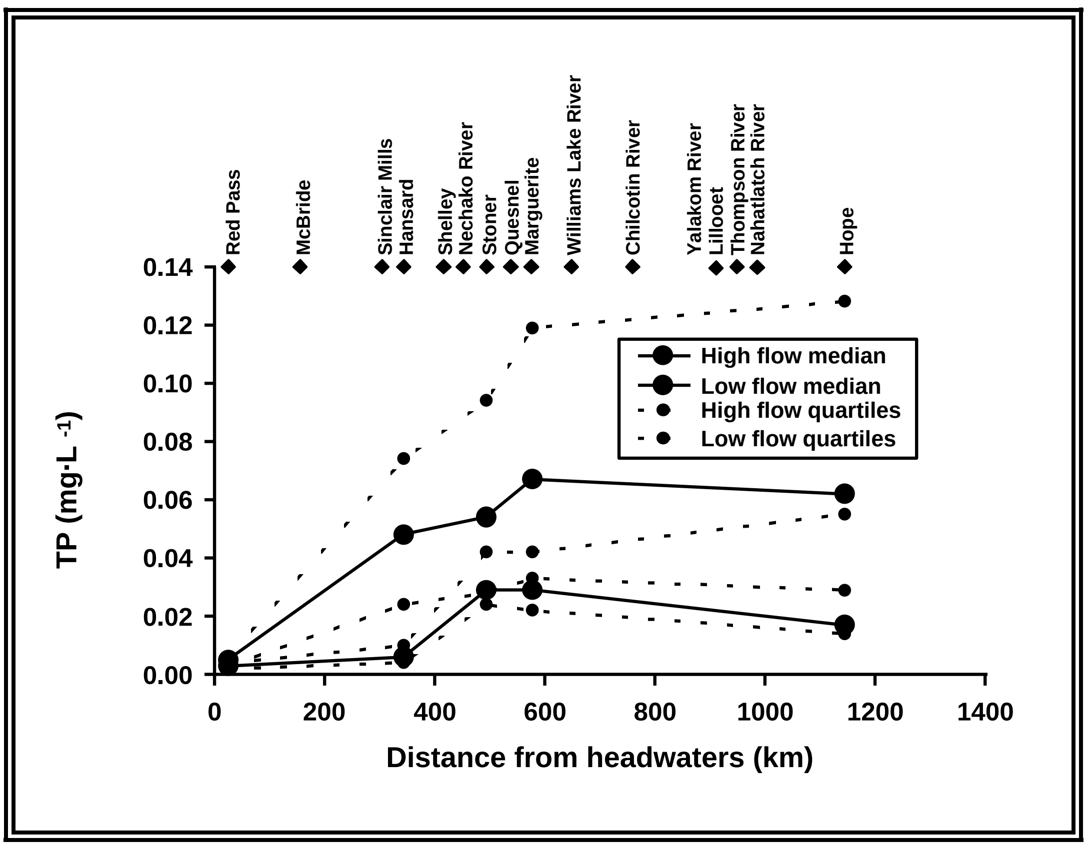
- longitudinal trends in nutrient chemistry
- contribution from anthropogenic point sources
- potential contribution from land-use practices

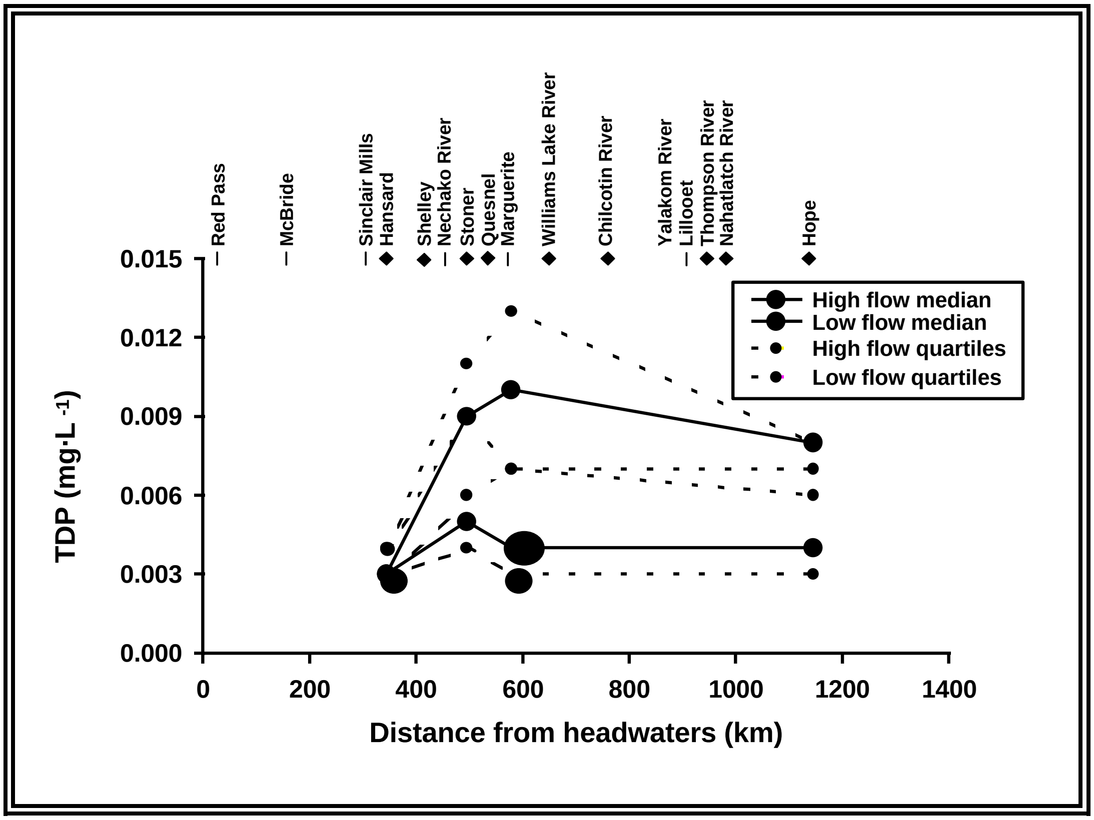
DATA LIMITATIONS

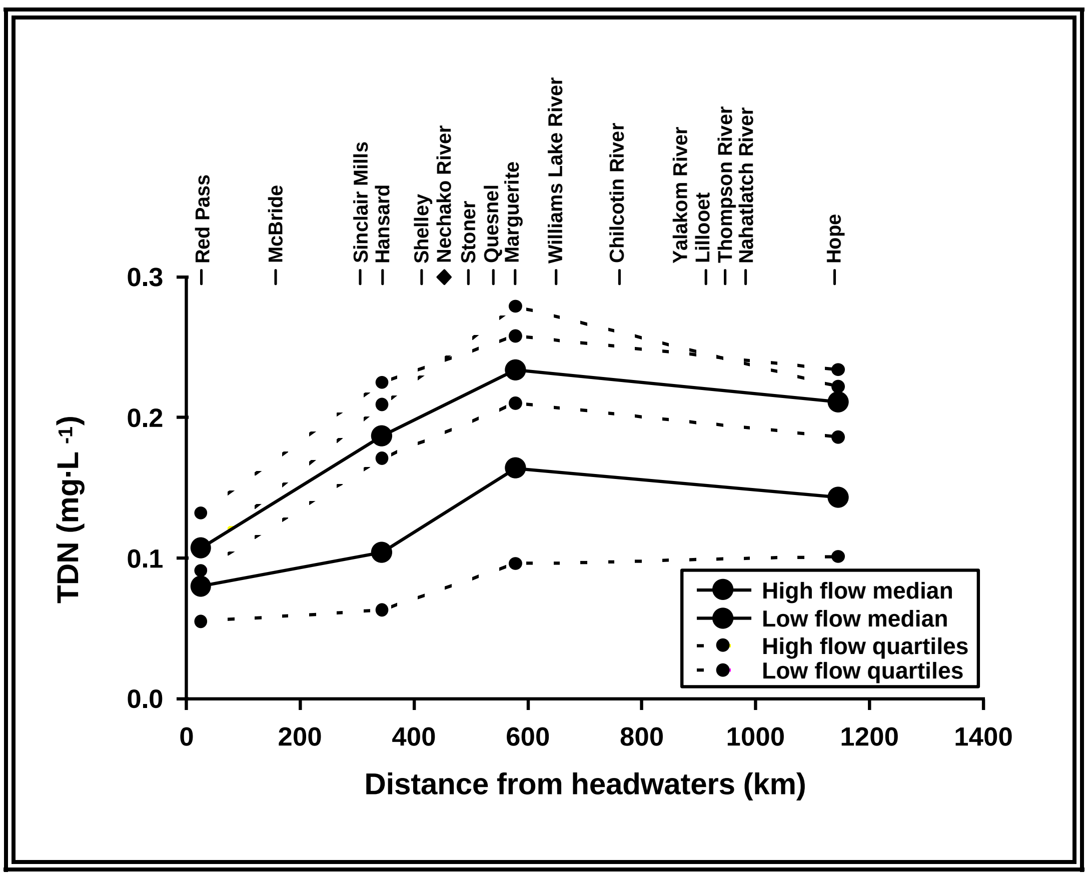
- no data for biologically active P (i.e., SRP)
- regular long-term data limited to sites at Red Pass, Hansard, Stoner, Marguerite and Hope
- except for Nechako and Thompson rivers, tributary data limited to infrequent TP samples
- limited and variable nutrient data from pulp mills (N & P monitoring not a license requirement)
- errors in data analysis/reporting

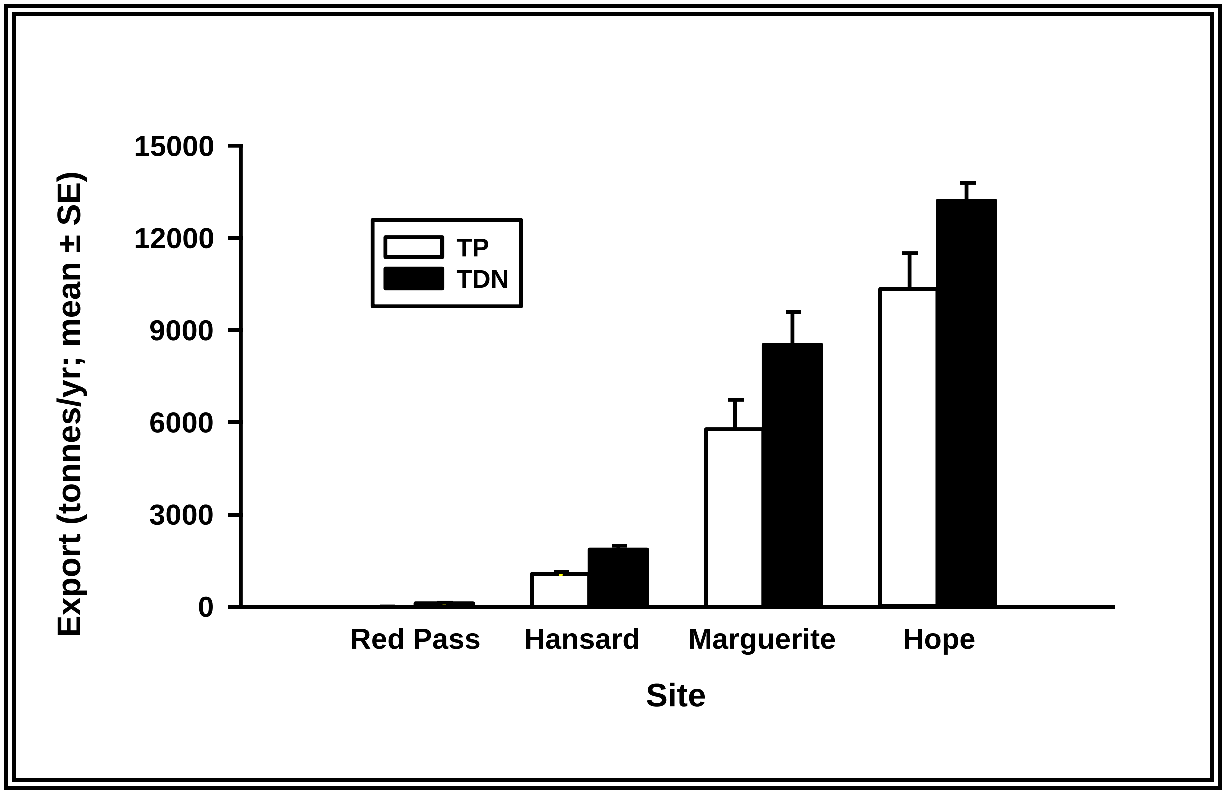

Water quality monitoring sites
Municipalities with discharges to the Fraser River basin
Pulp mills with discharges to the Fraser River basin
N
Burns Lake
Fort St. James
Fort Fraser
Nechako
Vanderhoof
River
Shelly
Prince George
Stoner
Hansard
Quesnel
Quesnel
River
McBride
Marguerite
Garners
Chilcotin River
Williams Lake
Red Pass
Valemont
100 Mile House
Fraser River
River
North
Thompson
Lillooet
Lillooet
River
Cache Creek
Ashcroft
Kamloops
Chase
Lytton
Salmon Arm
Vancouver
Hope

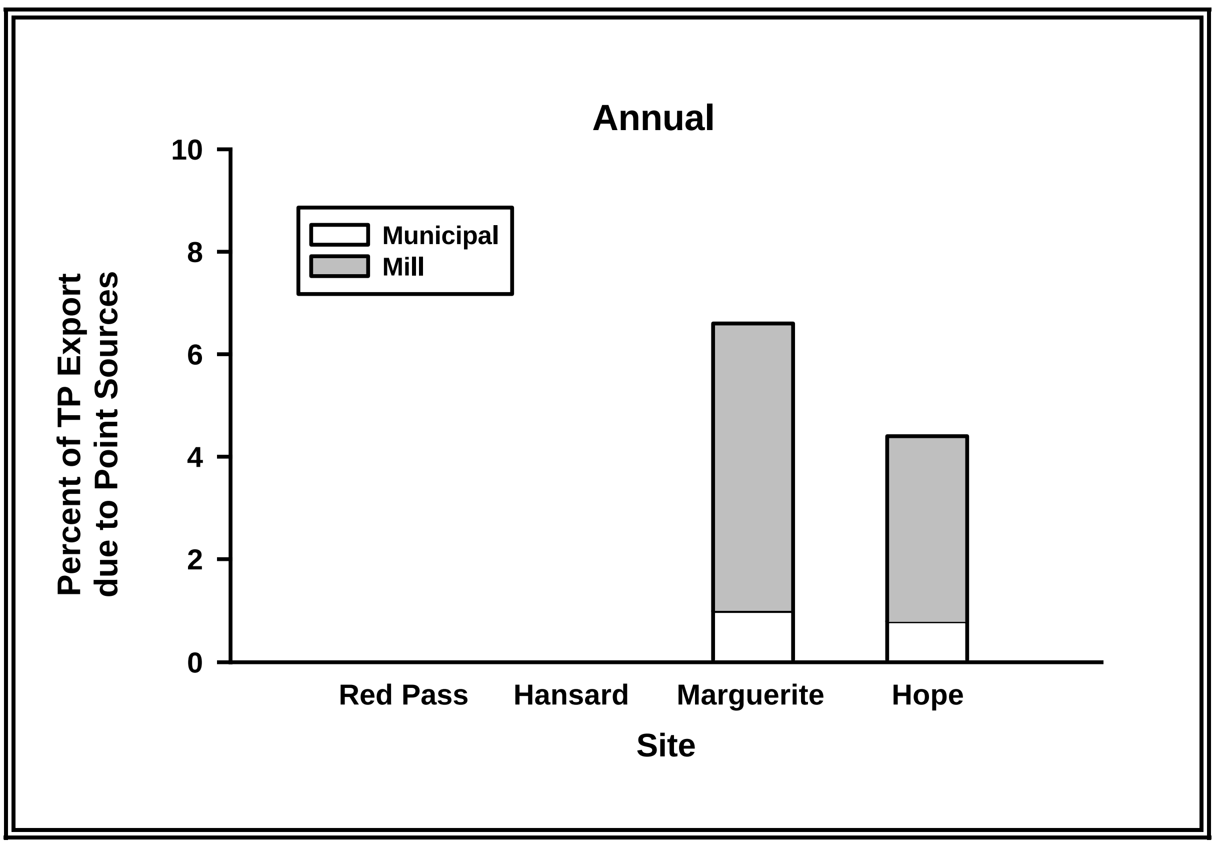

Red Pass
McBride
Sinclair Mills
Hansard
Shelley
Nechako River
Stoner
Quesnel
Marguerite
Williams Lake River
Chilcotin River
Yalakom River
Lillooet
Thompson River
Nahatlatch River
Hope
TP (mg·L-1)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
200
400
600
800
1000
1200
1400
Distance from headwaters (km)
Median
Quartiles

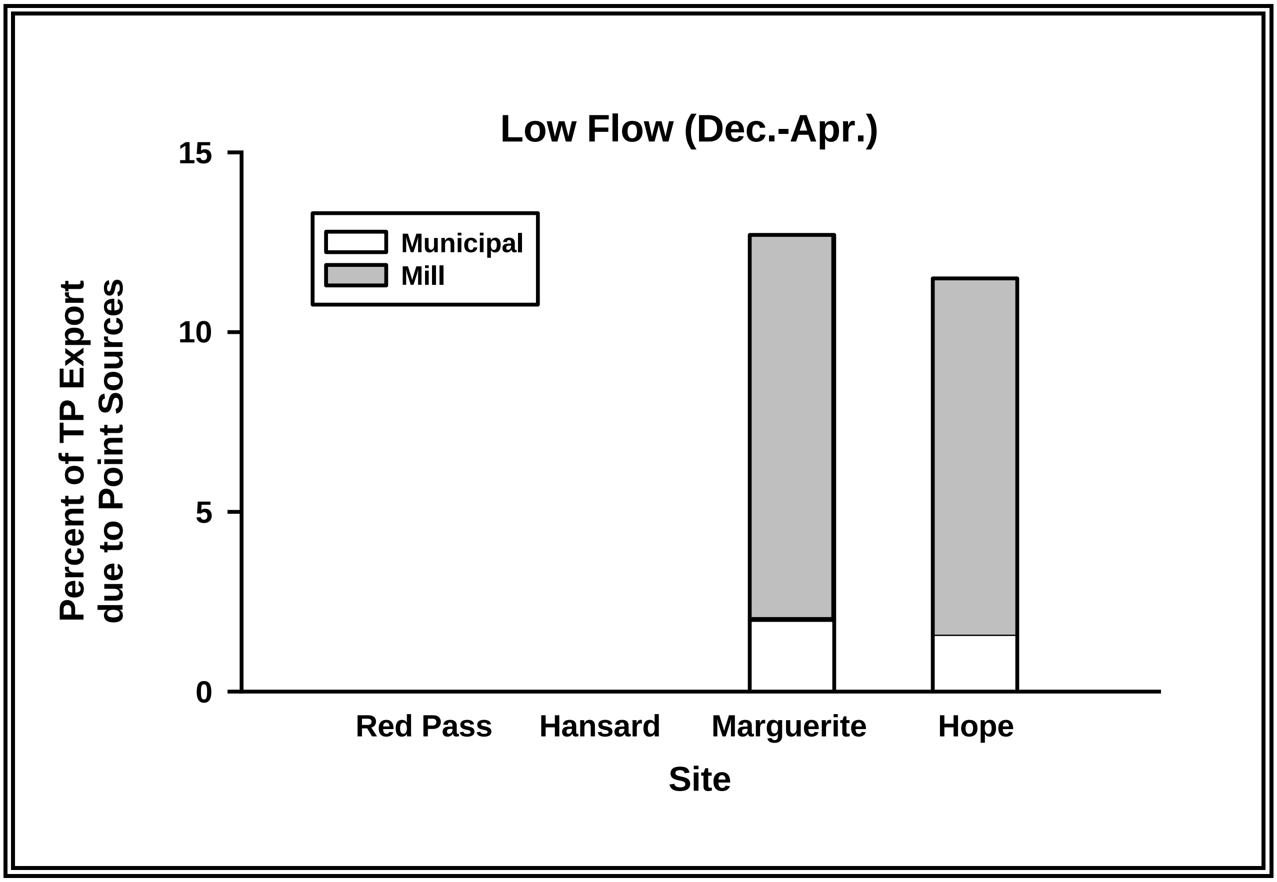

Red Pass
McBride
Sinclair Mills
Hansard
Shelley
Nechako River
Stoner
Quesnel
Marguerite
Williams Lake River
Chilcotin River
Yalakom River
Lillooet
Thompson River
Nahatlatch River
Hope
TP (mg·L -1)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
200
400
600
800
1000
1200
1400
Distance from headwaters (km)
High flow median
Low flow median
High flow quartiles
Low flow quartiles


Red Pass
McBride
Sinclair Mills
Hansard
Shelley
Nechako River
Stoner
Quesnel
Marguerite
Williams Lake River
Chilcotin River
Yalakom River
Lillooet
Thompson River
Nahatlatch River
Hope
TDP (mg·L -1)
0.015
0.012
0.009
0.006
0.003
0.000
0
200
400
600
800
1000
1200
1400
Distance from headwaters (km)
High flow median
Low flow median
High flow quartiles
Low flow quartiles


Red Pass
McBride
Sinclair Mills
Hansard
Shelley
Nechako River
Stoner
Quesnel
Marguerite
Williams Lake River
Chilcotin River
Yalakom River
Lillooet
Thompson River
Nahatlatch River
Hope
TDN (mg·L -1)
0.3
0.2
0.1
0.0
0
200
400
600
800
1000
1200
1400
Distance from headwaters (km)
High flow median
Low flow median
High flow quartiles
Low flow quartiles


15000
12000
9000
6000
3000
0
Export (tonnes/yr; mean ± SE)
TP
TDN
Red Pass
Hansard
Marguerite
Hope
Site


Annual
10
8
6
4
2
0
Percent of TP Export due to Point Sources
Municipal
Mill
Red Pass
Hansard
Marguerite
Hope
Site



Site	Point Source Contributions to TP Load (%) Pulp Mill	Sewage
Fraser River, BC (@Marguerite)	5.6	1.0
Athabasca River, AB (@Athabasca)	6.3	1.1
Wapiti River, AB (@Mouth)	13.0	9.7
Flint River, GA, USA	≤ 5.6	n/a
Gulf of Bothnia, Baltic Sea	10.0	14.0

CONCLUSIONS

- **Nutrient concentrations increased from headwaters to downstream of Quesnel and then remained relatively constant to Hope.**
- **Dissolved nutrient concentrations were greatest during lower flows whereas TP was greatest during high flows.**
- **Anthropogenic sources contribute 13% and 5% of the TP downstream of Quesnel, and 12 and 3% of the TP at Hope during low and high flows, respectively. Most of this is from pulp mill effluents.**

Anti-Sapstain Toxicology Studies

T. Wood, B. Johnston, T. Farrell and C. Kennedy

Biological Sciences
Simon Fraser University

Objective

To perform controlled, laboratory-based fish and invertebrate toxicological studies with DDAC and IPBC that will contribute towards Criteria development for anti-sapstain compounds.

Rationale

Annually, the lumber industry uses a considerable volume of anti-sapstain chemicals to protect cut lumber from stain-forming fungi during storage and transportation. Concern exists over anti-sapstains entering the Fraser River in stormwater runoff. DDAC (didecyldimethylammonium chloride) and IPBC (3-iodo-2-propynyl butyl carbamate) are the principle active ingredients of the anti-sapstain chemicals that have replaced the previously used pentachlorophenates, copper-8-quindinolate and TCMTB (2-(thiocyanomethylthylthio)benzothiozole), all of which have been withdrawn from use over environmental and human health concerns. To date, all toxicological studies on these compounds have been performed primarily by the industry, with little information in the primary refereed literature. The present regulations allow DDAC discharge in stormwater at concentrations of 700 ppb.

Approach

Pure test chemicals rather than formulations were used. The test species were selected based on availability and relevance to the Fraser River, and, in some cases, to act as reference organisms. The species tested will include:

- juvenile rainbow trout (reference)
- juvenile coho salmon (relevant)
- juvenile starry flounder (relevant)
- juvenile white sturgeon (relevant)
- coho embryos (reference)
- starry flounder embryos (relevant)
- white sturgeon embryos (reference)
- fathead minnow (reference)
- *Hyallela azteca* (reference)
- *Daphnia magna* (reference)
- *Neomysis mercedis* (relevant)
- *Mysidopsis bahia* (reference)

Standard toxicological testing techniques were used to test for lethal and sublethal effects. These included:

- 96-h LC_{50} flow-though testing for juvenile fish
- 24-h or 96-h LC_{50} static and flow-through testing for fish embryos and larvae
- 48-h LC_{50} static testing for invertebrates
- 24-h exposure for sublethal monitoring of juvenile fish (stress and swimming performance)

Short exposure durations were used because of the episodic nature of storm run off. All experiments used either dechlorinated Vancouver tap water or sea water from Burrard Inlet. Water temperatures were 8-12^{o}C for fish studies and 18-22 ^{o}C for invertebrate studies.

Results

The toxicity database collected to date for DDAC and IPBC are summarized in Tables 1, 2 and 3.

1. For DDAC (Table 1), the most sensitive fish species (and life stage) tested so far has been the juvenile white sturgeon (24-h LC_{50} was between 1 and 10 ppb for fry).
2. For DDAC, the most sensitive invertebrate species (and life stage) tested so far has been *Mysidopsis bahia* (48-h LC_{50} = 106 ppb).
3. The fish and invertebrate species that were selected as most relevant to the lower Fraser River (i.e., starry flounder and *Neomysis mercedis*), were the species tested that were least sensitive to DDAC. The 96-h LC_{50} value for juvenile starry flounder was four times higher than that for juvenile rainbow trout and around 1,000 times higher than that for juvenile white sturgeon. The 48-h LC_{50} value for *Neomysis mercedis* was 10 times higher than that for *Mysidopsis bahia*.
4. Non-lethal tests with juvenile rainbow trout and starry flounder revealed no major sublethal physiological effects to DDAC at concentrations 50% less than the LC_{50} concentration (Table 3). A 21-day life cycle test with *Dapnia magna* resulted in a NOEC of 37 ppb, which was also around half of the 48-h LC_{50} value. We suspect that the toxicity curve for DDAC is fairly steep and results in a threshold-type lethality within an order of magnitude of the LC_{50} value.
5. Coho embryos were less sensitive to both DDAC and IPBC than the emergent alevins and fry (Tables 1 and 2).
6. The fish species and life stages tested so far appeared to be more sensitive to IPBC than to DDAC. The LC_{50} values were generally two or three times lower with IPBC. An exception to this was the coho embryos which were more sensitive to DDAC.
7. The invertebrate species tested so far appeared to be more resistant to IPBC than to DDAC. The LC_{50} values were generally two or three times higher with IPBC.
8. To date, the information we collected have been qualitatively consistent with existing data (e.g., the relative toxicity of vertebrates vs. invertebrates to the two chemicals).
9. Quantitatively, we found differences in some of the LC_{50} values we derived. With the important exception of the data on juvenile sturgeon, most of our LC_{50} values have been within an order of magnitude of those reported in the BC MOELP documents on DDAC and IPBC.
10. Unless there are synergistic actions of IPBC and DDAC, we predict that IPBC will not have a major influence on the overall toxicity of certain anti-sapstain mixtures even though test fish species were more sensitive to IPBC, because IPBC is a small fraction of anti-sapstain mixtures compared with DDAC, and because IPBC appears to have a different mechanism of toxic action to DDAC.

Conclusions

Data collection has not been completed and so recommendations are tentative at this stage.

1. We have concerns about the use of starry flounder and *Neomysis mercedis* as relevant test species for the lower Fraser River ecosystem. Likely, they are not the most sensitive components of the vertebrate and invertebrate communities. In addition, we had initial difficulties obtaining and rearing *Neomysis*, and the collection sites may have pre-exposed the animals to the test chemicals.
2. The effects of salinity on the toxicity of DDAC were small, but we still need information on the possible role of the Fraser River sediments in modulating the toxicity of anti-sapstain chemicals.

3. The relevance of testing with larval sturgeon vs. other larval species needs to be established. It is not known whether or not juvenile sturgeon are exposed to these toxicants. Furthermore, we do not know if the sensitivity of the larval white sturgeon is similar to other species with a short (around one week) egg developmental stage. There are certainly substantial differences compared with coho salmon which have a much longer (more than four weeks) egg development stage.
4. Even with the above concerns and uncertainties, we suspect that the present regulatory level for DDAC will not protect sensitive invertebrate and fish species from the lethal effects of DDAC if stormwater concentrations approach 700 ppb. Our data are consistent with the idea that short-term (24- to 96-h) exposures to 700 ppb DDAC would result in a significant damage zone. Predictions on the extent of the damage zone will need information on the temporal and spatial characteristics of relevant stormwater discharge and dilution.

Table 1. Acute Lethal Toxicity Data - DDAC

Species	Lifestage	Test Duration*	LC_0 (mg/L)	LC_{50} (mg/L)	LC_{100} (mg/L)
Rainbow Trout	juvenile (1+)	96-h (f)	0.2	0.409	0.5
Coho Salmon	embryo (0-4 d)	96-h (s/r)	0.15	0.571	>1.20
	embryo (42-46 d)	96-h (s/r)	0.60	1.05	>1.20
	alevin (67-71 d)	96-h (f)	0.32	0.423	0.56
	alevin (76-80 d)	96-h (f)	0.32	0.385	0.56
	alevin (86-90 d)	96-h (f)	0.40	0.456	0.56
	fry (104-108 d)	96-h (f)	0.42	0.489	0.56
	smolt (0)**	96-h (f)	0.60	0.989	1.20
	smolt (15)**	96-h (f)	—	0.970	—
	smolt (30)**	96-h (f)	—	0.725	—
Starry Flounder	juvenile (1+)	96-h (f)	1.5	2.05	2.2
Fathead Minnow	juvenile	96-h (f)	0.050	0.172	0.300
White Sturgeon	fry	24-h (s)	<0.00001	0.001-0.01	0.01
Hyalella azteca	neonate	48-h (s/r)	<0.075	0.142	>0.24
Daphnia magna	neonate	48-h (s/r)	.030	0.052	0.075
Mysidopsis bahia	neonate	48-h (s/r)	0.020	0.039	0.040
Neomysis mercedis	adult	48-h (s/r)	≥0.32	0.32-0.56	≥0.56

* f - flow-through; s - static; s/r - static with replacement
** Test salinity (parts per thousand)

Table 2. Acute Lethal Toxicity Data - IPBC

Species	Lifestage	Test Duration*	LC_0 (mg/L)	LC_{50} (mg/L)	LC_{100} (mg/L)
Rainbow Trout	juvenile (1+)	96-h (f)	0.10	0.140	0.19
Coho Salmon	embryo (11-15 d)	96-h (s/r)	<1.0	1.320	4.6
	embryo (34-38 d)	96-h (s/r)	<1.0	1.90	3.2
	alevin (76-80 d)	96-h (f)	0.18	0.212	0.32
	alevin (88-92 d)	96-h (f)	0.12	0.166	0.20
	fry (104-108 d)	96-h (f)	TBD**	TBD	TBD
	juvenile (1+)	96-h (f)	0.10	0.118	0.14
Starry Flounder	juvenile (1+)	96-h (f)	0.32	0.367	0.42
Hyalella azteca	neonate	48-h (s/r)	0.1	0.496	2.20
Neomysis mercedis	adult	48-h (s/r)	TBD	TBD	TBD

* f - flow-through; s/r - static with replacement
** TBD - To be determined

Table 3. Acute Sublethal Toxicity Data - DDAC

Species	Lifestage	Parameter Measured	Exposure Duration*	NOEL (mg/L)	LOEL (mg/L)
Rainbow Trout	Juvenile (1+)	U_{crit}	24-h (f)	0.1	0.2
		Cortisol		0.2	0.4
		Lactate		0.2	0.4
		Glucose		0.2	0.4
		Haematocrit		0.4	>0.4
		Leucocrit		0.4	>0.4
		Haemoglobin		0.4	>0.4
		Disease Resist.		0.4	0.4**
Starry Flounder	Juvenile (1+)	Lactate	24-h (f)	0.5	1.0
		Haematocrit		2.0	>2.0
		Leucocrit		2.0	2.0
		Glucose		2.0	>2.0
		Haemoglobin		2.0	>2.0
Daphnia magna	Lifecycle	Fecundity	21-d (s/r)	0.037	>0.037

* f - flow-through; s/r - static with replacement
** marginally increased disease resistance

The Effects of Contaminants and Riparian Zone Integrity on Small Stream Ecosystems in the Lower Fraser Basin

J. Richardson

Westwater Research Centre and Department of Forest Sciences
University of British Columbia

Small streams represent an integrator of characteristics of a catchment. They are also most reflective of local conditions because of the tight linkages between land and water and the high ratio of edge-to-volume in small streams. In the lower Fraser basin the heavy influence of human activities on streams is detectable everywhere. It may be that there are no small streams in the alluvial portion of the lower Fraser basin that have not been severely modified by human activities. One of the challenges of our studies was to find appropriate reference conditions with which to compare stream communities of the streams of the lower basin. In these studies, we have combined comparative studies with experimentation and the laboratory bioassays of Dr. Ken Hall (University of British Columbia) to provide an analysis of the state of small streams of the lower Fraser basin.

Stream ecosystems can be affected by human activities in a variety of ways including a range of contaminants, changes in hydrology, yield of fine sediments, changes in temperature regime, alteration of riparian vegetation and physical rearrangement. Many such changes would be considered non-point source and are difficult to separate out by their individual effects and difficult to manage. Even where the aggregate effects of a particular factor have been considered, the problem of autocorrelation in space or time by comparing streams within a drainage hinders the ability to empirically test or estimate the effect.

The interpretation of differences in biological communities between sites may be confounded by the inability to refute hypotheses that are not independent of each other. For instance, in sites which are heavily impacted by heavy metals, the built-up nature of these areas would also result in reduced water retention and hence, higher peak flows, more people with greater chance of sewage leakage, and greater degree of habitat alteration and riparian vegetation removal. Thus, the coincidence of multiple insults restricts one’s ability to isolate individual perturbations in field studies.

Identifying the impacts of non-point sources of perturbation is further confounded by a variety of other factors. Within a given drainage there may be similar land use so that it is difficult to separate out general land use differences from other differences between streams and drainages. For instance, streams within a drainage may be more similar to each other for reasons of common underlying alluvium or other geologic features, access or occurrence of particular species (e.g., salmon), or other climatic or water quality factors. This could mean that drainages may have been historically different, and while this is unlikely, we have no clear means of rejecting it. The point being that drawing comparisons across drainages is fraught with limitations.

Another set of difficulties in interpretation of the effect of non-point sources of pollution is that biological communities may have adapted to the perturbation. For instance, studies have shown that in streams chronically affected by heavy metal pollution over the course of the past century have species populations which show higher tolerance levels for heavy metals than the same species in unaffected streams. Communities may have adjusted such that more tolerant species have replaced or expanded in the wake of the disappearance of less tolerant species. However, these substitutions may be within the same genus and, therefore, not be resolvable with the current state of invertebrate taxonomy. There is evidence of the latter from studies in the US midwest.

We had several guiding objectives for our studies:

- to assess the community structure of small streams as a means of identifying impacts of human land uses — including the degree of riparian modification and water quality measure;

- to compare fish and invertebrate assemblages across a range of environmental conditions as an index of ecosystem condition;
- experimentally assess the causal affects of heavy metal inputs in an unpolluted stream as a means of accounting for the potential impacts of heavy metals from among the other impacts on urban streams; and,
- interpret benthic community structure in urban and agricultural streams in the context of predicted effects of heavy metals on constituent taxa.

In this component of the Fraser River Action Plan we have three primary projects in Lower Mainland streams:

1. patterns in the structure of fish assemblages in small streams;
2. patterns in the structure of riffle macroinvertebrates in small streams; and,
3. a mesocosm experiment testing the dose-dependence of biological responses to heavy metals in solution.

All three of these studies are nearing completion and should be in final report form by the end of August, 1996.

Fish

A total of 40 streams have been sampled once for fish assemblages using baited minnow traps. Among these 40 sites were streams in the Brunette, Salmon and Sumas drainages as well as a further 16 sites in areas primarily on the north shore in areas relatively unaffected by urban and agricultural activities. The sites on the north shore were used for reference sites, or outgroup comparison, so that we could ascertain whether the relatively “pristine” sites in the Salmon River watershed could be assumed to be in good condition. Using ordination, most of the Salmon River sites clustered among those from the north shore sites, indicating that the Salmon drainage is a valid point of reference for comparison with other Lower Mainland streams.

Twenty-four of the streams referred to above have been sampled three times and are being compared for community composition relative to assemblages considered “pristine”. The results of preliminary analyses on these data using ordination showed clear separation between sites which were considered “pristine” and those affected by urban and agricultural impacts. Clean sites were characterized by higher densities of cutthroat trout, coho and crayfish, whereas impacted sites were more likely to have higher densities of sticklebacks, carp and prickly sculpin. Tests of association with the ordination scores and measures of environmental variables, mostly habitat attributes, showed no significant association suggesting that variables other than strictly habitat (i.e., water quality), might be linked to the patterns in fish assemblage. Integration of our results with water quality data from Drs. Ken Hall and Hans Schreier will test this latter hypothesis.

Benthos

Twenty-four streams were sampled for benthos in riffle substrate during late summer, 1995. Many of these streams coincide with those for which fish were sampled, mainly in the Brunette and Salmon drainages. Some additional streams were sampled to increase sample size, represent a broader set of streams, and also to avoid the spatial autocorrelative problem of having all the urban sites in the Brunette and all the cleaner semi-rural sites in the Salmon. Processing of these samples is proceeding well and the data will be subject to similar ordination and clustering analyses as for the fish. Comparisons with the fish assemblages, habitat attributes and water quality information will be the basis of analysis of those data.

Mesocosm Experiment

Given the difficulty with separating out the signals imposed on biological communities by heavy metal contamination in a system with multiple, non-point source impacts, we carried out an experimental test of the separate effects of heavy metal input on a small and pristine stream. The rationale for using a clean site was that any species sensitive to heavy metals would still be present and their responses would be illustrative of processes that may have led to their extirpation in urban streams. The experiment was carried out at the Malcolm Knapp

Research Forest of UBC in August - September, 1995. Sixteen plexiglass troughs of about 2.5 m length and 25 cm width were supplied with running water diverted from Mayfly Creek via a pipeline and distribution box. Flow was adjusted such that each trough received approximately 0.1 L/s of water. Heavy metals were added as a constant ratio of dissolved Cu:Mn:Zn:Pb, but at different doses from Marriot bottles at the head of each trough. The ratio of metals and range of doses were based on data for the Brunette River from Dr. Ken Hall.

A suite of biological and chemical parameters were measured as response variables. The concentration of heavy metals in effluent water was measured. Samples of leaf tissue which might be an adsorption surface were collected for analysis. Other measures included:

- microbial respiration rate on leaf tissue from each trough;
- emigration or “drift” rate of macroinvertebrates before and during treatment;
- benthos at the end of the experiment; and,
- algae — as chl a concentration and as relative abundance.

Most of these data sets are nearing completion. We would like to repeat this experiment with greater control over dosing rates and metal speciation in the test mixture. Repeating the experiment would also increase the overall statistical power of the experiment when combined with the 1995 results.

Next Steps

We need to put all these data together for publication. The direct comparison of experimental results to the community structure of lower Fraser basin streams will allow us to test the prediction that the species that show sensitivity to heavy metals additions are those that are absent from natural streams.

We have now compiled a large data set on stream communities in the lower Fraser basin including urban, agricultural, forested and montane streams. These data will be compared to determine a series of patterns that have been predicted based on the type of environmental perturbation. Ordination and other gradient analyses will be used to extract these patterns from the data set for community configuration and test for associations with characteristics of the channel and catchment.

It appears that some of the lower Fraser basin sites in the Salmon River drainage have fish assemblages similar to those of streams of mostly undeveloped drainages. Thus, the Salmon River sites can be considered as a reasonable reference drainage against which other catchments can be compared, but there are limitations to the degree of inference that can be made from such comparisons. Having further reference sites from drainages other than the Salmon River would permit one to make more definitive statements about the historical state of small streams rather than being constrained by the uncertainty about the uniqueness of the Salmon River watershed.

These data will only be useful as a baseline reference if further studies are continued to estimate the degree of variation attributable to several sources to resolve the true long-term mean condition of the system. Our studies are snapshots, but inclusion of a large number of sites reduces that problem somewhat although they can still be temporally autocorrelated signals. The indication that some sites in the Lower Mainland are “healthy” provides a useful point of reference for future studies.

Atmospheric Deposition in the Fraser Valley

W. Belzer

Environment Canada

Objectives:

To determine the contribution of the air pathway to the deposition of metals and PAHs to the Still Creek-Burnaby Lake-Brunette River watershed.

Location

- Burnaby Lake

This lake is the centre of several years of aquatic evaluation by the Westwater Research Center at UBC, as a part of the FRAP program.

Linkages

Metals and PAHs have been measured in this watershed area by the Westwater Research Centre at UBC. There should be some relationship between air, water and sediment measurements.

Wet Deposition

Definition: To deposit chemicals from the air in a solid or dissolved form, by the action of rain, snow or other precipitation, to the land and water.

Dry Deposition

Definition: To deposit chemicals, in dry or gaseous form, from the dry air to the land and water by the action of gravity, wind and random motion.

Chemicals of Interest

- PAHs
- Metals

Physical Properties

- Particulate matter in different size fractions.

Air Deposition

Still Creek — Burnaby Lake — Brunette River

Site

Burnaby Lake Rowing Facility

Sampling Period

January, 1995 - December, 1995

Wet Deposition — MIC Rain Sampler

Rainfall — inorganic

Cd, Cr, Cu, Pb (low level)
Ag, Al, As, B, Ba, Be, Ca, Cd, Co, Cr,
Cu, Fe, K, Mg, Mn, Mo, Na, Ni,
P, Pb, Sb, Se, Si, Sn, Sr, Ti, V, Zn

Rainfall — organic

PAHs

Dry Deposition — Cascade Impactor

Particulate — inorganic

Cd, Cr, Cu, Pb (low level)
Ag, Al, As, B, Ba, Be, Ca, Cd, Co, Cr,
Cu, Fe, K, Mg, Mn, Mo, Na, Ni,
P, Pb, Sb, Se, Si, Sn, Sr, Ti, V, Zn

Particulate + Gas — organic

PAHs

Deposition Methodology

Wet Deposition

1) Collect rainfall
2) Measure content for PAHs or Metals (different samplers)
3) Calculate deposition rate from concentration and surface area of sampler:
   - Depos’n Rate = $^{Conc/day}/_{Area}$
     (mg/m^2/day) = (mg/L/day) / (m^2)

Dry Deposition

1) Collect particulate on filter media in separated size fractions
2) Calculate volume of air sampled
3) Calculate deposition rate from relationship with particle size (diameter)
   - (too complicated to show here)

Calculate Average Atmospheric Contribution to Land and Water Areas

1) Calculate yearly dry deposition contribution
   - Yearly Dry depos’n = [Dry dep rate * #Dry Days/year]
2) Calculate yearly wet deposition contribution
   - Yearly Wet depos’n = [Wet dep rate * #Wet Days/year]
3) Determine yearly airborne input of PAHs/Metals to the Still Creek — Burnaby Lake — Brunette River watershed
   - Yearly Total depos’n = [Yearly Wet dep + Yearly Dry dep]

Sampling Period

January, 1995 to December, 1995

Results Expected

1. The site is between 2 major traffic arteries (HWY 1 and HWY 7), so we expected to see chemical composition similar to that for transportation sources.
2. A “finger print” of vehicle emissions will be compared to those at this site.
3. The topography and the meteorology of the area would indicate that the prevailing winds would be primarily from the east, then the west and then from other directions.
4. If the particulate is from transportation sources, than the expected particle size would be < 2 µm.

Actual Results

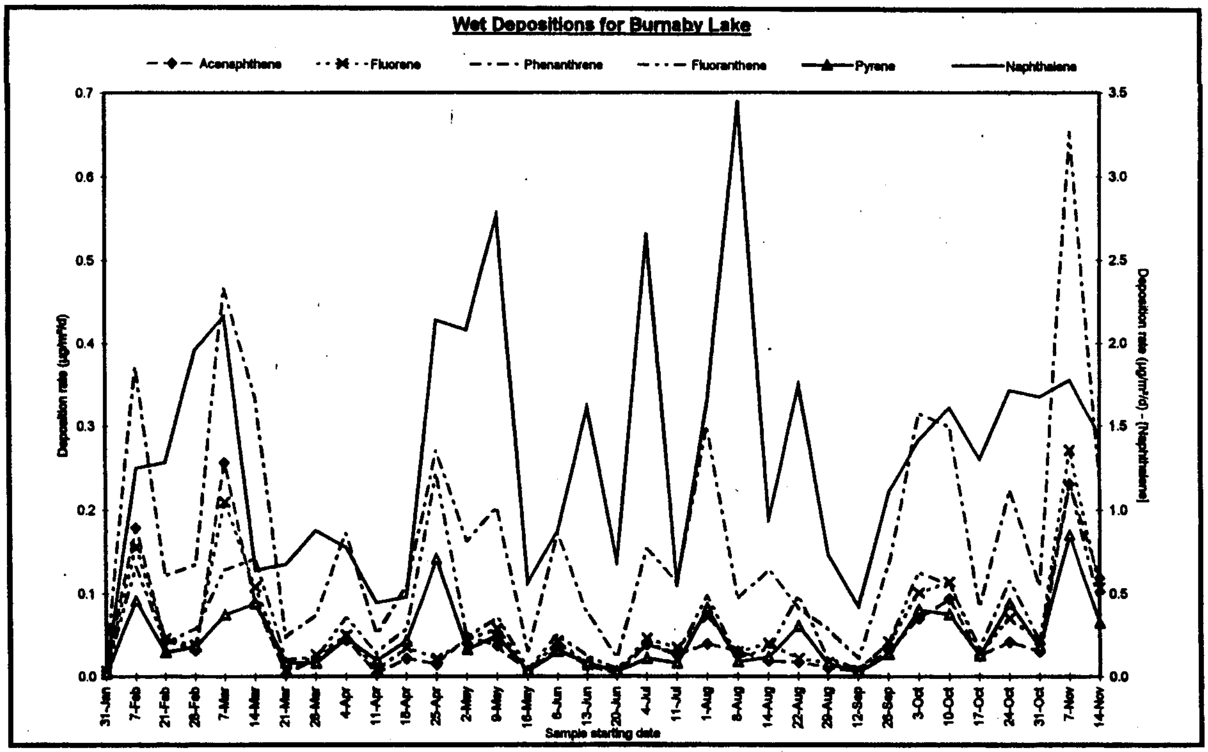
1. Because we have just received the bulk of the data we have not been able to evaluate most of the dry deposition data.
2. For the wet deposition, from partial data we see periods of short rainfall with higher concentrations of PAHs that will need to be evaluated for ‘toxic concentrations.’
3. Rainfall of longer duration is less concentrated because of dilution.
4. Particulate sizes have been generally < 2   m in size, and will be compared to vehicle traffic data from in the Cassiar Tunnel.
5. Wet deposition sources appeared to be from easterly wind-bearing sources.
6. PAH deposition values appeared to be relatively consistent in their amounts relative to each other.
7. A preliminary estimate of wet deposition of PAH to the area is about 1.9 µg /m^2/day, or about 0.7 mg/ m^2/year.

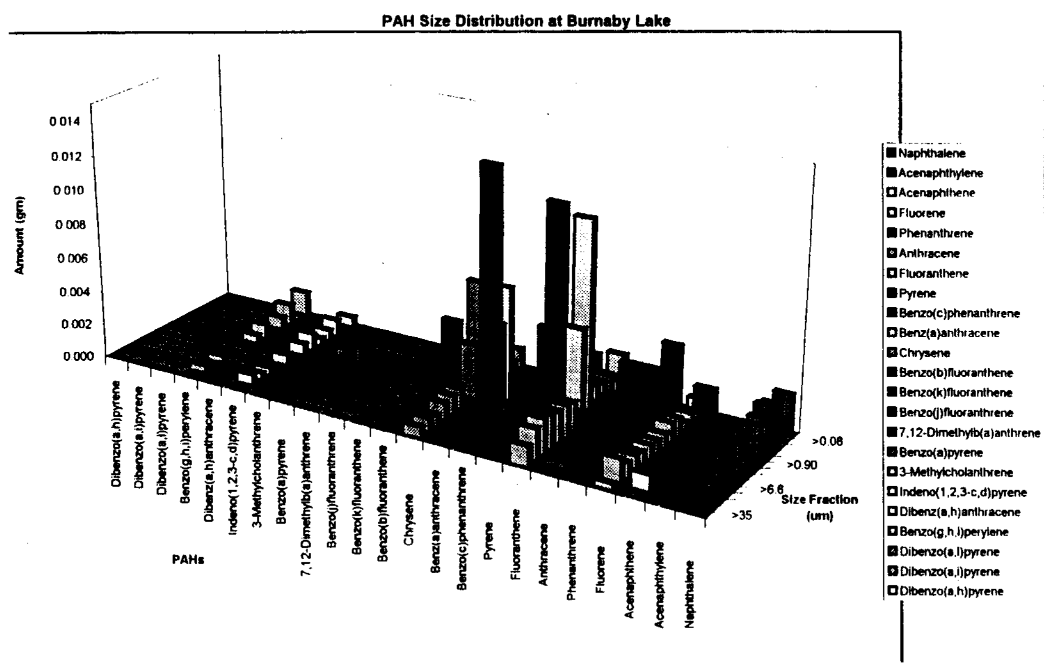
Other Studies

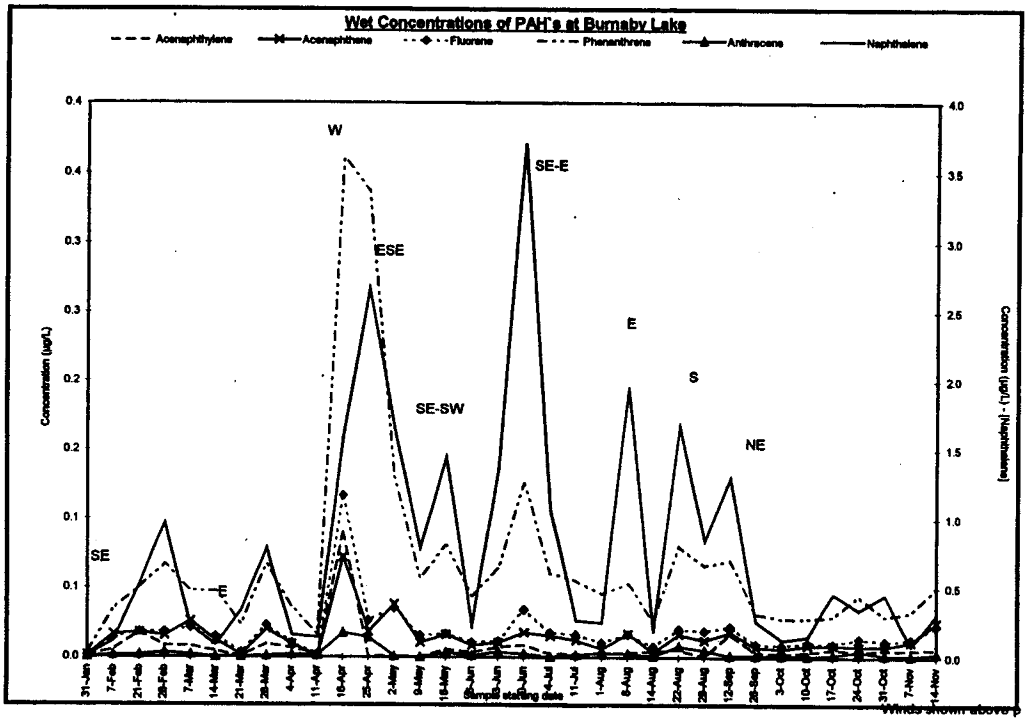
- Snowfall samples have been taken along the north shore mountains, as far as Hope, and they have been analyzed for metals, nutrients and pH. This data will be compared to previous sampling programs in 1982 and 1985.
- Air samples for ammonia, nitrate and sulfate will be taken in a current sampling program at Agassiz and Abbotsford to assess the contribution of airborne nitrogen to the deposition in the Fraser Valley.
- Air samples for organic agricultural chemicals will also be taken for wet and dry conditions at the Agassiz and Abbotsford sites, to determine their presence or absence.

Summary

1. Wet deposition data has had preliminary assessment for metals and PAH content.
2. Dry deposition has yet to be assessed.
3. Air emissions appear to have a bimodal size distribution (10 and 1.0 m)
4. PAH sources appear to be primarily from transportation sources.
5. Metals appear to be from diverse sources.
6. The prevailing winds appear to be primarily from the eastern quadrant.
7. Comparisons with aquatic and sediment data have yet to be done.


Wet Depositions for Burnaby Lake
Acenaphthene
Fluorene
Phenanthrene
Fluoranthene
Pyrene
Naphthalene
Deposition rate (µg/m²/d)
Deposition rate (µg/m²/d) - [Naphthalene]
Sample starting date


PAH Size Distribution at Burnaby Lake
Amount (gm)
PAHs
Size Fraction (um)
>0.08
>0.90
>6.6
>35
Naphthalene
Acenaphthylene
Acenaphthene
Fluorene
Phenanthrene
Anthracene
Fluoranthene
Pyrene
Benzo(c)phenanthrene
Benz(a)anthracene
Chrysene
Benzo(b)fluoranthene
Benzo(k)fluoranthene
Benzo(j)fluoranthene
7,12-Dimethylb(a)anthrene
Benzo(a)pyrene
3-Methylcholanthrene
Indeno(1,2,3-c,d)pyrene
Dibenz(a,h)anthracene
Benzo(g,h,i)perylene
Dibenzo(a,l)pyrene
Dibenzo(a,i)pyrene
Dibenzo(a,h)pyrene


Wet Concentrations of PAH's at Burnaby Lake
Acenaphthylene
Acenaphthene
Fluorene
Phenanthrene
Anthracene
Naphthalene
Concentration (µg/L)
Concentration (µg/L) - [Naphthalene]
W
SE-E
ESE
E
S
SE-SW
NE
SE
E
31-Jan
7-Feb
21-Feb
28-Feb
7-Mar
14-Mar
21-Mar
28-Mar
4-Apr
11-Apr
18-Apr
25-Apr
2-May
9-May
16-May
11-Jul
1-Aug
8-Aug
14-Aug
22-Aug
29-Aug
12-Sep
28-Sep
3-Oct
10-Oct
17-Oct
24-Oct
31-Oct
7-Nov
14-Nov
Sample starting date

Water Quality Conditions in an Urban Watershed

K. Hall

Civil Engineering and Westwater Research Centre
University of British Columbia

The Brunette River watershed is one of the most highly urbanized watersheds in the Lower Fraser Valley. The major transportation corridor in the valley passes through the watershed and with the exponential population growth, land use changes have resulted in more impervious surface areas that prevent the adsorption of contaminants by soil and vegetation. This results in the transport of contaminants to the waterways in stormwater runoff.

Dry weather monitoring shows high levels of fecal coliforms in several creeks, especially Still Creek where domestic wastewaters are entering the upper reaches. This severely restricts the recreational use of many of these areas. Low dissolved oxygen levels in lower Still Creek and the Brunette River, just below the dam at the outlet of Burnaby Lake, can cause fish mortality or restrict fish movement in these reaches in summer.

Stormwater runoff contains high levels of many contaminants such as trace metals, nutrients and suspended solids. Contaminant transport is closely coupled to the intensity of the rainfall event and the transport of suspended solids since many of the contaminants are readily adsorbed to this particulate material. The quality of the runoff from streets is related to the level of vehicular traffic in the area. Monitoring of contaminants over the period of a year along with flow measurements will allow the calculation of contaminant loading from stormwater runoff. A source control program integrated with best management practices will be necessary to regulate this source of non-point pollution and prevent further degradation of this urban watershed.

Non-Point Source Contamination and Ecosystem Health

Case Study of the Brunette River Watershed

Objective

To determine the relationship between land use and the generation of chemical contaminants, the transport of these contaminants in urban stormwater runoff, and the impacts of these contaminants on the aquatic environment.

Measuring the Health of Aquatic Ecosystems

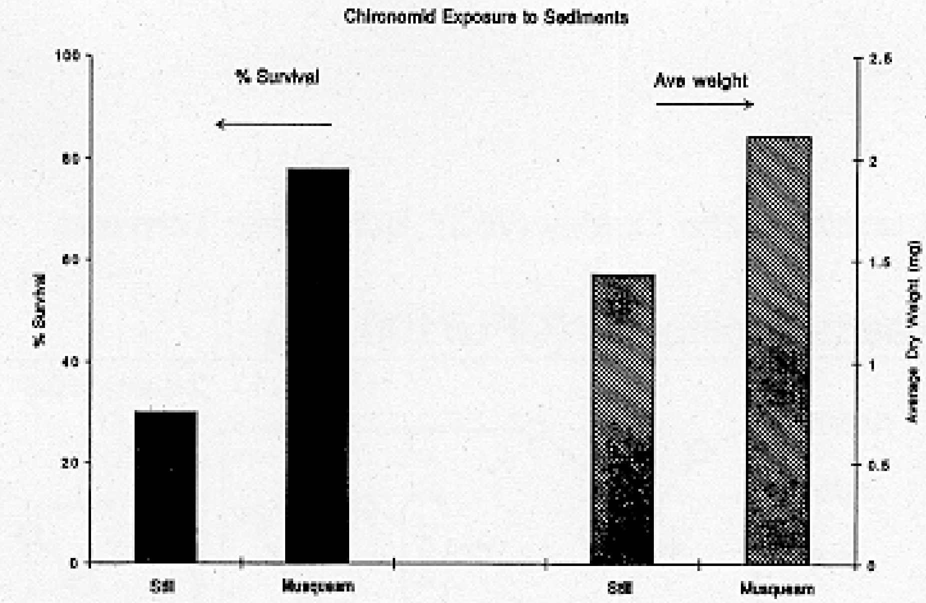
1) Comparing of contaminant levels to guidelines & criteria

2) Contaminant levels in organisms

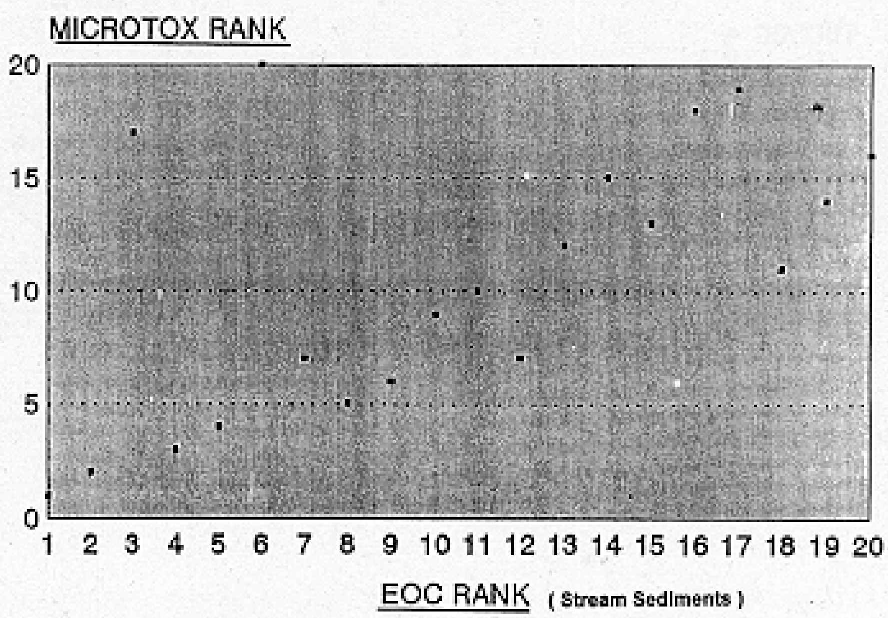
3) Bioassays

4) Community structure, organism abundance

5) Other:
   - enzyme, hormone levels
   - visual & histological pathologies
   - ecosystem processes



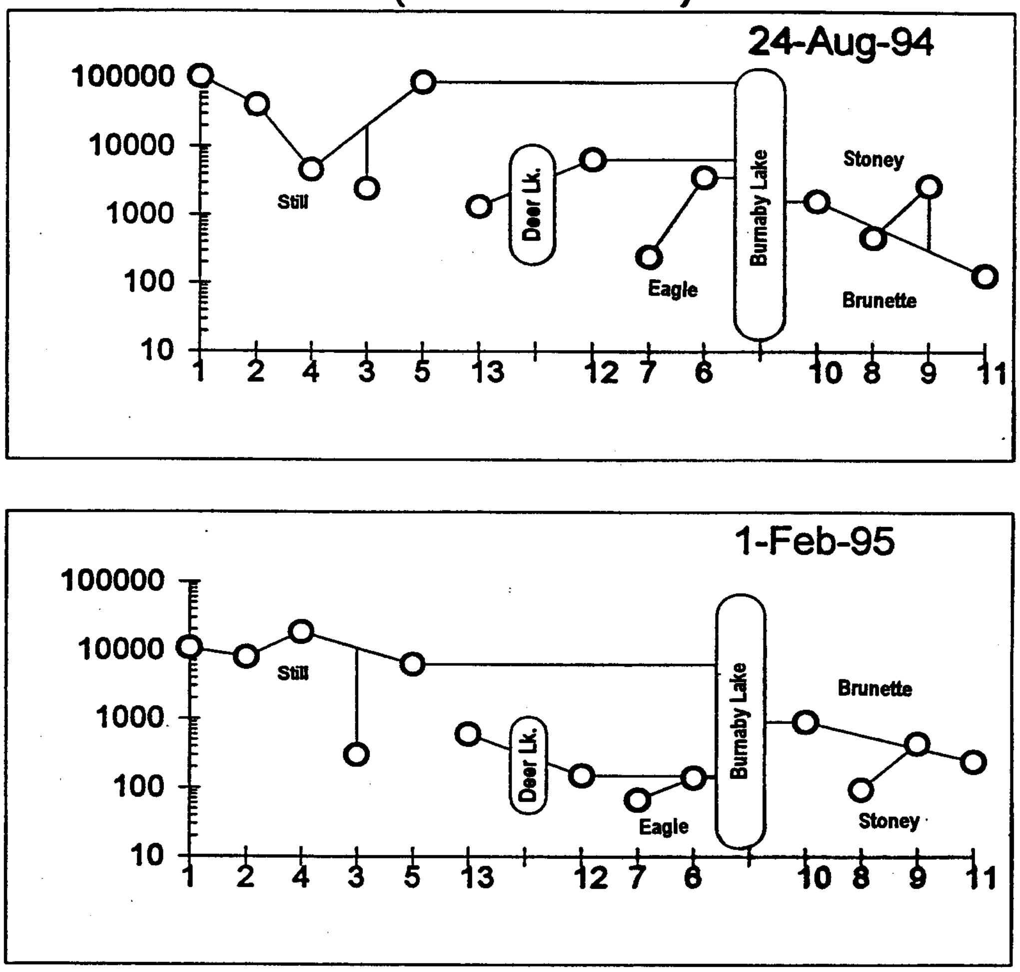
EOC vs Microtox (rank)



Note: 1= least EOC, least toxic & 20 = most EOC, most toxic

Brunette Water Quality (WQ): Schematic Transect

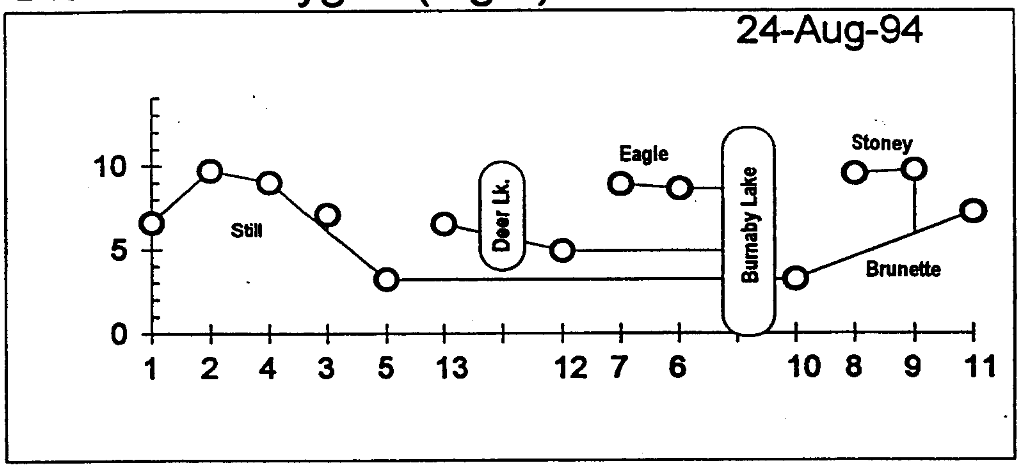
Feacal Coliforms (CFU/100 mL)

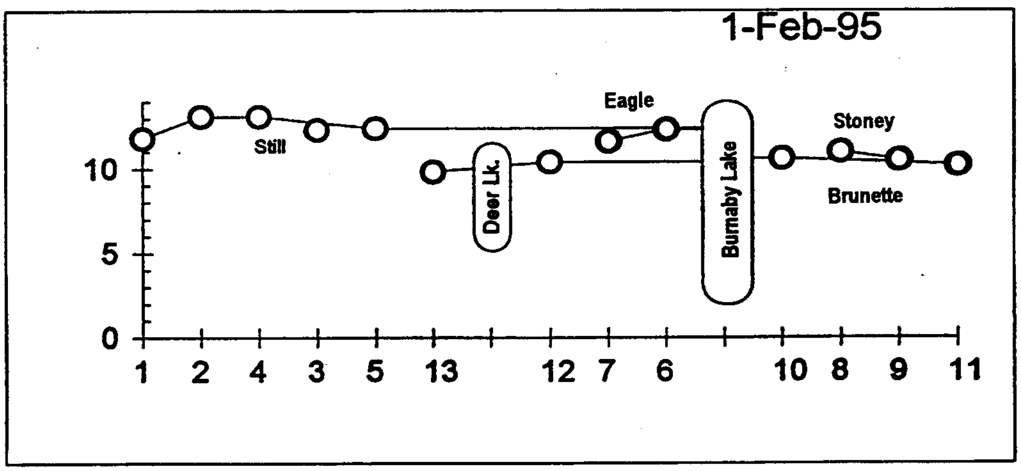


Number on x-axis is Station Number

Brunette Water Quality (WQ): Schematic Transect

Dissolved Oxygen (mg/L)

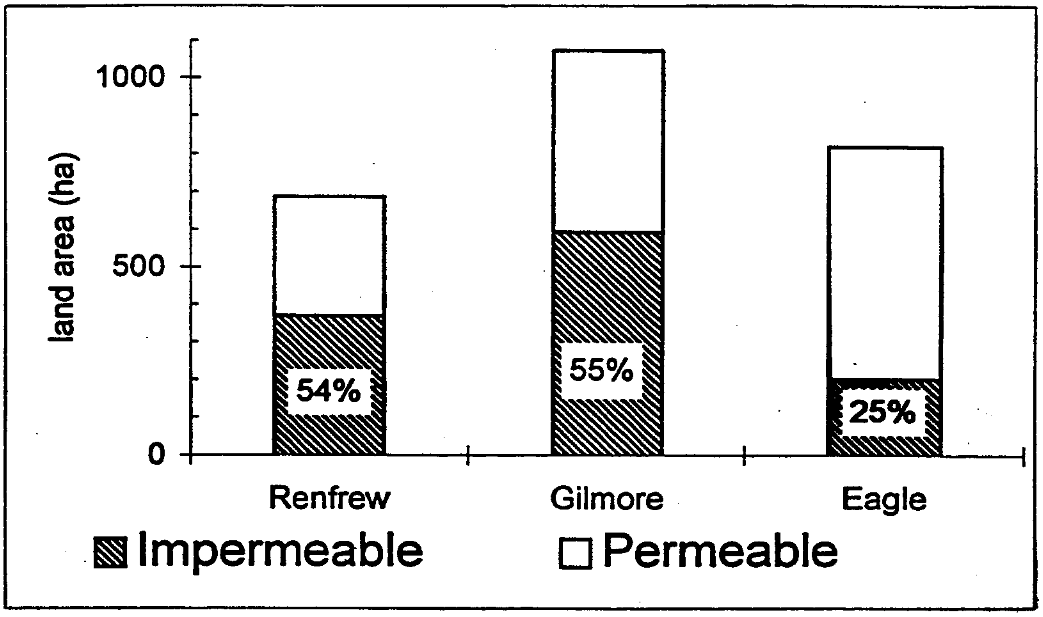




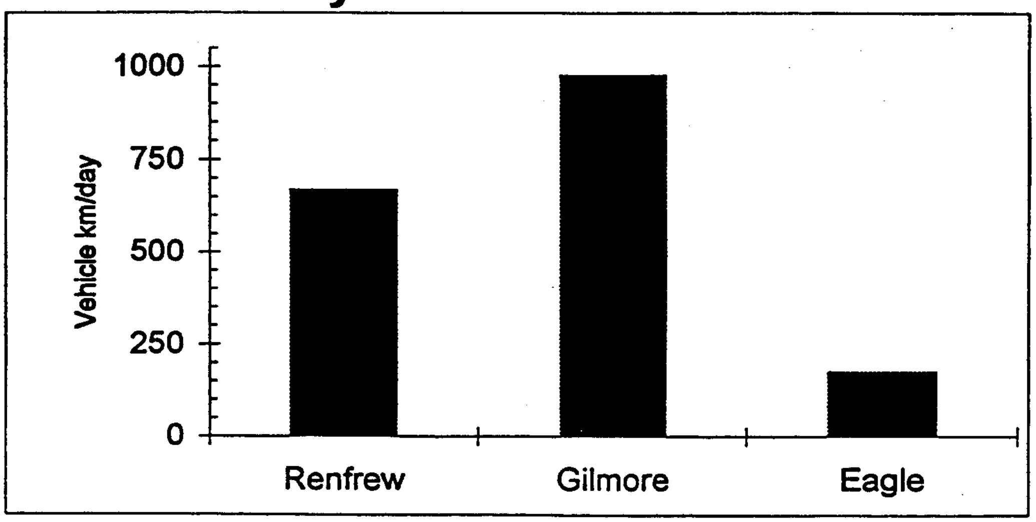
Number on x-axis is Station Number

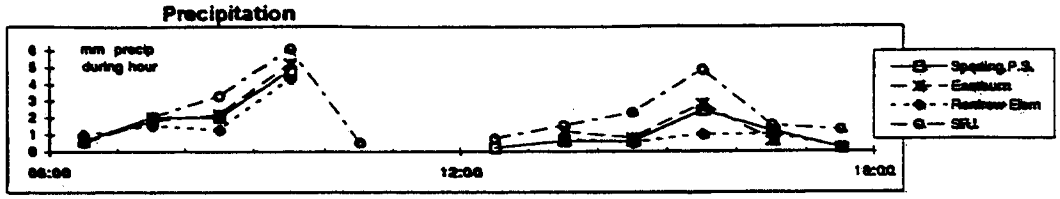
Brunette Watershed: Stormwater Site Characteristics

Land Use

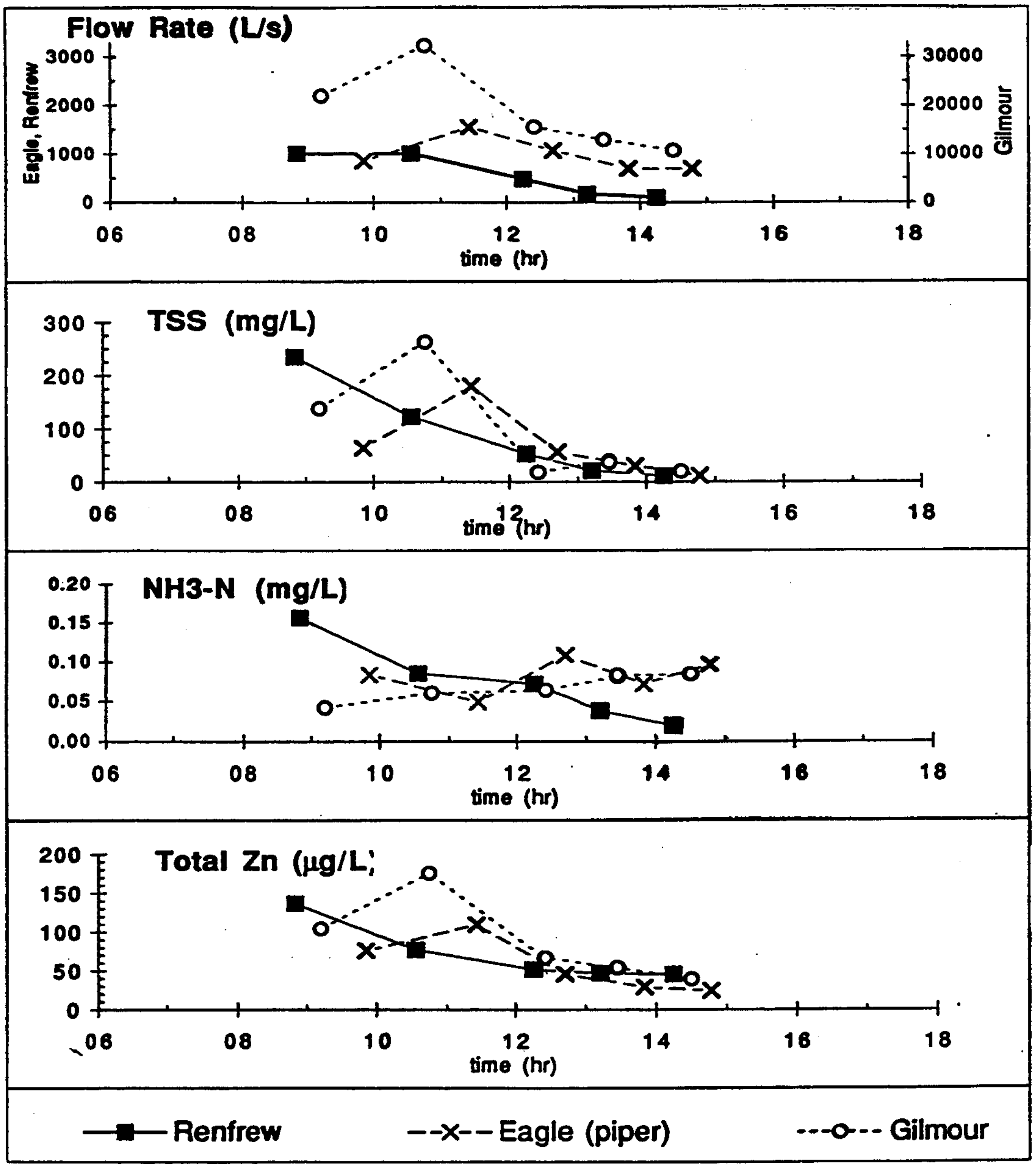


Traffic Density

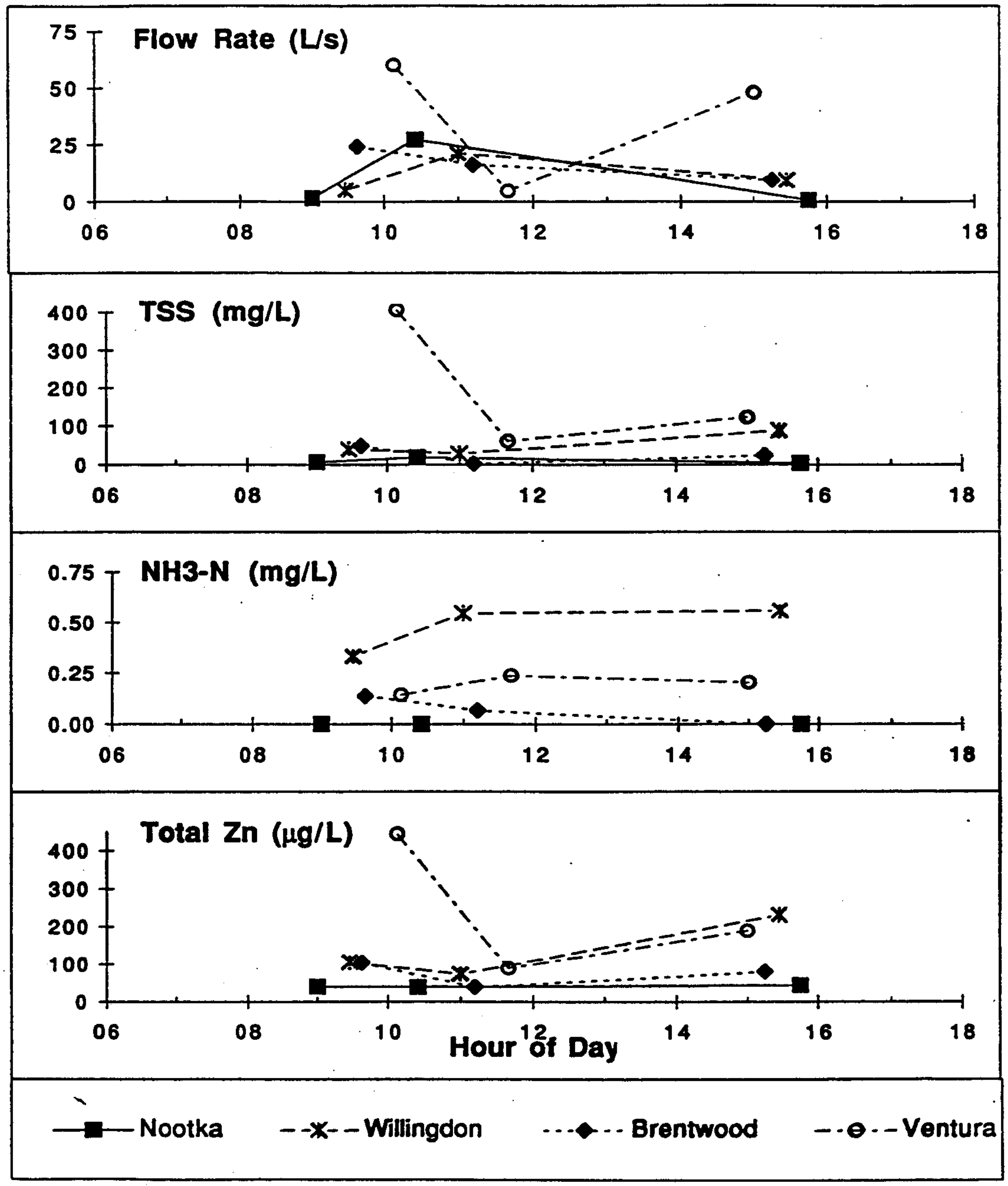




Storm Water (SW) Conditions during storm 94-10-20



Street Run-off (SRO) Conditions during storm 94-10-20



Traffic Density and Land Cover Permeability in Sub-Basins

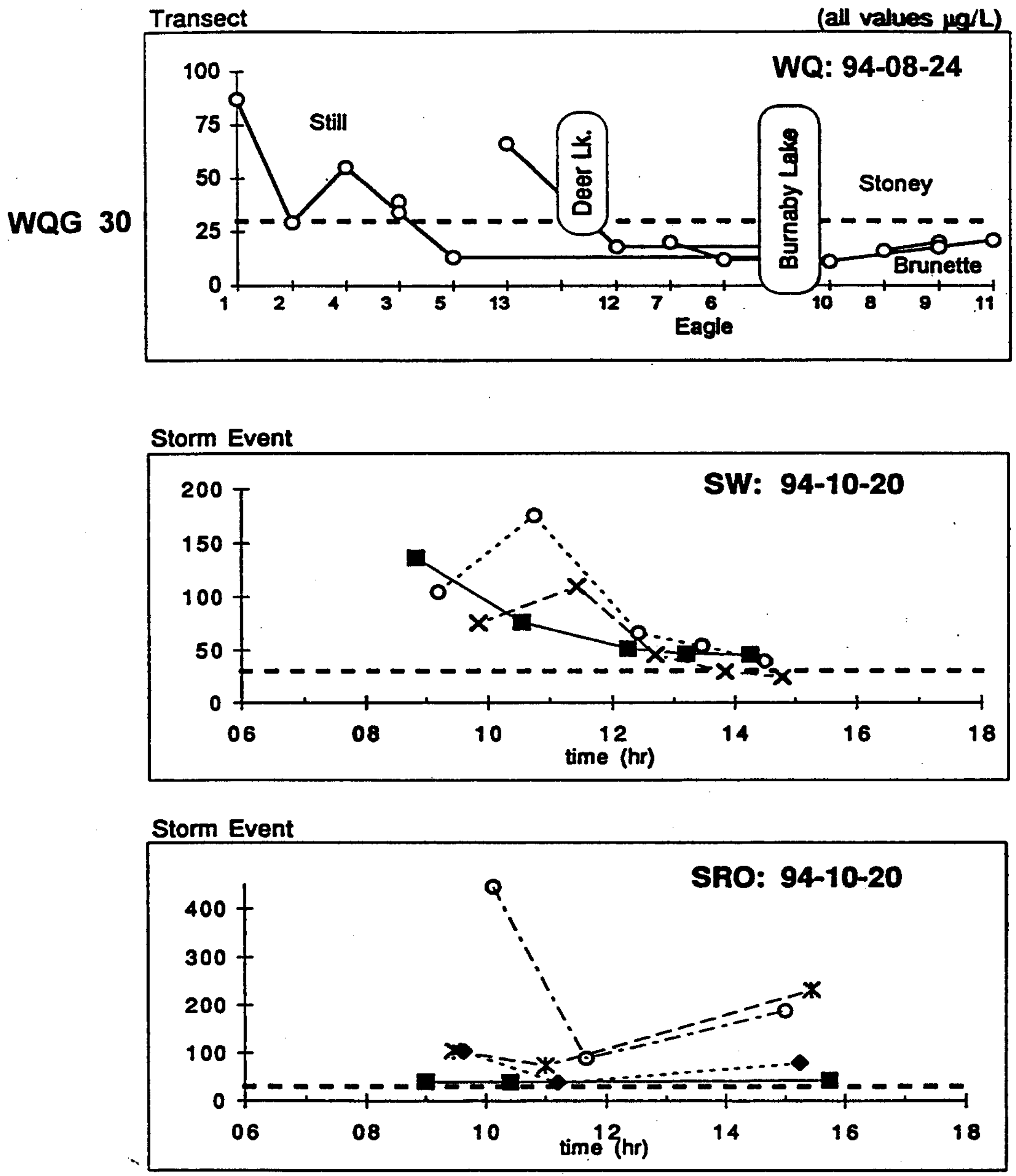
Station	Grandview	Gilmore	Eagle
Sub-Basin Size (hectares)	685.9	1,073.2	818.1
Traffic Density (vehicle km/day)	670	978	177
Impermeable Area (% of total)	54.0	55.4	24.6
Mean Stormwater Hydrocarbon Concentration (mg/L)	3.15	2.32	0.96
Normalized Hydrocarbon Concentration (µg/L/hectare)	4.59	2.16	1.17

Stormwater Hydrocarbon Concentration and Traffic Volume

Station	Nootka	Renfrew	Willingdon
Typical Traffic Volume (vehicles/hour)	38	1,140	2,560
Mean Runoff Hydrocarbon Concentration (mg/L)	1.14	3.68	4.04

Comparison of Total Zinc Levels to WQ Criterion

(all values µg/L)



Criterion for Zinc = 30 µg/L (from Nagpal, 1994)

Transportation, Industry and Dangerous Goods Consequences for Stream Ecosystem Health

P. Zandbergen[1], K. Hall[2]

[1] *Resource Management and Environmental Studies*
University of British Columbia

[2] *Westwater Research Centre*
University of British Columbia

Many diffuse sources contribute to the total discharge of pollutants into the Brunette River watershed. In addition to general transport, these include industrial and commercial sites, residential areas, spills, leaks, dumps and accidents. These discharges are measured in an integrated way by determining stormwater loadings; spatial analysis with land use intensity can reveal some of the contributing sources. However, source identification can be difficult and sporadic events can be missed. A closer examination of some of the sources is, therefore, considered useful.

Accidents with the transportation of dangerous goods have been a public health and emergency concern. Accident records have revealed approximately 50 incidents in the watershed over the period 1990-1994, but very few resulted in an actual spill. Reported spills to watercourses from other sources have been much more frequent; approximately 100 spills were reported for 1990-1994, with petroleum products accounting for the majority of identified substances. Preliminary comparisons with stormwater loadings indicated that while spills may in the short-term and locally have very significant impacts, in the long-term, other contributions are likely to be more damaging to overall stream ecosystem health.

In order to asses the ecological consequences of urbanization in the watershed, we have to interpret what the contaminant levels mean to living organisms. A variety of methods exist to relate exposure levels to stream ecosystem health. These include comparing water and sediment quality to agency criteria, measuring accumulation of contaminants in organisms, performing laboratory bioassays and determining changes in the population and community structure of aquatic organisms.

Water quality in streams in the Brunette River watershed frequently exceeds established criteria for the protection of aquatic life during periods of stormwater runoff, especially for trace metals such as copper and zinc. A very large percentage of the surface sediments in the watershed contain trace metal levels that fall between the TEL (Threshold Effect Level) and PEL (Probable Effect Level) criteria recently established by Environment Canada. Sediment bioassays with chironomids have demonstrated lower survival and poorer growth of these benthic invertebrates when compared to reference stations.

Trace Metal Contamination in Urban Sediment

D. McCallum

Civil Engineering
University of British Columbia

This study examined the trace metal contaminant history of lake, stream and street sediments in the Brunette watershed. Changes in land usage occurring over the last 20 years were quantified in an attempt to explain recent contaminant trends.

Trace metal levels increased rapidly in lake sediments deposited between the years 1950 and 1970. This increased contamination corresponded to a very rapid shift in land usage from rural to urban. More recent changes in lake sediment metal levels have been influenced by changing hydrological conditions in the watershed.

Concentrations of zinc, copper, manganese and mercury have increased in stream sediments since 1973 by 45, 81, 130 and 290%, respectively. Lead was the only element to exhibit reductions in sediment levels during this period. The changes in land activity and land cover permeability since 1973 were minor compared to the increase in traffic density observed.

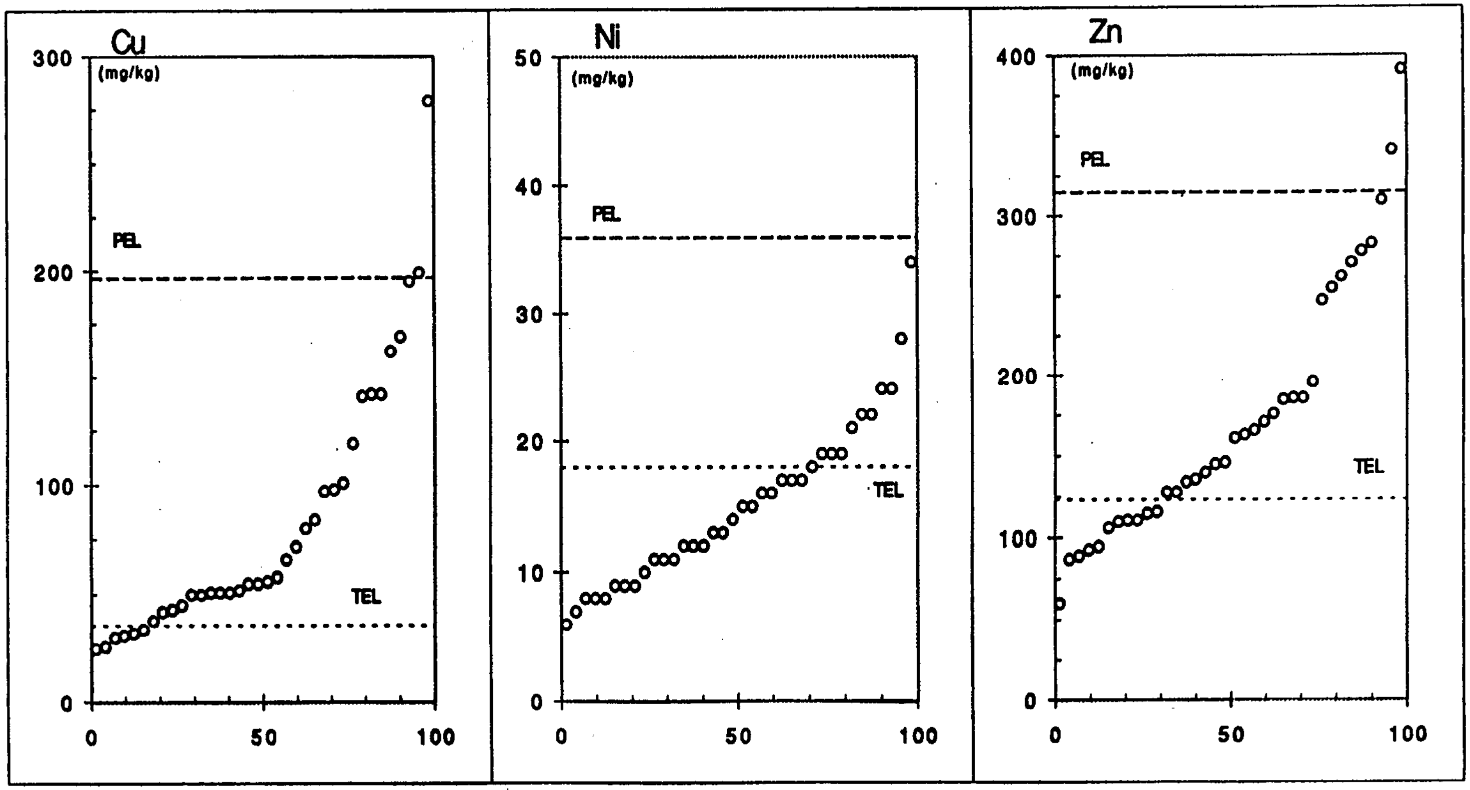
A spatial analysis of the influence of traffic density indicated that lead, copper and zinc are highly enriched in stream sediments as a probable result of automobile use. Measured levels of these three metals often exceeded criteria designed to protect aquatic health.

Median concentration differences and significance of ranked t-test for comparison of 1993 versus 1973 metal concentrations in streambed sediment (n=32)

Element	Digestion Method	Median percent difference, 1993 minus 1973 concentrations	p Value*
Mn	total	131	0.00
	extractable	2,600	0.00
Pb	total	-35	0.04
	extractable	-16	0.05
Cu	total	81	0.01
	extractable	49	0.01
Zn	total	45	0.00
	extractable	33	0.10
Ni	total	-7	0.56
	extractable	n.c.	
Hg	total	294	
Cd	total	n.c.	
	extractable	n.c.	
			0.02
Fe	total	-21	0.20
	extractable	-19	
Silt and Clay		92	0.00
LOI		10	0.27

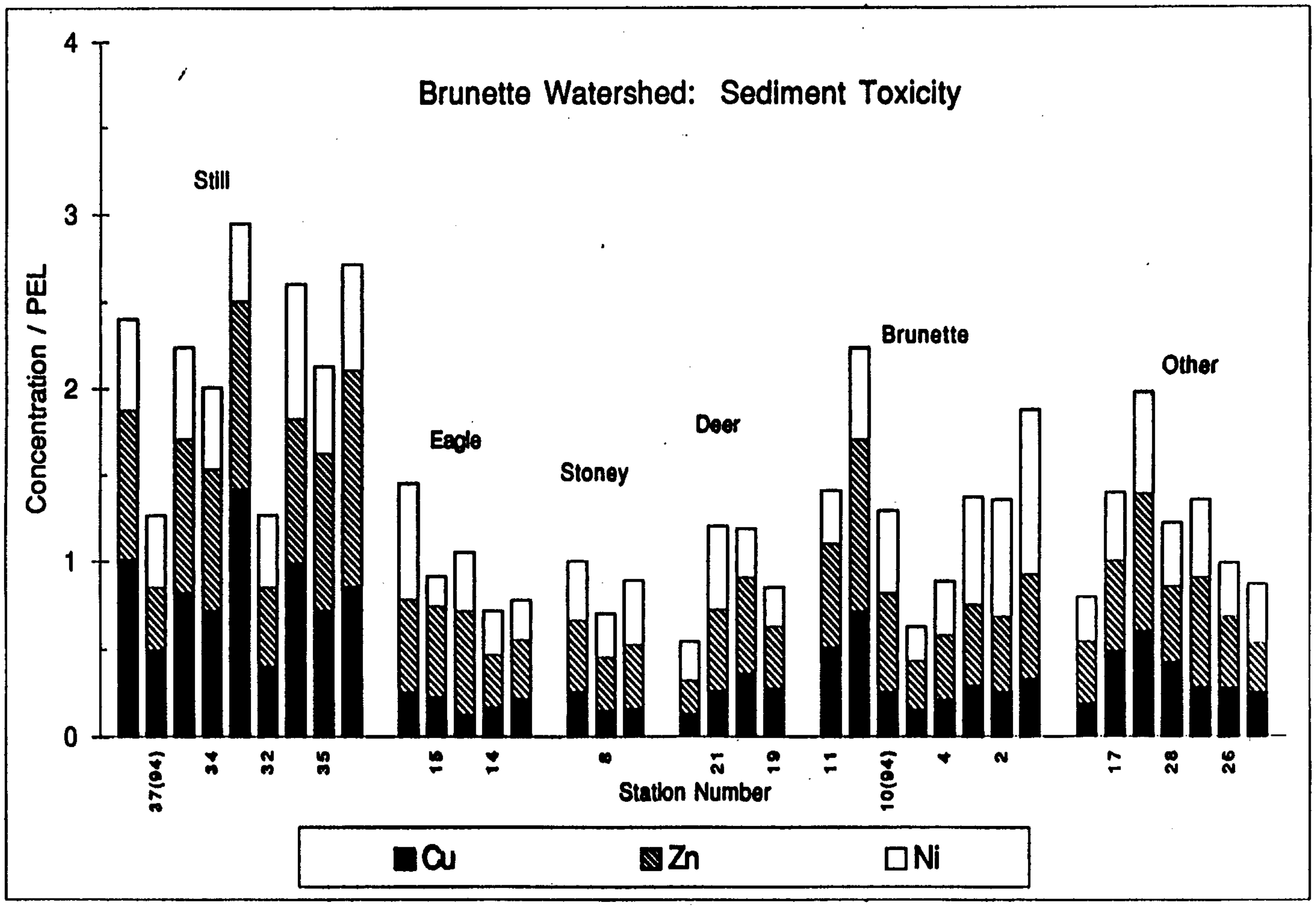
* - p values indicate the probability that the means are identical
n.c. - no comparison made because of high 1993 detection limit

Ranked Metal Concentration in Brunette System Sediments



Percent of Sediment Stations with Concentration less than Y value

NOTES: - data from McCallum (1995) based on < 180 um fraction
- PEL and TEL based on bulk sediments



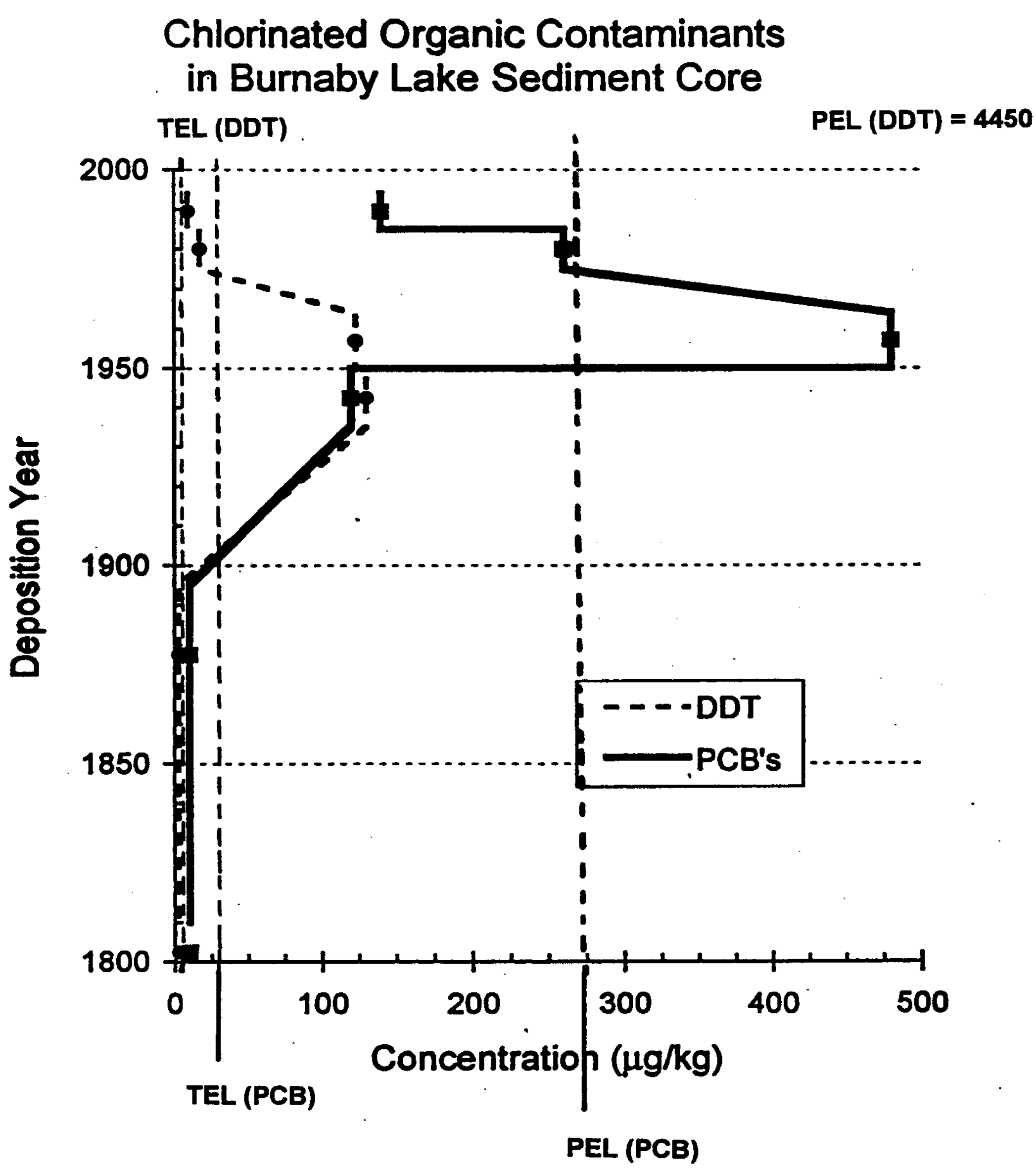
NOTES: Data from McCallum (1995) (mg/kg dry weight < 180 µm fraction)
PEL values from EC (1994) Cu= 197, Ni= 36, Zn=315 (mg/kg bulk, dry sediment)

Hydrocarbon Pollution from Urban Runoff in the Brunette River Basin

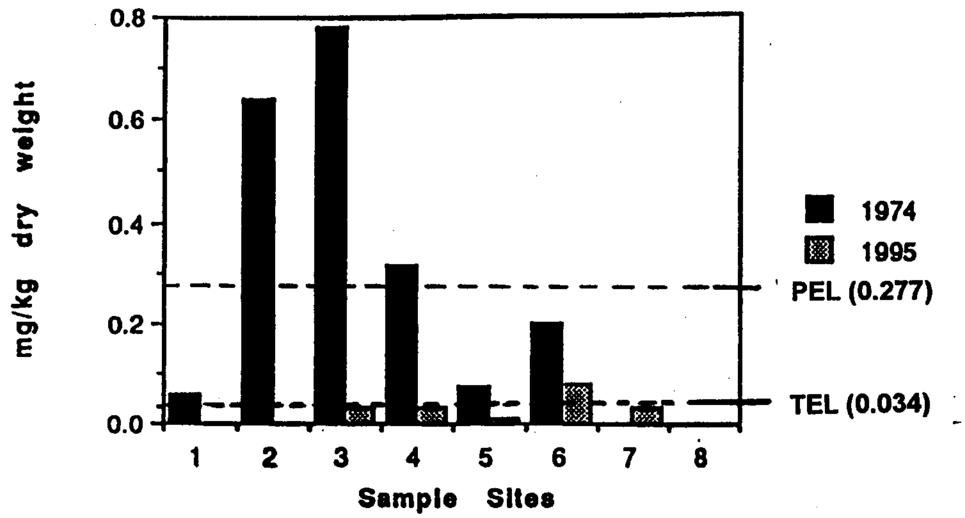
G. Larkin

Civil Engineering
University of British Columbia

The extent and severity of hydrocarbon pollution in lake core sediments, streambed sediments, street surface sediments and stormwater were investigated in the Brunette drainage basin of Burnaby, British Columbia. Hydrocarbon concentrations in Burnaby Lake sediments have increased tenfold since development of the region. Aliphatic hydrocarbons of anthropogenic origin are responsible for the increase. Land use was identified as a factor that influences the hydrocarbon concentrations, in streambed sediments, and in stream stormwater. Traffic volumes affected concentrations in road runoff. Hydrocarbon concentrations in street sediments were quite uniform throughout the basin and did not correlate well with land use, impermeable area or traffic density. Street surface sediments were determined to be poor indicators of the spatial distribution of hydrocarbons in streambed sediments or of potential loading to watercourses by stormwater. Washoff from road surfaces appeared to be an important source of hydrocarbons to stormwater and ultimately streambed and lake sediments. Urban runoff is an obvious target for pollution abatement measures in the Brunette watershed, such as source control or detention.


Chlorinated Organic Contaminants
in Burnaby Lake Sediment Core
TEL (DDT)
PEL (DDT) = 4450
2000
1950
1900
1850
1800
Deposition Year
0
100
200
300
400
500
Concentration (µg/kg)
TEL (PCB)
PEL (PCB)
DDT
PCB's

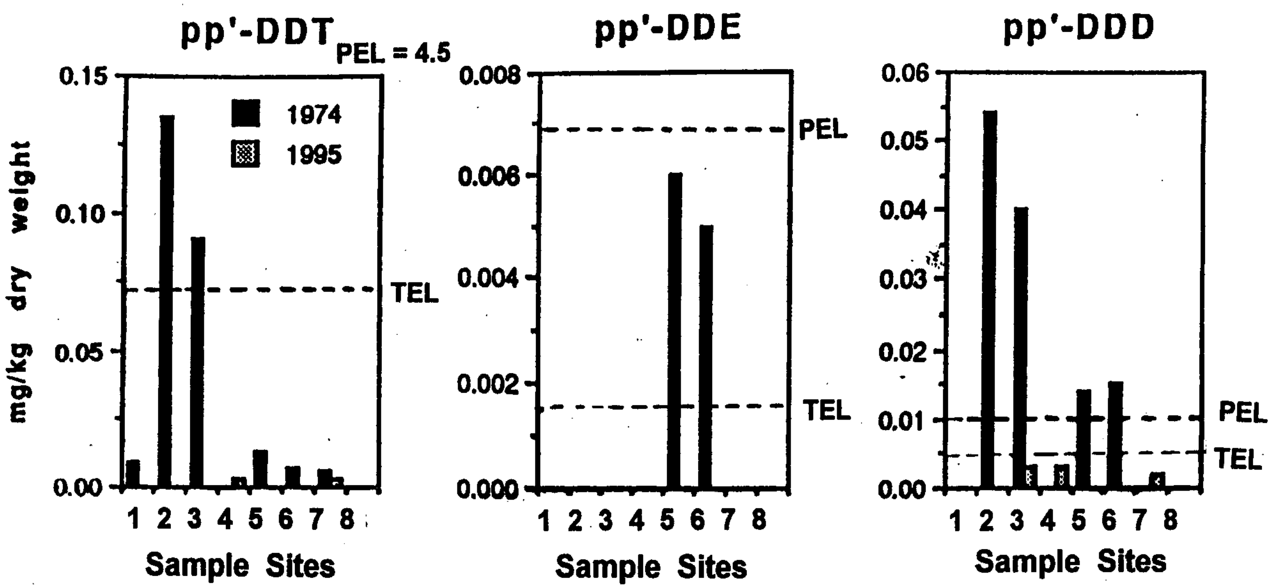
PCB levels measured in Brunette Watershed sediments in 1974 and 1995



Sources: - 1974 Data - Hall et al. (1976)
- 1995 Data - unpublished data from a joint Westwater Research Centre / Environment Canada (Fraser Pollution Abatement Office) study (K. J. Hall, personal communication)

Notes: - PCB congener 1254 measured in both studies
- levels below detection limit are not shown (detection limit = 0.010 mg/kg dry weight)
- sampling sites refer to: 1) Still Cr. @ Renfrew, 2) Still Cr. @ Gilmore, 3) Still Cr. @ Willingdon, 4) Still Cr. @ Douglas, 5) Still Cr. @ Sperling, 6) Still Cr. @ Lougheed, 7) Brunette R. @ Braid, 8) Brunette @ North Rd.

Organochlorine pesticide levels measured in Brunette Watershed sediments in 1974 and 1995



Notes: - levels below detection limit are not shown (1974 detection limit = 0.001 mg/kg dry weight; 1995 detection limit = 0.002 mg/kg dry weight)

Sediment Guidelines

Probable Effects Level (PEL) = level above which adverse effects are predicted to occur frequently

Threshold Effects Level (TEL) = concentration below which adverse effects are expected to occur rarely

Between PEL and TEL, the levels are occasionally expected to be associated with adverse biological effects.

CONCLUSIONS

1) Some point-source pollution is still affecting water quality conditions in our urban streams

2) Stormwater runoff can contain high levels of contaminants (metals hydrocarbons)

3) Many stormwater contaminants are associated with particles

4) Levels of contaminants that enter the waterways are related to the impervious land areas and vehicle numbers

5) Source control works (Pb, chlorinated HC)

6) Management strategies to remove suspended solids in stormwater will help to control contaminants in urban streams

7) Contaminants from stormwater runoff are affecting aquatic life in urban streams

SESSION 4

AGRICULTURAL ISSUES

Fraser River Action Plan -Agricultural Pollution Abatement Update

G. Derksen

Environment Canada

The Fraser River Action Plan (FRAP) is a six-year program established by the federal government to reduce the pollution source inputs to the Fraser River and restore the natural productivity of the Fraser River basin. The primary goal of the agricultural component of FRAP is to develop and implement a strategy to reduce the loading of nutrients, bacteria and agrochemicals from agricultural operations to ground and surface waters.

Qver the course of the program, various projects in cooperation with provincial and federal agencies and the private sector have been completed or are in progress in order to develop a better understanding of the issues in the basin, develop means to address them and develop a basis for measuring progress.

Items of particular interest include:

- development of an inventory and model to estimate where nutrient surpluses exist in twenty Agricultural Waste Management Zones (AWMZs) in the lower Fraser Valley (Figure I) and test management scenarios to deal with the surpluses (Figure 1a);
- development of an Environmental Sustainability Parameter (ESP) to rank current on-farm practices (Figure 2) and measure the distribution of other indicators of farming activity such as Milk Cow Equivalents (MCEs) in two watersheds (Figure 2a); and,
- use the model to estimate the partitioning of nutrients into ground and surface waters by AWMZ (Figure 3) to identify high risk zones and measure current surface water conditions in several tributary streams (Figure 3a and Figure 4).

Activities also include the support of ongoing initiatives in the Cariboo and Thompson regions (Table 1) to evaluate ranching practices and the lower Fraser Valley to evaluate on-farms problems. Several research and educational programs are being supported to improve on-farm farm operations (Table 2).

Fig. 1 : SURPLUS NITROGEN
FRASER VALLEY AGRICULTURAL WASTE MANAGEMENT ZONES

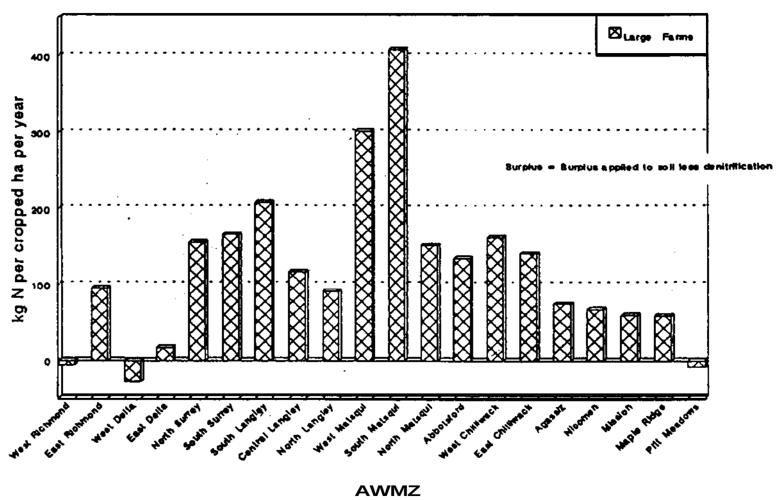


Fig. 1a: SURPLUS NITROGEN
FRASER VALLEY AGRIGULTURAL WASTE MANAGEMENT ZONES

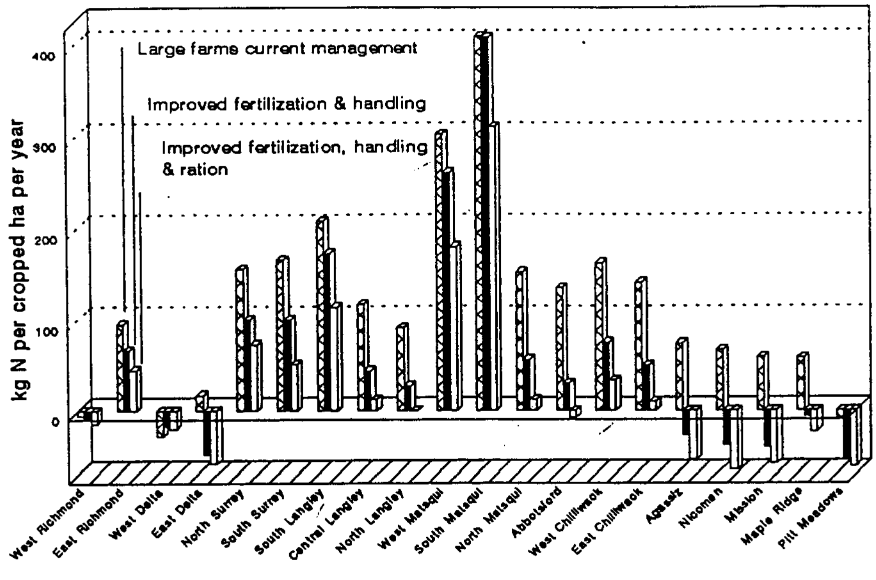


Fig. 2 : MATSQUI PRAIRIE AND SUMAS PRAIRIE WATERSHEDS - DAIRY FARM ENVIRONMENTAL SUSTAINABILITY PARAMETER DISTRIBUTION

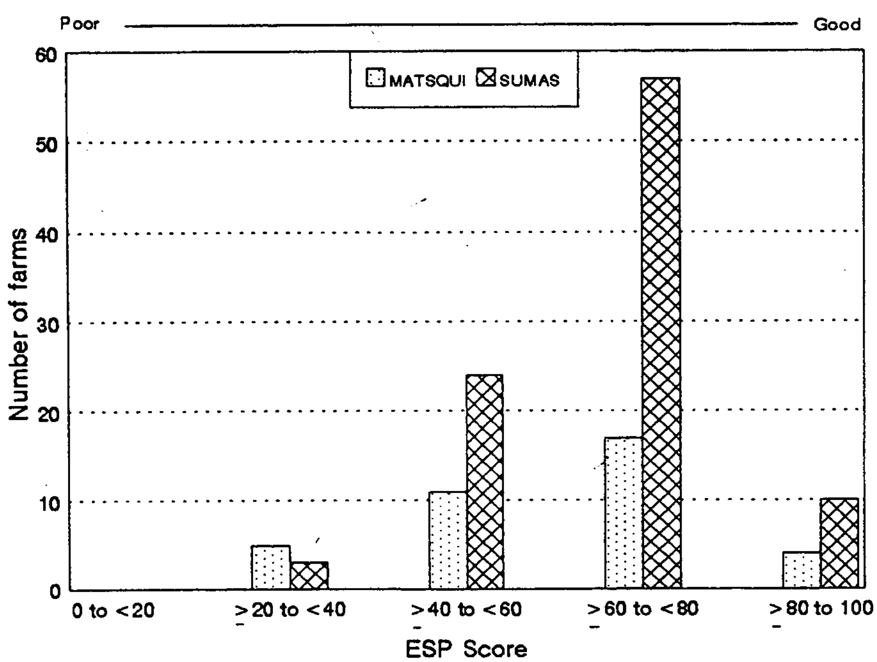


Fig. 2a: MATSQUI PRAIRIE AND SUMAS PRAIRIE WATERSHEDS
DAIRY FARM MILK COW EQUIVALENTS DISTRIBUTION

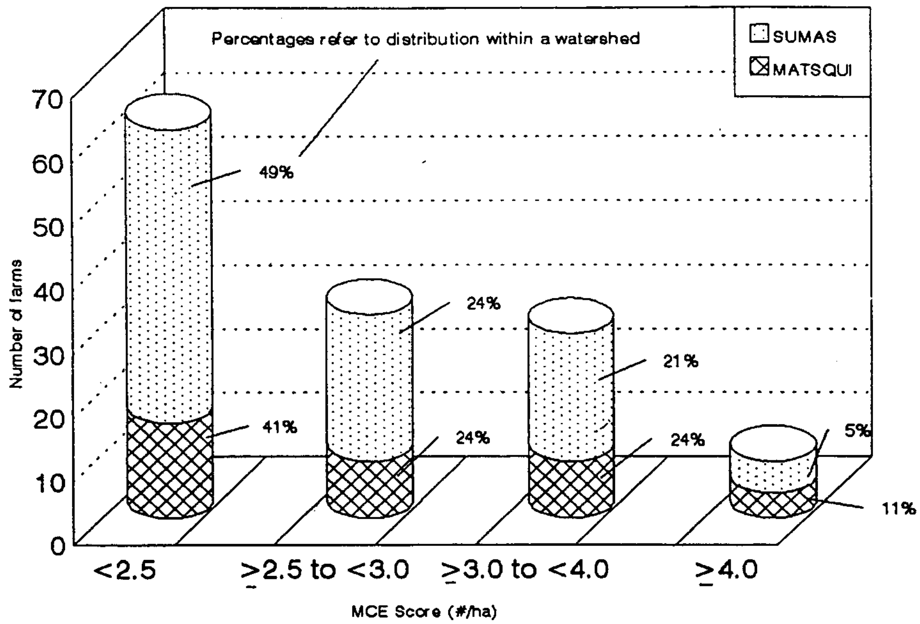


Fig. 3 : COMPARISON OF PARTITIONING OF SURPLUS NITROGEN TO
SURFACE WATER & GROUNDWATER - FRASER VALLEY AGRIGULTURAL WASTE MANAGEMENT ZONES

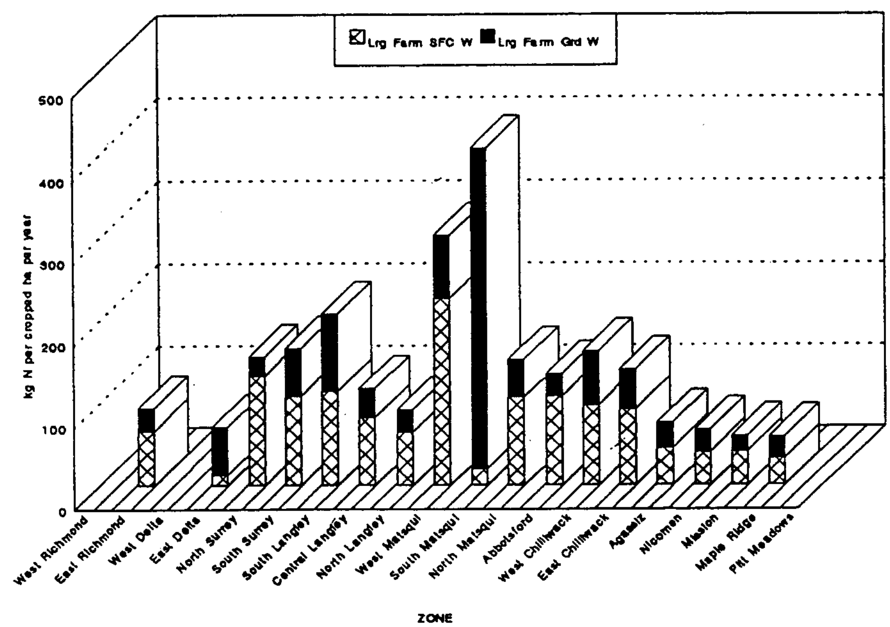


Fig. 3a: MATSQUI SLOUGH WATER QUALITY
NITRATE

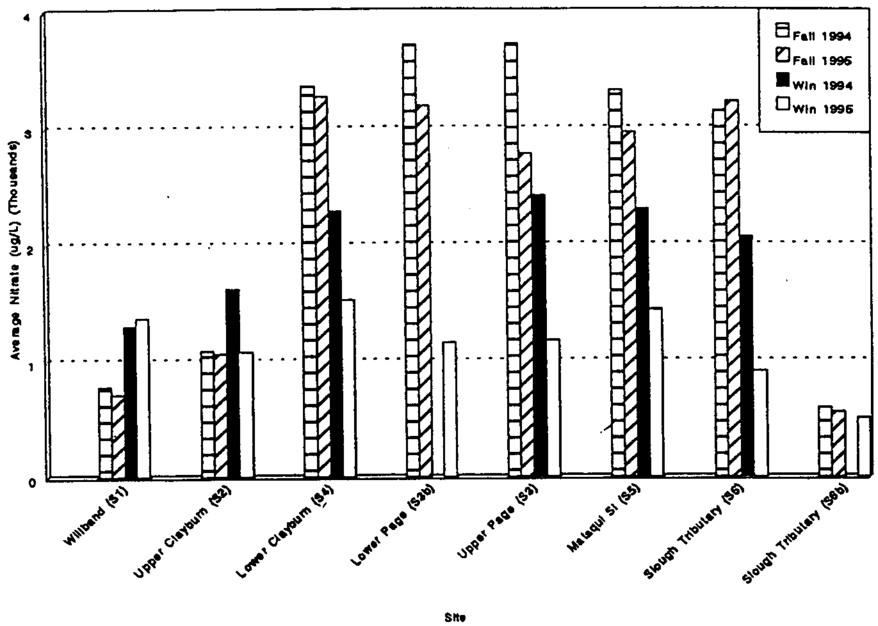


Fig. 4 : LOWER FRASER TRIBUTARIES
OXYGEN SATURATION

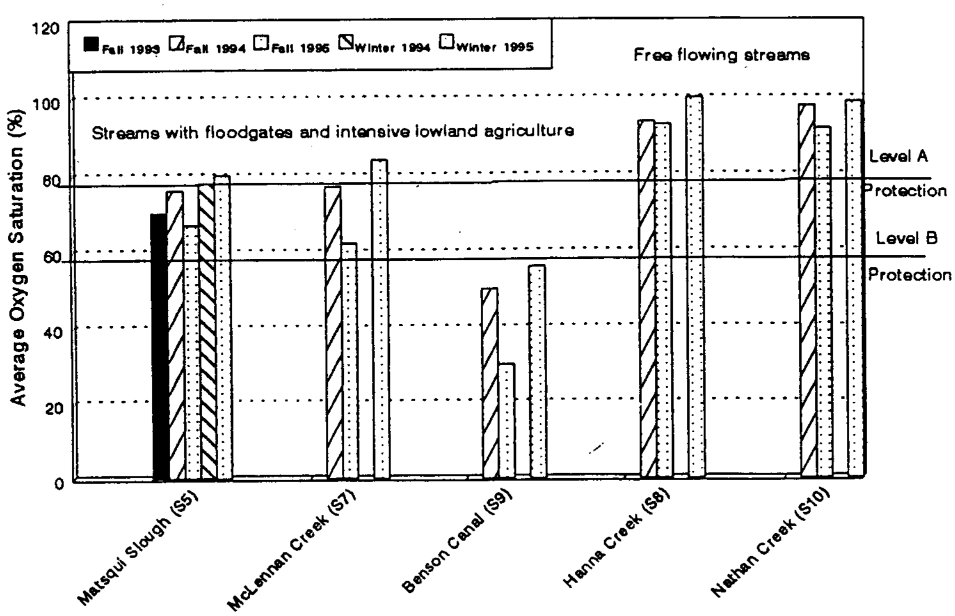


Table 1: SUMMARY OF THOMPSON BASIN AGRICULTURAL SITE FILES
THOMPSON BASIN AGRICULTURAL PRACTICES INITIATIVE

IMPACT RATING RELATIVE TO CODE OF PRACTICE	1994 SITES IDENTIFIED	1995 SITES IDENTIFIED
5 - HIGH	5	3
4	13	13
3 - MODERATE	13	28
2	12	13
1 - LOW	7	5
Referrals		
BC Cattleman's Association	26	0
AEPC	1	0
Educational follow-up	26	0
Ongoing from 1994		8
ACTIVITY TOTAL	103	70

* **90% of sites identified in 1994 and 1995 have been inspected at least once and 80% of all sites require ongoing, follow-up inspection**

Table 2: CROSS SECTION OF RESEARCH AND EDUCATIONAL PROGRAMS RELATED TO AGRICULTURE

PROGRAM	LEAD
Silage Corn - Optimization of Manure and Inorganic Fertilizer Use.	Agriculture Canada
Poultry Dietary Rations & Ammonia Emissions	Agriculture Canada
Greenhouse Wastewater Wetland Treatment	UBC
Mushroom Farm Wastewater Characterization & Diposal	UBC
Poultry Manure Handling & Hauling Strategy	Sustainable Poultry Group
Manure Management & Runoff Quality - Silage Corn	Agriculture Canada
Raspberry Production - Improved Manure Application Technology	Agriculture Canada
Environmental Guidelines & Best Management Practices Manual	BCMAFF/BCFA
Agriculture and Stream Stewardship	DFO

Investigation into the Distribution of Non-Point Source Nitrate in Two Unconfined Aquifers

J. Atwater

Civil Engineering
University of British Columbia

Most of the groundwater in unconfined aquifers in the lower Fraser Valley contains elevated levels of nitrate. These aquifers are important sources of drinking water for many people; however, they also provide the base flow for many of the tributary streams in the valley. Nitrate contamination of unconfined aquifers is not unique to the valley but rather is found in almost every jurisdiction world wide. In a number of these locations there have been reports of *in situ* denitrification. Included in these reports are local sites. The analysis of the groundwater from three MOEPL wells located in the Abbotsford Aquifer suggest that denitrification was occurring at depth.

If *in situ* denitrification is occurring, then it is reasonable to assume that it could be easily enhanced through the introduction of a carbon substrate. A study was initiated to determine and demonstrate the feasibility of enhancing denitrification in the local unconfined aquifers. The project consisted of two parts; a laboratory study to determine the influence of various carbon substrates as well as the influence of flow rates and a field study. In order to carry out a field demonstration, it was necessary to first determine that denitrification was occurring and at what location within the aquifer. Three wells were installed for this purpose as part of a larger program sponsored by the Geological Survey of Canada. One of these wells was located in the Abbotsford Aquifer adjacent to the three Ministry wells. The other two were in the Brookswood Aquifer downgradient from an Environment Canada demonstration site. It is the monitoring results from these three wells that is the focus of this presentation.

The wells were monitored using a string of dialysis membranes which allowed for discrete sampling every 30 cm. The well in the Abbotsford Aquifer intercepted water that had passed under an extensive area of raspberry canes. The Brookswood wells were located downgradient of residential properties serviced with septic tanks (south well) and within a potato field (north well) but a short distance downgradient of treed property.

Conclusions

The water from the Abbotsford well contained nitrate levels in excess of 40 mg/L as N with a vertical gradient and a pronounced seasonal variation in the zone influenced by the fluctuating water table. Variation was also seen below the recharge zone but becoming less apparent with depth. The data did not support the likelihood of significant *in situ* denitrification so an alternate mechanism for the nitrate gradients is suggested.

The analysis from the Brookswood wells showed a much lower concentration of nitrate in those groundwaters as well as a limited depth of nitrate contaminate penetration. The south well, influenced by the housing, showed little evidence of nitrate. The north well, approximately 300 m from the south well and obliquely downgradient, appeared to be influenced by farming practices with nitrate contamination in the upper couple of metres.

Community Establishment of Goals, Objectives and Indicators of Ecosystem Health

F. Mah[1], G. Butcher[2], D. Argent[3], M. Wallis[4]

[1] *Environmental Integrations*
Environment Canada

[2] *B.C. Ministry of Environment, Lands and Parks*

[3] *Salmon River Watershed Roundtable*

[4] *Wallis Environmental Aquatics Ltd.*

Abstract

The Salmon River watershed in British Columbia has experienced serious deterioration due to the effects of logging, urbanization and agriculture. Historically, the Salmon River was one of the largest salmon producers in the Fraser River basin. Today, the river's sockeye salmon is nearly extinct and other species are in serious decline. Over a number of years, little remedial action was possible due to inconsistencies in policies between government agencies and failure to include all stakeholders in the decision-making processes. In response, local concerned citizens established the Salmon River Watershed Roundtable where respect for all stakeholder interests, cooperative action and coordinated management of all resources in the basin are operating principles for restoration of ecosystem health. In a pilot project with the British Columbia Ministry of Environment, Lands and Parks, and Environment Canada, the Roundtable is using the ecosystem approach in establishing goals, objectives and indicators of ecosystem health for the watershed. The project will investigate the process involved and the lessons learned. Promotion and maintenance of community participation, volunteer remedial actions and citizens' monitoring programs for ecosystem objectives will be described.

Evaluating the Ecosystem Objective Setting Process in the Salmon River Watershed

K. Grant

Resource Management and Environmental Studies
University of British Columbia

This presentation reviewed the application of the “ecosystem objective setting process” in the Salmon River watershed, and then outlined a current research project to evaluate the success of the process. The “ecosystem objective setting process” is a process by which a community complies and reviews relevant information about the ecosystem in which they live, and then develops a long-term vision for their ecosystem based on what the community knows, and how ecosystem residents want to live. The vision is articulated in terms of “ecosystem objectives” (narrative statements which describe the desired state of an ecosystem). Over the past year, the Salmon River Watershed Roundtable has undertaken the ecosystem objective setting process in the Salmon River watershed. The main objective of the evaluation project was to:

1. place the case study in the context of current literature on watershed management and collaborative processes;
2. describe the procedures used in the case study;
3. evaluate the success of the process from both the participant’s and academic point of view; and,
4. make recommendations regarding the applicability of the process to other watershed ecosystems.

Data collection methods included record collection, participant observation, interviews with process participants and a survey of watershed residents. Results of this study should be available in the form of a graduate thesis in August, 1996.

Development of a Citizen's Monitoring Program for Benthic invertebrates in the Salmon River Watershed

K.J. Cash and J.M. Culp

National Hydrology Research Institute

In consultation with the Salmon River Watershed Roundtable, we have been developing a monitoring program for the Salmon River that incorporates local knowledge and assists in the development of environmental objectives and bio-indicators. This program included the development of a simple, but rigorously designed, scientific monitoring program intended to be carried out by volunteers. Local stakeholders are involved in all aspects of the monitoring program from the setting of objectives, through field monitoring of the system and the interpretation of the collected data. In this way, the shareholders become more aware of and involved in local water quality issues, while providing considerable financial savings to provincial and federal governments. Our model is intended to serve as a template for the development of similar programs elsewhere in British Columbia. In addition, we are developing a simple reporting system for relating our scientific findings to the Roundtable and general public. This reporting system will be developed in consultation with the Roundtable and will be based on existing models such as the Save Our Streams and TVA (Tennessee Valley Authority) River Pulse and Department of Fisheries and Oceans, Stream Keepers programs.

Effects of Agricultural Pollutants on Amphibians in the Lower Fraser Valley

K. Pettit

Department of Animal Science
University of British Columbia

Introduction

Amphibians are among the world's most ancient terrestrial vertebrates — the fossil record extends back more than 350 million years. Recently, however, scientists have become alarmed by world-wide amphibian declines in population due to habitat losses and other, unknown causes.

Amphibians, such as anurans (frogs and toads), caudata (salamanders and newts), and caecelians are cryptic and difficult to survey successfully. Often, populations of these animals experience large temporal fluctuations.

Intensive study of amphibian populations have shown that natural populations are often fragmented and smaller populations may be interconnected by dispersal into larger "metapopulations." In these, some individual populations may act as a "source" population, providing the overall population with individuals through dispersal, and others as "sink" populations, receiving individuals from the source but not contributing to overall population growth. In metapopulations of this type, removal of a significant source population can have impacts beyond what may normally be expected as the sink populations normally dependent on it fail as well. Individual population fluctuations and dynamics may be complicated by the existence of the metapopulation super-structure.

In the lower Fraser Valley, human population levels have been growing since 1862. Accompanying this growth have been extensive changes in habitat, including the drainage in the 1920s of Lake Sumas and the extensive wetlands associated with it. Overall a large percentage of wetlands have been drained or altered in the lower Fraser Valley since 1862.

As natural wetlands are drained and watercourses altered, amphibian populations become more dependent on wetland fragments adjacent to agricultural land for breeding and foraging habitat. These are susceptible to further alterations, erosion and fertilizer and pesticide use.

Water quality testing and guidelines are often performed and written for common test organisms such as *Daphnia* sp. and the fathead minnow. It is unknown whether these would be suitable for application to amphibian species. As well, different amphibian species have different susceptibilities to pesticides and other aquatic parameters, such as nitrogen and/or dissolved oxygen levels.

Literature Review

Objectives of Proposed Research

1. to assess reproduction of amphibians living within the Sumas watershed;
2. to assess whether habitat quality within the Sumas watershed is suitable for sustaining a diverse and viable amphibian population; and,
3. to determine whether water quality guidelines for agricultural pollutants developed using common indicator species will be sufficient to protect amphibians.

Hypotheses to be Tested

1. • Population density (measured as: numbers of tadpoles, froglets, and breeding and non-breeding adults encountered per unit time) of natural populations of *R. pretiosa* and *R. aurora* living within the Sumas

watershed will be lower than normal for these species and lower than similar populations in reference areas.

- Rates or reproduction (measured as: number of breeding adults, number of eggs masses, hatching success, survival to transformation) of natural populations of *R. pretiosa* and *R. aurora* living within the Sumas watershed will be lower than normal for these species and lower than similar populations in reference areas.

2. • Compared to the reference site, habitat in the Sumas watershed will be of lower quality (measured by: structural diversity of vegetation, distance to other habitats, amount of shading).

- Compared to water from the reference sites, water from the Sumas watershed will have higher levels of agricultural pollutants, higher temperatures, higher nutrient levels, higher turbidity and lower dissolved oxygen.
- Compared to water from the reference sites, water from the Sumas watershed will depress hatching success in the laboratory of eggs of *R. pretiosa* and *R. aurora* from populations in both the Sumas watershed and reference areas.
- Compared to water from the reference sites, water form the Sumas watershed will depress hatching success in the field of eggs of *R. pretiosa* and *R. aurora* from populations in both the Sumas watershed and reference areas.
- Eggs from *R. pretiosa* and *R. aurora* living within the Sumas watershed will be less sensitive to agricultural pollutants than eggs from similar populations in reference areas. Eggs of *R. pretiosa* will be more sensitive than those of *R. aurora.*

3. • Eggs from *R. pretiosa* and *R. aurora* will be more sensitive to agricultural pollutants than common indicator species**.**

Methods

1. • Starting in March, roadside surveys of calling male amphibians following NAAMP protocol (3x/week/site - i.e., three nights in Sumas, three nights in control). Intensive daytime and nighttime searches for adult amphibians, tadpoles and froglets as appropriate to the season in pond and surrounding habitat. Note numbers found per unit effort. On adults, use mark-recapture (toe clipping) and possibly age and genetic analyses (save toe-clip fragments) to assess community size and structure; measure length and mass to calculate condition indices; blood sample population for enzyme and hormonal biomarkers. Record any deformities found (March to July/August).

- Starting in March, intensive daytime pond searches for egg masses, etc. Frequently during breeding season (March to May).

2. • Starting in March, once monthly measurement of physical parameters of habitat (until winter). Measure character and distances to nearby habitat elements (roads, woodlots, other ponds, crops), surface area, volume, maximum depth, slope, shore perimeter only once (June/July). Measure perimeter buffer characters (%, width, height, composition), perimeter crop characters (composition, %, pesticides used, other critical crop practices), predators, aquatic vegetation monthly (March to October).

- Starting in March, periodic samples of water from Sumas and control sites. Special emphasis on times when spray and/or fertilization events are expected (before and after samples), and during period of hatching success trials (daily for two weeks). Continuing weekly until amphibian transformation, if possible. Measure minimum and maximum temperatures (daily or weekly), pesticide residues levels in water and biota, dissolved oxygen, conductivity, color, turbidity, dissolved inorganic and organic carbon, nitrites, nitrates, ammonia, total Kjedahl nitrogen, and total phosphorus (March to July/August).

- When each species of amphibian is breeding, eggs will be collected (from the wild, if possible; by force from gravid females, if not) and brought into the laboratory. Egg masses will be divided into lots of approximately 100 eggs each and, prior to stage eight, introduced to 6" diameter tubs containing water from each site. Each tub will be aerated, and covered with mesh lid. Containers will be kept at constant temperature (~15°C). Water will be changed daily with fresh water collected from each site (collected in chemically cleaned 1L bottles and transported covered on ice as quickly as possible to the laboratory). Water will be tested daily for pH, conductivity and CO_2. Eggs will be incubated until hatching, and assessed for hatching success and deformity rates (March to May).
- In the above two experiments, trials will be run with eggs from both the Sumas and the reference sites (if possible).

3. - Eggs from *R. pretiosa* and *R. aurora* will be hatched in the laboratory using water containing known concentrations of agricultural contaminants (pesticides and fertilizers) at environmentally relevant concentrations and at concentrations relevant to *Daphnia* and fathead minnow literature. NOEL and LOEL concentrations determined for trials of *Daphnia* and fathead minnow.

Secondary Poisoning of Birds of Prey by Anticholinesterase Insecticides

J.E. Elliott[1,2], L.K. Wilson[1,2], K.M. Langelier[2] and P. Mineau[2]

[1]*Canadian Wildlife Service*

[2]*Environment Canada*

Abstract

The effects of persistent organochlorine (OC) contaminants, such as DDT and dieldrin, on raptor populations has been widely documented. OCs have largely been replaced by organophosphorus (OP) and carbamate insecticides which are considered non-persistent, non-bioaccumulative and therefore, of low risk for secondary poisoning of raptors. However, we present evidence that granular formulations of OP and carbamate insecticides can persist long enough in the wet, low pH conditions of the Fraser River delta of British Columbia, to cause waterfowl kills and secondary poisoning of raptors several months after pesticide application. Various raptors, particularly bald eagles *(Halaeetus leucocephalus)* and red-tailed hawks *(Buteo jamaicensis)*, have been obtained, dead or debilitated, from government and non-government sources. All specimens were analyzed for plasma and/or brain cholinesterase activity. Based on those results, ingesta were analyzed for pesticide residues.

From 1990 to 1994, mostly in the Fraser delta, more than 40 cases were documented of raptors poisoned by anticholinesterases. Over a three-year period in the delta, an average of 20% of bald eagles examined (N=157) were poisoned by anticholinesterases. At least seven insecticides have been implicated, resulting in the withdrawal of some compounds from the local market.

PCDDs and PCDFs in Eagle and Osprey Eggs Near Kraft Pulp Mills in British Columbia, Canada

P.E. Whitehead[1], J.E. Elliott[1], J. Van Oostdam[2], and R.J. Norstrom[3]

[1]*Canadian Wildlife Service*
Environment Canada

[2]*B.C. Environment, Lands and Parks*
Victoria

[3]*Canadian Wildlife Service*
Ottawa

Introduction

For several years, the Canadian Wildlife Service has monitored polychlorinated dioxin (PCDD) and furan (PCDF) levels in the eggs of colonial fish-eating birds such as herons and cormorants. These studies helped focus public and regulatory attention on the issue of Kraft pulp mill pollution in coastal British Columbia. Herons and cormorants, however, only nest in the southern parts of the province and are primarily associated with marine habitats. In 1990, studies were begun to assess other possible sentinel species such as the bald eagle (*Haliaeetus leucocephalus*) and osprey (*Pandion haliaetus*), that are more widely distributed and forage in aquatic as well as marine systems. If these species could be shown to accumulate chlorinated hydrocarbons similar to herons and cormorants, then analysis of their eggs would provide a broader picture of environmental contamination in the province. This paper reports the results of PCDD and PCDF analysis of bald eagle eggs collected in the Strait of Georgia and Johnstone Strait beginning in 1990, and osprey eggs collected annually since 1991 from nests on the Columbia and Fraser River systems in the interior of British Columbia.

Methods

Bald eagle eggs (1 egg/nest) were collected from 1990 through 1992 in six areas of the south coast of British Columbia. Four of the areas were in the Strait of Georgia basin and receive effluent from Kraft pulp mills which, until recently, were significant sources of PCDDs and PCDFs. A reference area in Johnstone Strait distant from direct sources of PCDDs and PCDFs was also surveyed. Additional samples were collected from: 1) Alberni Inlet, 25 km from the pulp mills at the head of the inlet; 2) Clayoquot Sound; and, 3) at Langara Island in the Queen Charlotte archipelago. In 1991 and 1992 osprey eggs (1 egg/nest) were collected from several nests upstream and downstream of Kraft mills on the Thompson River near Kamloops, and the samples were collected in 1993 and 1994 near the Castlegar mill.

Individual eagle and osprey eggs were analyzed for PCDD/Fs, PCBs, several OC pesticides and chlorophenol. Only the PCDD/F data will be presented here. Detailed descriptions for the collection, storage and analytical methods are given elsewhere. Due to the skewed nature of the data, geometric means and 95% confidence intervals were calculated.

Results and Discussion

All eagle eggs sampled in the Strait of Georgia and Johnstone Strait contained PCDDs and PCDFs. Levels of 2,3,7,8 - substituted tetra-, penta- and hexa-chlorinated congeners were highest in eggs sampled near Kraft mills at Crofton and Powell River. Concentrations of these congeners were also high in eggs collected in Johnstone Strait, although 2,3,7,8-tetrachloro-p-dibenzodioxin (TCDD) levels were generally lower than elsewhere. Eggs from Clayoquot Sound and Langara Island were the least contaminated. The general pattern of congeners in the eagle eggs was, 1,2,3,6,7,8 HxCDD > 1,2,3,7,8 PnCDD > TCDD, similar to that found in the eggs and tissues of marine birds overwintering or resident in the Strait of Georgia. Possible sources of these PCDDs in Kraft mill processes have been discussed. HpCDD and OCDD levels were near detection limits in all samples, while elevated levels of TCDF and PnCDF were present in most of the eggs. PCDFs are believed to be rapidly metabolized so elevated levels would require continuous exposure to high concentrations in the diet and direct deposition in the yolk during egg formation. Verneer *et al*. reported that more than 50% of the diet of nesting eagles in the Strait of Georgia consists of seabirds (mostly gulls but also cormorants and herons), as well as grebes, ducks and shoreline birds. Fish, marine invertebrates and mammals make up the remainder. There are no Kraft mills in Johnstone Strait to account for the elevated levels of PCDD/F found in the eggs of eagles nesting there. Those eagles might be preying on waterbirds migrating northward in the spring after overwintering in the Strait of Georgia where they accumulated substantial amounts of PCDD/F. TCDF levels in eagle eggs sampled near the Kraft mill at Crofton were lower than those in eggs collected in Johnstone Strait. Possibly herons and cormorants, which are abundant near Crofton and contain only small concentrations of TCDF, make up a significant part of the diet of eagles nesting there. Although only one nest was sampled twice during the course of this study, the data generally showed PCDD levels had fallen over the sampling period. The decline was similar to that seen in other biota sampled in the Strait of Georgia over the past several years and is likely due to a sharp fall in PCDD/F output by Kraft mills since 1989. Information about process and product changes made by Kraft mills in the Strait of Georgia to eliminate PCDD/Fs in their effluent has been presented.

Osprey forage exclusively on fish swimming near the surface in shallow water. In the study area, about half the fish delivered to the nest were whitefish or sucker. Studies have shown these fish are contaminated with 2,3,7,8-substituted PCDD/Fs. Measurable levels of PCDD/Fs were found in most osprey eggs sampled. Eggs collected downstream of Kraft mills had significantly higher levels of 2,3,7,8-TCDD and 2,3,7,8-TCDF than eggs collected above mill sites. Concentrations of 2,3,7,8-substituted penta- and hexa- congeners in osprey eggs were, however, much lower than in eagle eggs in the Strait of Georgia. The difference in penta- and hexa- substituted congeners is likely attributable to lower chlorophenol use by interior Kraft mills compared with coastal mills. Lowest tetra-, penta-, and hexa- substituted PCDD/Fs were generally found in eggs collected above the Kraft mill at Castlegar and on the Nechako River. PCDD/F congener patterns were much more variable in osprey eggs than they were in eagle eggs. Some of the variability was due to differences in TCDD and TCDF levels between osprey nesting upstream of mills and those nesting downstream. In addition, some eggs contained remarkably high levels of HpCDD and OCDD while others contained only trace amounts. The presence of these congeners is unrelated to urban development or industrial activity near nest sites. Often nests with high levels of HpCDD and OCDD were located just short distances from others containing only trace amounts. Reported HpCDD and OCDD levels in fish foraged by osprey were below detection limits. We suggest that the osprey accumulate these contaminants on their wintering grounds or during migration. Studies are underway to track the seasonal movements of osprey by satellite and locate areas of contamination. In 1990, the mill at Castlegar implemented process and product changes that significantly reduced PCDD/F levels in effluent. 2,3,7,8-TCDD/F levels in fish have fallen since the measures were implemented. 2,3,7,8-TCDD/F levels in osprey eggs, however, remain elevated downstream of the Kraft mill at Castlegar.

Our data show that eagle and osprey are useful sentinels of environmental contamination by persistent chlorinated hydrocarbons. However, establishing sources and pathways for contaminants in these species can be difficult. Eagles, while resident on the west coast, may move considerable distances to take advantage of seasonal foraging opportunities. As well, their diet consists of a variety of birds (migratory and non-migratory), fish, invertebrates and mammals. Osprey, of course, are migratory so contaminants are accumulated during migration and on the wintering grounds, as well as at the nest site.

Agricultural Impact on Water Quality in the Sumas River Watershed

H. Schreier, C. Berka and K. Hall

Institute for Resources and Environment
University of British Columbia

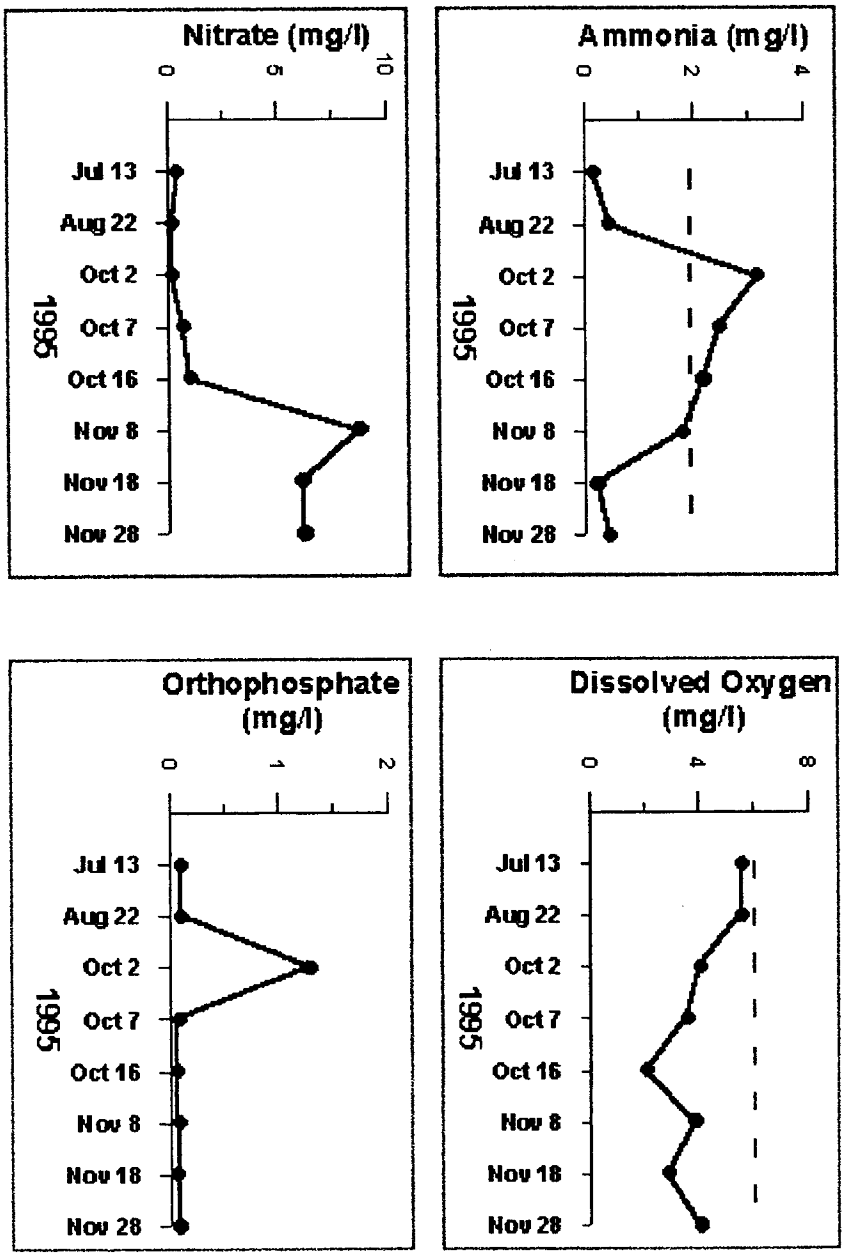
The Sumas River basin contains some of the best agricultural land in Canada. The dairy and vegetable producers remain the dominant agricultural force, but over the past five to ten years, hog and poultry operations have undergone considerable intensification leading to an oversupply of manure. The combined nutrient application (manure and fertilizers) on many fields is exceeding the crop demand and absorption capacity of the soils by 100 - 200 kg/ha/year. This is leading to pollution of the surface water resource. The water quality was monitored at 15 stations over a one-year period. Results showed elevated nitrate values in the late summer in Lonzo (alias Marshall) Creek, which receives groundwater inputs from the Abbotsford Aquifer. In contrast, some streams have been more affected by manure management and direct surface runoff during the early winter period of October to December. Consistently low dissolved oxygen and elevated ammonia levels, both failing to meet the criteria set by the province, were observed in the Arnold Slough and Central Canal area (see Figure 1).

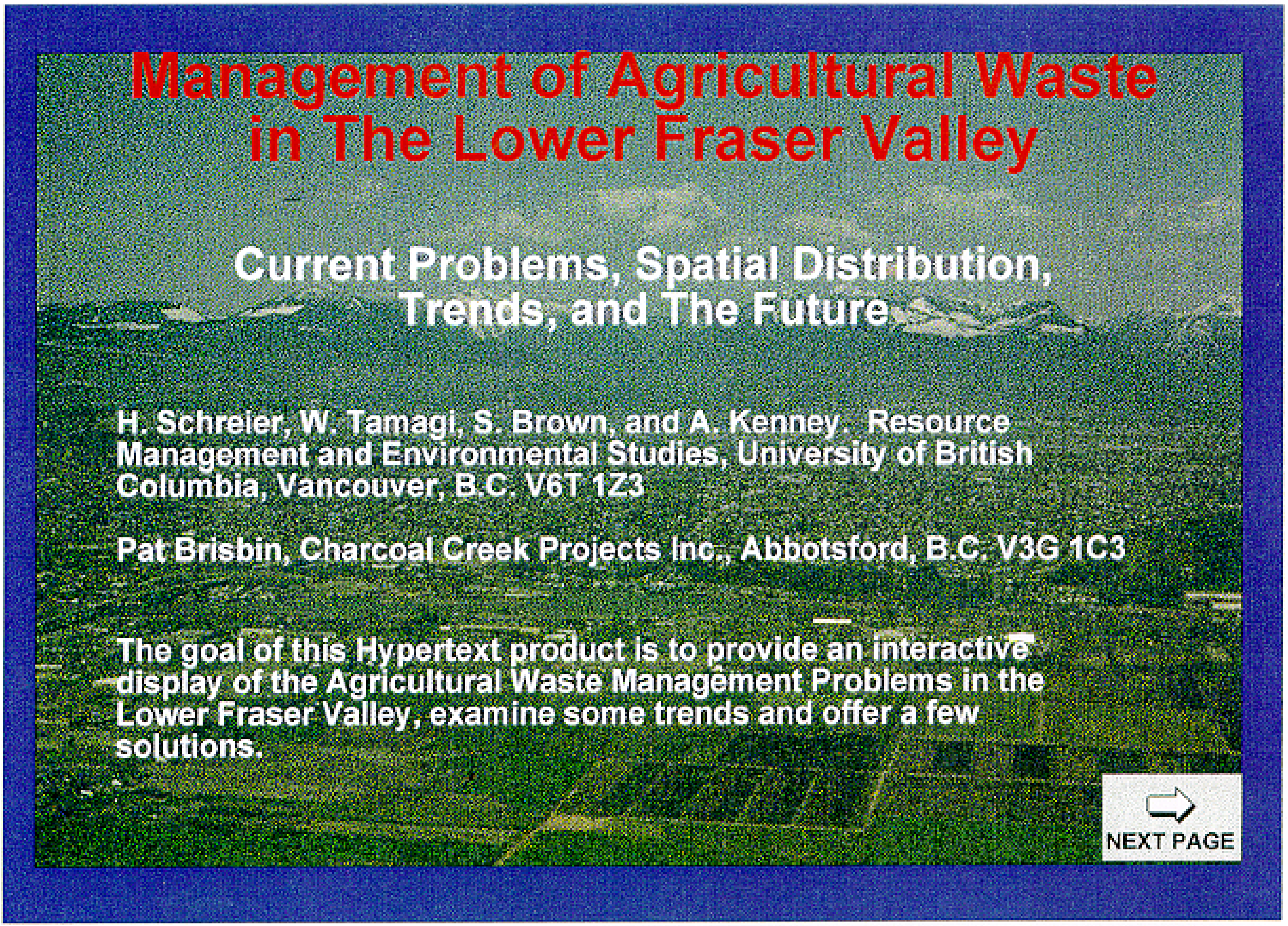
A GIS resource database was created for the watershed, and land use changes were examined quantitatively between 1954 and 1991 using large scale historic aerial photos. The latter source was also used to document the introduction of new farms into the watershed since 1954. Similarly, changes in animal numbers between 1986 and 1991 were obtained from the agricultural census data. The results suggested that agricultural intensification, including the expansion of hog and poultry operations, is largely responsible for the generation of excessive nutrients. This is now the major non-point source of pollution for the stream system. A nitrogen mass balance was used to determine excessive nutrient applications within each contributing area draining to a sampling station, and the results were then related to water quality. Significant negative correlations were obtained between excessive rates of nitrogen loading to the land and dissolved oxygen levels in the stream. Positive correlations were obtained between excess nitrogen loadings and ammonia levels in the stream during the winter season. Animal stocking densities were calculated for each contributing area also. The densities in some areas exceeded the standards used by several European countries to regulate manure application rates.

Nutrient production and application is clearly excessive in the watershed. The overall surplus nitrogen application in the watershed typically ranged between 135 to 185 kg/ha/year. The effects of this surplus application is most evident in the late fall/early winter period when plant uptake is minimal and there is heavier rainfall. A number of steps need to be taken to reduce the generation of manure, the applications of N, P and K, and to protect the stream. Manure processing, best management practices, better storage of manure and timing of its application, reduction of fertilizer use, and development of buffer zones are all positive measures that can reduce the impact of agricultural non-point source pollution on the stream ecosystem.

FIGURE 1: Arnold Slough

- **Arnold slough identified as critical area**




Management of Agricultural Waste in The Lower Fraser Valley
Current Problems, Spatial Distribution, Trends, and The Future
H. Schreier, W. Tamagi, S. Brown, and A. Kenney. Resource Management and Environmental Studies, University of British Columbia, Vancouver, B.C. V6T 1Z3
Pat Brisbin, Charcoal Creek Projects Inc., Abbotsford, B.C. V3G 1C3
The goal of this Hypertext product is to provide an interactive display of the Agricultural Waste Management Problems in the Lower Fraser Valley, examine some trends and offer a few solutions.
NEXT PAGE

Animal Numbers For Each District

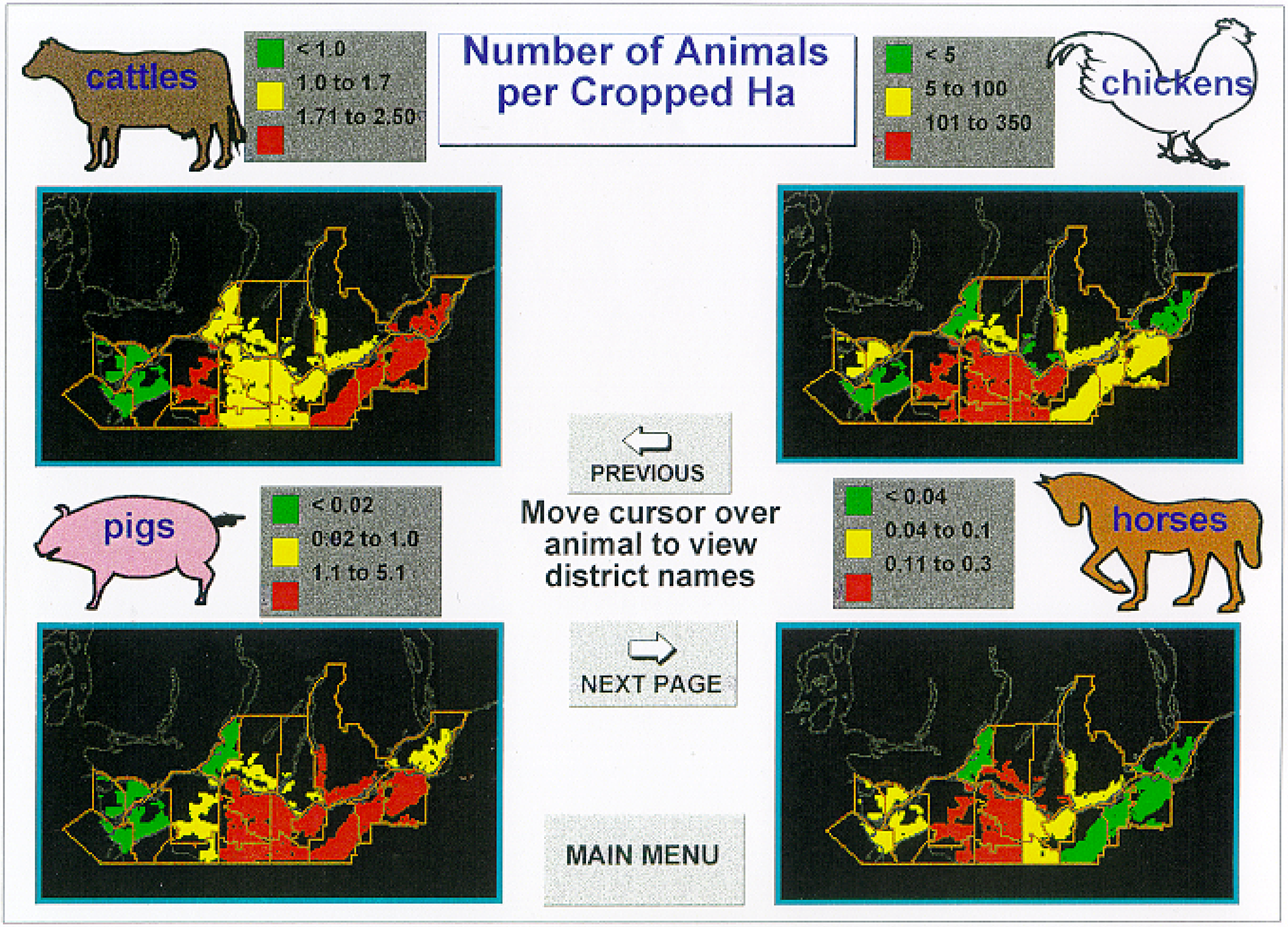
Enumeration Area	Cattle	Chickens	Pigs	Horses	Mink
Chilliwack	28445	951953	34285	499	9300
Surrey	19101	1133045	4442	1225	25752
Abbotsford	18535	481453	38862	214	0
Matsqui	17131	4150177	51207	670	54044
Langley	14303	1585054	17428	3860	100137
Nicomen	9114	71965	6112	294	0
Agassiz	8058	16040	1626	89	0
Pitt Meadows	6475	1341	58	134	0
Delta	5147	1088	81	591	0
Maple Ridge	2022	45173	209	587	0
Richmond	1632	356601	50	325	0
Mission	1509	2825	366	147	0

Animal numbers can be sorted from high to low for each type of animal and the associated maps are displayed on the next page.

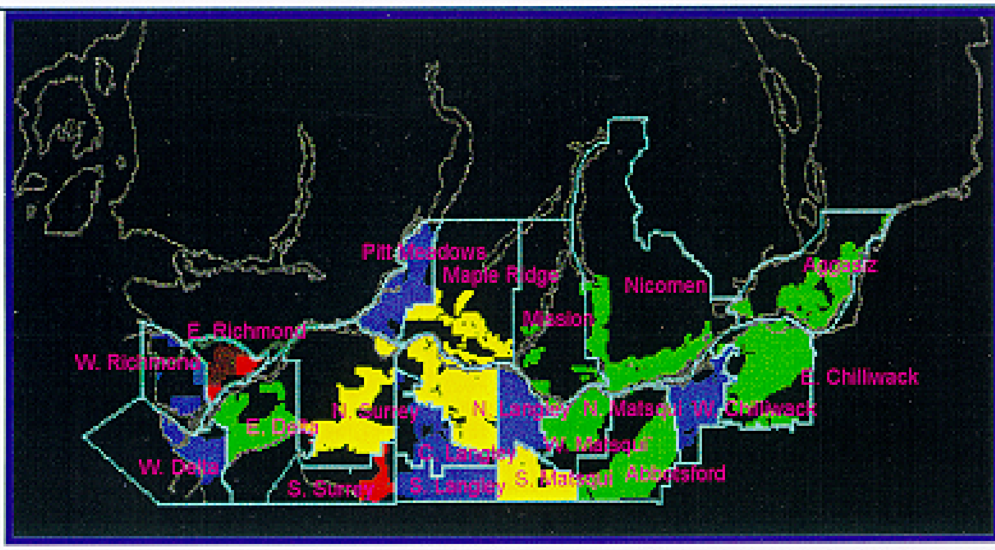
Cattle | Chickens | Pigs | Horses | Mink

MAIN MENU

NEXT PAGE

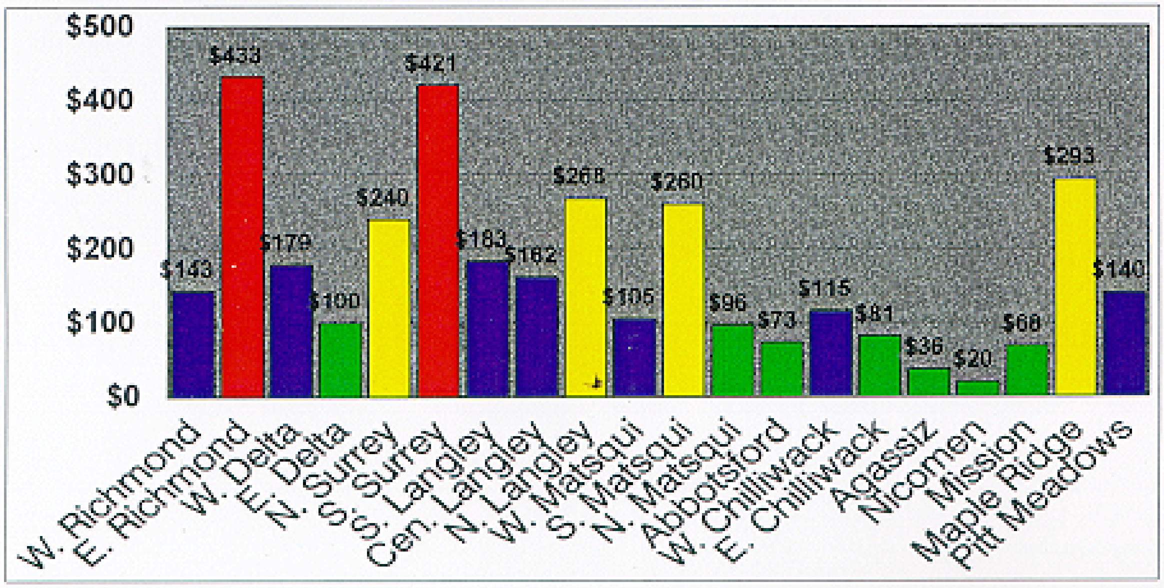

Number of Animals
per Cropped Ha
cattles
< 1.0
1.0 to 1.7
1.71 to 2.50
chickens
< 5
5 to 100
101 to 350
pigs
< 0.02
0.02 to 1.0
1.1 to 5.1
horses
< 0.04
0.04 to 0.1
0.11 to 0.3
PREVIOUS
Move cursor over
animal to view
district names
NEXT PAGE
MAIN MENU

Agricultural Chemicals ($) per Cropped Ha



Dollars ($) per Cropped Ha

- $251 to $310
- < $100
- $100 to $200
- $200 to $250



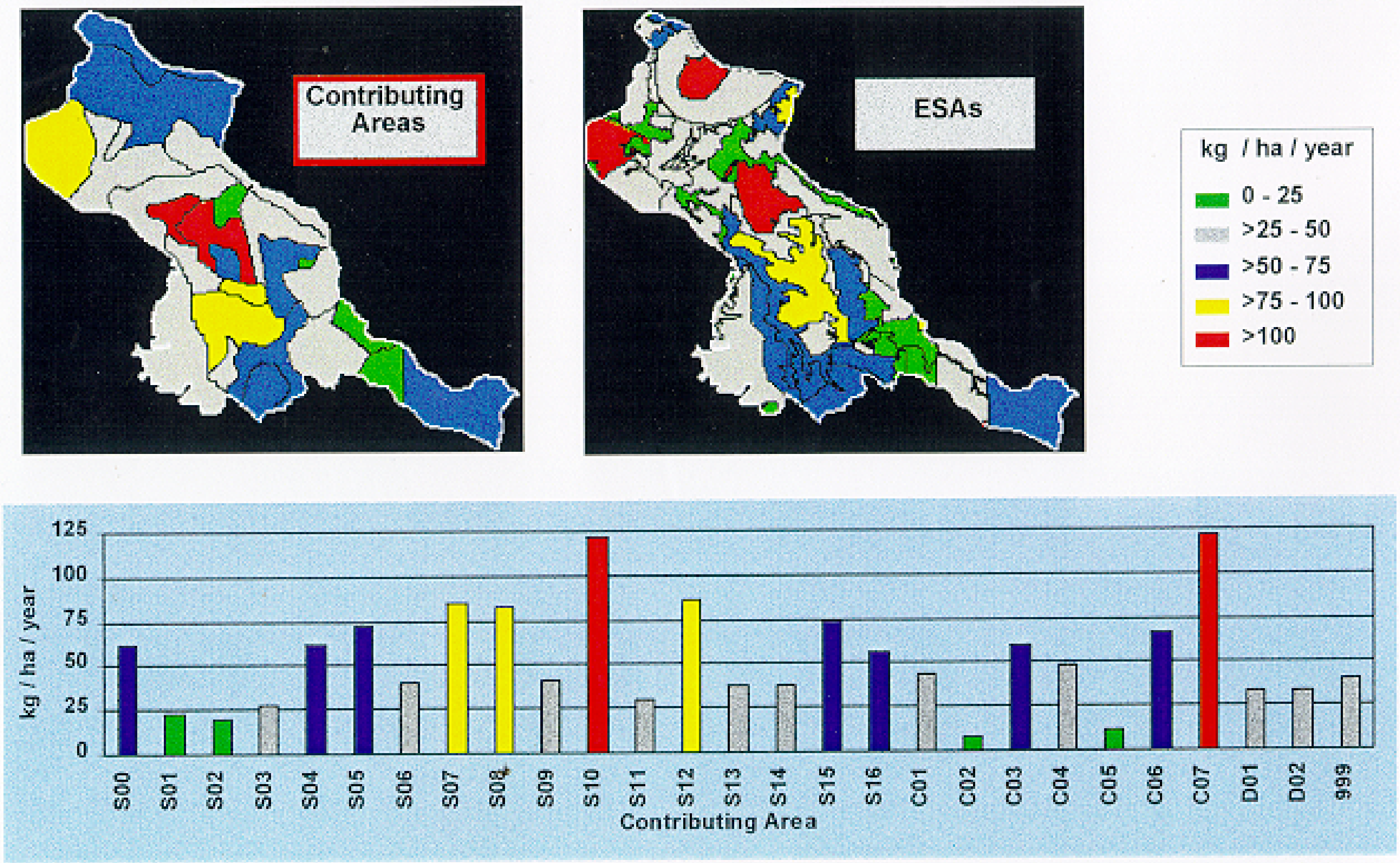
MAIN MENU

Dynamics of the Urban/Rural Fringe: Puzzling Times in the Salmon River Watershed

A. Kenney, B. Wernick, S. Brown, W. Thompson, W. Tamagi and H. Schreier

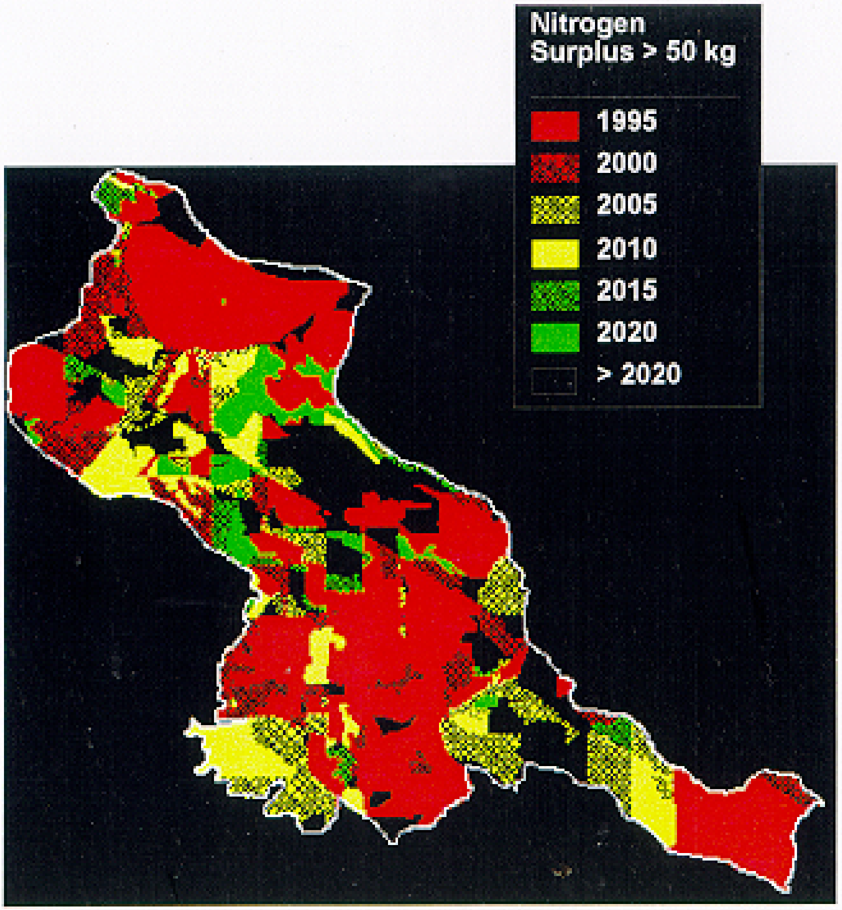
Financial contribution for this research was provided by:
Tri-Council Eco-Recearch Project, Vancouver Realestate Foundation, Environment Canada (FRAP), and Department of Fisheries and Oceans (DFO).

1995 Nitrogen Surplus



Nitrogen Surplus Exceeding Environmental Tolerance

Population 5 %, hobby farms
- no restriction

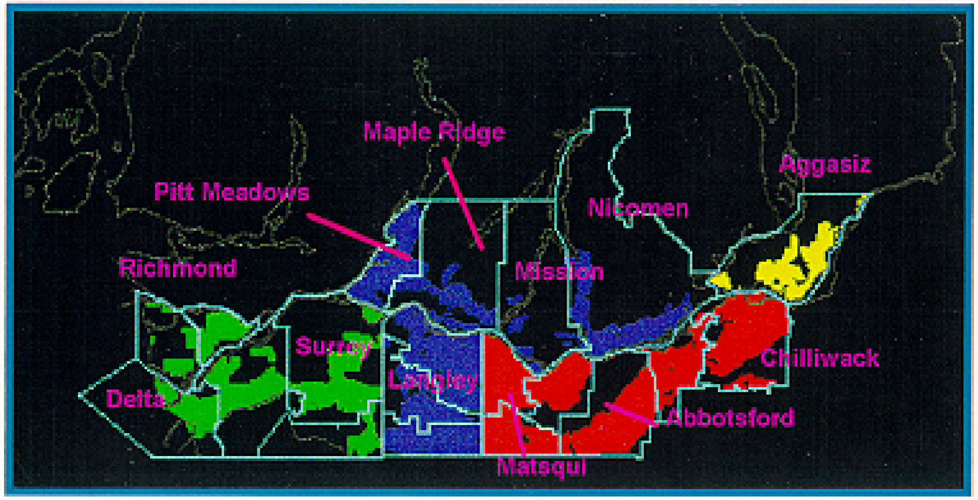


Choose Scenario

People	Agriculture	Combined
		2 %, 1/2 ag
		2 %, Hobby
		5 %, 1/2 ag
		5 %, Hobby

- (●) No Restrictions
- ( ) ESA #1 Restriction
- ( ) Aquifer Restriction

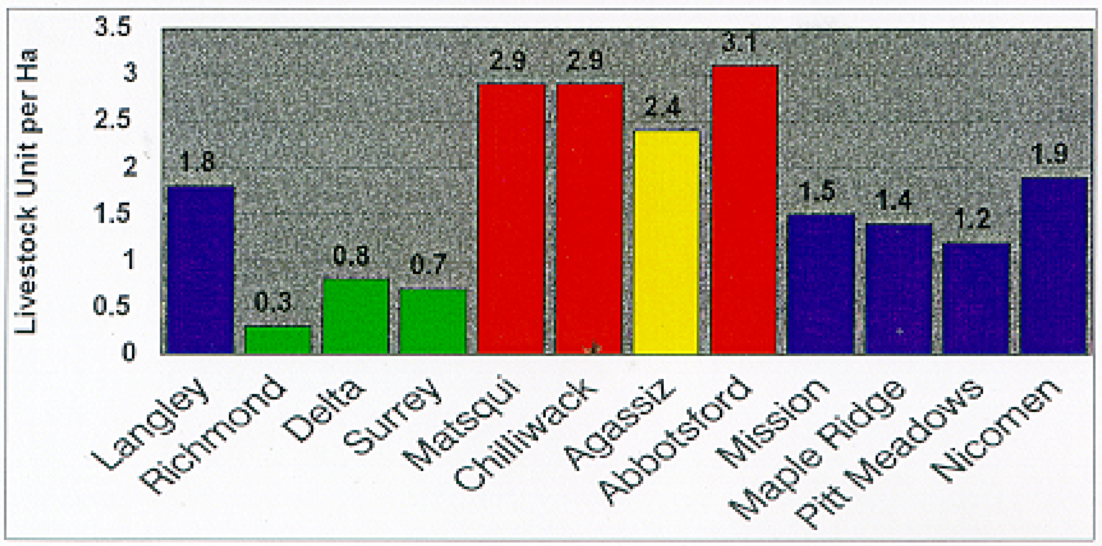
Stocking Density of Livestock Units Equivalents



Livestock Units/Ha

- < 1.0
- 1.1 to 1.9
- 2.0 to 2.5
- 2.6 to 3.1

1 LU = 1 cow, bull, or steer
= 15 hogs
= 4 dry sows
= 125 laying hens
= 300 pullets & turkey broiles
= 1000 chicken broilers
= 1 horse
= 4 sheep



The livestock unit index is used in many European countries to regulate nutrient inputs to the soils system. 2.5 LU/ha is considered carrying capacity.

PREVIOUS

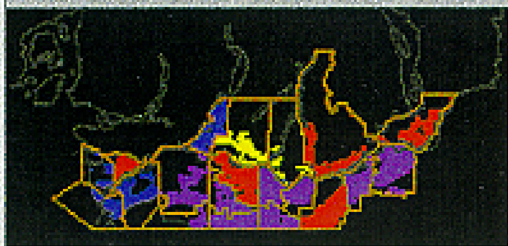
MAIN MENU


Agricultural Trends
The trend in agriculture in the Lower Fraser Valley is towards greater intensification and
higher animal numbers. Since the agricultural land base is not increasing significantly
the results will be greater environmental degradation. This is particularly evident in the
What are the Options
There are no simple solutions to the problem of excess nutrient production and application to the land. Impacts on the atmosphere and the water resources have reached proportions where action is needed.
There are a range of options and some of the most obvious ones are:
- Limiting animal stock densities
- Requirements for nutrient budgets for each farm
- Develop manure processing facilities
- Move manure to nitrogen deficient areas (Delta, Interiors, Forest Land etc.)
- Restrict the use of fertilizers
- Provide incentives to move poultry and hog operations to nitrogen deficient areas
- Requirement for treatment of manure (treatment plants)
Runka, G.G. 1996 (In Press)
Livestock Waste Management
Practices and Legislation Outside British Columbia
Report For B.C. Ministry of Environment
Victoria, BC
MAIN MENU

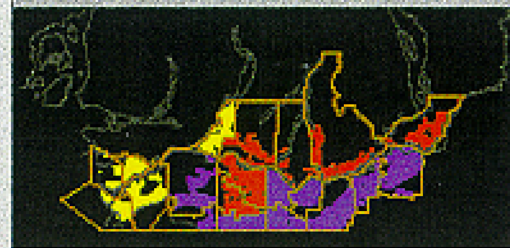
Nitrogen Plots and Graphs

Large Farms

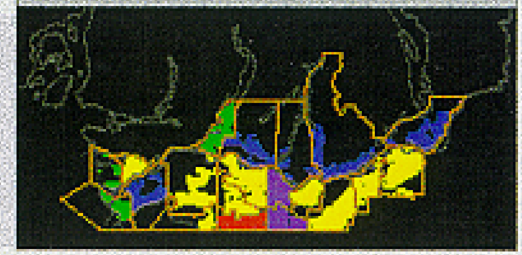
Manure Produced



Manure and Fertilizer Applied



Applied Surplus/Deficit

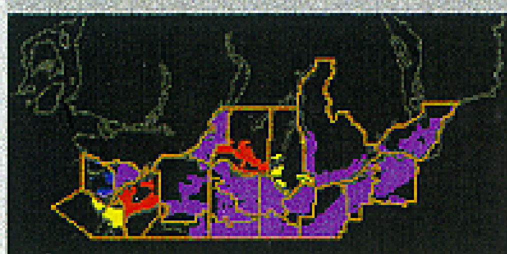


These maps show the differences in nitrogen generated and applied in the different waste management zones.

MAIN MENU

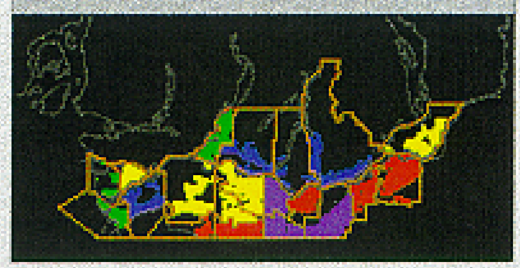
Click on button bars for more details.

Manure Produced



Total Large and Small Farms

Applied Surplus/Deficit



Modeling the Impact of Non-Point Source Pollution in the Salmon River Watershed (Langley) in a Hypertext Framework

H. Schreier, A. Kennedy, B. Wernick, W. Thompson, S. Brown and K. Hall

Institute for Resources and Environment
University of British Columbia

Over the past three years, a comprehensive resource database was compiled for the Salmon River watershed including water quality and land use information. A Geographical Information System (GIS) served as a digital base for geo-referenced information such as surficial materials, soil types, land cover and activity, commercial and hobby farms. Recent changes in the different land use activities were determined from census data, municipal records, field measurements and historic documents. GIS overlay techniques and statistical analyses were used to calculate rates of change in land activity, land cover and water quality. Stream and groundwater quality were related to land uses which were potential sources of contaminants. Both agriculture, in the form of manure and organic fertilizers, and septic systems contribute significant amounts of nutrients to the environment. While water quality in the Salmon River is still good in comparison to other urban-rural fringe streams, there is clear evidence that nitrate concentrations are elevated in approximately one-third of all groundwater wells. Because groundwater maintains stream flows during the summer, streamwater nitrate concentrations are also elevated in the Hopington Aquifer area of the watershed.

In order to estimate the future impact of land use on water quality, the watershed was subdivided into 460 unique management units, which were defined by overlaying contributing area units (CA), environmentally sensitive area units (ESA) and planning units (PU). Four different growth scenarios were projected for each management unit:

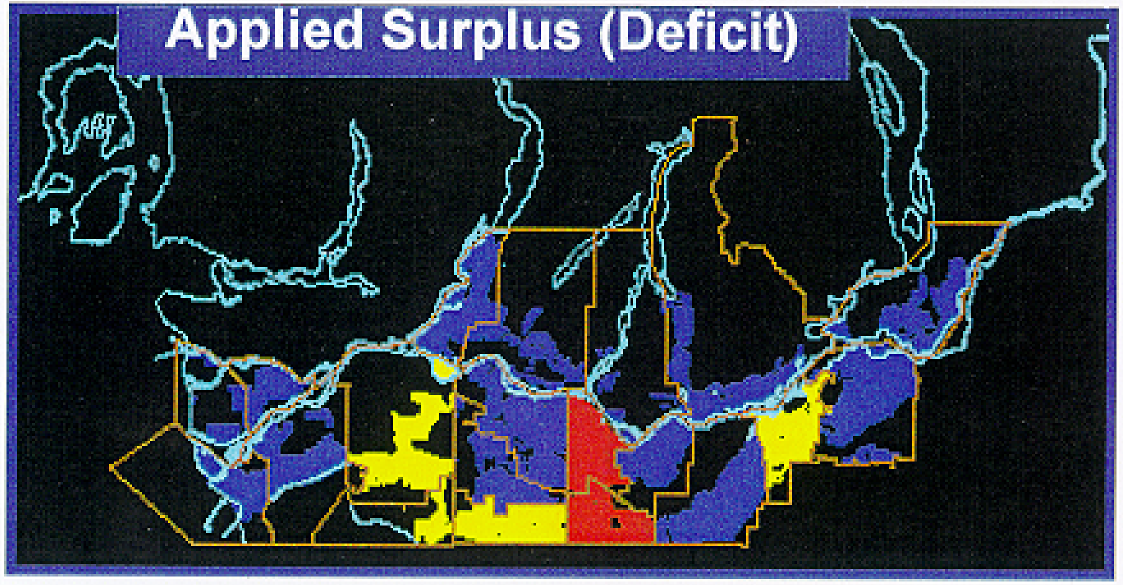
- 2% population increase;
- 5% population increase;
- 50% increase in commercial agriculture with current increase in hobby farms; and,
- current increase in both commercial agriculture and hobby farms.

Total current and future water consumption, surplus nitrogen, % residential areas, green space, population density and animal unit density were used as indicators of environmental conditions. The results could be combined into the contributing areas, ESAs or planning units for community planning purposes.

GIS maps, spreadsheet graphs and images showing the results of the data analysis and modeling were incorporated into a Hypertext system that allows the user to explore the past, current and projected future conditions in the watershed. Hypertext is an electronic operating system which is a means of extending text and graphics into multi-dimensional space. Essentially, a Hypertext document is non-linear text which allows the user to work interactively in a non-structured way with cross-references, annotations, graphics and images at multi-levels. Pulldown screens containing graphic displays and images are interspersed into the text of the document.

The Hypertext is a self-contained, self-executable product that can be displayed in color on any personal computer with VGA graphics capability (10 MB hard drive space and 1 MB of RAM is also required). The Salmon River Hypertext product is a new way to display and communicate research results which we hope will reach a wider audience. We consider this an educational tool that will be useful to managers as well as schools and the public in general. Three examples of the more than 70 screen displays in the document are shown in Figures 1 - 3).

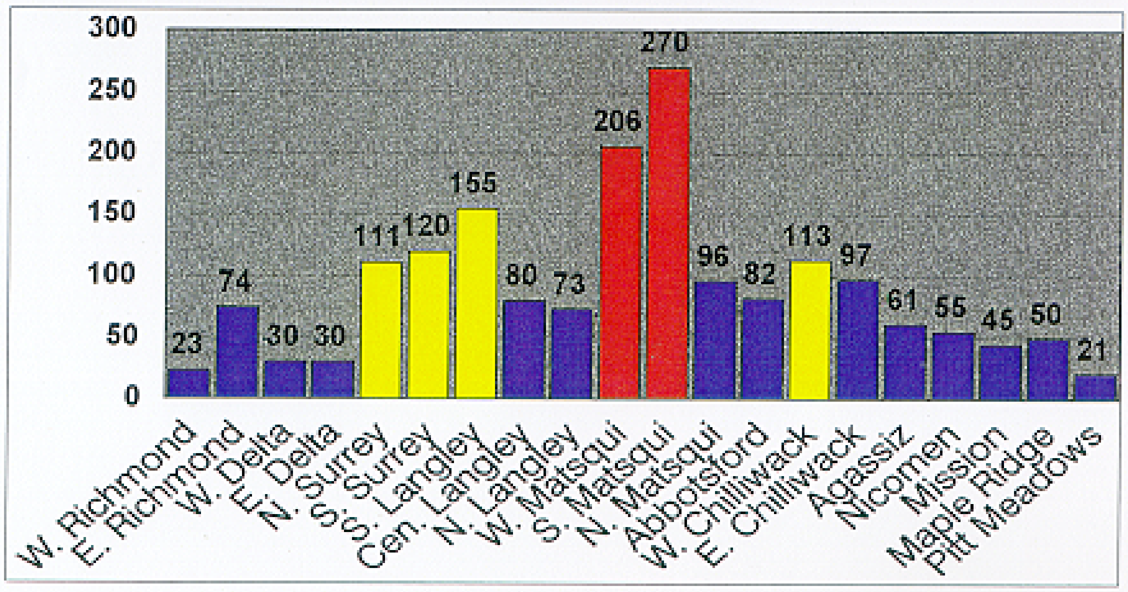
The fully functioning Hypertext model will be delivered to the Municipality of Langley on April 20, 1996, and a number of copies will be available at that time.



Large Farms
Current Management

Phosphorus (kg/cropped ha)

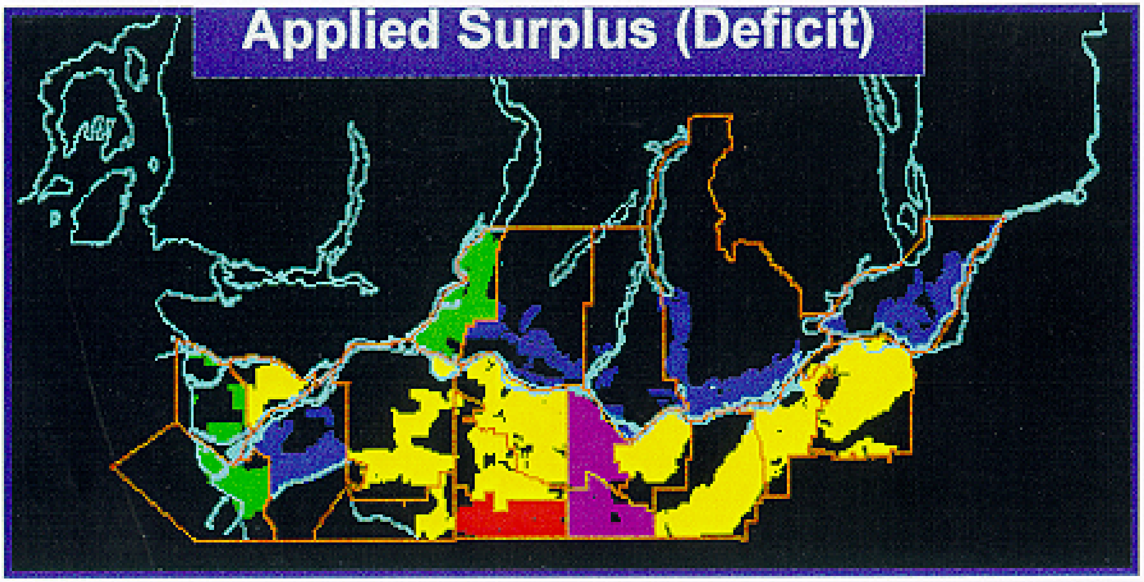
- < 1
- 1 - 100
- 100 - 200
- 200 - 300
- 300 - 1000



Surplus is based on total P applied minus crop uptake.

PREVIOUS

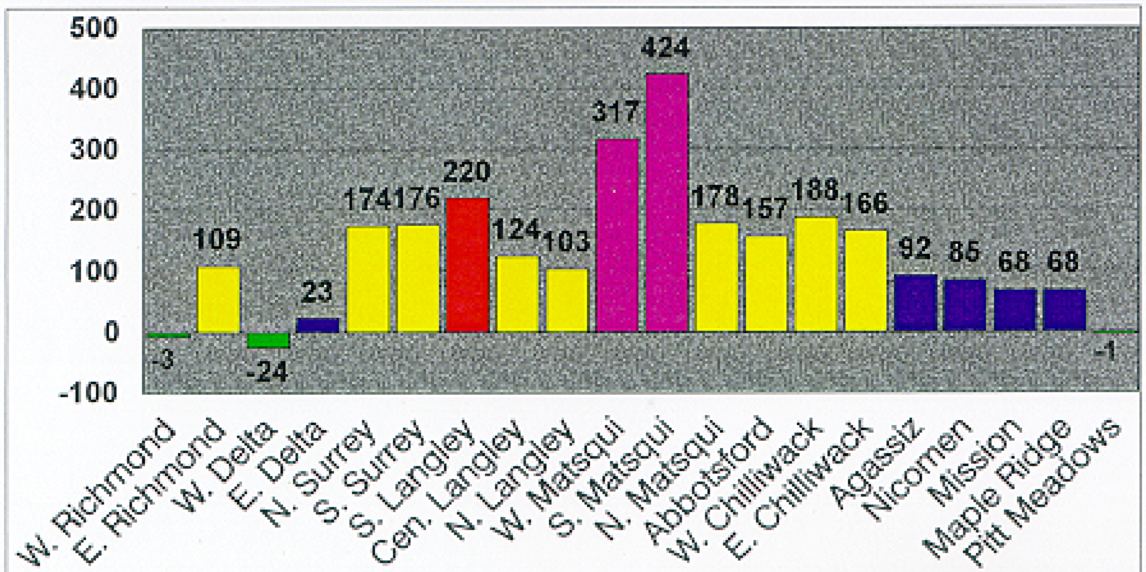
NEXT PAGE



Large Farms
Current Management

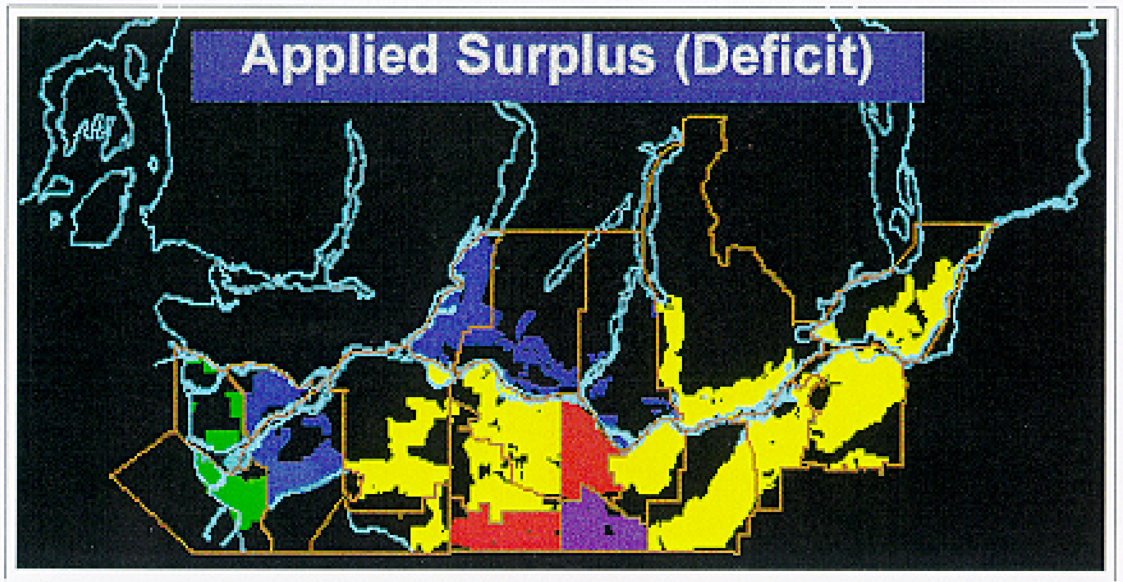
Nitrogen (kg/cropped ha)

- < 1
- 1 - 100
- 100 - 200
- 200 - 300
- 300 - 1000



Surplus is based on total N applied, minus losses to the atmosphere, crop uptake and denitrification.

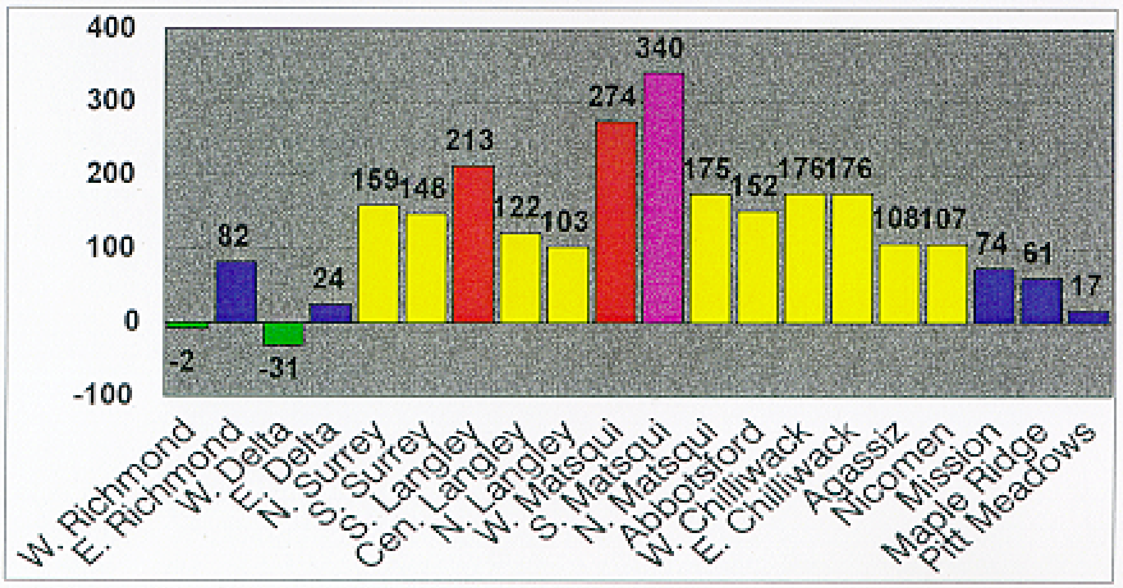
PREVIOUS
NEXT PAGE



Large Farms
Current Management

Potassium (kg/cropped ha)

- < 1
- 1 - 100
- 100 - 200
- 200 - 300
- 300 - 1000



PREVIOUS NEXT PAGE

SESSION 5

BIOLOGICAL INDICATORS

Identification of Sentinel Species, Distributions and Life-History Patterns

J. D. McPhail

Department of Zoology
University of British Columbia

FRAP Summary

This project examined the distribution and life-history patterns of fish in the upper Fraser system (Prince George area) with the aim of identifying potential sentinel species. The primary focal species was the mountain whitefish, *Prosopium williamsoni*, but information also was gathered on other native species. From May 15 - November 20, 1995, we examined habitat use, feeding, growth and movements in young-of-the-year (y-o-y), juvenile, and adult mountain whitefish in the mainstem Fraser and in six major tributaries: Chilako, Nechako, Salmon, McGregor, Bowron and Willow Rivers.

Young-of-the-Year

Newly emerged whitefish fry were present in the mainstem Fraser and all the major tributaries (except the McGregor) by mid-May. From emergence to a size of about 40 mm, whitefish fry were associated with low velocity, turbid sites, and typically occur over silt or sand substrates and at depths of <0.05 m. The condition of newly-emerged fry was good, except in the Bowron River where the weight of fry (for their length) was noticeably lower than at other sites. At all sites, whitefish fry feed primarily on benthic organisms, particularly chironomid larvae, while chinook fry took predominately surface prey (mostly winged insects and spiders). Growth in the y-o-y whitefish was rapid but differed among sites and ceased at different sizes in different tributaries in the fall. At about 40 mm, the y-o-y whitefish shifted to deeper water, but were still found predominately over sand or fine gravel substrates. They were still strongly associated with turbid water and chinook fry. In the late fall (November), they disappeared from areas where they were abundant and, perhaps, moved into deeper water.

Juveniles

In May and June, juvenile whitefish (mostly 1^+ but some 2^+) were not as abundant as newly-emerged fry and were found over cobble or coarse gravel substrates in higher water velocities and deeper water. They also occured in all the major tributaries and in the main river. At all these sites, the scales of 1^+ and 2^+ fish showed no evidence of winter growth. Juveniles continued to forage predominately on benthic organisms but also contained proportionately more mayflies and cased caddis flies than the y-o-y. Over the course of the summer, the growth performance of juveniles varied among tributaries with the maximum variation in growth rate in samples from the main river (e.g., fish 150 mm in fork length could be in either their second or third summer). In October, juveniles appeared to aggregate in the lower reaches of the tributaries, especially in pools immediately below step-off riffles.

Adults

During the summer, adults were found in both tributaries and the main river. Typically, adults were associated with areas where riffles break into pools, usually in water <1.5 m deep, over large to medium cobbles and strong current. In the main river the adults were associated with bars, especially those on the inside edges of bends. The adults continued to feed primarily on benthos, and at times appeared to concentrate on stoneflies. Growth rates in adults were not high and the largest individual taken was 306 mm (fork length) and in its 10th summer. Sexual maturity, at least in some males, was achieved at 2^+ and in females, a year later. Most adults were 2^+ and 3^+ and this suggested there may be high post-spawning mortality. Adults, tagged in tributaries in late August and early September, were recovered in October within 50 m of the original tag site. This suggested that they spawn in the tributaries; however, aggregations of adults were detected in the lower Nechako and Willow rivers in mid-October. Many of these fish were close to spawning. Five such fish were radio-tagged in the lower Nechako and eight fish near spawning (males running milt) were radio-tagged in the mainstem Fraser. These radio-tagged fish were followed until freeze-up (late November). Two of the Nechako fish made micro-movements (a few 100 m) but stayed in the aggregation area. Three Nechako fish moved downstream in the Fraser where they stayed for several days and then moved downstream in fits and starts (e.g., they would hold position for a few days and then suddenly move 15 km, stop and hold position again, and then suddenly make another spurt of movement). The maximum tracked downstream movement of these Nechako fish was 50 km. The radio-tagged Fraser fish showed a similar pattern of movement: hold for a few days, then move 10 - 20 km downstream and hold again. All of the radio-tagged fish that moved, moved downstream. It is not clear if this was a spawning migration or if the tags were too large and the fish were slowly losing ground.

For adults, it was not clear how much mixing there was between the major tributaries and the main river. There was a scale signature (a false annulus) that was only found in mainstem fish. However, not all fish sampled in the mainstem showed this scale mark. So far, the data suggest some fish move from the tributaries into the main river and some stay in the tributaries. We took tissue samples (adipose fin clips) from all adult fish and are using single locus probes to ascertain if there are genetically different stocks in this area.

Another problem with adults that is being examined is the presence of two “forms” of mountain whitefish in the area: a long-nosed “pinocchio” form and a normal form. The pattern of head growth in the two forms starts to diverge at about 80 mm and becomes more exaggerated with size. It looks like a foraging polymorphism and we collected paired samples (collected at the same site and same time) of both types. These are being examined for both trophic and genetic differences.

Other Species

During the course of collecting whitefish data, information was also collected on the movements of redside shiners, squawfish, peamouth chub and suckers. The general pattern of movement that appeared in these animals was a spawning movement into tributaries in the spring, use of the lower reaches of tributaries by y-o-y, movement into the main river in September, and then movement to a winter refuge (deeper water?) in October.

Fraser Fish Database

Goal

Assemble information on distribution (past and present), macro-habitat use, and life-histories of Fraser River fish.

Information Sources

- UBC collection, Ministry of Environment, Lands and Parks fish database

Operating Modes

1. **Access** - for quick queries
   - Access mode - typical Access queries (e.g., species by tributary, species by macro-habitat, and co-occurences)
   - Advantages: will plot large-scale distribution maps fast
2. **Arcview -** for more detail
   - Arcview mode - slow, but can zoom down to 100 m reaches (if the data exists)

Beta Version

On-line in about three months

Whitefish Life-Histories

Habitat Use

Y-O-Y
Juveniles and Adults

Food

Y-O-Y
Juveniles and Adults

Growth

Y-O-Y
Juveniles and Adults

Movements

Y-O-Y
Juveniles and Adults

Stock Structure

Genetics
Morphology

Other Species

Table 1: Habitat of young-of-the-year mountain whitefish in the upper Fraser region

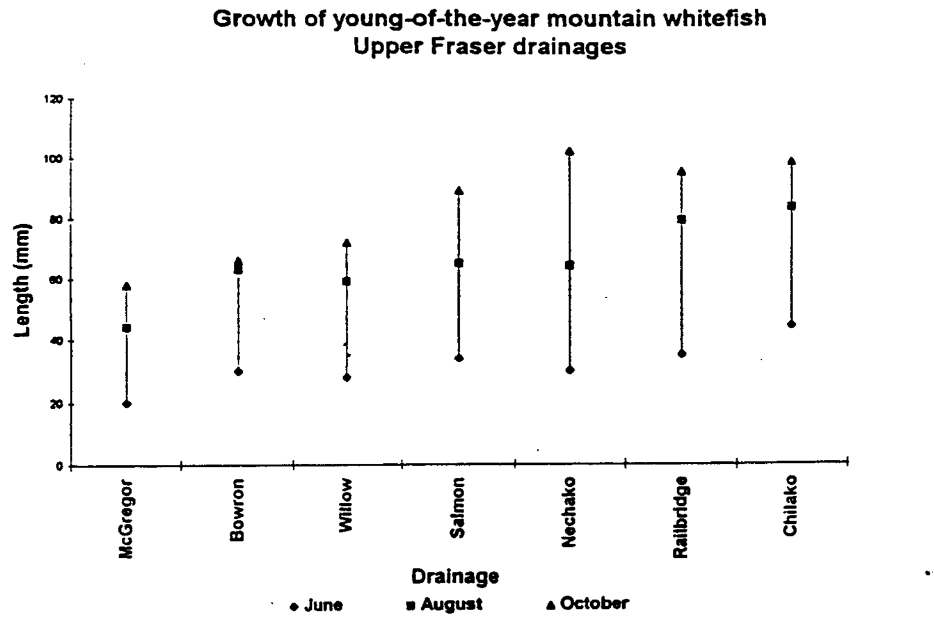
DRAINAGE	Turbid/ Clear	Cobble/ Fast	Gravel/ Moderate	Silt/ Slow
Avrial Cr.	C	-	-	-
Bowron river	T	-	+	+
Chilako river	T	-	-	+
Fraser Mainstem	T	-	-	+
George Cr.	C	-	-	-
Herring Cr.	C	-	-	-
McGregor river	T	-	-	+
Nechako river	T	-	-	+
Olssen Cr.	T	-	+	+
Pitoney Cr.	C	-	-	-
Red Rock Cr.	T	-	-	-
Salmon river	T	-	-	+
Seeback Cr.	T	-	-	+
Stone Cr.	T	-	-	-
Thursday Cr.	C	-	-	-
Wansa Cr.	C	-	-	-
Willow river	T	-	+	+
Wright Cr.	C	-	-	-

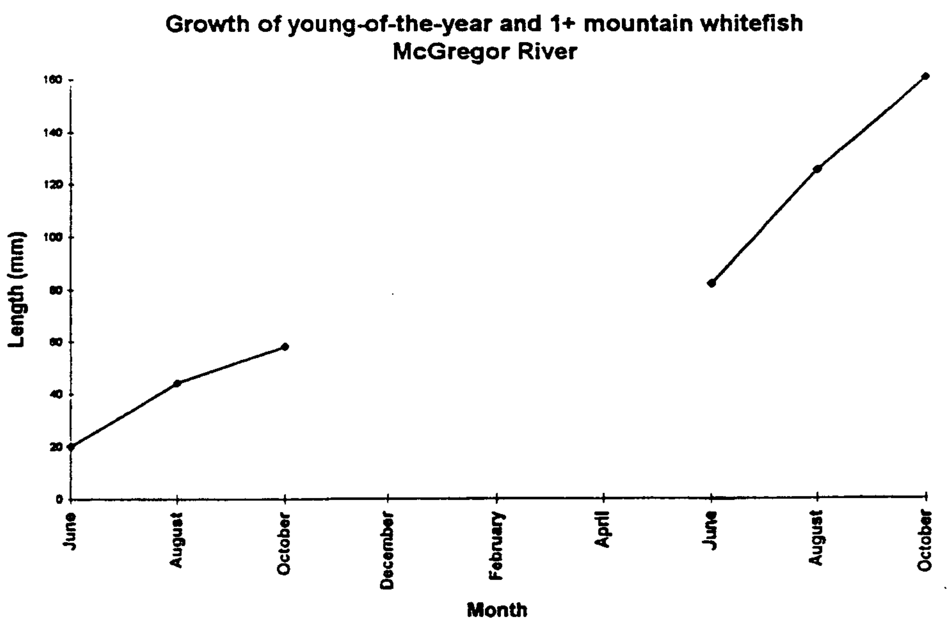
Table 2: Habitat of Juvenile and Adult Mountain whitefish in the upper Fraser region

DRAINAGE	Turbid/ Clear	Cobble/ Fast	Gravel/ Moderate	Silt/ Slow
Avrial Cr.	C	-	-	-
Bowron river	T	-	+	-
Chilako river	T	-	+	+
Fraser Mainstem	T	+	+	-
George Cr.	C	-	-	-
Herring Cr.	C	-	-	-
McGregor river	T	+	+	-
Nechako river	T	+	-	-
Olssen Cr.	T	-	-	-
Pitoney Cr.	C	-	-	-
Red Rock Cr.	T	-	-	-
Salmon river	T	+	+	-
Seeback Cr.	T	-	-	-
Stone Cr.	T	-	-	-
Thursday Cr.	C	-	-	-
Wansa Cr.	C	-	-	-
Willow river	T	+	+	-
Wright Cr.	C	-	-	-

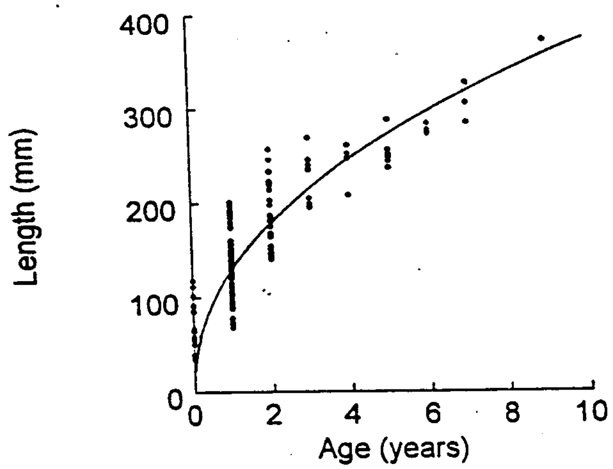
STOMACH CONTENTS
(BY NUMBER OF PREY ITEMS)

	BENTHIC	SURFACE
YOUNG-OF-THE YEAR	0.96	0.02
(Whitefish)	0.91-1.0	0.0-0.09
YOUNG-OF-THE YEAR	0.06	0.94
(Chinook)	0.03-0.10	0.90-1.0
ADULTS	0.98	0.02
(Whitefish)	0.90-1.0	0.0-0.06

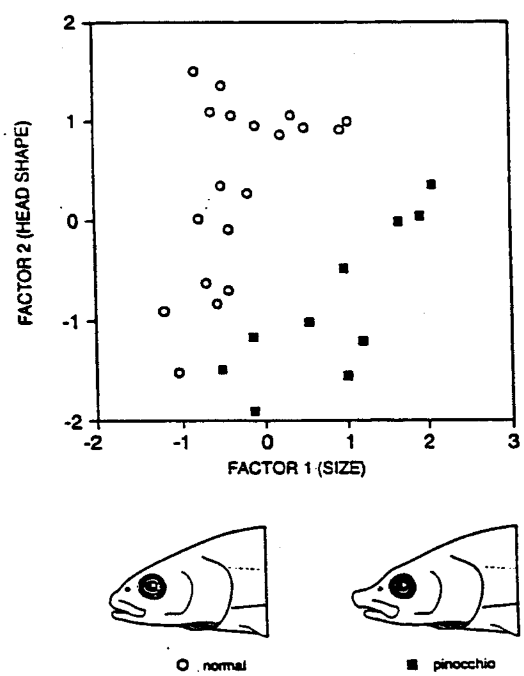

Growth of young-of-the-year mountain whitefish
Upper Fraser drainages
Length (mm)
120
100
80
60
40
20
0
McGregor
Bowron
Willow
Salmon
Nechako
Railbridge
Chilako
Drainage
June
August
October


Growth of young-of-the-year and 1+ mountain whitefish
McGregor River
Length (mm)
160
140
120
100
80
60
40
20
0
June
August
October
December
February
April
June
August
October
Month

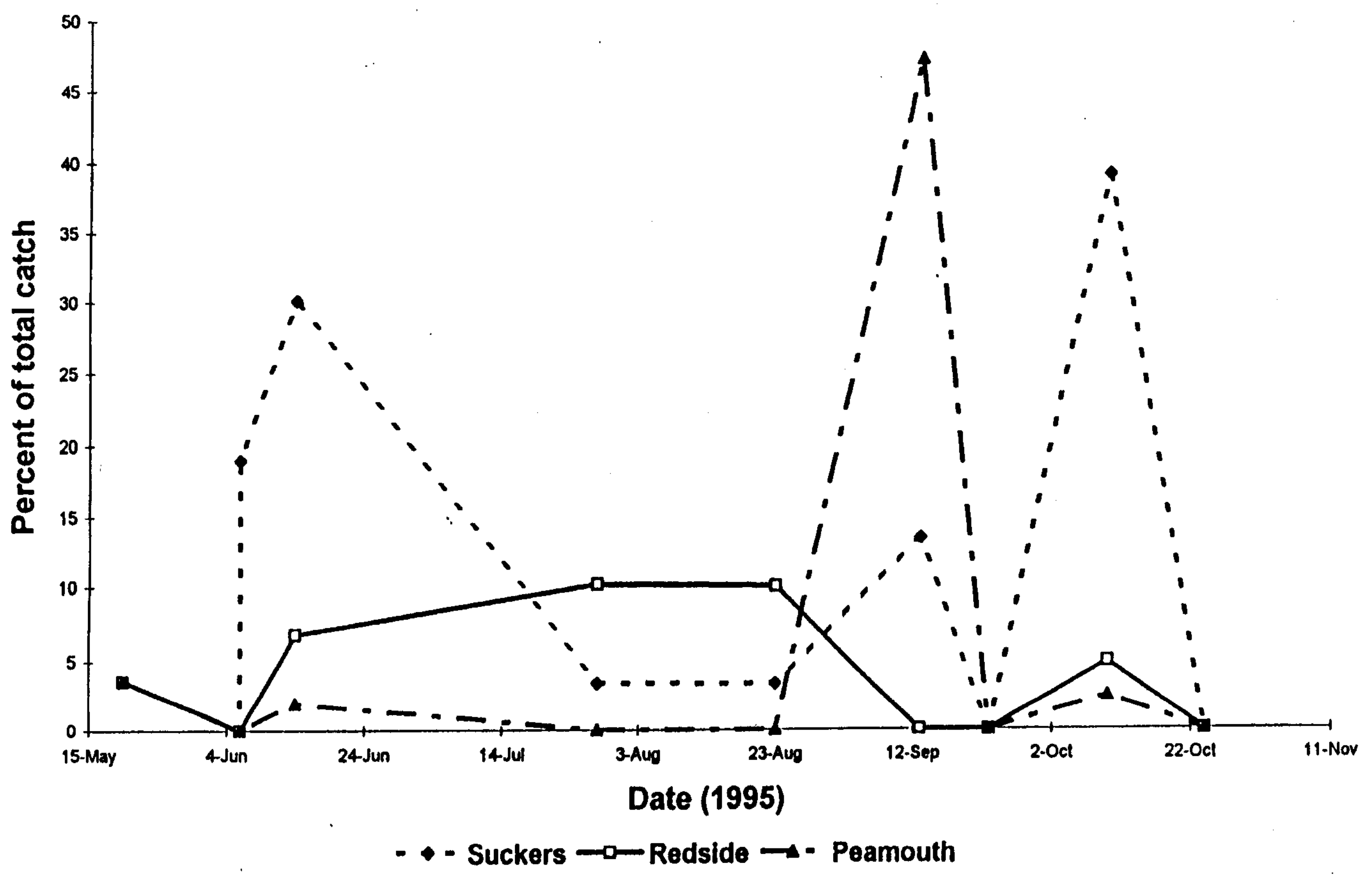
Age/Length relationship for upper Fraser mountain whitefish



PRINCIPAL COMPONENTS ANALYSIS *Prosopium* HEAD SHAPE



Proportional catch of suckers, redside shiners, and peamouth chub
Fraser River (railbridge site)



Resident Fish Condition and Contaminants Assessment

B.A. Raymond and D.P. Shaw

Environment Canada

Summary

The Fraser River Action Plan is assessing the condition of resident fish in the Fraser basin, based on health and contaminant levels of mountain whitefish and peamouth chub. The health of resident fish populations is important as an indicator of ecosystem health, and as a factor that can affect human health. Resident fish spend their entire lifespan in the river and reflect more local conditions than migrants such as salmon.

Mountain whitefish were selected for this study because previous studies indicated that they accumulate contaminants to higher levels than other species sampled, and research is being conducted on their life history in the upper Fraser River. Peamouth chub are widely distributed and abundant in the Fraser River, are the target of fish condition research in the upper Fraser River, and have been used in the Environmental Effects Monitoring Program for pulp and paper mills on the Fraser River.

Mountain whitefish and peamouth chub were collected by beach seining between July and November, 1994, from eleven reaches (Figure 1). All fish were examined in the field for external and internal abnormalities and tissue samples were collected for histological assessment. The health assessment index (HAI) of Goede and Barton (1990) [1] was incorporated because it is being widely applied in environmental studies. This study was an opportunity to link the HAI to other variables, such as contaminant levels and histology.

Preliminary results for the HAI indicated that:

- A high incidence of HAI abnormalities occurred in peamouth chub and mountain whitefish;
- HAIs were significantly different among reaches;
- HAIs were not correlated with histological abnormalities (i.e., HAI abnormalities may not be signs of "disease");
- HAIs appeared to be unaffected by age (fish ages were significantly different among reaches);
- HAI was highest in the Nechako where contaminant and MFO levels were low; and,
- Factors other than contaminant exposure appeared to account for variability in the HAI.

HAI information gaps included:

- Cause-effect studies to determine causes of variability in the HAI and allowed application of this technique to environmental management;
- Assessment of user variability (planned for 1996-7); and,
- Assessment of histological data quality (underway).

Analyses for contaminant exposure included MFO activity in liver; trace metals, PCBs, organochlorine pesticides, chlorophenolics, dioxins and furans in muscle and liver; and PAH metabolites, chlorophenolics and resin acids in bile.

Preliminary results for the contaminants indicated that:

- Contaminant levels in fish varied among reaches and species;
- Contaminant levels were generally low, near or below detection limits and guidelines (where guidelines exist);
- TCDD and TCDF levels were highest in the Thompson system;

- Total PCB levels were highest in lower Fraser Valley;
- Total chlorophenolics levels were highest at Marguerite, downstream of Quesnel; and,
- The PAH metabolite pattern varied between the two species; levels were high at Marguerite.

A more thorough review and analysis of the data must be conducted before conclusions can be presented.

Contaminants information gaps included:

- Additional contaminants we should be measuring (e.g., non-ionic surfactants);
- Sources of contaminants;
- Non-toxic levels in fish (i.e., guidelines); and,
- Migratory patterns and life histories of fish.

[1] *Goede, R.W., and B.A. Barton. 1990. Organismic indices and an autopsy-based assessment as indicators of health and condition of fish. Am. Fish. Soc. Symp. 8:93-108.*

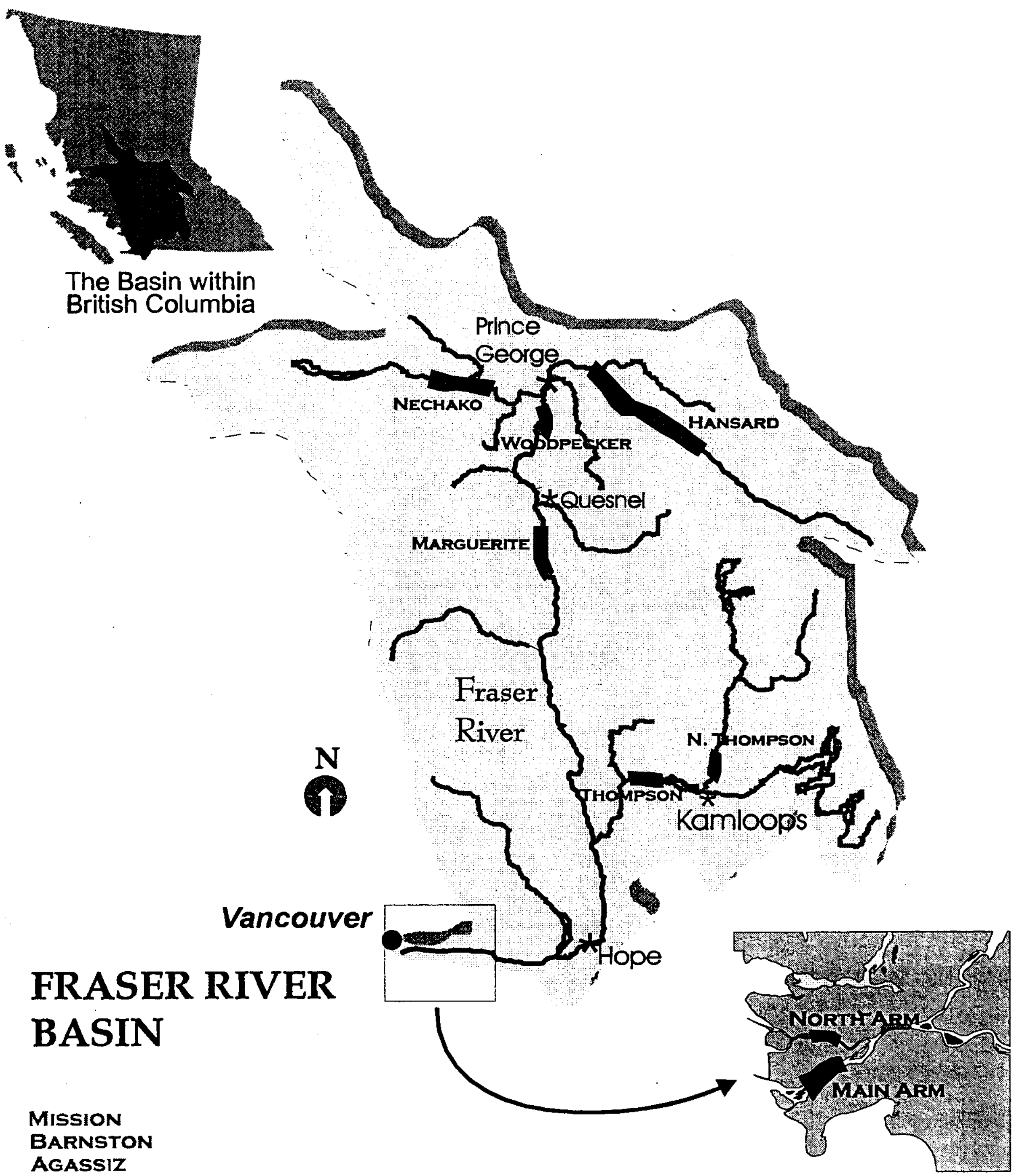
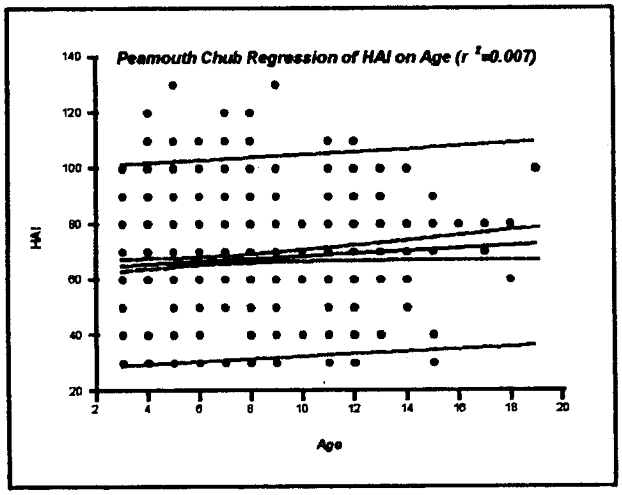
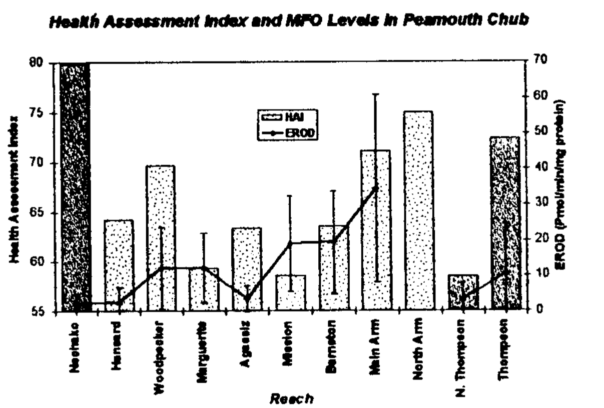


Figure 1. Fraser River Basin showing locations of fish sampling reaches.

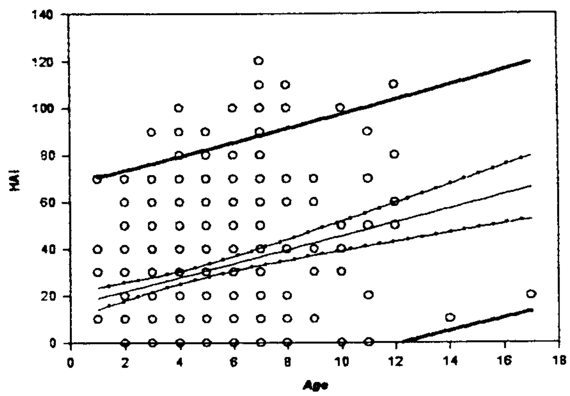


• HAI is independent of age within the size categories sampled



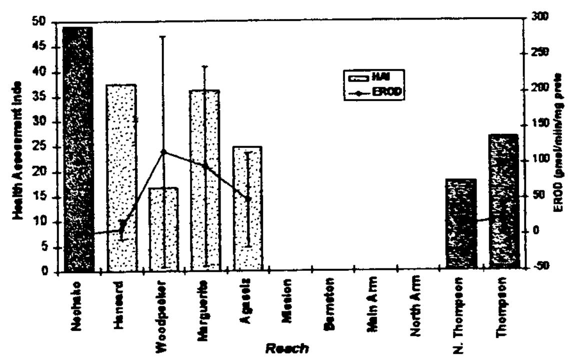
• HAIs appear to be correlated with MFO levels, except in the Nechako and at Agassiz

Mountain Whitefish Regression of HAI on Age (r^2=0.08)

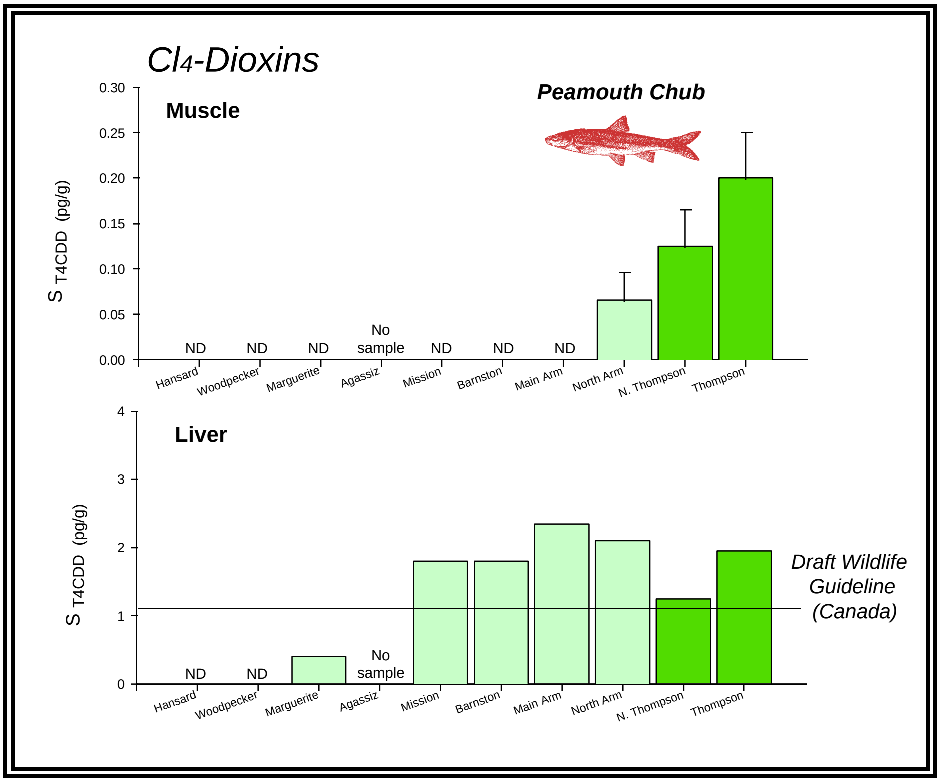


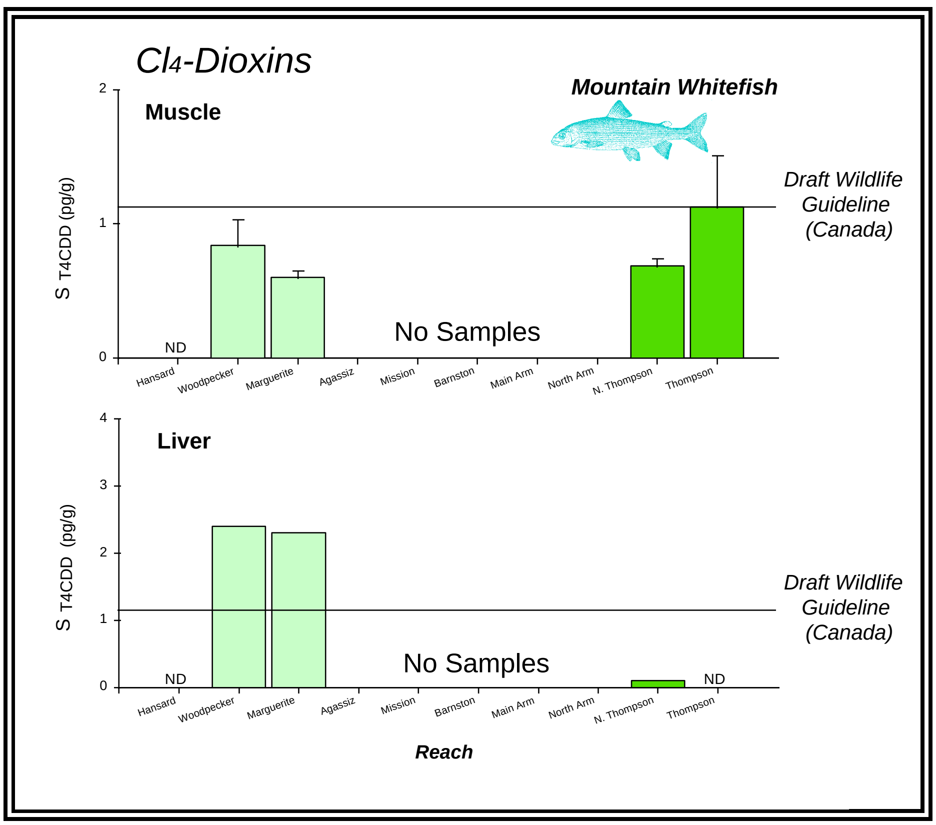
•Age varied among reaches (Kruskal-Wallis ANOVA on ranks, p<0.001)
•HAI is independent of age within the size categories sampled

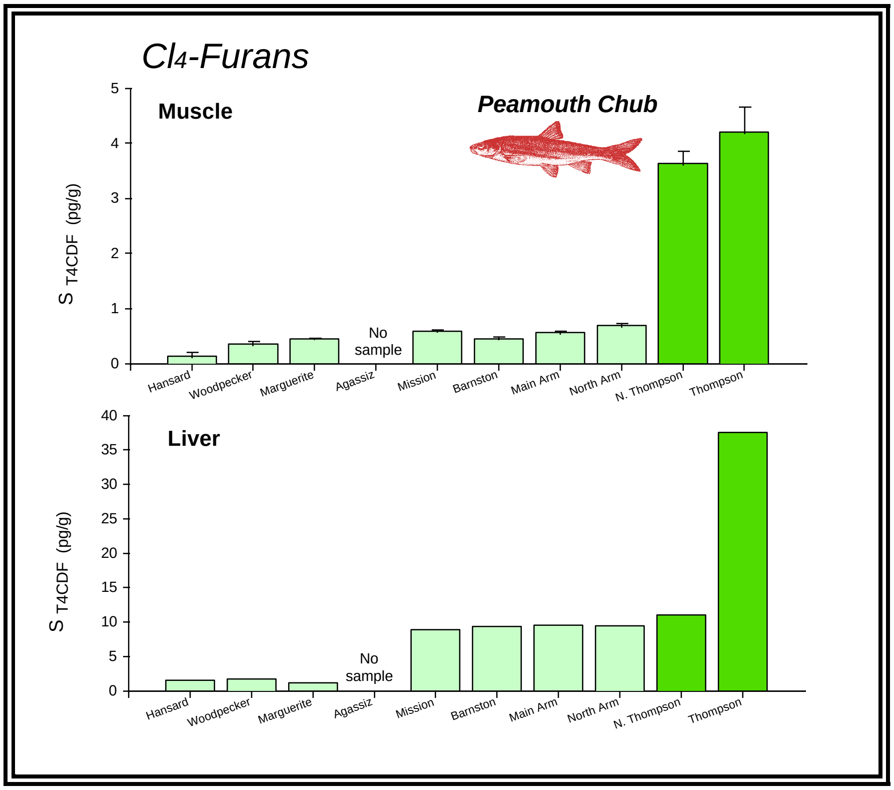
Health Assessment Index and MFO Levels in Mountain Whitefish

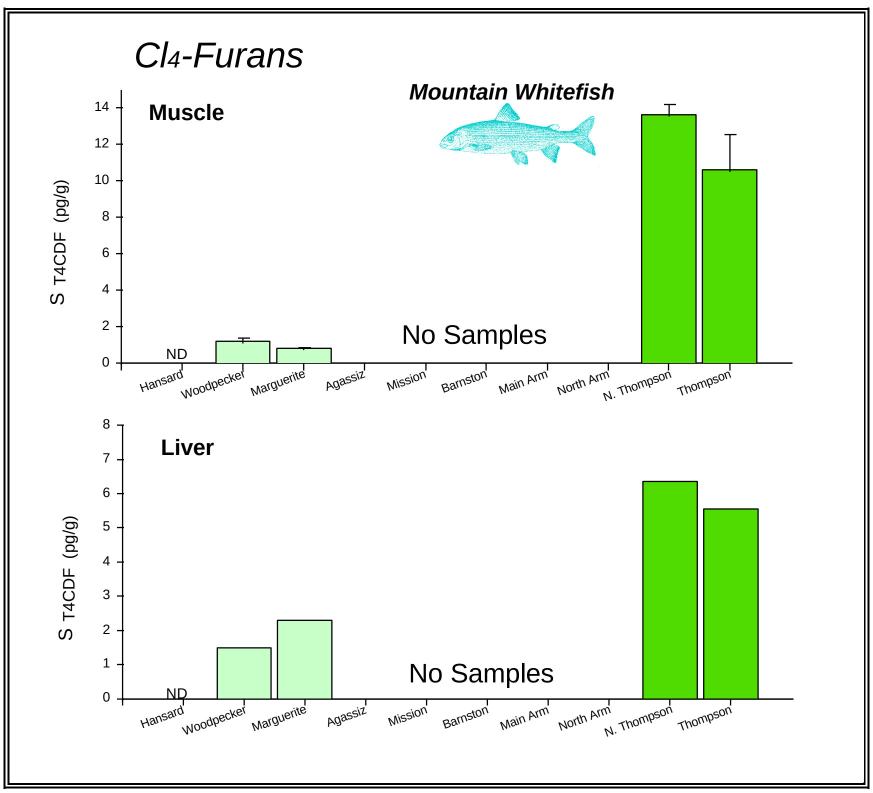


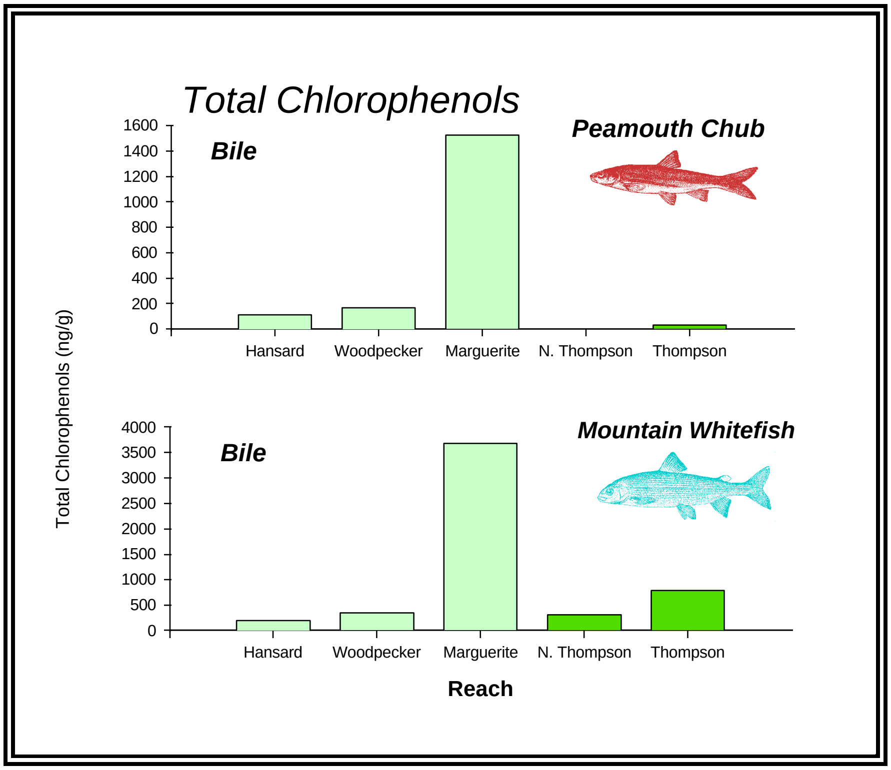
•HAIs appear to be uncorrelated with MFO levels, except in the Thompson system

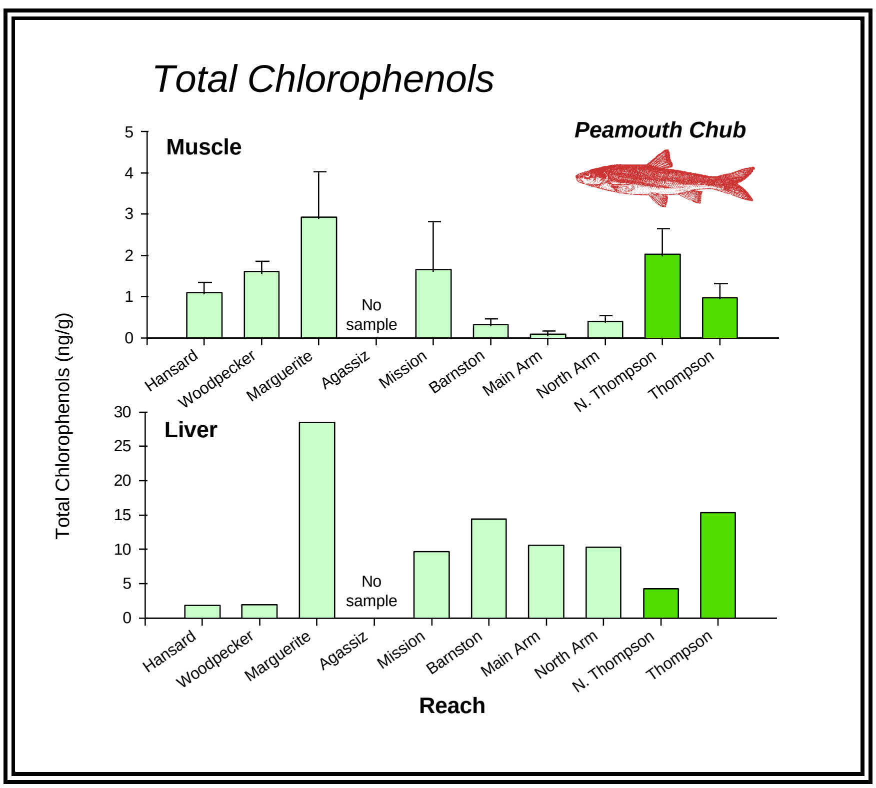

Cl4-Dioxins
Peamouth Chub
Muscle
S T4CDD (pg/g)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
ND
ND
ND
No sample
ND
ND
ND
Hansard
Woodpecker
Marguerite
Agassiz
Mission
Barnston
Main Arm
North Arm
N. Thompson
Thompson
Liver
S T4CDD (pg/g)
4
3
2
1
0
ND
ND
No sample
Draft Wildlife Guideline (Canada)
Hansard
Woodpecker
Marguerite
Agassiz
Mission
Barnston
Main Arm
North Arm
N. Thompson
Thompson

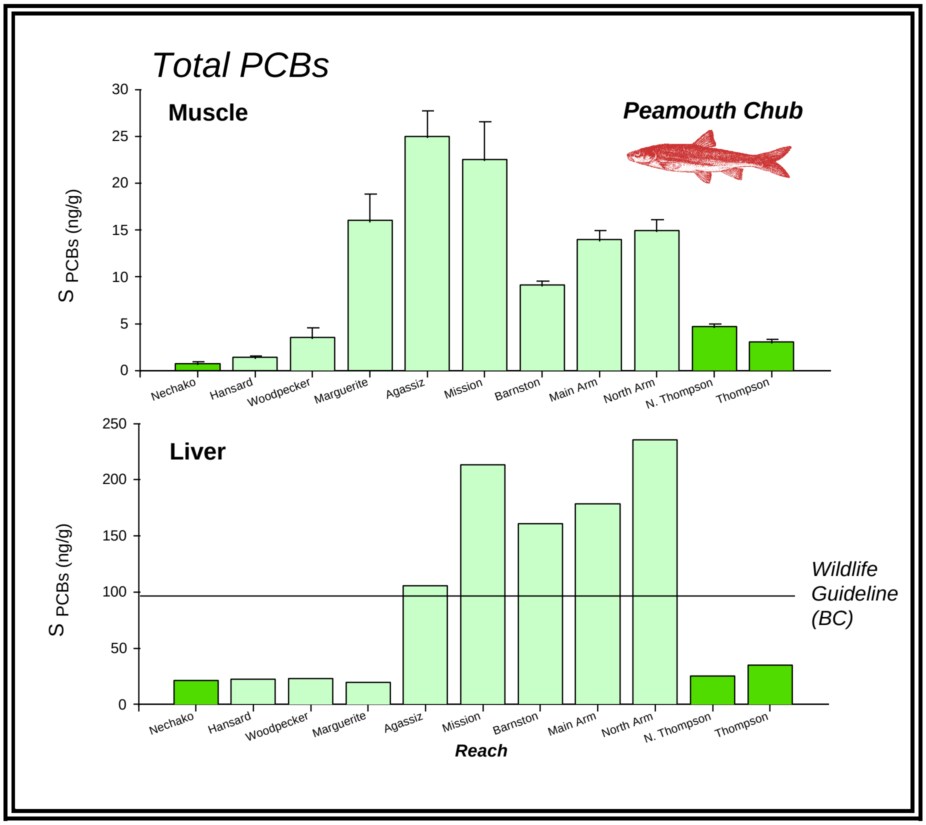

Cl4-Dioxins
Mountain Whitefish
Muscle
S T4CDD (pg/g)
2
1
0
ND
No Samples
Draft Wildlife Guideline (Canada)
Hansard
Woodpecker
Marguerite
Agassiz
Mission
Barnston
Main Arm
North Arm
N. Thompson
Thompson
Liver
S T4CDD (pg/g)
4
3
2
1
0
ND
No Samples
ND
Draft Wildlife Guideline (Canada)
Hansard
Woodpecker
Marguerite
Agassiz
Mission
Barnston
Main Arm
North Arm
N. Thompson
Thompson
Reach

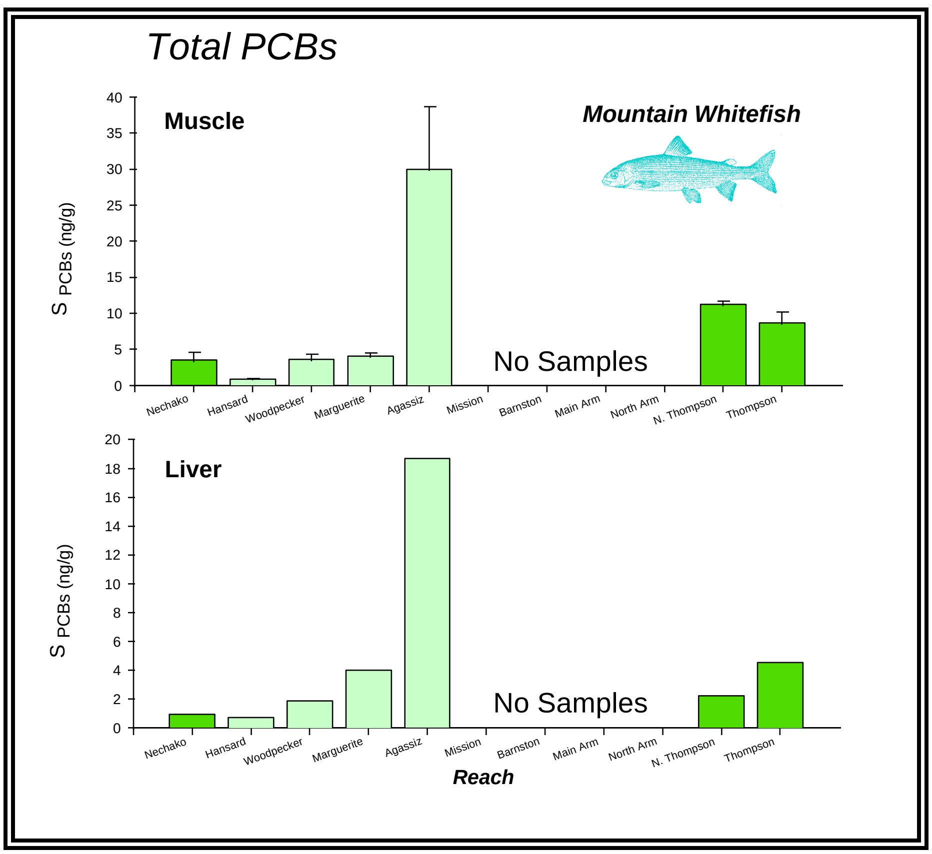

Cl4-Furans
Muscle
Peamouth Chub
S T4CDF (pg/g)
No sample
Liver
No sample
Hansard
Woodpecker
Marguerite
Agassiz
Mission
Barnston
Main Arm
North Arm
N. Thompson
Thompson

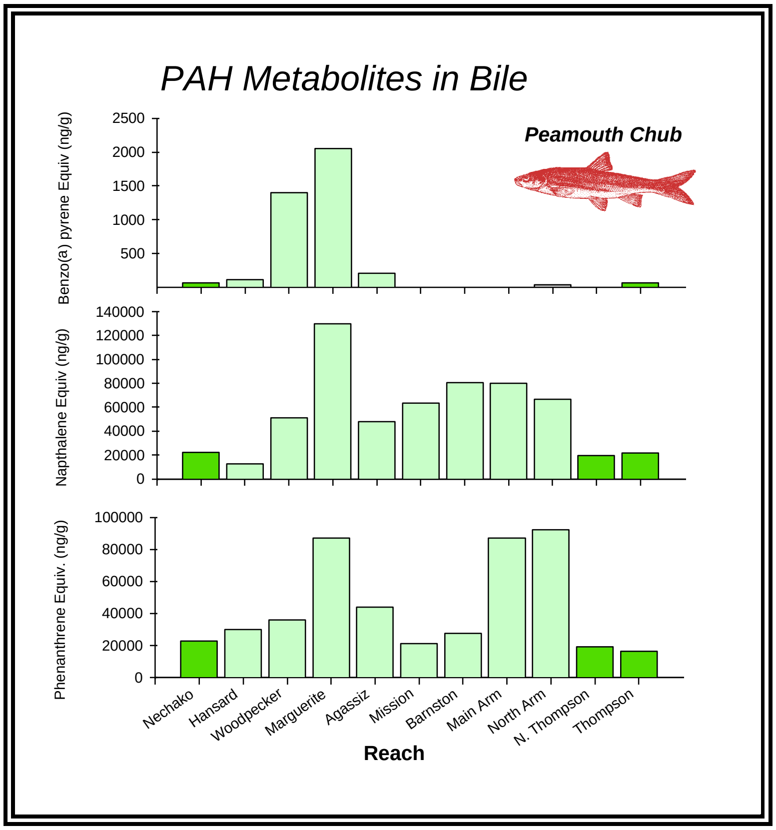

Cl4-Furans
Muscle
Mountain Whitefish
S T4CDF (pg/g)
ND
No Samples
Liver
ND
No Samples
Hansard
Woodpecker
Marguerite
Agassiz
Mission
Barnston
Main Arm
North Arm
N. Thompson
Thompson

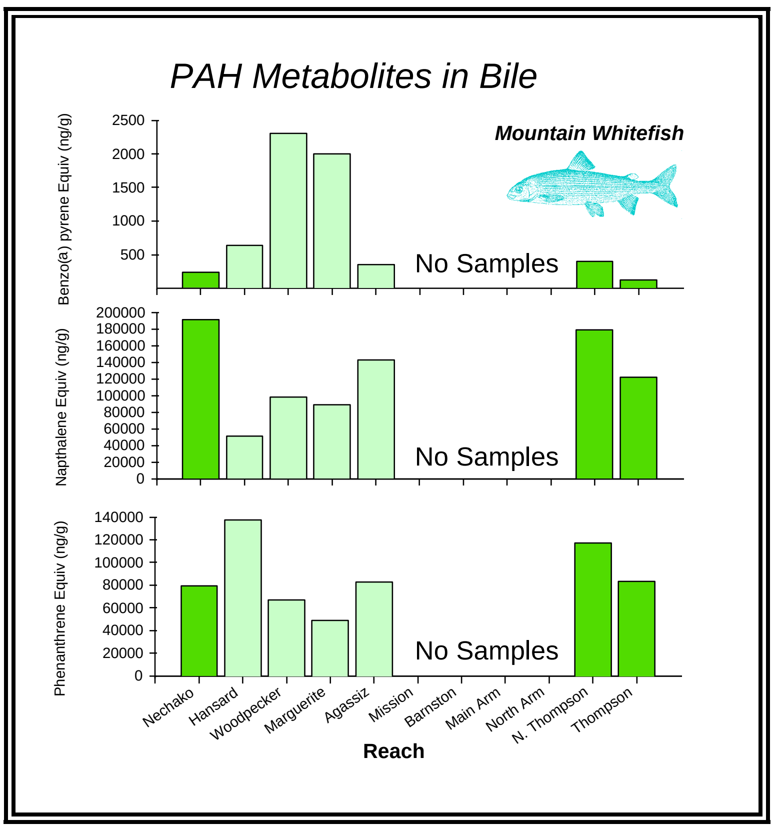

Total Chlorophenols
Bile
Peamouth Chub
1600
1400
1200
1000
800
600
400
200
0
Hansard
Woodpecker
Marguerite
N. Thompson
Thompson
Total Chlorophenols (ng/g)
4000
3500
3000
2500
2000
1500
1000
500
0
Bile
Mountain Whitefish
Hansard
Woodpecker
Marguerite
N. Thompson
Thompson
Reach

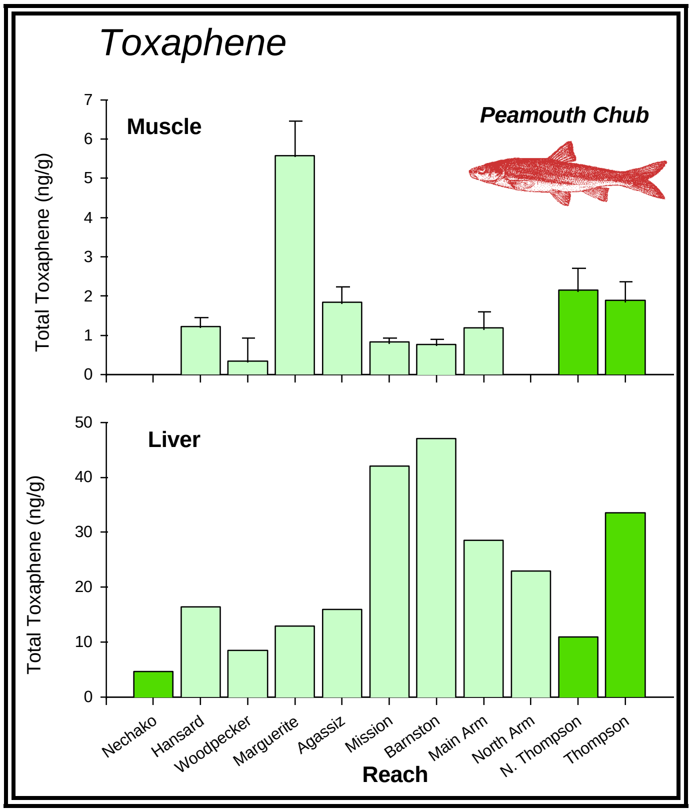

Total Chlorophenols
Muscle
Peamouth Chub
5
4
3
2
1
0
No sample
Hansard
Woodpecker
Marguerite
Agassiz
Mission
Barnston
Main Arm
North Arm
N. Thompson
Thompson
Total Chlorophenols (ng/g)
Liver
30
25
20
15
10
5
0
No sample
Hansard
Woodpecker
Marguerite
Agassiz
Mission
Barnston
Main Arm
North Arm
N. Thompson
Thompson
Reach

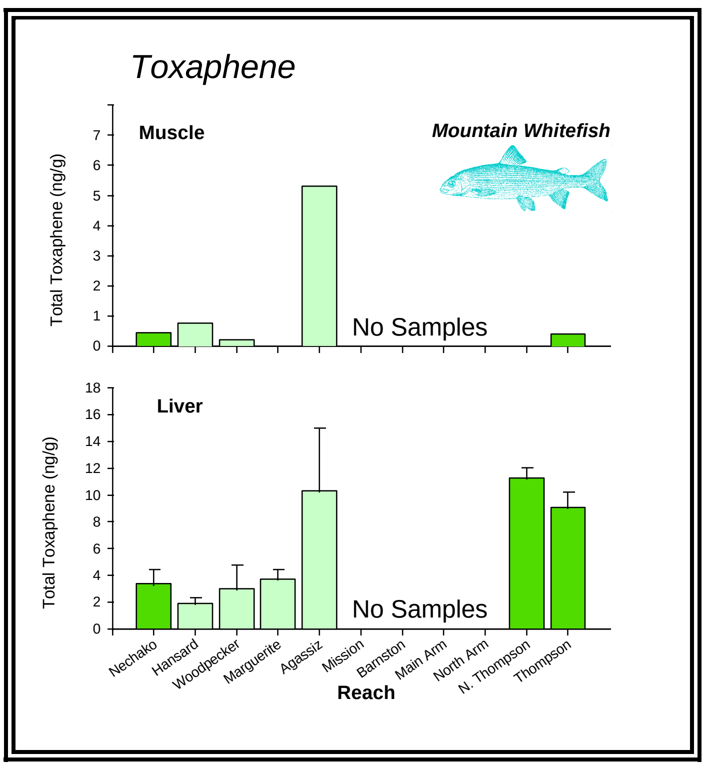

Total PCBs
Muscle
Peamouth Chub
S PCBs (ng/g)
0
5
10
15
20
25
30
Nechako
Hansard
Woodpecker
Marguerite
Agassiz
Mission
Barnston
Main Arm
North Arm
N. Thompson
Thompson
Liver
0
50
100
150
200
250
Wildlife Guideline (BC)
Reach


Total PCBs
Muscle
Mountain Whitefish
S PCBs (ng/g)
0
5
10
15
20
25
30
35
40
No Samples
Nechako
Hansard
Woodpecker
Marguerite
Agassiz
Mission
Barnston
Main Arm
North Arm
N. Thompson
Thompson
Liver
0
2
4
6
8
10
12
14
16
18
20
No Samples
Reach


PAH Metabolites in Bile
Peamouth Chub
Benzo(a) pyrene Equiv (ng/g)
2500
2000
1500
1000
500
Napthalene Equiv (ng/g)
140000
120000
100000
80000
60000
40000
20000
0
Phenanthrene Equiv. (ng/g)
100000
80000
60000
40000
20000
0
Nechako
Hansard
Woodpecker
Marguerite
Agassiz
Mission
Barnston
Main Arm
North Arm
N. Thompson
Thompson
Reach


PAH Metabolites in Bile
Mountain Whitefish
Benzo(a) pyrene Equiv (ng/g)
2500
2000
1500
1000
500
No Samples
Napthalene Equiv (ng/g)
200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
No Samples
Phenanthrene Equiv (ng/g)
140000
120000
100000
80000
60000
40000
20000
0
No Samples
Nechako
Hansard
Woodpecker
Marguerite
Agassiz
Mission
Barnston
Main Arm
North Arm
N. Thompson
Thompson
Reach


Toxaphene
Muscle
Peamouth Chub
Total Toxaphene (ng/g)
Liver
Total Toxaphene (ng/g)
Nechako
Hansard
Woodpecker
Marguerite
Agassiz
Mission
Barnston
Main Arm
North Arm
N. Thompson
Thompson
Reach


Toxaphene
Muscle
Mountain Whitefish
Total Toxaphene (ng/g)
No Samples
Liver
Total Toxaphene (ng/g)
No Samples
Nechako
Hansard
Woodpecker
Marguerite
Agassiz
Mission
Barnston
Main Arm
North Arm
N. Thompson
Thompson
Reach

Survey of Toxaphene in Burbot from Four Fraser Basin Lakes

C. Gray

Environment Canada

This survey was initiated after elevated levels of toxaphene were reported in fish sampled from selected lakes in the southern Yukon and the Banff/Jasper region. Because the source of toxaphene, in most cases, was long-range atmospheric transport, it seemed logical that similar levels of toxaphene would be found in fish from the Fraser basin. As the Yukon-based study found highest levels in burbot liver tissue, this species was chosen for the survey. In spring of 1995, five adult burbot were collected from Moose, Stuart, Kamloops and Nicola lakes. These fish were shipped frozen to the lab for determination of sex, age and the presence of tumors before removing the liver for analyses of PCBs, organochlorine pesticides and toxaphene. Only a preliminary evaluation of the toxaphene data will be available for this workshop.

Toxaphene analyses were reported in three ways:

1. total toxaphene;
2. total Hexa-, Hepta-, Octa-, Nona-, & Deca- chlorinated homologues; and,
3. individual “Parlar” Chorobornanes.

Average total toxaphene in male burbot varied by an order of magnitude:

- 16 ng/g in Nicola;
- 123 ng/g in Stuart;
- 139 ng/g in Kamloops; and,
- 610 ng/g in Moose.

The most commonly detected and abundant Chlorobornane was “P4” (2-exo,3-endo,5-exo,6-endo,8,8,9,10,10-Nonachlorobornane). The Hepta- and Nona- chlorinated homologues were the most commonly detected homologues.

The total toxaphene levels in burbot from Stuart, Kamloops and Nicola lakes were similar to the Yukon lakes, which displayed low biomagnification of toxaphene by fish such as burbot. The levels of toxaphene in Moose Lake. was about half that measured in Lake Laberge, which displayed a high biomagnification because its food chain length is longer than the other Yukon lakes in the study. Measuring stable nitrogen isotope ratios in our burbot samples to determine food chain position is required before the relatively high levels in Moose Lake burbot can be attributed to a long food chain or to a local source of toxaphene.

Fraser Basin Burbot Samples (Spring 1995)

Lake	Length (cm)	Weight (kg)	Sex	Age (yrs)
Moose	53 ± 7	0.9 ± 0.4	4M:1F	
Stuart	79 ± 12	3.0 ± 0.7	4M:1F	
Kamloops	54 ± 7	1.2 ± 0.3	4M:1F	
Nicola	52 ± 4	0.9 ± 0.2	4M:1F	

Burbot Liver Toxaphene Mean for 4 Male Fish

Lake	Tot. Toxaphene (ng/g)	Chlorobornane "P4" (ng/g)
Moose	610 ± 125	115 ± 17
Stuart	123 ± 55	33 ± 16
Kamloops	139 ± 50	32 ± 5
Nicola	16 ± 17	3 ± 2

Development of a Biomonitoring Programme for the Fraser River Catchment Basin using Reference Condition

T.B. Reynoldson[1], K.E. Day[1] and D.M. Rosenberg[2]

[1]*National Water Research Institute*

[2]*Freshwater Institute*

Presentation Slides by S. Kirby

The assessment of the ecological risk (ERA) of various impacts to watersheds from anthropogenic activities often involves the comparison of biological communities at sites with suspected disturbance to sites in so-called pristine reference areas. In riverine environments, this usually includes a comparison of communities located upstream from point-source pollutants to communities located downstream from the source(s) of disturbance. Many of these comparisons use methods which are traditional to freshwater biological studies (i.e., biotic indices and univariate statistics with relatively few control sites) which may be located either within the same body of water or, more rarely, in differing bodies of water.

There are a number of problems with these traditional approaches which have received discussion in recent years, including:

- difficulties in finding unimpacted sites and in matching habitats of ‘clean’ sites with contaminated sites;
- problems in the interpretation of the inherent natural variability in species composition;
- abundances at sites with differing environmental characteristics; and,
- interpretation of the ‘ecological relevance’ of the results.

The definition of a ‘reference site’ has changed in the past few years (Davis and Simon, 1995) and it is now accepted that there are no ‘pristine’ sites in most areas near anthropogenic activities. However, candidate reference sites should represent ‘least disturbed’ conditions, as well as cover the range of ‘best attainable conditions’ given the current use patterns for any stressors in any given region.

In recent years, there have been a number of studies which have expanded the concept of a few reference sites to ‘sets of reference sites’ located either regionally or grouped by similarities in characteristics such as the structure of the floral and faunal communities or by chemical and physiographic variables. This grouping of reference sites has been termed the ‘reference condition’ (Wright *et al.*, 1988; Johnson and Wiederholm, 1989; Corkum, 1989; Norris and George, 1993; Reynoldson *et al.*, 1995; Hughes, 1995; Rosenberg *et al.*, 1995). The reference condition approach tried to find common patterns in the structure of biological communities at ‘least impacted sites’ using multivariate classification techniques and then determine the environmental variables which constitute these community structures. The result of the multivariate analysis is the formation of a number of groups of community types which form the ‘reference’ condition. The environmental variables which drive these groupings are then used in a predictive model to determine the structure of the biological community at test or impacted sites (i.e., the model predicts what communities should be present at a site if the site was undisturbed). The actual community at a test site can then be compared to the reference community group for similarities in structure. This provides a method to separate ecological variability from true stress-related changes.

We are currently using this multivariate statistical approach at a large number of ‘reference’ sites in the Fraser River watershed and are in the process of developing a predictive model for erosional zones in first to ninth order streams. This approach involves an extensive sampling regime over a three-year period for such ‘least impacted’ sites and has the following objectives:

- To classify least-impacted, reference stream and river sites (approximately 250) in the Fraser River watershed based on benthic macroinvertebrate and attached algal communities;
- To determine whether the type of biological community at unstressed sites can be predicted using simple physical and chemical environmental variables measured in the streams and rivers;
- To develop a model which allows predictions of biological communities at potentially contaminated sites based on these measured environmental variables and comparisons of predicted communities to 'reference' communities; and,
- To incorporate the information developed in the predictive model into a software program for use by managers in making environmental decisions regarding disturbed sites in the Fraser River watershed and the adequacy of current or proposed regulatory approaches.

Site Selection

The multivariate method used in this study required approximately 250 reference sites to establish the reference condition. The sites chosen were distributed among as many different ecoregions and stream orders as possible and obtained the broadest possible set of reference conditions. A series of workshops with provincial experts served to identify non-, moderately and heavily impacted subcatchments and to choose reference sites with minimal impact. The high number of reference sites required a sampling program staged over three years. In October, 1994, 50 sites were sampled in the Stuart, Chilcotin, Clearwater, Pitt, Salmon and Fraser rivers. Of these 50 sites, 14 were considered impacted by logging, agriculture or pulp and paper mills and served as test sites. Over 100 sites were sampled in September, 1995 from the Fraser, Herrick, Stein, Nicola and Chelaslie rivers. The final year of sampling will include the Fraser, Torpy, Bowron, West Road, Eucheniko, Tyaughton and Chehalis rivers and will take place in September, 1996. Ten percent of the sites were repeated in each of the study years to address annual variability, and an additional four to six sites were sampled seasonally to examine seasonal variation.

Samples Collected

1. The collection of benthic invertebrates was the focus of the Fraser River biomonitoring program. After a preliminary study to determine which methods were logically feasible and robust among operators, the following methods were adopted:
   - a kick net was utilized for semi-quantitative sampling of erosional zones;
   - five replicates were collected at each site in 1994; one replicate in 1995;
   - kick-time was standardized for three minutes; and,
   - mesh-size of the kick net was optimized at 400 µm.
2. A sub-component of the study included the collection and analysis of attached algal communities by taxonomic identification of periphyton samples. In addition, subsamples for chlorophyl A and carbon measurements were determined.
3. A set of common physical and chemical variables was measured at each site based on previous studies examining the relationship between environmental characteristics and benthic macroinvertebrate community structure in lotic ecosystems as follows:

Map	Site/Reach	Channel	Water
- Ecoregion - Latitude - Longitude - Altitude - Stream Order - Upstream Drainage Area	- Date of Sampling - Flow State - Canopy Coverage - Macrophyte Coverage - Riparian Vegetation - Extent of Logging in Riparian Zone	- Flow State - Bankfull Width - Wetted Width - Mean Depth - Maximum Depth - Discharge - Substrate Score - Substrate Composition - Periphyton CHL & Suspended C	-pH - Dissolved Oxygen - Conductivity - Temperature - Total P - Nitrate - Alkalinity - Major Ions - Total Suspended Solids

Preliminary Results

Data have been analyzed for the macroinvertebrate and periphyton communities present at the fifty sites sampled in October, 1994. Sorting and identification of macroinvertebrates and taxonomic determination of the attached algal communities from the 100 sites sampled in October, 1995, are currently underway.

Clustering and ordination of the macroinvertebrates found in the first year of sampling formed four distinct reference community types (Figures 1 and 2). The abundance of several families differed significantly, especially chironomids and mayflies.

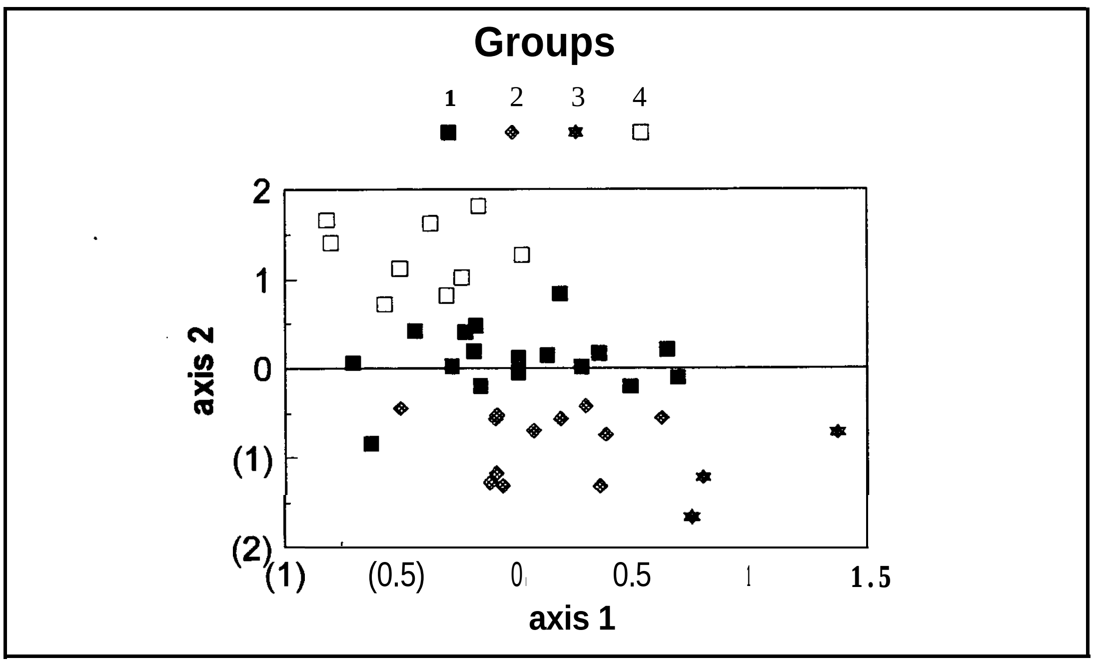


Figure 1: Results of the MDS ordination on 4 1 sites on the Fraser River

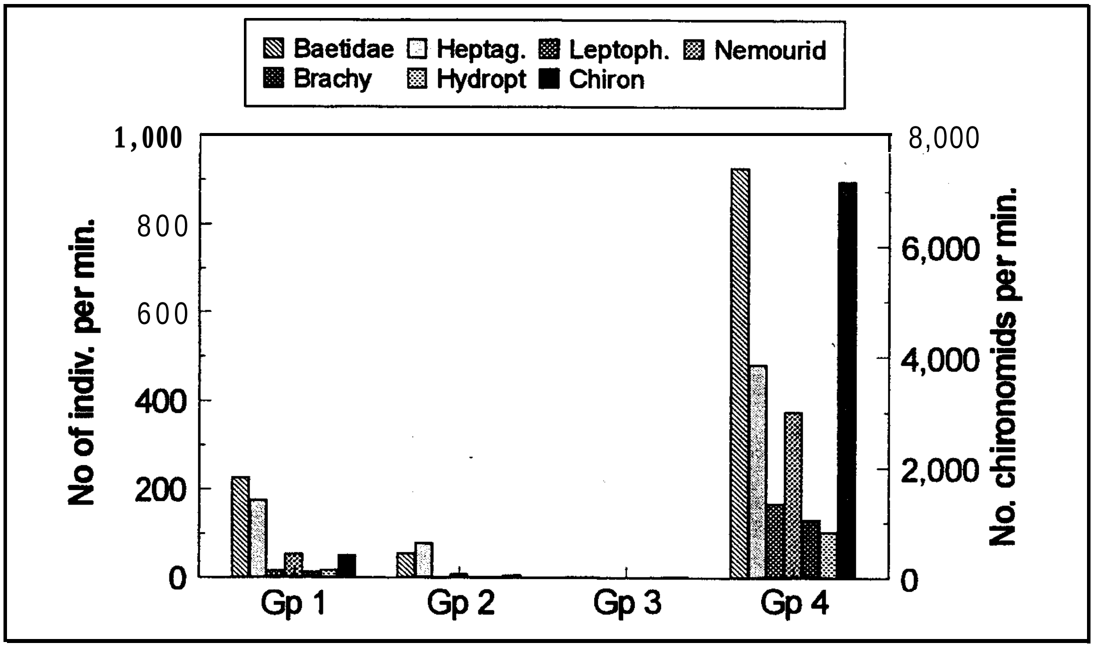


Figure 2: Families correlated with ordination scores.

The environmental variables which were correlated with the overall structure of the data are shown in Figure 3. From the step-wise discriminant analysis, the optional set of variables for predicting differences between the four groups were stream order, altitude and maximum velocity, as well as alkalinity of the water and suspended carbon (arrows in Figure 3).

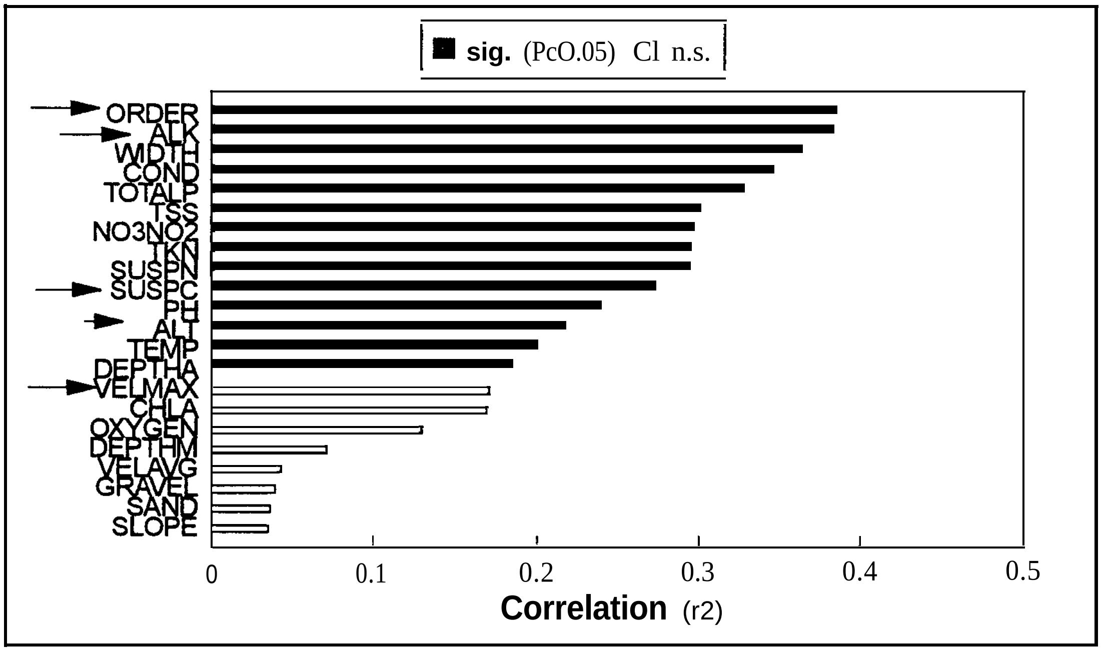


Figure 3: Correlation of environmental variables with biological groups.

Prediction of the sites to each of the groups based on these five environmental variables ranged from 52.9% to 100% with an overall prediction accuracy of 74.4%.

Several test sites with suspected anthropogenic impacts were tested with the predictive model with the following results:

- One test site on the Willow River having suspected impact from logging was found to lie on the 70% probability ellipse for the reference community type to which it should belong based on the environmental variables for that site. This result suggested that minimal impact was occurring at this site; and,
- Four test sites on the Salmon River (Sal01 - upstream of agricultural impact; Sa102, Sa103, and Sal04 - downstream of agricultural impact) showed the unimpacted site (SalOl) to lie within the ellipse of the reference community type. The three potentially impacted sites were found to lie well outside the 70% probability ellipse which demonstrated impact at these sites (Figure 4).

It must be stressed that these results are preliminary and that the development of the definitive predictive model must wait until all results are in at the end of the three-year programme.

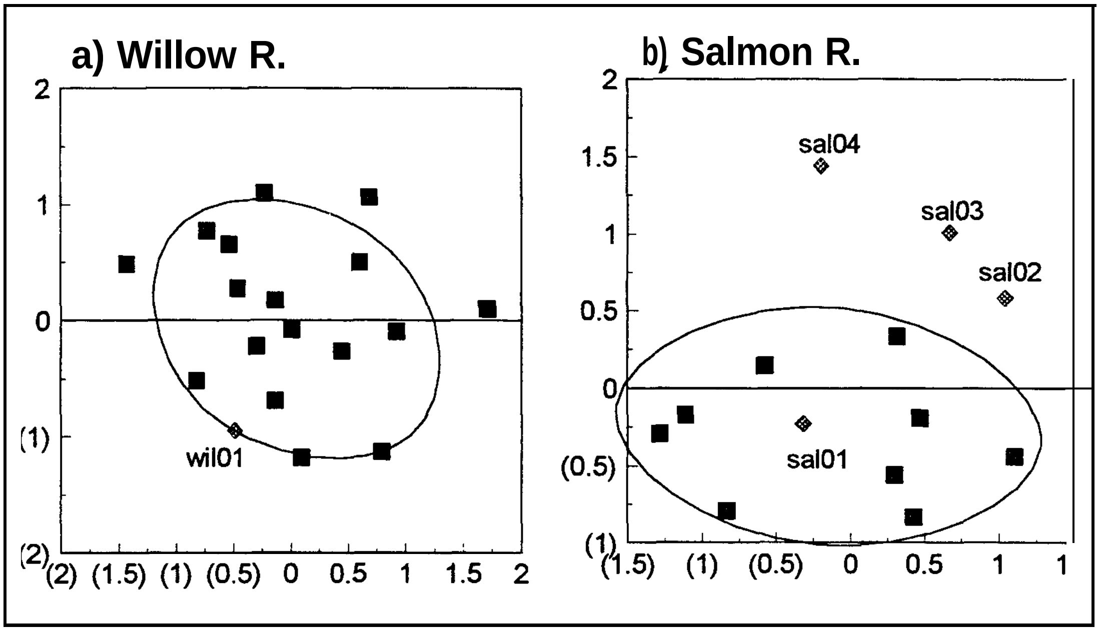


Figure 4: Reference and test sites on ordination plots with 70% ellipses.

Deliverables

The primary deliverable for this project is the development of a software package, for use by managers, which will provide two options as follows:

1. The software package will allow a site assessment. In this mode, the operator will have collected information on site attributes (e.g., location, depth, substrate, alkalinity, etc.) together with data on the biological community (either macroinvertebrate or algal or both). These data will be entered into the software package, the program will predict the biological community which should be present and provide output on the degree of difference from the 'real' community, the degree of impairment and some indication of causation. The primary focus of this study is the establishment of the reference condition for the basin which allows biological objectives to be developed. Although the data are being collected from the Fraser River basin, the baseline dataset will probably be applicable to other areas of the province with similar geographic and ecological attributes. There will be a need for a testing period where the model is used by practitioners in order for it to gain acceptance.
2. A second operational mode could allow some "what if' scenarios. This would allow entry of potentially changed states (i.e., logging, mining, remediation, etc.), and predictions of what changes to the biological community could occur under the various scenarios. It should be noted, however, that developing this option may require additional data collection at sites along impairment gradients (logging, mining, agriculture).

Reference List

Corkum, L.D. 1989. Patterns of benthic invertebrate assemblages in rivers of northwestern North America. *Freshwat. Biol. 21:*195-205

Davis, W.S., and T.P. Simon [Eds.]. 1995. *Biological Assessment and Criteria: tools for water resource planning and decision making.* Lewis Publishers, Boca Raton.

Hughes, R.M. 1995. Defining acceptable biological status by comparing with reference conditions. In *Biological Assessment and Criteria: tools for water resource planning and decision making*. W.S. Davis and T.P. Simon [Eds.]. 1995. Lewis Publishers, Boca Raton.

Johnson, R.K., and T. Wiederholm. 1989. Classification and ordination of profundal macroinvertebrate communities in nutrient poor, oligo-mesohumic lakes in relation to environmental data. *Freshwat. Biol. 21:*375-386.

Norris, R.H., and A. George. 1993. Analysis and Interpretation of Benthic Invertebrate Surveys. *Freshwater Biomonitoring and Benthic Macroinvertebrates.* D.M. Rosenberg and V.H. Resh [Eds.]. 1993. pp. 234-286. Chapman and Hall, New York.

Reynoldson, T.B., R.C. Bailey, K.E. Day and R.H. Norris. 1995. Biological guidelines for freshwater sediment based on Benthic Assessment of Sediment (the BEAST{XE “BEAST”}) using a multivariate{XE “multivariate”} approach for predicting biological state. Aust. J. Ecol. 20:198-219.

Rosenberg, D.M., T.B. Reynoldson, K.E. Day and V.H. Resh. [in prep]. *Role of abiotic factors in structuring benthic invertebrate communities in freshwater ecosystems: implications for ecological risk assessment of sediment.* Setac.

Wright, J.F., P.D. Armitage, M.T. Furse and D. Moss. 1988. A new approach to the biological surveillance of river quality using macroinvertebrates. Int. Ver. Theor. Angew. Limnol. Verh. 23:1548-1552.

S. Kirby

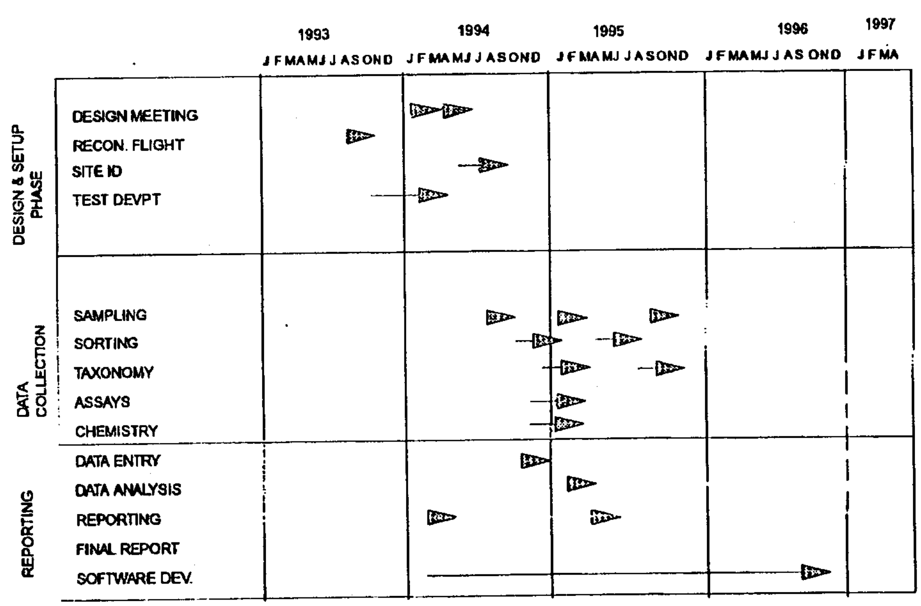
National Water Research Institute

Reference Condition Concept

- Creates groups of 'least-impacted' sites with similar biological communities/environmental characteristics
- May cover a broad geographic scale
- Groups contain sites which represent the range of natural variability among clean sites
- Allows comparison of contaminated sites to a 'reference condition'

FRASER RIVER ECOLOGICAL MONITORING (BENTHIC INVERTEBRATES)

PROJECTED STUDY FORECAST



Site Selection

- Sub-basin (13)
- Ecoregion (11)
- Stream Order (up to 7 orders at 1:250,000 scale)
- Defined as a reach that is a 6:1 ratio of length to width
- 84 strata and 2-3 sites per stratum

Habitats

- **Erosional**
  - Community structure (benthic invertebrates & periphyton)
  - Environmental characteristics
- **Depositional**
  - Survival, growth & reproduction bioassays
  - Community structure
  - Environmental characteristics

Environmental Variables Known to Correlate with Benthic Invertebrate Community Structure in Lotic Systems

- **United Kingdom**
  (Wright *et al.,* 1984; 1989; 1995)
  - Slope
  - Discharge category
  - Mean channel width
  - Surface velocity
  - Mean substrate
  - Dominant particle
  - pH, Phosphorus
  - % macrophyte cover

- **United Kingdom**
  (Corkum & Currie, 1987; 1989)
  - Distance from source
  - Altitude
  - Geology
  - Vegetation cover
  - Land use
  - Water width, depth
  - Overhanging vegetation

Software Development

- **based on B.E.A.S.T. software currently being developed for Great Lakes**
- **developed in collaboration with D. Lam and colleagues in Environmental Information Technology Branch, N.W.R.I.**
- **user-friendly**
- **database will be internalized in software**

Stage 1

- **Data Entry**
  - Entry of test site data:
    - taxonomic data
    - core variables
    - supplementary variables
  - Spreadsheet files
  - Database form entry

Stage 2

- **Prediction**
- **Selection of best predictors**
  - core predictors - latitude, longitude, depth
  - optional variables
- **Discriminant Analysis**
- **Assigning test site group membership**

Stage 3

- **Construction of new data sets - biological & chemical**

  Test Data + Reference Data Sets = Combined Data

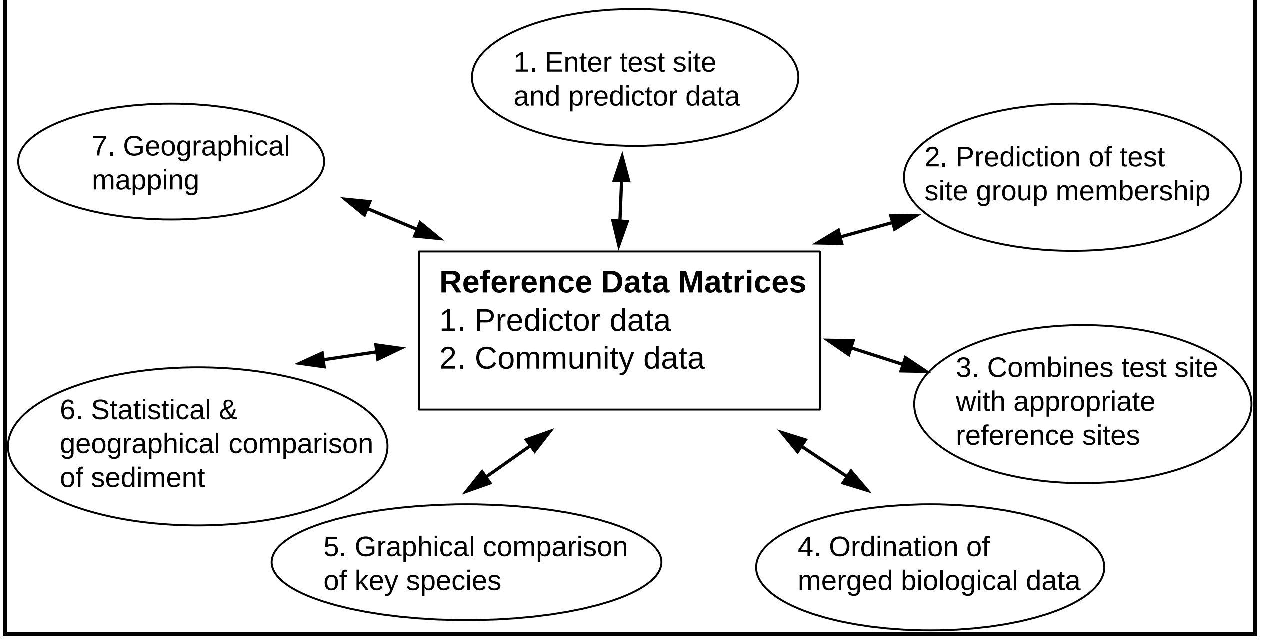
Stage 4

- **Ordination of merged biological data**

Stage 5

- **Graphical comparison of indicator species**

Biological Guidelines for Fraser River Catchment
Conceptual Framework for Software



Post-FRAP

- **Adoption by the province and other agencies**
  - test period for model to be used by practitioners
- **Geographic relevance**
  - applicability to other areas in province with similar geographic and ecological attributes
- **Further refinement**
  - inclusion of more reference sites
  - use in determining effects of remediation

Human Impact on Aquatic and Riparian Ecosystems in Two Streams of the Thompson River Drainage

R.L. Vadas

CWS/NSERC Research Chair in Wildlife Ecology
Simon Fraser University

Introduction

In order to determine biological indicators of deforestation, aquatic and riparian fauna and habitat were sampled in two agriculturally impacted river valleys of the southern interior. The mainstems of the Salmon (SR) and Nicola (NR) rivers were examined during the fall of 1994 for riparian vertebrates (identified by sight and sound), riparian invertebrates (caught with a sweep net and aquatic emergence traps), drift and benthic invertebrates (respectively caught with drift vs. Hess nets), and aquatic mega-invertebrates and fishes (caught with seine nets and an electroshocker). Whereas vertebrates were indentified to species, invertebrates were identified to higher taxonomic levels (usually order, suborder or family). Riparian and aquatic habitat were sampled to determine the relative abundance of habitat types, which included five lower riparian floral substratum categories, five aquatic-lateral habitat types and seven aquatic-hydraulic categories.

For both streams, middle and lower river sites were examined to make triplet-wise comparisons among sites of differing upper riparian intactness. The habitat types included forested (FO), semi-forested (SF), shrubby (SH), and grassy (GR); FO-SF-GR and SF-SH-GR comparisons were made in SR vs. NR, respectively.

Riparian and Aquatic Habitat

Habitat diversity, which was compared in the middle and lower sections of the two rivers (four comparisons), was often highest at semi-forested sites. Treed sites showed the highest habitat diversity in the lower riparian zone, via greater abundance of woody vegetation. Aquatic habitat diversity along the lateral gradient was also hoghest at treed sites of SR, reflecting the greater abundance of edge habitats (backwaters and/or side channels), whereas NR trends were ambiguous. Semi-forested sites showed the highest hydraulic diversity because pool, run, and riffle habitats were all abundant, whereas diversity differences among other floral habitat types were inconsistent. The two most sedimented sites (i.e., the uppermost reaches sampled in SR and NR), were relatively low in aquatic habitat diversity.

Riparian Vertebrates

Riparian-vertebrate assemblages differed among sites. Higher species diversity and percent abundance of agricultural species were seen at less-forested sites, whereas logging-sensitive, cavity-nesting birds showed highest percent abundance at semi-forested sites. Trends for species richness were inconsistent across rivers. Classification of species into floral habitat-use guilds, as defined in the literature for western North America, showed that:

- generalists were usually dominant; and,
- treed sites (FO-SF) did not always show greater abundance of treed guilds; and lesser abundance of unforested guilds.

Guild classification based on the SR-NR data set yielded two ‘treed’ habitat-use guilds (i.e., ‘forested’ (one bird species) and ‘semi-forested’ (one amphibian and three bird species). There were also five ‘generalist’ bird species and two ‘unforested’ guilds of birds, including ‘shrubby-grassy’ (one species) and ‘grassy (two species).

Micro- and Macroinvertebrates

Invertebrate assemblages also differed among sites, taxonomic diversity generally being higher for more-forested conditions. Riparian invertebrates were most diverse at treed sites in three of four comparisons, the general order was FO > SF > SH & GR. Drift invertebrates were also most diverse at treed sites in three of four comparisons; the general order was SF > FO > SH & GR. Benthic invertebrates showed the highest diversity at forested sites in SR, but differences among less forested sites were inconsistent. The percent abundance of terrestrial invertebrates was inconsistent across samples; whereas benthic samples showed highest values at grassy sites, drift samples showed lowest values for grassy (SR) or shrubby sites (NR).

In contrast, invertebrate density in the river was generally higher for agricultural (grassy) conditions. Drift invertebrates were more dense at grassy sites in three of four comparisons; the general order was GR > FO > SF & SH. Benthic invertebrates were also more dense at grassy sites in SR, but differences among NR sites were inconsistent; the general order was also GR > FO > SF & SH.

Based on literature trophic data, herbivorous aquatic invertebrates were generally more dominant for unforested conditions. Drift invertebrates showed higher herbivore: predator (H:P) ratios at shrubby and grassy sites, whereas benthic invertebrates showed highest values at grassy sites.

Pollution indices gave ambiguous results. The percent abundance of large-bodied, pollution-sensitive taxa, namely mayflies, stoneflies and caddisflies (EPT), was partially consistent across sites. Semi-forested sites had the highest values in SR benthic samples and SR-NR drift samples, whereas % EPT was highest for grassy conditions in the NR benthos. Pollution indices that required assignment of points based on pollution tolerance gave inconsistent results across rivers and samples (drift vs. benthos).

Floral guild classification based on the SR-NR data set yielded a ‘treed’ guild (three aquatic taxa), a ‘generalist’ guild (eight aquatic, two semi-aquatic, and three terrestrial taxa), and an ‘unforested’ guild (one semi-aquatic and four aquatic taxa). Aquatic insect larvae and pupae and microcrustaceans were in the treed and/or unforested guilds, suggesting that both micro- and macroinvertebrate taxa are useful as agricultural indicators.

Aquatic Megainvertebrates and Fishes

Nekton assemblages also differed among sites. Mesonekton diversity (megainvertebrates and fish larvae) and percent abundance of fish larvae (relative to megainvertebrates) were higher for treed sites in SR, wheras NR showed lowest values for shrubby conditions. Larger fishes were most diverse at semi-forested sites in three of four comparisons, but differences among other floral habitat types were inconsistent. Trends for percent abundance of pollution-sensitive shiners (relative to larger fishes) and fish species richness were ambiguous; redside shiners were relatively rare at semi-forested and grassy sites.

Nekton density was often lowest for agricultural (grassy) conditions. Mesonekton showed highest density for semi-forested sites in SR, whereas wooded sites (SF-SH) had the highest densities in NR; grassy sites were consistently lowest. Trends were inconsistent for larger fishes; grassy sites showed lowest values in middle-river sections, whereas semi-forested sites showed lowest values in lower-river sections (where grassy sites showed intermediate densities).

Floral-guild classification based on the SR/NR data set were done on multi-specific fish families and individual nekton species. The family analysis yielded two wooded guilds (i.e., ‘generalized-forest’ [salmonids] and ‘partially-wooded’ [minnows]. Two families were ‘generalists,’ namely suckers and sculpins. The species analysis yielded three wooded guilds (i.e., ‘treed-shrubby’ [four fish species], ‘semi-forested’ [one megainvertebrate taxon], and ‘generalized-SF’ [two fish species]). There were four unforested guilds (i.e., ‘generalized-shrubby’ [one megainvertebrate taxon], ‘shrubby’ [one fish species], ‘shrubby-grassy’ [two fish species], and ‘grassy’ [three fish species]). Because aquatic insect nymphs and fishes were in the treed and unforested superguilds, both taxa appeared to be useful as agricultural indicators.

Conclusions

To summarize, these results suggested that semi-forested conditions are conducive to maintaining ecosystem balance. Although assemblage trends differed among taxa and were not always consistent across sites, biodiversity for riparian and aquatic fauna should both be maintained under partially forested conditions. Such conditions:

1. allow bank stabilization, contaminant filtering, shading, and detrital input that benefit aquatic invertebrates and fishes; and,
2. maintain floral habitat diversity for riparian wildlife.

The trends for habitat and biological diversity may reflect the fact that semi-forested (cottonwood-pine) and unforested (bunchgrass-sagebrush) conditions have historically characterized southern interior stream valleys, such that native riparian and aquatic animals are adapted to partially wooded conditions.

Recommendations

Habitat and biological trends may not have been consistent across sites because of confounding factors such as urbanization, mining, irrigation, pesticide and other human impacts, as well as differing compositions of riparian-floral species and benthic sediments (not assessed here). Therefore, examination of several biological parameters should provide a more robust assessment of human impacts. Ability to establish biological indicators should be improved by increasing spatio-temporal replication (examining a greater number of sites and comparing samples sollected among seasons) and by conducting manipulative experiments (where possible, such as in northern B.C.). Such efforts will require interdisciplinary coordination. The information provided in the present paper should benefit researchers and managers in the province, by providing solid databases and standardized methodologies for human-impact assessment of inland watersheds. Local (SR-NR) citizens developing biological monitoring programs should find the biological indicators developed here useful for monitoring the success of their tree planting programs.

I. Methodology

A. Types of Data

1. % Abundance
2. Density (#/m^2)

B. Types of Analysis

1. Species Diversity and Richness
2. Factor Analysis
3. Triplet-Wise Ranking

C. Riparian and Aquatic Habitat

D. Taxa

1. Riparian Invertebrates
   a. Reptiles, Mammals and Birds
2. Micro- and Macroinvertebrates
   a. Riparian and Drift
   b. Benthic
3. Aquatic Nekton (Including Diet Data)
   a. Fish Larvae and Megainvertebrates
   b. Juvenile and Adult Fishes

E. Environmental Gradients

1. Longitudinal
2. Hydraulic and Bottom-Topographic
3. Lateral and Vertical
4. Floral (Upper-Riparian, 4 Types)
   a. Forested (FO)
   b. Semi-Forested (SF)
   c. Shrubby (SH)
   d. Grassy (GR)

II. Habitat Classification

A. Lower Riparian (5 Types)

1. Tree, Woody Shrub, Tall Herbs
2. Bare-Coarse or Bare-Fine Substrata

B. Aquatic Lateral (5 Types)

1. Main Channel (MC)
2. Side Channel (SC)
3. Backwater (BW)
4. Transitional (MC/SC & SC/BW)

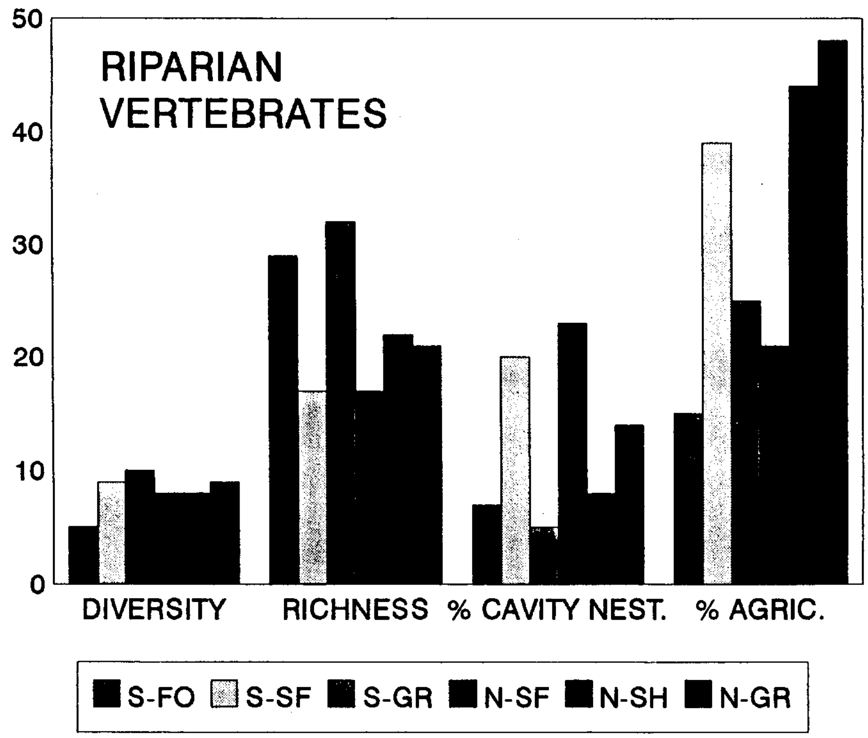
C. Hydraulic (Mesohabitat, 7 Types)

1. Medium & Shallow Pools
2 Medium & Shallow Runs
3. Medium Torrents
4 Slow and Fast Riffle

Habitat Diversity

Site	Riparian	Lateral	Hydraulic
• SM	SF > FO > GR	FO & SF > GR	SF > FO > GR
• SL	FO > SF > GR	SF > FO > GR	SF > GR > FO
• NM	SF > SH > GR	GR > SF > SH	GR > SH > SF
• NL	SF > SH > GR	SH > GR > SF	SF & SH > GR

Simpson-Levins Diversity Index



Riparian-Vertebrate Guilds

Floral Habitat Use

I. Treed

A. FO = Yellow-rumped Warbler

B. SF = Spotted Frog, Redbreasted Merganser, Chestnut-backed Chickadee & Cedar Waxwing

II. Generalist

= Belted Kingfisher, American Robin, American Crow, Black-billed Magpie & Brewer's Blackbird

III. Unforested

A. SH-GR = Common Merganser

B.GR = Barn Swallow & Common Yellowthroat

Varimax-Factor Analysis

Invertebrates

Ecological Classifications

I. Macrohabitat (3 Types)

A. Aquatic, Semi-Aquatic & Terrestrial

II. Pollution Tolerance (5 Types)

A. Sensitive (S = 3 Pts.)

B. Moderate (M = 2 Pts.)

C. Tolerant (T = 1 Pt.)

D. Transitional (SM = 2.5 Pts. & MT = 1.5 Pts.)

III. Trophic (5 Types)

A. Herbivorous or Predatory

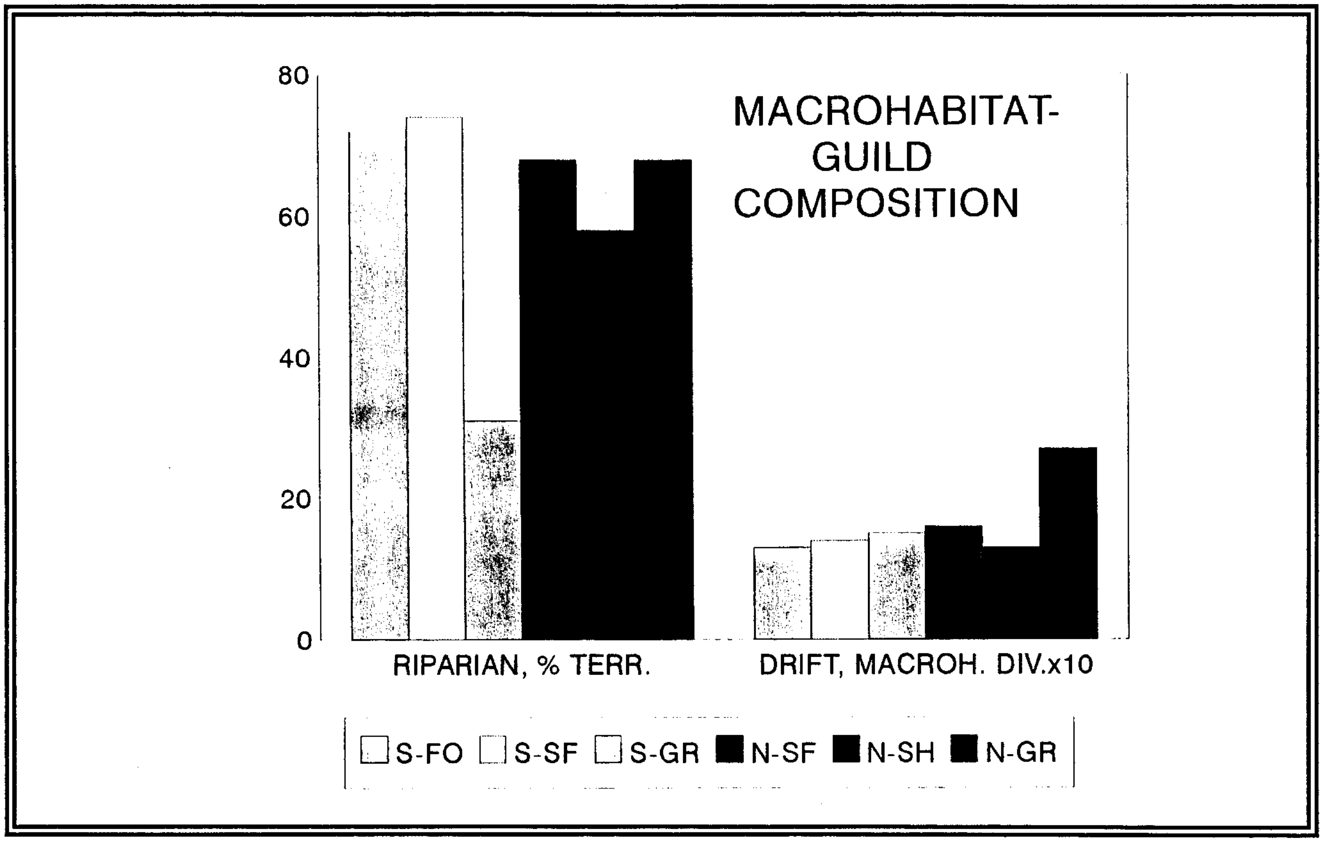
B. GR = Predominantly Herbivorous or Predatory

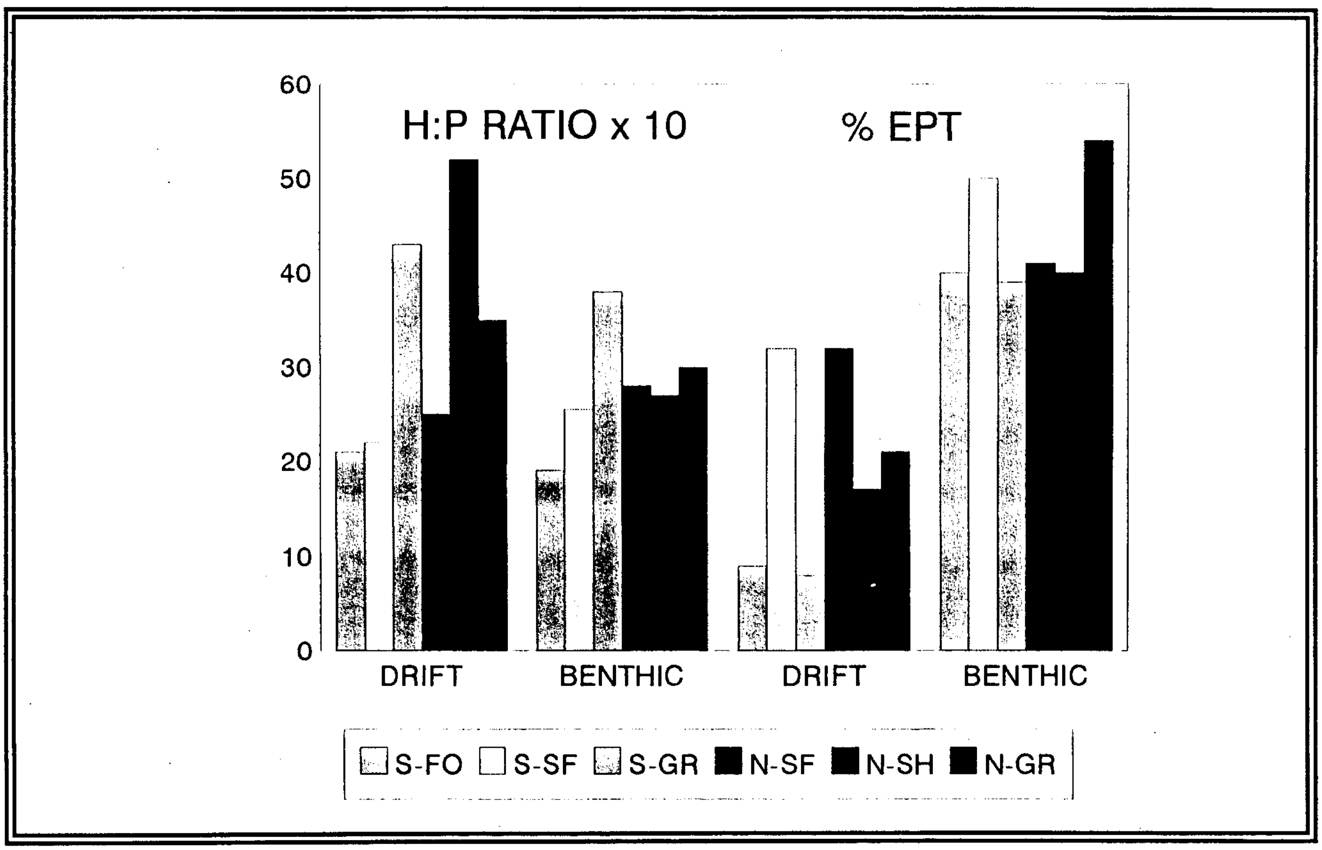
C. Omnivorous (Herbivorous-Predatory)

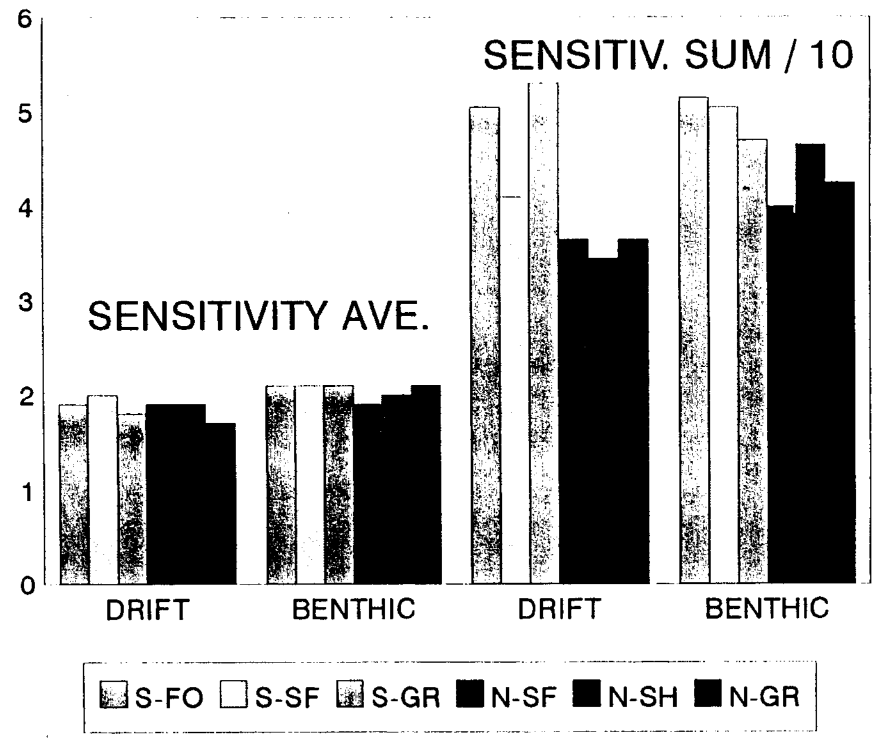
Invertebrate Diversity

Site	Riparian	Drift	Benthic
• SM	FO > SF > GR	SF > FO > GR	FO > SF & GR
• SL	GR > FO > SF	SF > FO > GR	FO > GR > SF
• NM	SF > GR > SH	GR > SF > SH	GR > SF > SH
• NL	SF > SH > GR	SF > SH > GR	SH > SF & GR

Simpson-Levins Diversity Index


MACROHABITAT-GUILD COMPOSITION
80
60
40
20
0
RIPARIAN, % TERR.
DRIFT, MACROH. DIV.x10
S-FO
S-SF
S-GR
N-SF
N-SH
N-GR


H:P RATIO x 10
% EPT
60
50
40
30
20
10
0
DRIFT
BENTHIC
DRIFT
BENTHIC
S-FO
S-SF
S-GR
N-SF
N-SH
N-GR



Aquatic-Invertebrate Density

Site	Drift	Benthic
• SM	GR > FO > SF	GR > FO > SF
• SL	GR > FO > SF	GR > FO > SF
• NM	SH > SF > GR	SH > GR > SF
• NL	GR > SH & SF	SF > SH > GR

#/m^2

Micro- and MacroInvertebrate Guild

Riparian-Floral Habitat Use

I. Treed-Aquatic

= Ostracod, Ceratopogonid larva & Sand-cased Caddisfly larva

II. Generalist

A. Aquatic = Mayfly nymph, Stonefly nymph, Chironomid larva, Uncased Caddisfly larva, Oligochaete, Mite, Roundworm & Hydroid

B. Semi-Aquatic = Springtail & Nematoceran adult

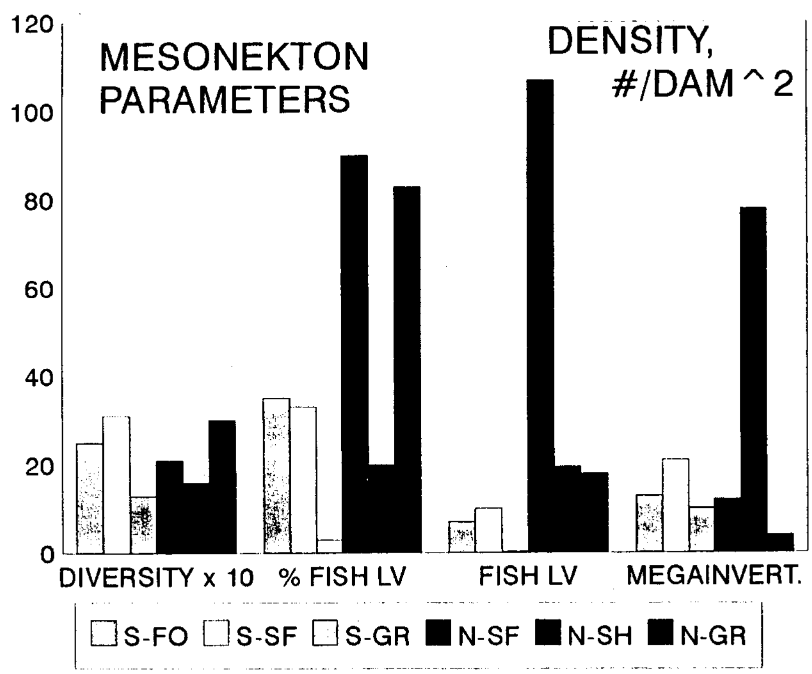
C. Terrestrial = Homopteran, Hymenopteran & Spider

III. Unforested

A. Aquatic = Cladoceran, Lepidopteran larva, Tipulid larva & Nematoceran pupa

B. Semi-Aquatic = Brachyceran adult

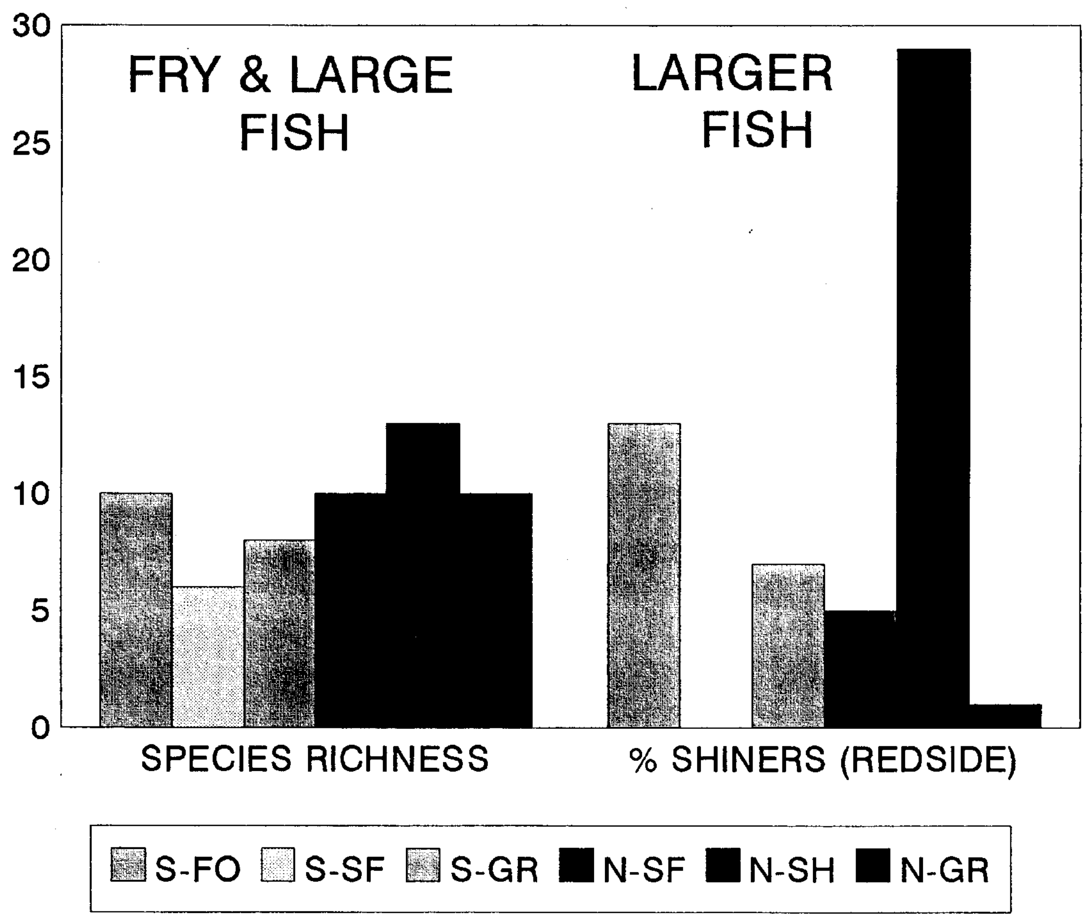
Riparian, Drift & Benthic Samples



Larger Fish

Site	Diversity	Density
• SM	GR > SF > FO	SF > FO > GR
• SL	SF > FO > GR	FO > GR > SF
• NM	SF > GR > SH	SF > SH > GR
• NL	SF & SH > GR	SH > GR > SF

Simpson-Levins Diversity Index, Density = #/m^2



Fish-Family Guilds

Riparian-Floral Habitat Use

I. GEN-FO

= Salmonids

II. SF-SH (Moderately Wooded)

= Cyprinids (Minnows)

III. GEN

= Catostomids (Suckers) & Cottids (Sculpins)

Larger-Fish Analysis for Multi-species Families

Aquatic-Nekton Guilds

I. Wooded

A. FO-SF-SH = Redside Shiner, Juv. Chinook Salmon, Rainbow Trout/Steelhead & Pacific Lamprey

B. SF = *Pteronarcys* nymph

C. GEN-SF = Chiselmouth & Longnose Dace

II. Unforested

A. GEN-SH = Gomphid nymph

B. SH = Leopard Dace

C. SH-GR = Mountain Whitefish & Largescale Sucker

D. GEN-GR = Bridgelip Sucker, Prickly Sculpin & Perlid nymph

Riparian-Floral Habitat Use

Conclusions

I. Biodiversity & Abundance
- A. Ambiguous Patterns
- B. Effects of Riparian Vegetation
  1. Enrichment vs. Habitat Protection
  2. Semi-Forested Conditions

II. Indicator Taxa for Riparian Intactness
- A. Riparian Birds and Frogs
- B. Aquatic Micro-, Macro- & Megainvertebrates
- C. Larval & Larger Fish

III. Future Research Needs

SESSION 6

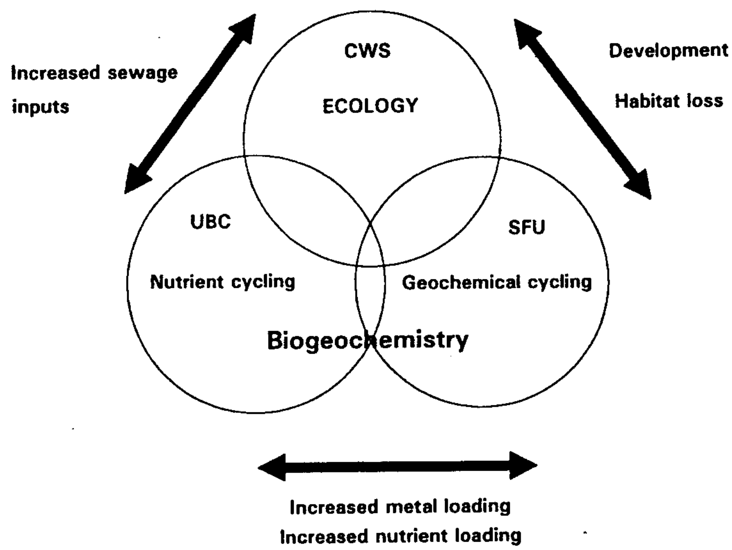
ESTUARY ISSUES

Introduction

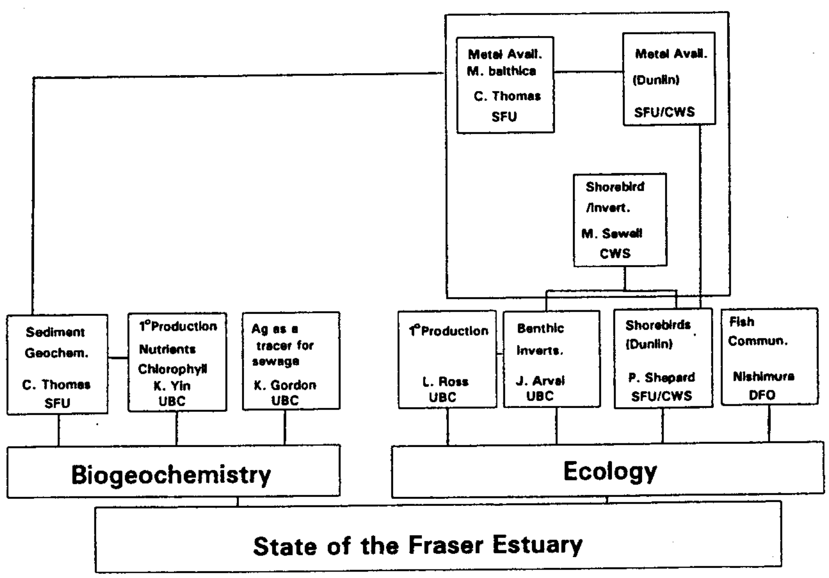
L. Bendell-Young

Department of Biological Sciences, Simon Fraser University

State of the Fraser River Estuary



Intergration of ongoing studies CWS/SFU/UBC



Linking Sediment Geochemistry in the Fraser River Estuary to Metal Bioaccumulation in Lower Trophic Levels

C. Thomas and L. Bendell-Young

Department of Biology
Simon Fraser University

The Fraser River estuary is the largest estuary on the Pacific coast of Canada. It provides a vital habitat for a wide variety of birds, fish and wildlife, as well as playing an integral role in the lives of many people in B.C. Metals released into the Fraser River ultimately end up in the estuarine sediments. Once in the sediment, these metals represent a potential source of metals to benthic-dwelling organisms. The objectives of this study were to contrast the geochemistry of trace metals (Cd, Pb, Zn, Mn, Fe and Hg) at three sites along the mudflats of the Fraser River estuary (Sturgeon Bank, Roberts Bank and Boundary Bay) and to relate differences in trace metal geochemistry to metal availability in *Macoma balthica* (a deposit-feeding bivalve). These three sites were chosen to reflect a range in grain size, concentration of organic matter and metal contamination. The most northerly site is Sturgeon Bank, which, before 1989, received primary-treated sewage directly onto its foreshore. To its south is Roberts Bank, which is strongly influenced by the main arm of the Fraser River. At the far end of the estuary is Boundary Bay which has very little freshwater input and consists of coarse-grained sand.

The fate and bioavailability of a metal depends on the geochemistry of the sediment, as well as the partitioning of the metal among the different geochemical components. Sediment geochemistry is defined as concentrations of organic matter, reducible Fe (Fe oxides) and easily reducible Mn (Mn oxides). A selective chemical extraction procedure was employed to assess the partitioning of metals onto the different geochemical fractions in the sediment. Porewater samples were collected to assess the contribution of diagenesis to concentrations of particulate Mn and Fe at the sediment-water interface. To determine the bioavailable fraction of the sediment, a correlation analysis will be done between levels of metals in *M. balthica* and concentrations of metals recovered in the different sediment fracions.

Conclusions

Sediment matrix vs. metal concentration results revealed extreme variation in concentrations of Fe and Mn in the surficial sediments. Conversely, the range of organic matter was considerably less than expected (1.5% - 6.5%), with a surprisingly low percentage (4%) measured by the sewage treatment plant (STP). Boundary Bay was found to be distinctly different from the other two sites in terms of low to non-existent concentrations of Fe and Mn oxides. The highest concentrations of Hg (0.22 µg/g) were found closest to the STP where they exceeded the maximum acceptable value set by the Ministry of Environment (0.15 µg/g). A strong association between organic matter and Hg was also found between all sites. Maximum concentrations of Zn were found at Roberts Bank, which points to the Fraser River as an important source of metals. Porewater results indicated that the sediments were a source of Fe and Mn to the surficial sediments at Sturgeon and Roberts banks; however, at Boundary Bay, this was not the case.

Objectives

Long-Term

1. To provide baseline information on the geochemical components and processes influencing metal availability in the mudflats of the Fraser River estuary; and,
2. Apply this information in developing predictive models to assess which sites pose a greater risk of metal bioaccumulation.

Short-Term

1. To contrast the geochemistry of trace metals Cd, Pb, Hg and Zn at three sites along the mudflats of the Fraser River estuary; and,
2. Relate these differences in trace metal geochemistry to metal availability in *Macoma balthica*.

1. Sediment Geochemistry

- sediment matrix plays an important role in the bioavailability of metals;
- the key geochemical components in terms of metal binding are organic matter and oxides of Fe and Mn; and,
- it is the sediment matrix, as well as the partitioning of a metal among these geochemical components, that will influence metal availability.

2. Porewater

- used to obtain profiles of total dissolved Fe and Mn in the interstitial water at different depths; and,
- profiles reveal contribution of diagenesis to concentrations of particulate Mn and Fe at the sediment water interface (i.e., whether the sediments are a sink or source of these elements).

3. Tissue Chemistry

Why use *Macoma balthica?*

- it lives and feeds in the upper portion of the deposit sediments;
- tissue levels tend to reflect levels of metals in the sediment; and,
- it forms an important link in the estuarine food web and ingestion by higher trophic levels could lead to transfer of metals to higher trophic levels.

Methods

- levels of metals in *Macoma balthica* were measured in the tissue and shell; and,
- by correlating tissue levels with sediment levels, it will give us indication of the source of the bioavailable fraction of metals, as well as which sites pose a greater risk of metal bioaccumulation.

Objective One

To contrast the geochemistry of trace metals Cd, Pb, Hg and Zn at three sites along the mudflats of the Fraser River estuary. Will be addressed by:

Sediment geochemistry

- grain size, % LOI, concentrations of Fe and Mn oxides and concentrations of the above mentioned metals in the different sediment fraction.

Porewater

- will reveal profiles of dissolved Fe and Mn at depth in the sediment; and,
- help determine whether the sediments are a source or a sink of Mn and Fe oxides.

Objective Two

Relate these differences in trace metal geochemistry to metal availability in *Macoma balthica* and, potentially, other benthic dwelling organisms. Will be addressed by:

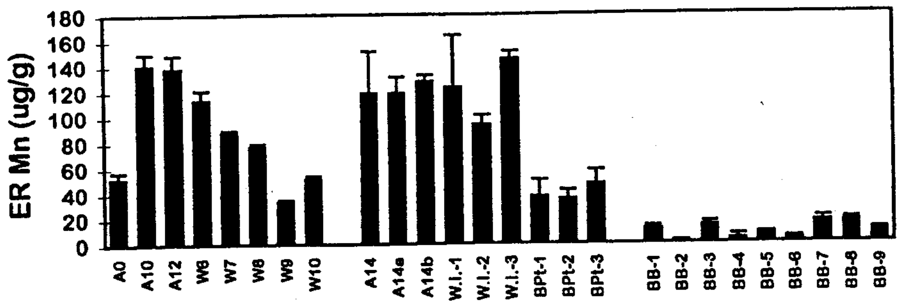
Field Component

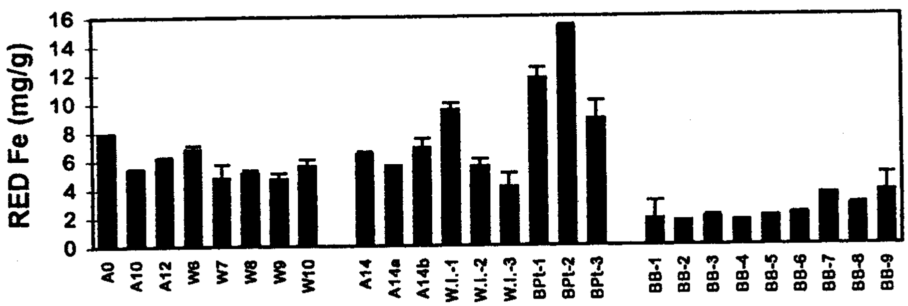
- benthic samples have been collected from each site;
- *Macoma balthica* only found at Sturgeon Bank and part of Roberts Bank;

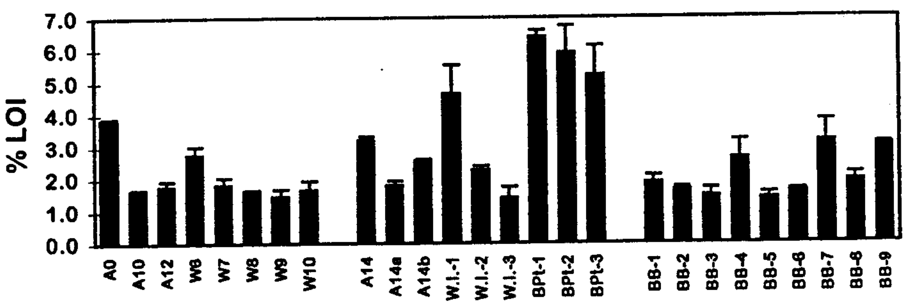
- tissues and shells will be digested separately and analyzed for these metals; and,
- will try to correlate levels of metals in tissues to levels in certain sediment fractions (organic and Fe and Mn oxides).

Lab Component

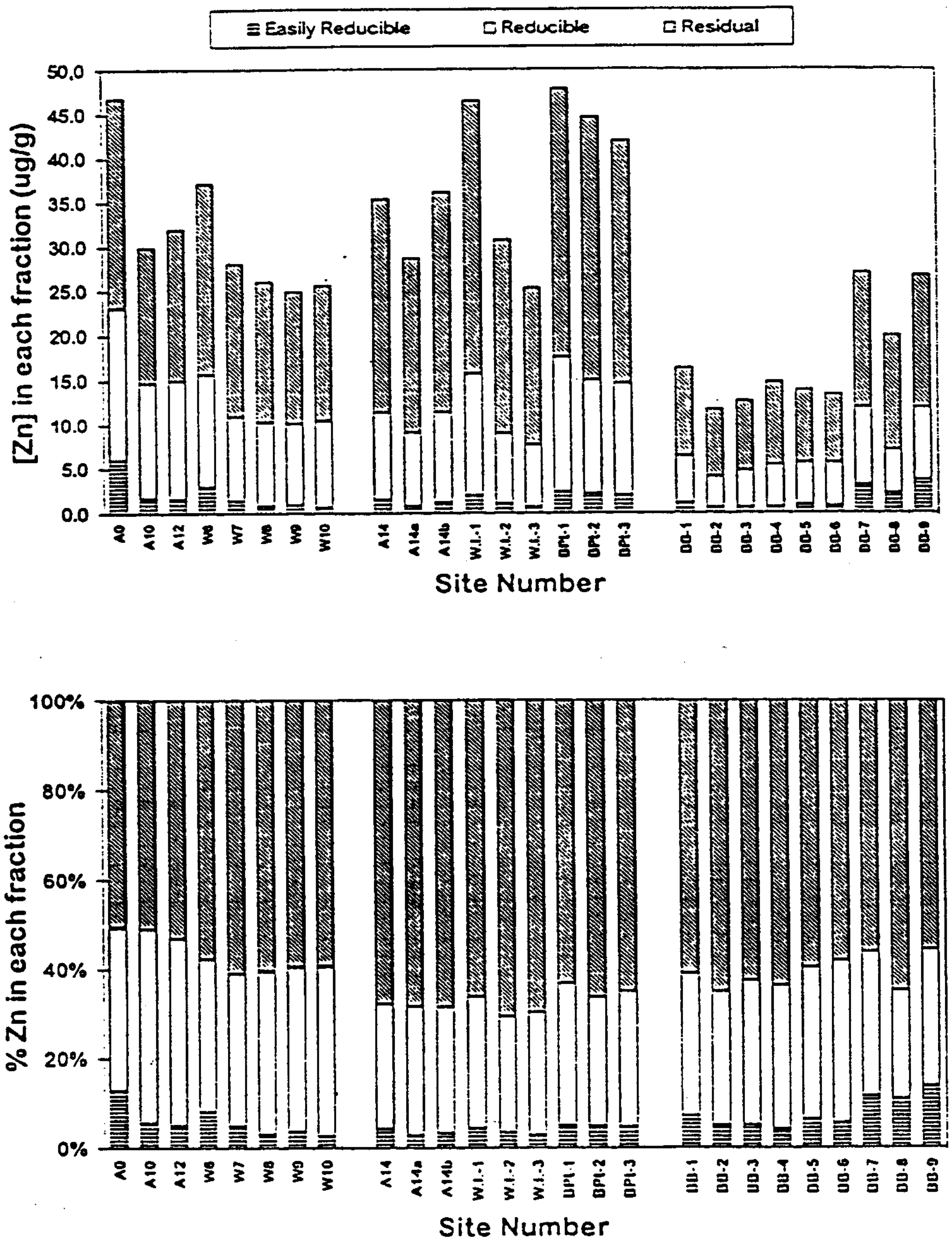
- radioisotope experiment; and,
- will spike natural sediment collected from two sites that show variation in sediment geochemistry.

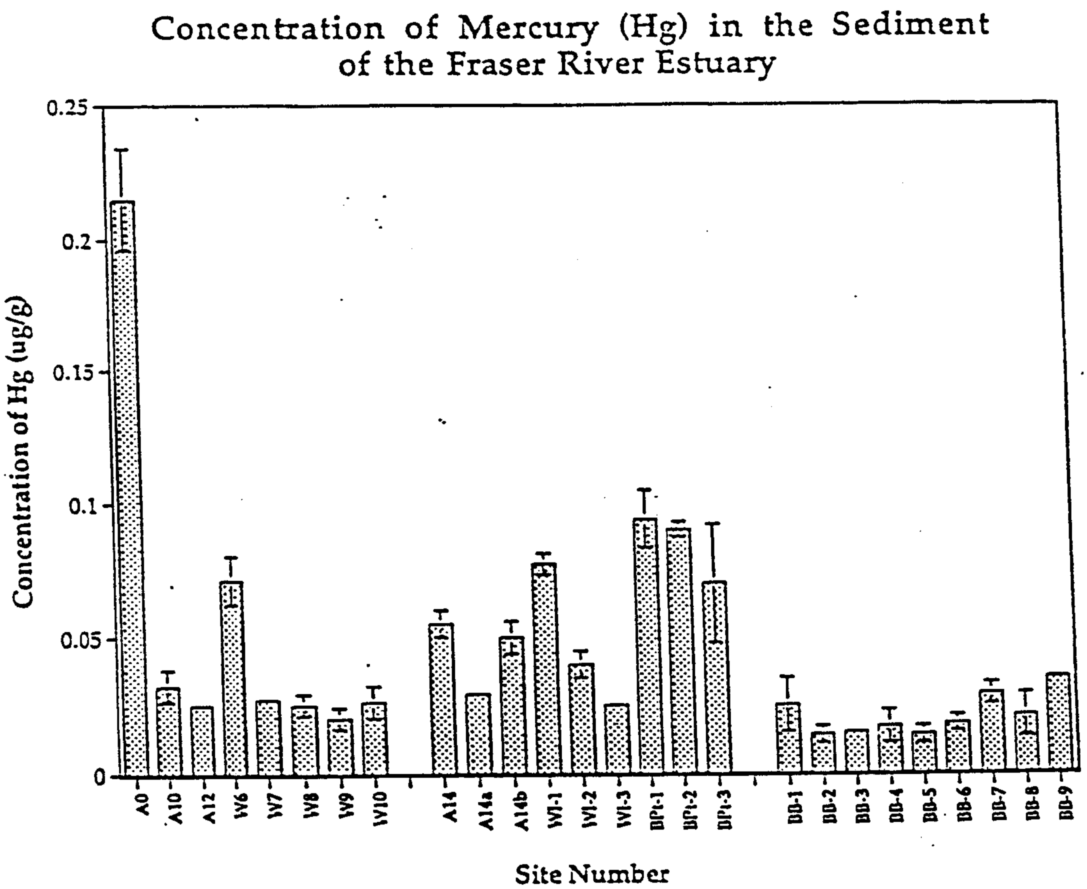

ER Mn (ug/g)
180
160
140
120
100
80
60
40
20
0
A0
A10
A12
W6
W7
W8
W9
W10
A14
A14a
A14b
W.I.-1
W.I.-2
W.I.-3
BPt-1
BPt-2
BPt-3
BB-1
BB-2
BB-3
BB-4
BB-5
BB-6
BB-7
BB-8
BB-9

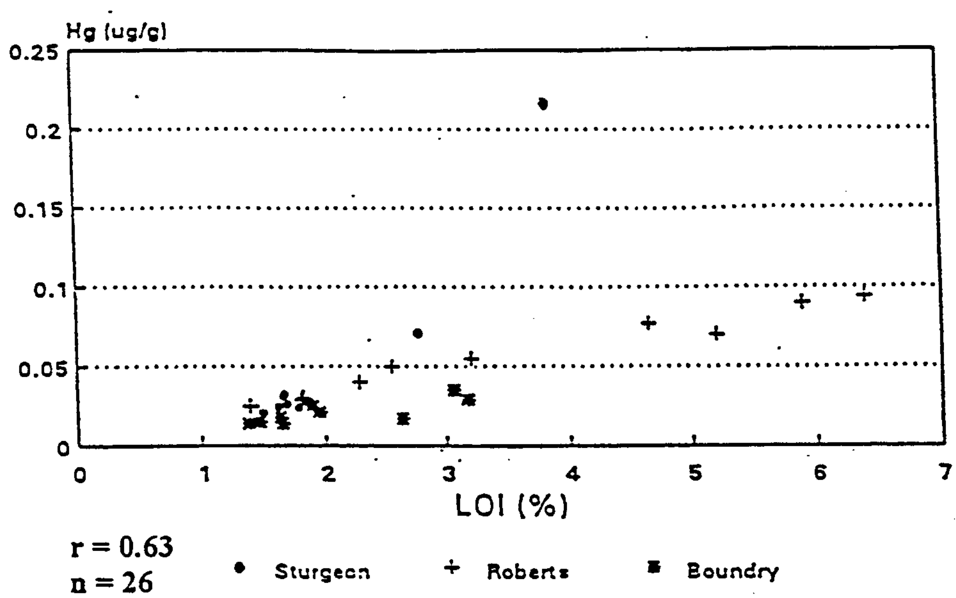

RED Fe (mg/g)
16
14
12
10
8
6
4
2
0
A0
A10
A12
W6
W7
W8
W9
W10
A14
A14a
A14b
W.I.-1
W.I.-2
W.I.-3
BPt-1
BPt-2
BPt-3
BB-1
BB-2
BB-3
BB-4
BB-5
BB-6
BB-7
BB-8
BB-9

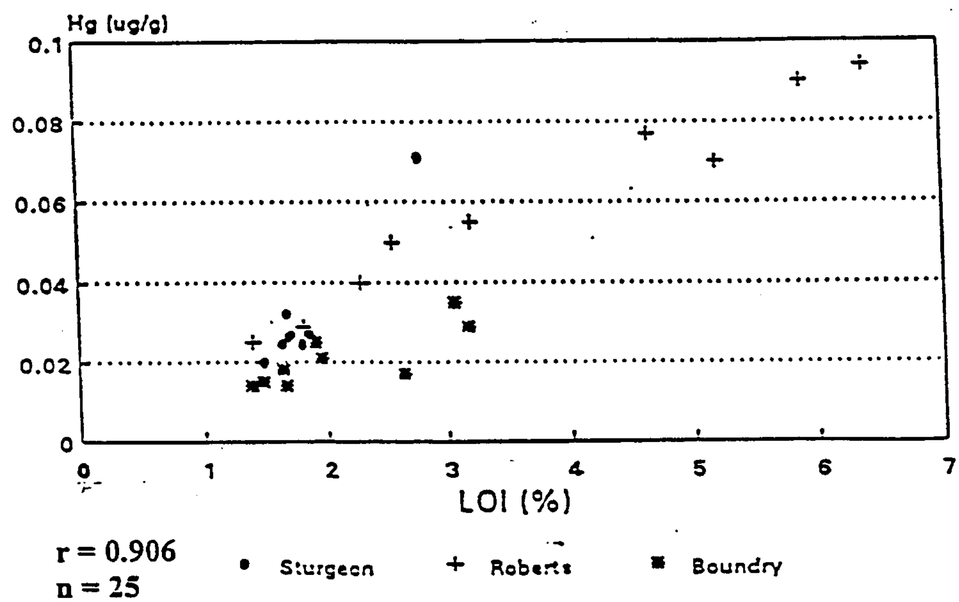

% LOI
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
A0
A10
A12
W6
W7
W8
W9
W10
A14
A14a
A14b
W.I.-1
W.I.-2
W.I.-3
BPt-1
BPt-2
BPt-3
BB-1
BB-2
BB-3
BB-4
BB-5
BB-6
BB-7
BB-8
BB-9

Zinc Partitioning in the Sediment




Concentration of Mercury (Hg) in the Sediment of the Fraser River Estuary
0.25
0.2
0.15
0.1
0.05
0
Concentration of Hg (ug/g)
A0
A10
A12
W6
W7
W8
W9
W10
A14
A14a
A14b
WI-1
WI-2
WI-3
BPt-1
BPt-2
BPt-3
BB-1
BB-2
BB-3
BB-4
BB-5
BB-6
BB-7
BB-8
BB-9
Site Number


Hg (ug/g)
0.25
0.2
0.15
0.1
0.05
0
0 1 2 3 4 5 6 7
LOI (%)
r = 0.63
n = 26
Sturgeon
Roberts
Boundry


Hg (ug/g)
0.1
0.08
0.06
0.04
0.02
0
0 1 2 3 4 5 6 7
LOI (%)
r = 0.906
n = 25
Sturgeon
Roberts
Boundry

The Use of Silver Measurements in Sediments as a Tracer of Sewage Inputs to Coastal Waters

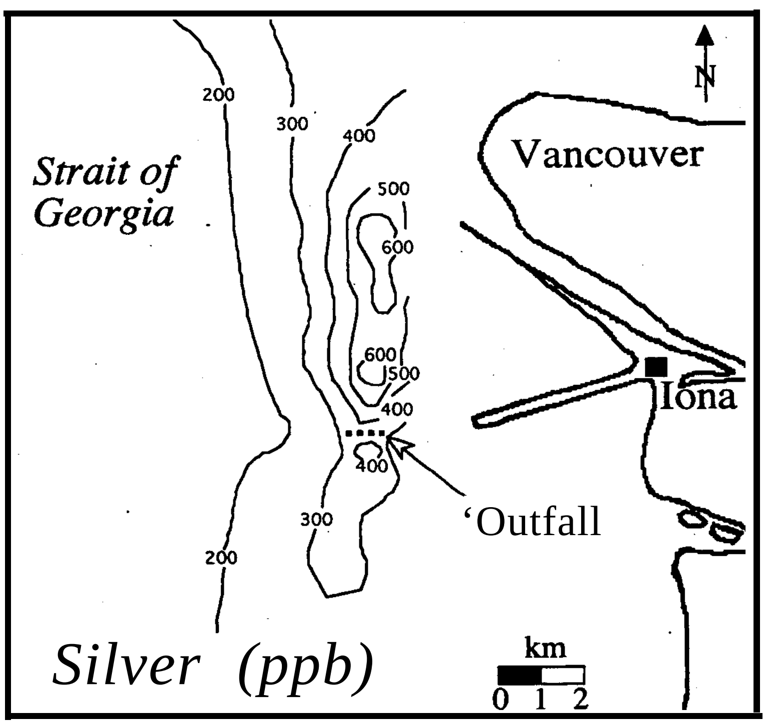
K. Gordon’, T.F. Pedersen’ and R.W. MacDonald [2]

‘Department of Oceanography
University of British Columbia

Institute of Ocean Sciences

Elevated silver concentrations in surface sediments from the Strait of Georgia reflect the submarine discharge and northerly flow of primary-treated sewage from the Iona Island Wastewater Treatment Plant immediately south of Vancouver. Silver can be used to trace sewage because silver concentrations in sewage particles and, therefore, sewage-contaminated sediments, are higher than in uncontaminated sediments. Silver tends to be more enriched in sewage wastes than other metals mainly because the metal is introduced to municipal wastewater primarily from the photographic industry.

Silver concentrations near the Iona outfall were up to six times greater, around 600 ppb, than concentrations in the middle of the Strait of Georgia, at about 100 ppb, indicating that sewage particles accumulate near the outfall. The plume appeared to move northward from the outfall since higher silver concentrations extend to the north. This observation was consistent with the northerly flow of deep water at this location.



Recovery of a Contaminated Mudflat from Sewage Treatment Plant Effluent at Iona and Sea Islands

K. Yin, P.J. Harrison

Department of Earth and Ocean Sciences
University of British Columbia

Abstract

The objective of our project is to study the estuarine benthic ecology with respect to a long-term response to diversion of sewage treatment plant effluent in 1989 at Iona and Sea Islands. Two years of data were collected during April, 1994 and December, 1995 on the mudflats of Sturgeon Bank and Roberts Bank. The data included measurements of physical parameters (salinity and temperature), chemical parameters (pH and oxygen), nutrients (NO_3, NO_2, NH_4 and PO_4) in the water column during flood and ebb tides, benthic chl a, sediment pore water nutrients (NO_3, NO_2, NH_4, and PO_4), and total sediment organic carbon and nitrogen. Our main findings for the water column were that surface oxygen levels in the incoming and outgoing water on Sturgeon Bank remained above 4 ml/L; phytoplankton biomass in the water was lost to benthic animals during a tidal cycle; and nutrients (ammonium) were released from sediment to the water column during a tidal cycle. Algal biomass was lowest at the contamination site (A_0) near the Iona Sewage Treatment Plant outfall but its seasonal fluctuation was apparently parallel to a site on Roberts Bank. This indicated that the two sites have been subjected to the same natural environmental forcing, suggesting that the contamination site is recovering, but its lower biomass points to the suppressing effect of contamination.

Objectives

- Spatial and seasonal (inter-annual as well) variations in biological variables (nutrients and biomass) on the mudflat
- Ecological processes — interaction between the water column and mudflat

Sampling & Data Collected

A) Mudflat sampling (twice a month, April - Sept; once a month, Sept - March)

- Benthic biomass — chl a
- Porewater nutrients: nitrate, ammonium, urea, phosphate
- Organics (not analyzed)

B) Water column (twice a month, April - Sept; once a month, Sept - March)

- Biomass — chl a
- Nutrients: nitrate, ammonium, urea, phosphate
- Suspended load (not analyzed)
- Particulate organics (not analyzed)
- Dissolved oxygen

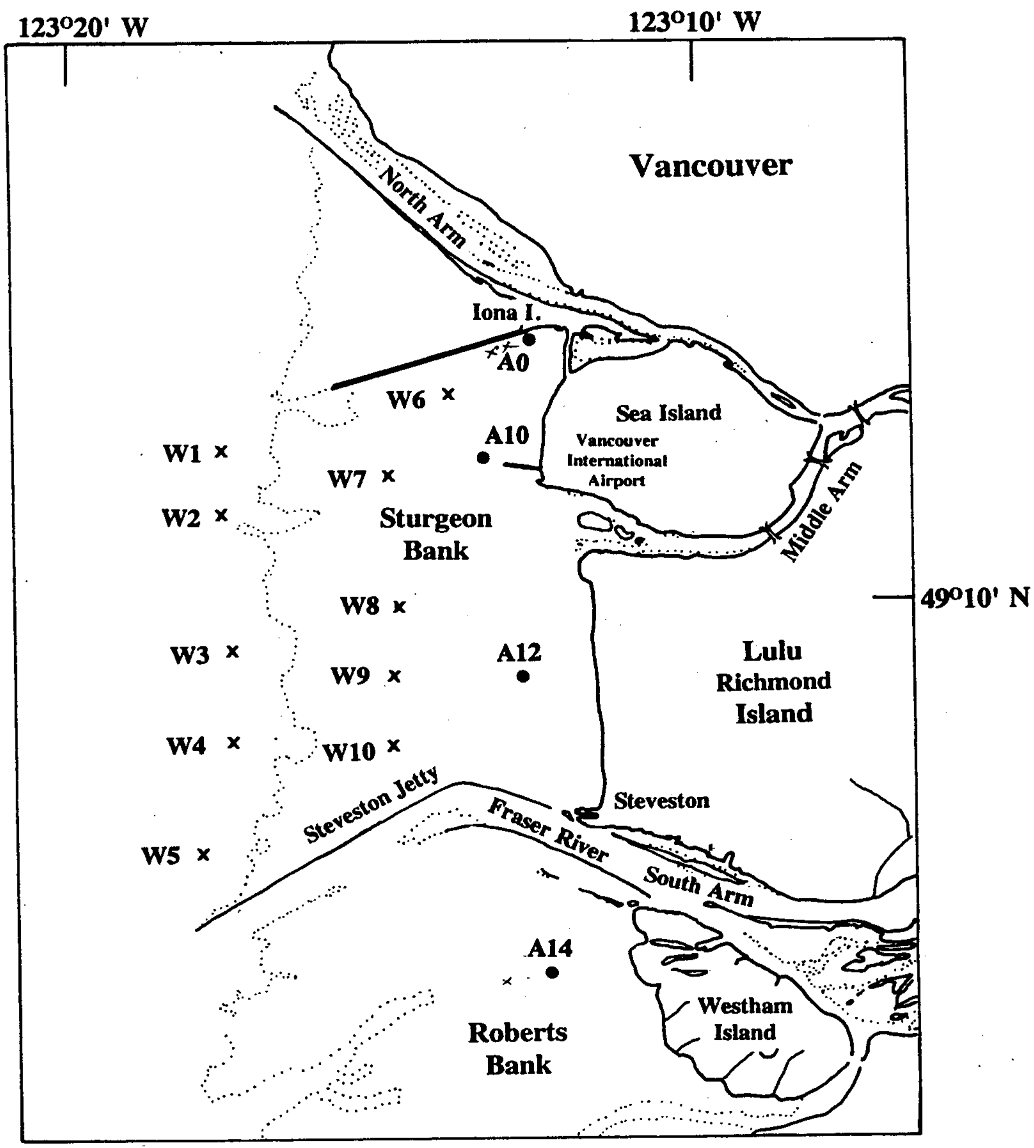
Conclusions

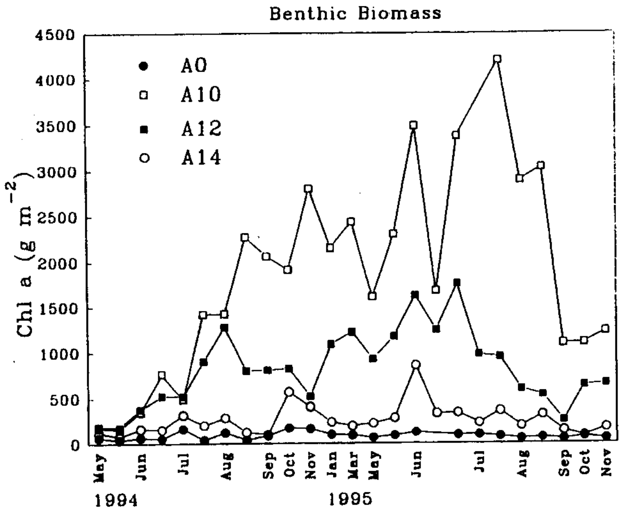
A0 - Contaminated Site

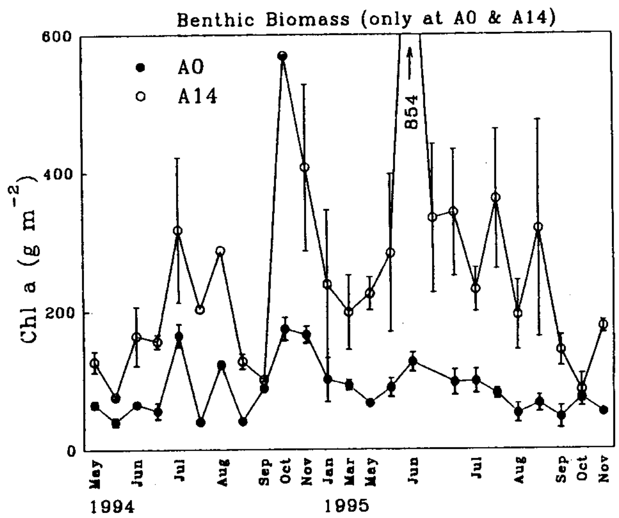
- The lowest chl a biomass
- Parallel temporal change to A14: still under the effect of contamination, but is recovering
- No apparent trend in NH_4 over time — recovery from organics contamination may have passed the fastest stage

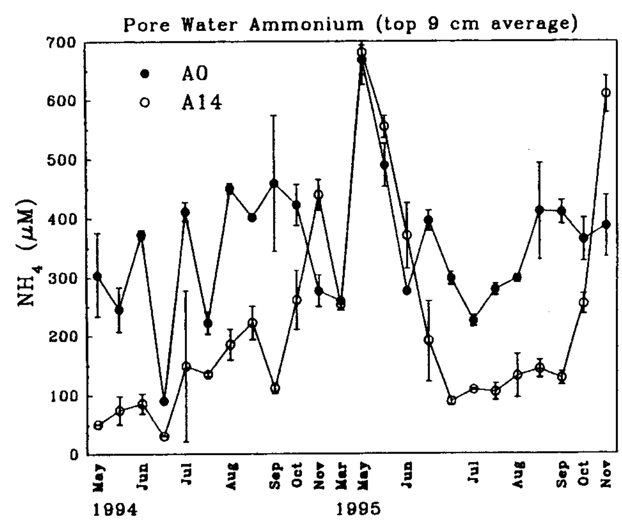
Water Column During a Tidal Cycle

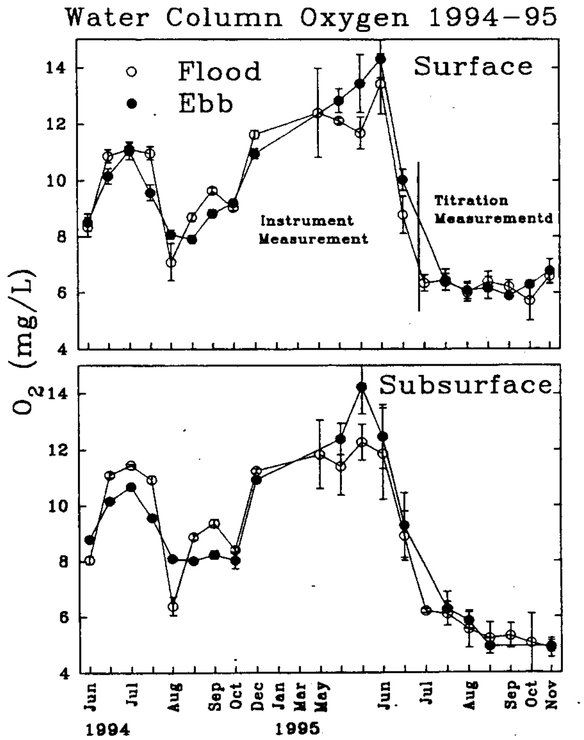
- O_2 is not low enough to be suffocating to juvenile fish
- Chl a loss from the water column — benthic animal feeding
- Nutrients are released from sediments — the Bank is a nutrient source for the Strait of Georgia

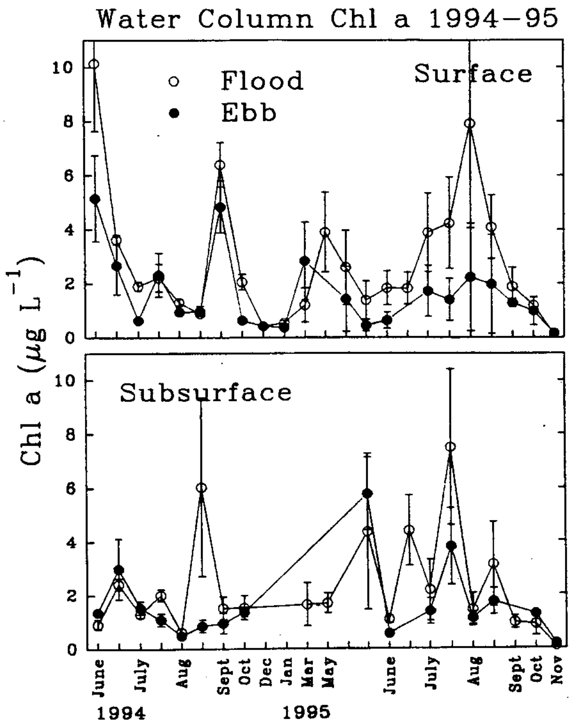

123°20' W
123°10' W
Vancouver
North Arm
Iona I.
A0
W6
Sea Island
A10
Vancouver International Airport
W1
W7
W2
Sturgeon Bank
Middle Arm
49°10' N
W8
W3
A12
W9
Lulu Richmond Island
W4
W10
Steveston Jetty
Steveston
W5
Fraser River
South Arm
A14
Westham Island
Roberts Bank

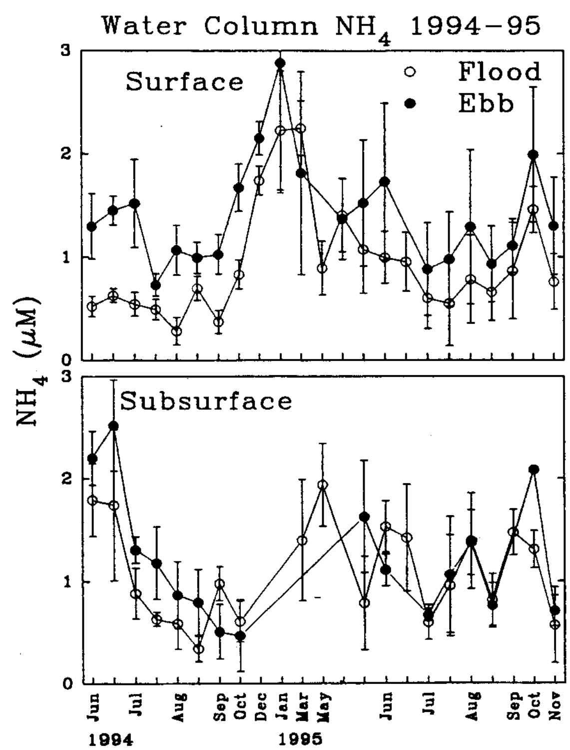

Benthic Biomass
A0
A10
A12
A14
Chl a (g m^{-2})
May Jun Jul Aug Sep Oct Nov Jan Mar May Jun Jul Aug Sep Oct Nov
1994
1995


Benthic Biomass (only at A0 & A14)
A0
A14
854
Chl a (g m^{-2})
May Jun Jul Aug Sep Oct Nov Jan Mar May Jun Jul Aug Sep Oct Nov
1994
1995


Pore Water Ammonium (top 9 cm average)
A0
A14
NH_4 (μM)
May Jun Jul Aug Sep Oct Nov Mar May Jun Jul Aug Sep Oct Nov
1994
1995


Water Column Oxygen 1994-95
Flood
Ebb
Surface
Instrument Measurement
Titration Measurementd
Subsurface
O_2 (mg/L)
Jun Jul Aug Sep Oct Dec Jan Mar May Jun Jul Aug Sep Oct Nov
1994
1995


Water Column Chl a 1994-95
Flood
Ebb
Surface
Subsurface
Chl a ($\mu g\ L^{-1}$)
June July Aug Sept Oct Dec Jan Mar May June July Aug Sept Oct Nov
1994
1995


Water Column NH_4 1994-95
Surface
Flood
Ebb
Subsurface
NH_4 (μM)
Jun Jul Aug Sep Oct Dec Jan Mar May Jun Jul Aug Sep Oct Nov
1994
1995

Intertidal Primary Productivity Following the Diversion of Sewage Effluent on Sturgeon Bank, near Iona Island

L. Ross and P.J. Harrison

Department of Oceanography
University of British Columbia

Abstract

This study looks at the rate of primary productivity in the intertidal area on Sturgeon Bank near Iona Island, as well as the environmental factors that influence it:

- nutrient concentrations;
- solar irradiance;
- water turbidity;
- sewage effluent pollutants; and,
- the abundance and diversity of primary producers.

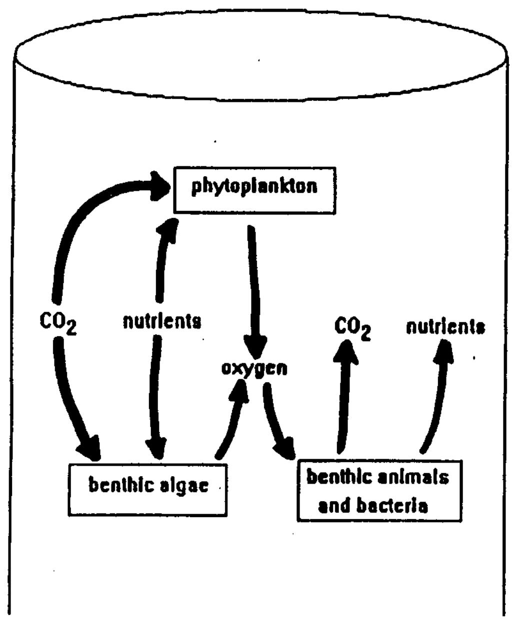
The rate of primary production serves as an indicator of recovery of the phycological populations, namely benthic diatoms and phytoplankton. The net difference of nutrient (ammonium and nitrate) concentrations provide a rate of consumption or production that reiterate the conclusion from the primary productivity results. Benthic chambers were employed for up to 22 hours to create a self-contained, yet natural environment in which the change in the oxygen concentration was measured over the incubation period. Water inside the chambers was stirred with bilge pumps to maintain natural water movement and avoid unnatural stratification. Both photosynthesis and respiration were measured in light chambers and benthic respiration alone from the dark chambers which allowed for the isolation of benthic animal respiration. Sampling was conducted from July to November, 1995, and is planned to continue March to September, 1996. Variability was found between the sampling stations revealing a greater abundance of chlorophyll a at the polluted station than the control. However, the control station showed a greater concentration of nitrate in November and ammonium in August. Productivity was also generally higher at the control site than the polluted site near Iona Island. Results from this project will establish a reference for future studies to use in primary production measurements, as well as determine the change in algal and phytoplankton productivity over a two-year period.

What Do We Want to Know?

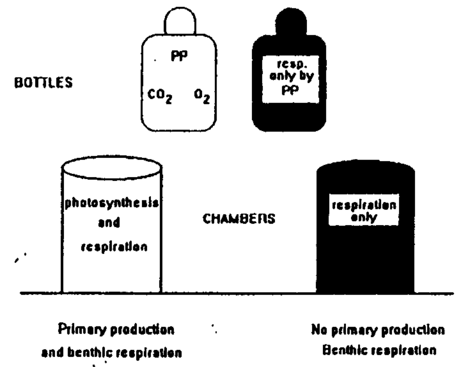
- Does the estimate of primary productivity vary between polluted and unpolluted areas on Sturgeon Bank?
- Does this estimate vary either seasonally or annually?

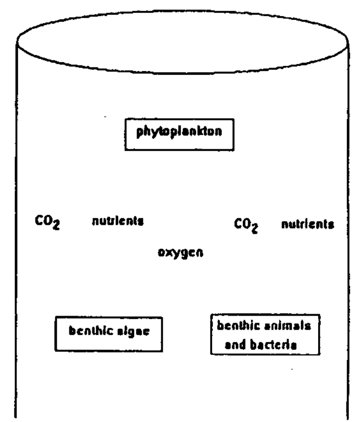
Why Study Primary Productivity?

- sensitive index revealing the rate of production of algal biomass
- algal standing stock is an important food source which influences the entire food web
- indicator of the health of phytoplankton and algal communities
- provides measurements of both photosynthesis and respiration which can be related to secondary production results



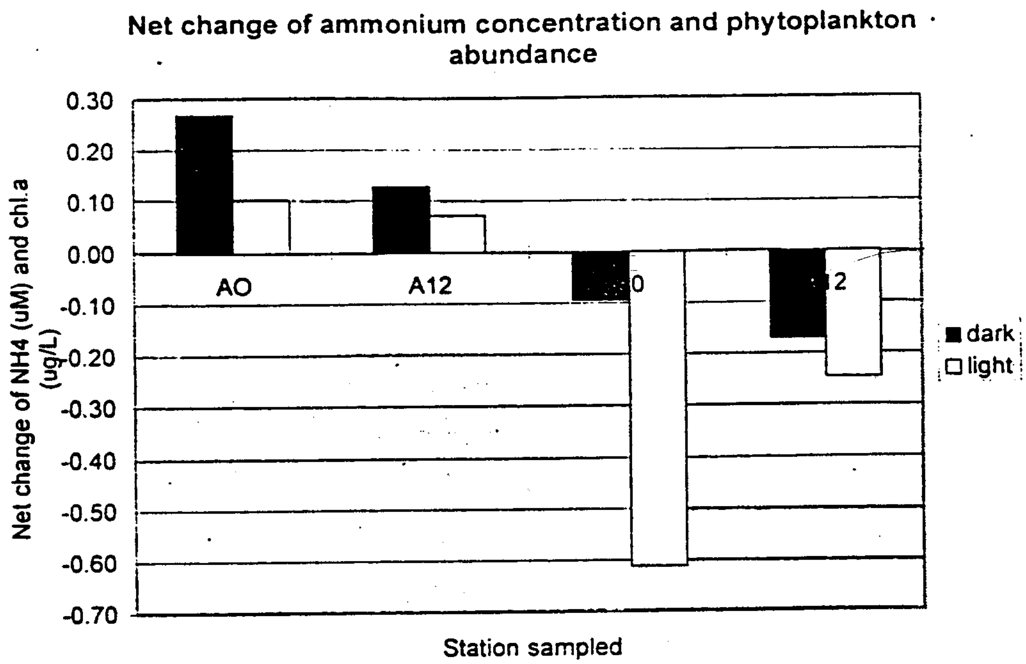
Primary production = increase O2 and decrease nutrients



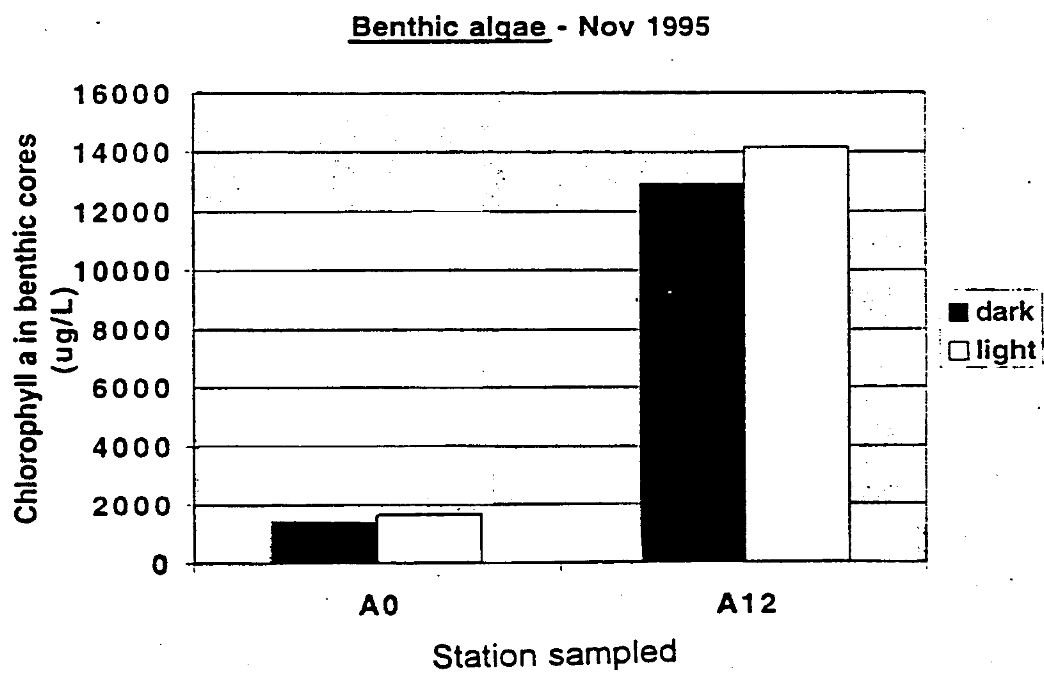


Primary production = increase O2 and decrease nutrients

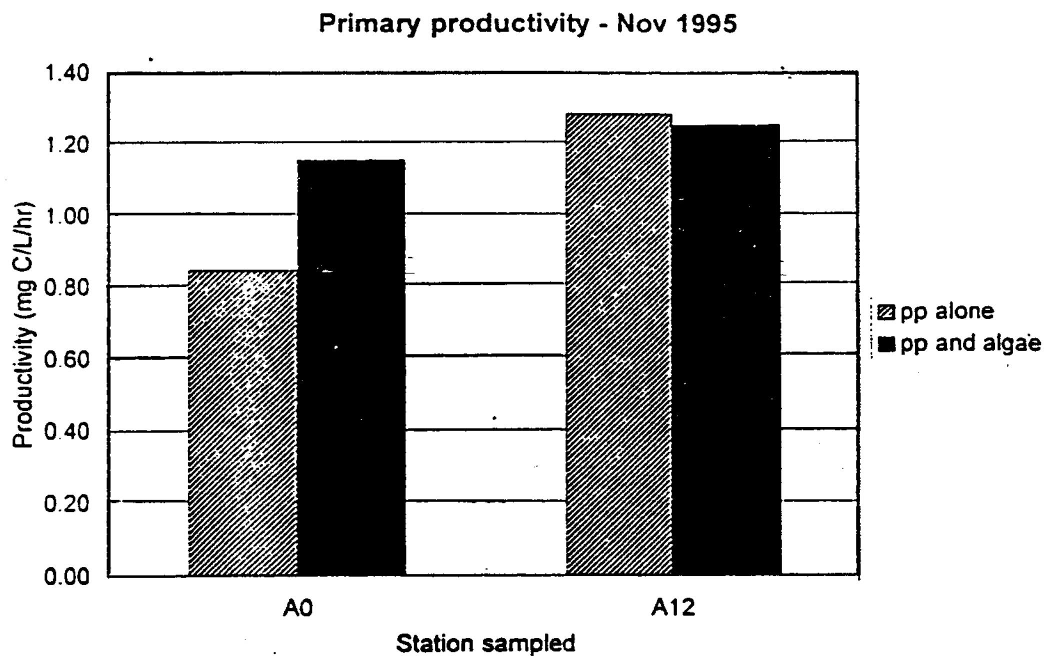
Benthic respiration = decrease O2 and increase nutrients



Net change of ammonium concentration and phytoplankton abundance
Net change of NH4 (uM) and chl.a (ug/L)
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
-0.60
-0.70
AO
A12
dark
light
Station sampled



Benthic algae - Nov 1995
Chlorophyll a in benthic cores (ug/L)
16000
14000
12000
10000
8000
6000
4000
2000
0
A0
A12
dark
light
Station sampled



Summary

- chlorophyll and primary productivity values are both lower at the polluted site than the less contaminated site on Sturgeon Bank
- the contaminated site seems to be an ecologically healthier area
- trends are apparent in seasonal production and will be confirmed with further results as will annual production

Assessing the Relative Bio-Recovery of Select Invertebrate Fauna on an Ecologically Important Tidal Flat, Sturgeon and Roberts Banks, B.C.

J.L. Arvai and P.J. Harrison

Department of Oceanography
University of British Columbia

Abstract

As part of a project to better understand the ecology of Sturgeon and Roberts Banks and the responses of benthic invertebrates to the diversion of sewage effluent, density and secondary production analyses are currently being conducted on two ecologically important indicator species (*Corophium salmonis* [Amphipoda], *Macoma balthica* [Bivalvia]).

Preliminary density data indicated an increase in abundance of these two species at two contaminated sites — one located at the northern tip of Sturgeon Bank adjacent to the Iona Island Sewage Treatment Plant (STP) and the other near the mouth of the South Arm of the Fraser on Roberts Bank. These increases in abundance were in sharp contrast to density measurements taken at two control sites (essentially unaffected by effluent contaminants) located on Sturgeon Bank. In addition, these density analyses clearly indicated that significant benthic recovery has taken place immediately adjacent to the Iona Island STP (a site that was reported to be entirely azoic prior to 1988).

This observation of recovery on Sturgeon Bank is further supported by preliminary data which seems to indicate that additional winter cohorts of *Corophium salmonis* are being supported adjacent to the Iona Island STP and on Roberts Bank, whereas they do not seem to exist at any of the control stations. It is hypothesized that this may be the result of anthropogenic organic loading occurring during the winter months at these two sites. However, it should be noted that these observations are preliminary in nature and will be further examined in extensive cohort analyses.

It is expected that a completed presentation of the results of this project will be available by the summer of 1997.

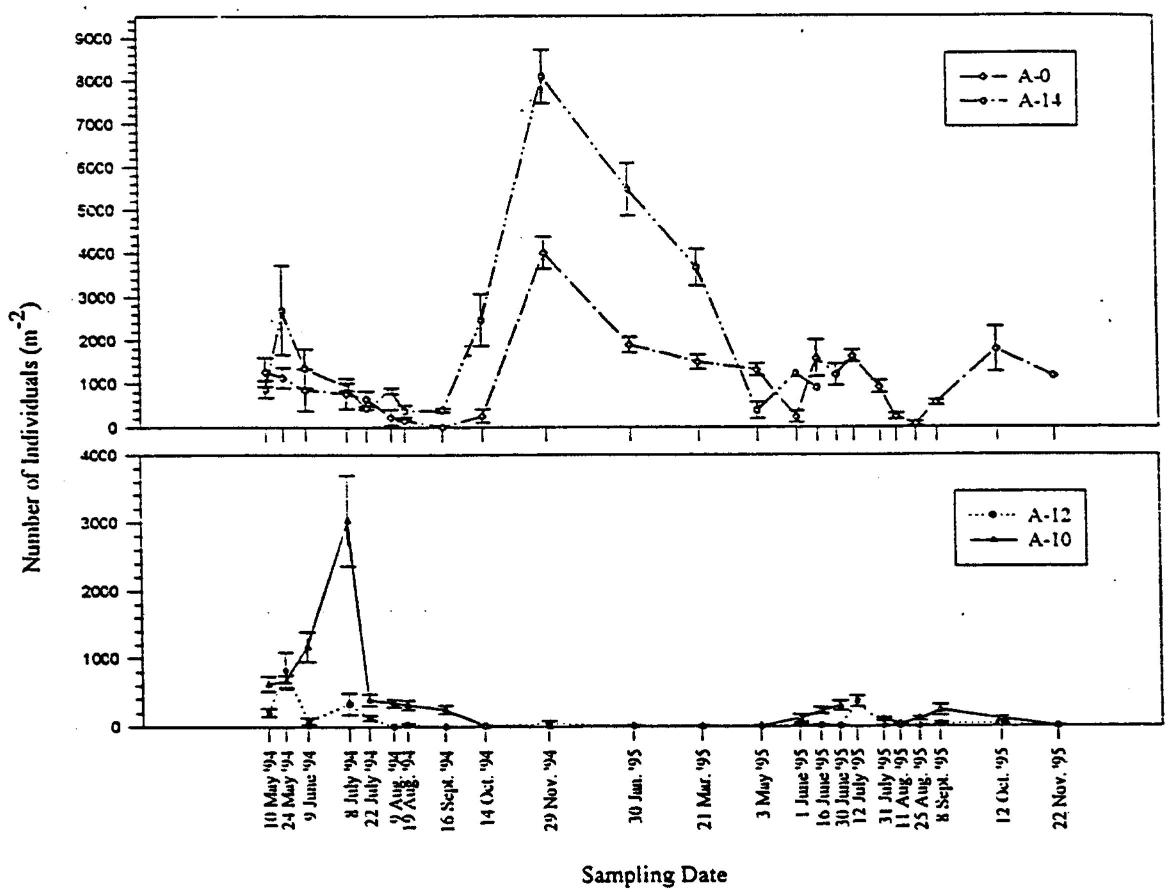
Outline

- Research objective and background information
- Research methods and results to date

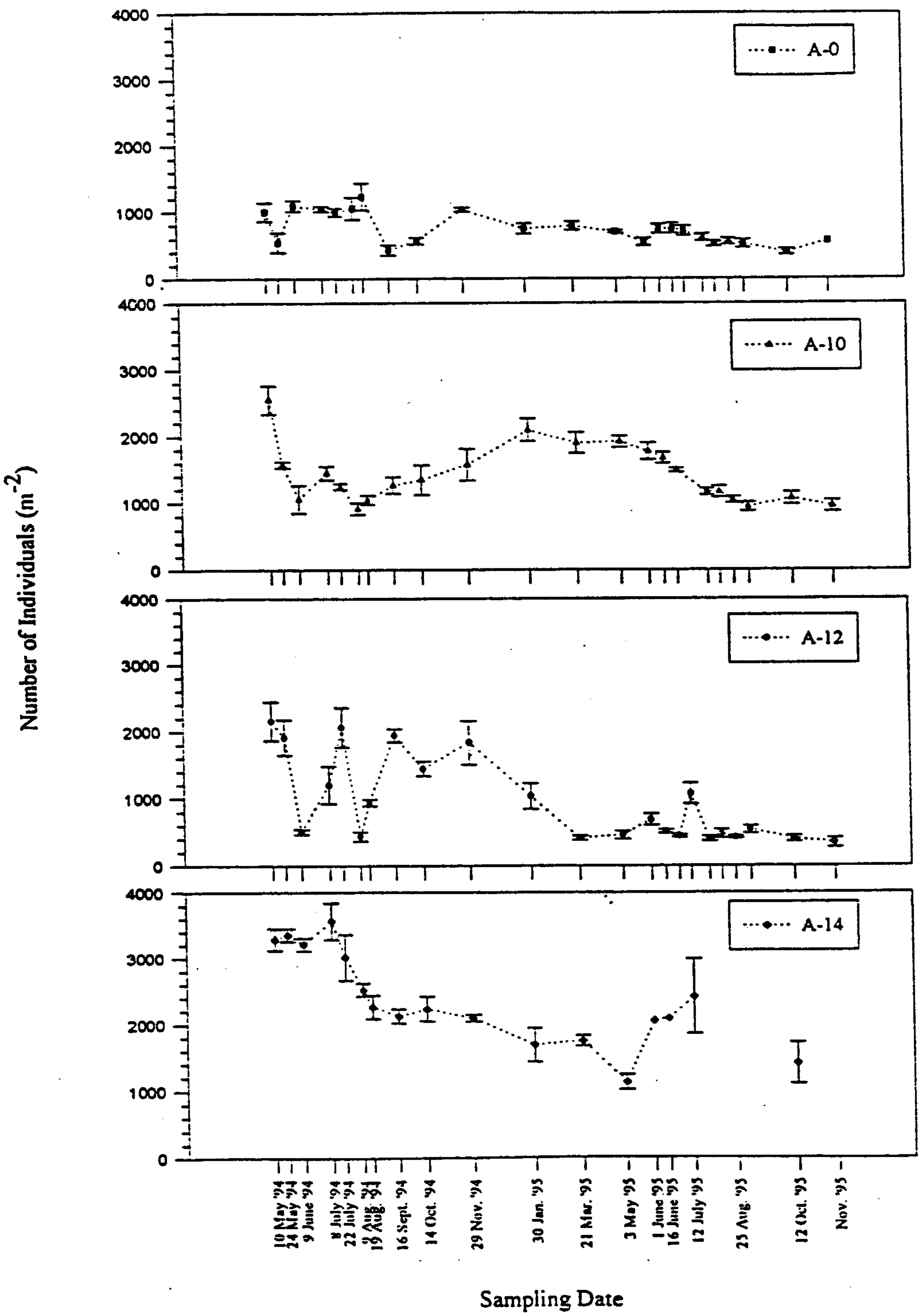
Research Objective and Background Information

- To study the effects of effluent diversion at Iona Island STP on the secondary production of two ecologically important benthic invertebrate indicator species (*Macoma balthica* [Bivalvia], *Corophium salmonis* [Amphipoda]).
- This will be achieved through production rate comparisons of polluted sites with relatively undisturbed control sites.
- The secondary production analysis phase of the project, initiated in May, 1994, and ending August, 1996, involved the sampling of two experimental sites (A0, A14) and two control sites (A10, A12) using standard sampling techniques.
- Collected samples were then analyzed to determine secondary production.

Summary of *Corophium salmonis* density data (number of individuals m^{-2}). Error bars denoted by standard error.

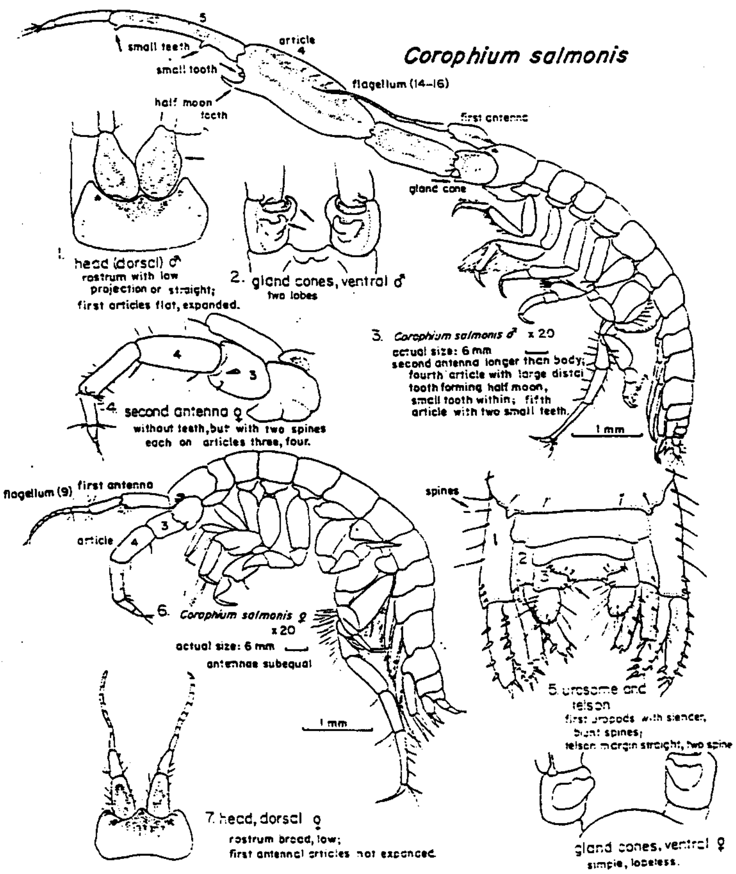


Summary of *Macoma balthica* density data (number of individuals m^{-2}).
Error bars denoted by standard error.

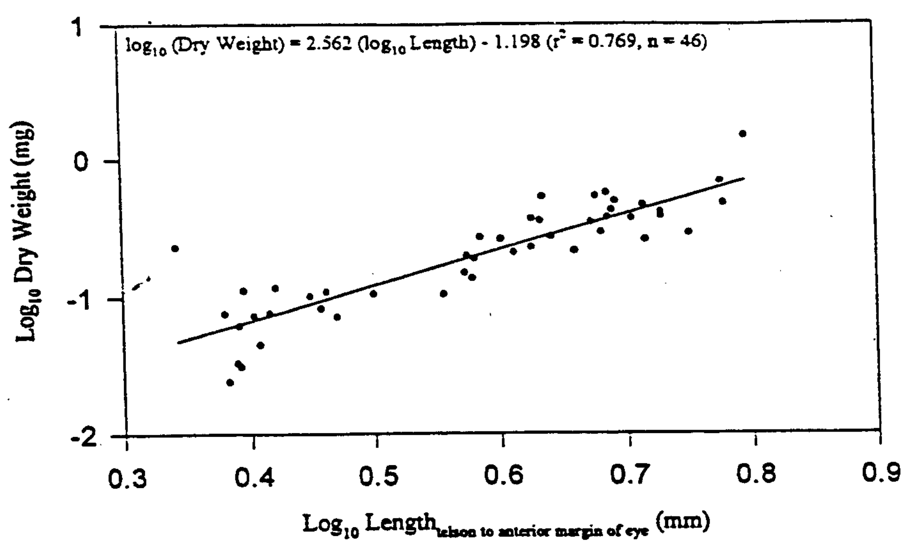


Calculating Secondary Production

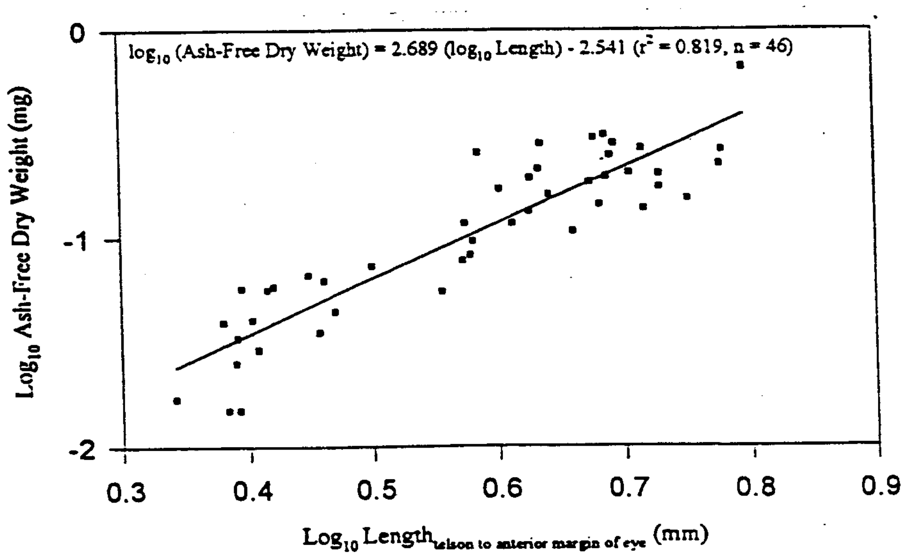
- involved the determination of individual growth rates best expressed in units of change in mean individual weight per unit time.
- due to the complexity of weighing each sampled individual, lengths were measured instead and correlated with body weights.
- change in mean individual weight per unit time was established using length-frequency histograms.
- these histograms also provided information with regard to the number of cohorts present at a location in a given time unit.



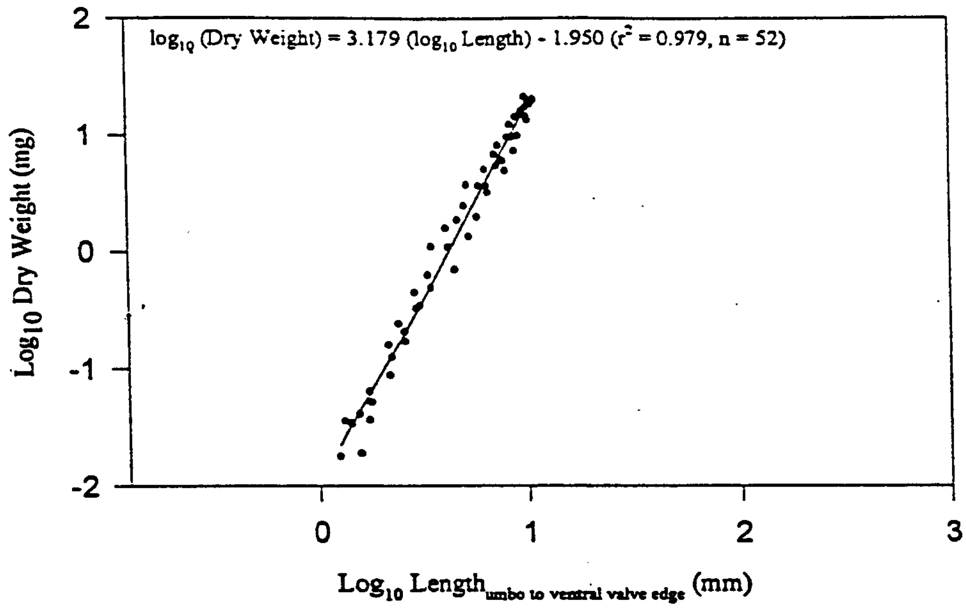
Plot of $\log_{10}$ dry weight on $\log_{10}$ length of *Corophium salmonis*.



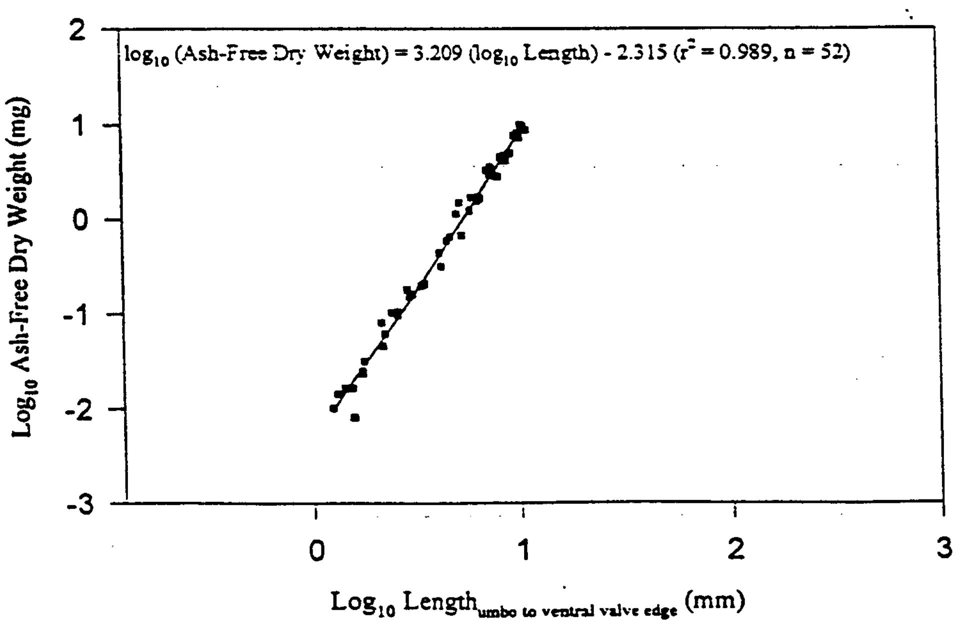
Plot of $\log_{10}$ ash-free dry weight on $\log_{10}$ length of *Corophium salmonis*.



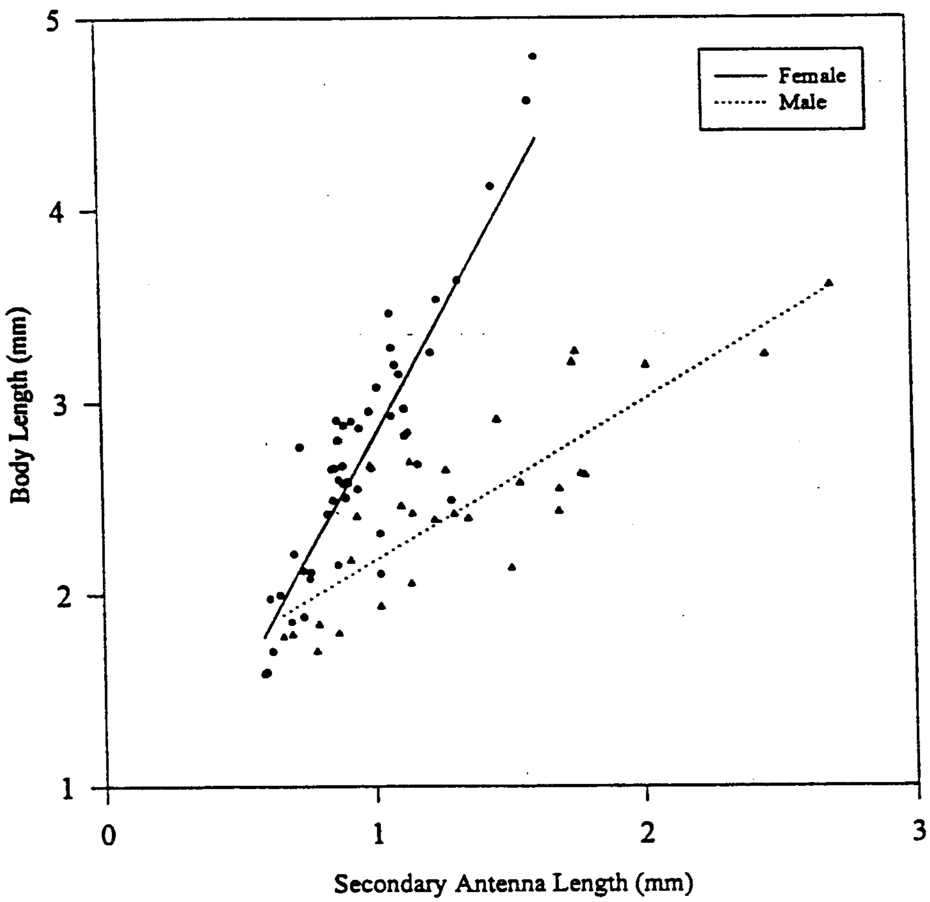
Plot of $\log_{10}$ dry weight on $\log_{10}$ length of *Macoma balthica*.



Plot of $\log_{10}$ ash-free dry weight on $\log_{10}$ length of *Macoma balthica*.

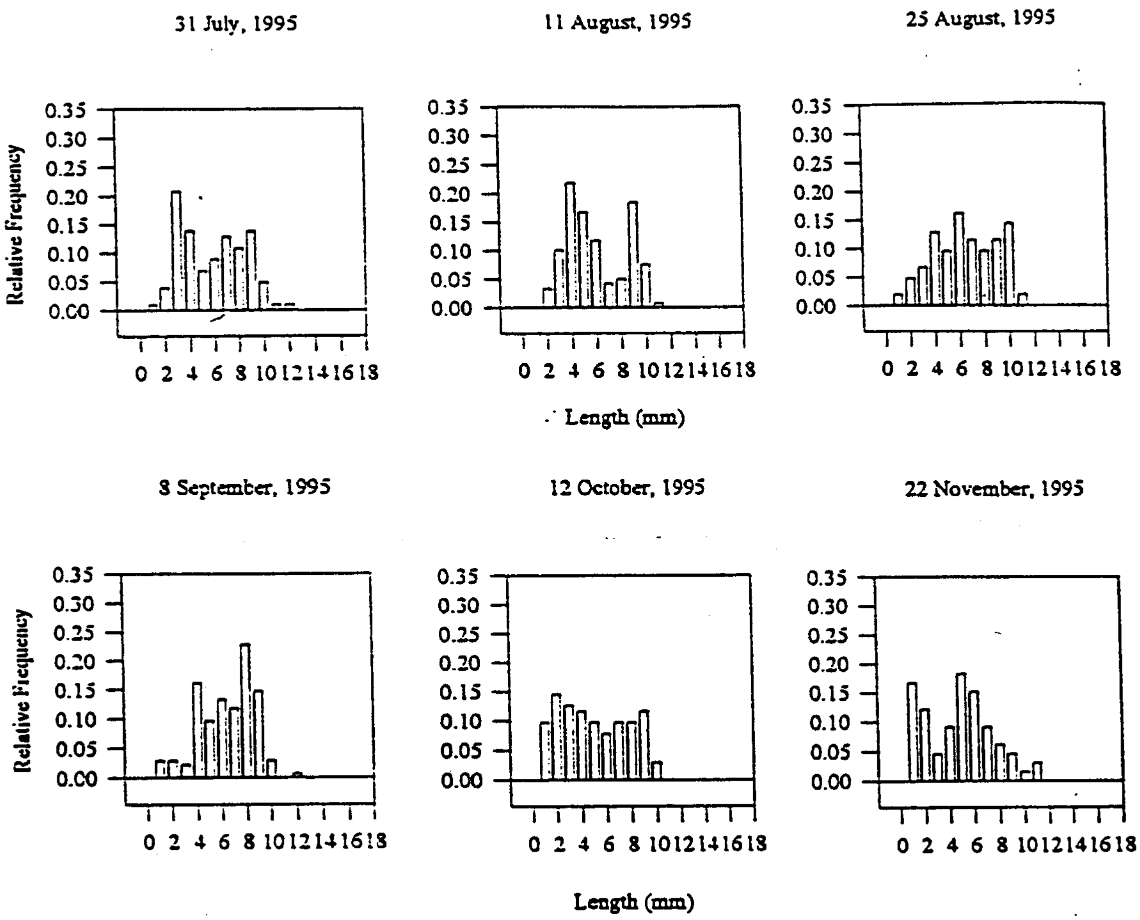


Corophium salmonis male / female secondary antenna length - body length relationship.



Female Body Length (mm) = 2.5103 (Secondary Antenna Length) + 0.2862 (r^2 = 0.7883, n = 50)

Male Body Length (mm) = 0.8333 (Secondary Antenna Length) + 1.3359 (r^2 = 0.7178, n = 30)



Summary of size-frequency data for *Macoma balthica* (Station A-12).

Concluding Remarks

- The fact that organisms are recolonizing Station A0 indicates that some degree of recovery has taken place.
- Preliminary data indicated that organic loading at A0 (and A14) may result in the appearance of an additional cohort of *Corophium salmonis* during the winter months.
- As a result, secondary production values are projected to be higher at the previously polluted stations.
- Potential sediment structure differences between experimental and control sites are as yet unresolved (i.e., sediment grain size fractionation and relative differences in organic content).

Changes in Fish Communities and Water Chemistry after Cessation of Municipal Sewage Discharge near the Iona Island Foreshore, Fraser River Estuary

D.J.H. Nishimura, G.E. Piercy, C.D. Levings, K. Yin and E.R. McGreer

Department of Fisheries and Oceans

Fish abundance, fish diversity and water chemistry were examined seven years after cessation of disposal of sewage effluent into the foreshore area of Sturgeon Bank in the Fraser River estuary. In July and August, 1995, a total of 7,902 fish, comprised of nine species, were captured at six sites along the south side of Iona Jetty. The number of fish observed at the three sites closest to the former outfall was greater than that observed at the three sites furthest from the outfall. A significant difference (ANOVA; $p<0.05$) among sites was observed in the number of fish recorded for all species combined and for selected taxonomic groupings. Temperature, salinity and dissolved oxygen were not significantly different (ANOVA; $p>0.05$) among sites.

A similar study, when sewage effluent was being discharged, was conducted in 1980. Although the number of fish species recorded in 1980 was higher than in 1995, a significant increase (ANOVA; $p<0.01$) in the total number of fish captured was observed in 1995 over the earlier study. Increased abundance was also observed in selected groupings of fish. In 1980, significantly fewer fish were observed at the sites closest to the outfall compared to the outer sites. In contrast, greater numbers of fish and fish species were observed at the sites closest to the former outfall in our study. Of the water chemistry variables measured, only temperature was significantly higher (ANOVA; $p<0.05$) at each site (average of 3.6°C higher) compared to 1980.

Conclusions

Based upon a comparison of the data on fish distribution, abundance and water chemistry pre- and post-cessation of the sewage effluent discharge, it was apparent that the number of fish was significantly greater in an area previously affected by sewage and wastewater effluent. The two sites closest to the former outfall, where very few fish were captured in 1980, showed the greatest improvement. Our study concluded that greater numbers of fish were able to utilize this foreshore area than had been possible when the area had been seriously degraded by the presence of sewage effluent. An overall improvement in fish habitat in the area previously degraded by sewage effluent was also documented.

Shorebird and Invertebrate Interactions

M.A. Sewell[1] and R.W. Elner[2]

[1]*CWS/NSERC Research Chair in Wildlife Ecology*
Simon Fraser University

[2]*Canadian Wildlife Service*
Environment Canada

Each spring, the extensive intertidal mudflats of the Fraser River estuary are a stopover for millions of migratory shorebirds, especially Western Sandpiper (*Calidris mauri*), enroute to breeding grounds in the north. Many of these same birds and their young pass through the area again in the fall. Other migratory shorebirds, such as Dunlin (*Calidris alpina pacifica*) overwinter around the estuary. Infaunal and epifaunal intertidal invertebrates form a prey-base for many shorebirds and, also, fish and crab in the estuary. A series of sediment cores were taken at various sites between Boundary Bay and Westham Island to examine, variously, community composition, relative abundance and spatial and temporal patterns of invertebrates. The macrofaunal (>500 micron) component was numerically dominated by a few species: amphipods (*Corophium* spp.), podocopid ostracods, polychaetes and the gastropod *Batillaria zonalis*. However, the highly patchy spatial distribution of these invertebrates was a major barrier to establishing monitoring protocols and deriving relative abundance estimates. Exclosure and random sampling experiments were performed to assess expected depressions in macrofaunal invertebrate densities during the spring migration period. However, there was little evidence for any reduction in invertebrate numbers due to shorebird predation. The possible reasons were:

1. the scale of patchiness prevented detection of any depression in prey density; and,
2. shorebirds are focusing on meiofaunal (<500 micron), rather than macrofaunal, prey which is the subject of continued study.

Overall, improved statistical and ecological contexts are required before responses to anthropogenic factors (including contaminants) can be reliably monitored and assessed. In particular, further research is required on the biological basis to productivity in the estuary and foodwebs in order to elucidate contaminant pathways and identify biological indicators.

The Winter Ecology of Dunlin (*Calidris alpina pacifica*) in the Fraser River Delta

P. Shepherd

CWS/NSERC Research Chair in Wildlife Ecology
Simon Fraser University Background

Bird populations have long been used as indicators of the health of riverine and estuarine ecosystems. Their position in the food chain makes them vulnerable to the effects of contaminant bioaccumulation, and fluctuations in their populations can be a first indication of problems within an ecosystem. As well, high visibility and the ease with which estuarine bird populations can be monitored makes them good indicators of the effects of effluent clean-up efforts on the one hand, and good predictors of the potential effects of further development on the other.

The Fraser River delta is the largest estuary on Canada's Pacific coast and supports the country's highest densities of waterbirds, shorebirds and raptors in winter, including between 35,000 and 60,000 Dunlin. It is also a key wetland stopover site for many species of migrant birds flying between breeding habitat in Canada, Alaska and Russia and wintering habitat in southern USA and Central and South America. Over one million shorebirds use the Fraser River delta annually, including internationally important populations of Dunlin and Western Sandpipers (*Calidris maurii*).

As with many of the remaining wetlands worldwide, the Fraser River delta is presently experiencing a great deal of pressure due to the rapidly expanding human population around Vancouver and the resulting increases in housing, recreational and industrial development in the area. As well, the river carries effluent from paper mills and agricultural lands throughout the Fraser system out to sea via the delta. Dunlin feed on invertebrates in the sediment and are in turn fed on by many of the species of raptors that winter in the area (Vermeer & Levings, 1977; McEwan & Whitehead, 1984), but we know little about the dynamics of their role in the Fraser River delta ecosystem. Once the ecology of Dunlin in the delta has been studied, mathematical models can be constructed to predict the effects of further human activities on the population, and informed monitoring programs can be generated. The high visibility of these birds in the delta, present from October through April, should in turn make the implementation of such programs relatively simple.

Objectives

This study is using radio telemetry to investigate habitat use, movements, home ranges, and activity budgets of four segments of the Dunlin population (male and female adults and juveniles) with reference to environmental variables (time of day, tide, weather, season). At the same time, we are investigating prey availability and predator interactions with reference to habitat and environmental variables (time of day, tide, weather, season). All of the above data will be integrated into interactive GIS maps using the Arcview II program. Vermeer's (in prep) data on diet will also be incorporated to create a data set that can be used to set up a sentinel species program and to make recommendations for the conservation of wintering shorebirds in the Fraser River delta.

Results to Date

Statistical analysis has not been started yet, but so far some very interesting trends have been noticed. Habitat use appears to be driven by time of day and precipitation to a much greater extent than expected. Due to the nature of winter tidal fluctuations in the delta, a great deal more and a greater diversity of mudflat habitat is available at night than during the day. Since these birds are able to feed at night (Mouritsen, 1994), and since there is less predation at night, it is expected that the Dunlin would choose to forage more at night than during the day, and that they would do so out on the mudflats. The radio-tracking data appears to show that the Dunlin are feeding at night, but that they tend to do so in the adjacent farmers' fields to a much greater extent than expected. Whenever it is raining, or when the wind is above approximately 15 km/h, Dunlin are found feeding in the fields rather than on the flats, but generally only at night. Day/night movements (fields mostly only at night and flats mostly only during the day) are probably driven by predation. Dunlin tend only to be susceptible to avian predators when the tide pushes them up close to the dyke. When they are further out on the flats, they can see predators coming and initiate escape flight. Therefore, it makes sense that they should only choose to feed in the fields at night. The only time I saw the majority of the population in the fields during the day was when the wind was severe (over 25 km/h from the SE).

Since it rains quite a lot here during the winter, the birds spend a good deal of time feeding in the fields. Fresh water falling on the mudflat tends to drive marine invertebrates further down into the sediment, and perhaps out of reach of Dunlin. But fresh water falling on terrestrial habitats tends to bring invertebrates (especially worms) closer to the surface. It is not yet clear which of these two situations is the driving force behind the birds' movements, but an experiment has been initiated looking at differences in available invertebrates in terrestrial vs. marine habitats during day vs. night, and with and without precipitation.

Conservation Applications

It is important to identify all of the habitats used by Dunlin during their life cycle in the delta, and to establish the level and nature of use of each different habitat type. The fact that these birds are feeding in the fields might affect the bioaccumulation of organics, depending on the types of fields the Dunlin use and the fertilization and pest control techniques used by farmers. In order for Dunlin to be useful as a sentinel species for the delta in winter, we need to know how much feeding they're doing in each habitat type so as to be able to attribute any changes in status to the proper cause. Due to its proximity to Vancouver, farmland in the delta is slowly but surely (and not so slowly in some areas) being converted into housing developments, golf courses, etc. Since Dunlin wintering here appear to require terrestrial as well as marine habitat, further development of farmland must first take this into account. This project will provide information on which habitats (both marine and terrestrial) are important to Dunlin.

Reference List

McEwen, E.W., and P.M. Whitehead. 1984. Seasonal changes in body weight and composition of Dunlin (*Calidris alpina*). Can. J. Zool. 62:154-156.

Mouritsen, K.N. 1994. Day and night feeding in Dunlins *Calidris alpina*: choice of habitat, foraging technique and prey. J. Avian Biol. 25:55-62.

Vermeer, K., and C.D. Levings. 1977. Populations, biomass and food habits of ducks on the Fraser Delta intertidal areas, British Columbia. Wildfowl 28:49-60.

Vermeer, K., R.W. Butler and G.E.J. Smith. (in prep). Diets of Dunlins and Western Sandpipers as related to prey availability. Canadian Wildlife Service Report.

Summary of Pollutants and the Intertidal Community Status

P.J. Harrison[1] and R.W. Elner[2]

[1]*University of British Columbia*

[2]*Canadian Wildlife Service*
Environment Canada

Conclusions — Three Areas

1. Iona Island — Unique Opportunity
   - decrease sewage input onto mudflat — follow response
   - missed rapid response (between 1989-94)
   - Our three-year time series may represent mid- or near-end point
   - silver — good tracer for sewage (horizontal distribution)
   - Zn and Hg still high — but small area
   - AO site — recovering as indicated by nutrients, chl a, 1^o and 2^o productivity, fish from previous azoic state
   - benthic invertebrate populations are dynamic and patchy (important implications for monitoring)
   - Dunlin — overwinters — sustainable population — its toxic loadings are good indicator of health of estuary
   - birds may be eating meiofauna (<500 µm)
   - future work should sample meiofauna
2. Mouth of Fraser (A14 Site)
   - metals indicate broader, low level pollution site
   - need good baseline data for this area — before 2^o sewage treatment plants
3. Fraser Estuary Mudflat (Sturgeon Bank, Roberts Bank and Boundary Bay)
   - high stress site (MacDonald Slough, airport, coal port ferry terminal, housing developments
   - need better understanding of basic ecology of mudflat and how pollutants affect area

Deliverables

1. Pollutant Status
   - metals (Hg, Pb, Cd, Zn)
   - sewage tracer - Ag
   - organics - PAHs, OCs
2. Abundance and Distribution
   A. Dominant Primary Producers
      - benthic microalgae
      - marsh grasses

   B. Infaunal Macro/Invertebrates (e.g., *Macoma, Corophium)*

   C. Fish

   D. Birds
      - overwintering Dunlin
3. Estuarine Rate Processes — Influence of Pollutants On

   A. Nutrient Recycling

   B. Primary Productivity

   C. Secondary Productivity

   D. Bird Predation on Benthic Invertebrates

   E. Pollutant Transfer from Sediment to Invertebrates to Birds
4. Recovery of Iona Island Site (Present vs. Past Azoic Site) - Review Chapter - Overview of Recovery
5. Baseline Data for A14 (Mouth of Fraser River) - Before Annacis & Lulu Island Convert to Secondary Treatment
6. Increased understanding of Ecology of Mudflat and its Biogeochemical Processes

Year 3 — Additional Measurements

1. More sampling around A0 to map horizontal and vertical extent of pollution (silver as a sewage tracer)
2. Analyze archived benthic invertebrate samples at A14 (mouth of Fraser River)
3. Measure PAHs and possibly OCs

Future Directions

1. Pollutant Status
   - Fraser estuary mudflat
   - mouth of Fraser River
2. Identification of Components of Food Web
   - role of macrophytes and meiofauna
3. Establish Ecological Reference Point

Knowledge Gaps

- meiofauna (<500 µm)
- Macrophytes
  - role in pollutant uptake and food web transfer
- identification of food web structure (implications for alteration of food web components)
- linkage to biological effects (i.e., significance of contaminant exposure levels to sentinel species such as the Dunlin
- relevance of the Fraser River estuary relative to other estuaries with respect to potential impacts on migratory species
- habitat loss: implications for wildlife use and pollutant exposure (i.e., what habitat will be left for use by wildlife, now and projected, and what will be pollutant exposure regimes, now and projected

General Conclusions

1. rudimentary knowledge of Fraser estuary mudflat
2. focus on mouth of Fraser River for contaminant effects on ecology
3. Boundary Bay — a reference area
4. interactions of large intertidal mudflat with adjacent Strait of Georgia

SUMMARY AND CONCLUSIONS

Included in this section are:

- The material presented by each chair at the end of each session;
- Edited discussion material from each session, as well as discussions that occurred at the final summary session; and,
- Information regarding data gaps and research needs which were identified in the presentation material and/or extracted from the written submissions.

Session 1:
Pulp Mill Issues

Chair: C. Gray and J. Culp

General Conclusions

- Chemical signals (i.e., organochlorine compounds like dioxins/furans) are reduced but still traceable in bed and suspended sediments, in fish, and some aquatic-based wildlife, e.g., eagles, osprey, otters and mink.
- Biological effects appear to be subtle or hidden, or we're not looking at the right endpoints.
  - looked at MFO in peamouth chub (Gibbon's work complete), and Rocky Mountain whitefish (Raymond's work on-going); what does induction mean physiologically?
  - there is a statistically significant depression in osprey productivity, particularly below Kamloops mill; will this impact at the population level? Don't know (Elliott's work completed, but continue embryo/egg sampling to determine impacts).
  - there is measurable toxicity of three chlorophenols (guaicol, catechol, vanillin) to sturgeon (Farrell's work to be completed by next workshop).
  - suspended sediments have a potential to moderate impacts of contaminants, as reflected by MFO induction, from pulp mills (Parrot's work to be completed by next year).
- Effects of nutrients in stimulating benthic community growth still unclear. It seems that turbidity/suspended sediments may be great enough, during non-freshet periods, to inhibit growth.

Questions Raised:

Does benthic community enrichment lead to increased contaminant uptake, and therefore represent more rapid transfer to fish? or,

Does an increase in benthic production create more biomass to dilute uptake? or,

In a eutrophic system are food chains just shorter resulting in less biomagnification?

- By virtue of capture success, peamouth chub represent the best, of several potential sentinel species, for monitoring in the upper Fraser. Even though field data are limited, evidence suggests mill effluents are capable of inducing physiological responses in lab and resident fish species (immature chub).
- With good loading estimates, the models can predict contaminants in both particulate and soluble loading, as well as simulate effects of seasonal hydrology, temperature and suspended sediment concentrations. The model will also plot changes in contaminant concentrations in fish as they age.

Discussion

Johnstone: *A lot of comments on MFO induction. Are we down the wrong path?*

Parrott: *In general, I think MFO is a good indicator of exposure. The problem is extending it beyond identifying that the fish were exposed recently. The relationship of a specific MFO level and a physiological change has not been determined.*

Hall: *I understand that pulp mills add nutrients to their treatment systems whereas STPs are trying to remove it. Why not get this together?*

Gray: *This is done in Quesnel ...*

Gobas: *As new toxicology data becomes available (especially with respect to the complex nature of contaminant mixtures) it needs to be made available for use in some kind of framework for regulators.*

Farrell: *We need to take a more hard-nosed approach: if contaminants kill fish, discharges must be shut off.*

Bendell-Young: *There should be more focus on ecological studies; we need to know the life histories of these fish. There is enough dose-response information.*

Parrott: *Both lab studies and an ecological approach are necessary.*

Culp: *There exists an obvious need for serious thought on synthesis: how to integrate ecosystem and toxicology studies and take the information to the next (management/regulatory) level.*

Data Gaps/Recommendations

- With respect to aquatic-based birds, further research on toxicological implication, particularly on endocrine system endpoints, from chlorinated compounds, as well as others such as nonyl-phenols.
- Need to assess the degree of mobility of peamouth chub.
- Continue to develop near-field evaluation techniques for sites with dramatic seasonal flow changes and habitat differences. Use of chub as sentinel species needs to be restricted to far-field zones until capture success improves.
- Source and pathways for bioaccumulation in eagles and ospreys difficult to establish; seasonal movements of osprey need to be tracked.
- Role of modifying factors in MFO induction (exercise, temperature, particle size/nature) needs to be resolved. Further laboratory induction tests to be made, using black liquor and field sources of sediments.
- No comparative toxicity data for chlorinated phenolics for fish larvae other than white sturgeon.
- Establish a B.C. source of sturgeon, standardized rearing and testing protocol for white sturgeon.
- Cannot evaluate consequences of chlorophenol exposure to sturgeon without relevant environmental chemical concentrations and rate of chemical degradation.
- Life history of white sturgeon must be studied.

Session 2:
Transport and Sedimentation

Chair: G. Lawrence

General Conclusions

The flocculation of biosolids with sediments is an important process, but difficult to model.

- With pulp mills, concentration of contaminants definitely higher downstream than upstream. The main contaminant source is from biosolids.
- The mechanism of contaminant transport is flocculation of biosolids with sediments. In the process of flocculation, biosolids settle out and are deposited leading to a significant reduction in sediment load moving downstream from the pulp mill.
- Modeling of contaminant transport is very difficult. The physics of transport processes are complicated and site-specific, depending on the nature of outfall, location in river, proximity to river bends, turbulence, and temperature.
- The potential for greatest effluent interaction occurs when the Fraser's natural sediments are in approximately the same concentration as the biosolids. Whereabouts downstream this occurs is dependent on the nature of the diffuser.
- Temperature of sediment/biosolid mixture and level of turbulence is very important in the flocculation process.
- Size fractionation may help determine settling rates and to predict where flocs may eventually deposit, but the difficulty with this is that flocs that have formed in the water column and fallen toward the river bed encounter shear forces at the boundary layer which break them apart again.
- During winter low flow periods, deposition occurs just downstream of discharges. During spring freshet, they are picked up again and dragged downstream.
- We're still far from formulating a powerful near-field model; hopefully we have enough information to get some empirical results.

Discussion

Sekela: *Archiving field samples for the future is a good idea, but we have no definite plans yet.*

Gray: *With regard to the flocculation process, aside from Kamloops Lake, do we have sites with contaminated sediment accumulating over periods greater than a year?*

Krishnappan: *During base-flow periods (winter) you can get temporary storage of sediments, even in the middle of river, over a period of 4-6 months, and whether this duration is ecologically significant (how will it effect benthic organisms?) is something we should probably look into.*

Sekela: *I don't think bed sediments are the main problem — in the mainstem, sediment accumulation, at the longest, is on the order of 4-6 months and it is really a fall snapshot. Suspended sediments are more of an issue from a contaminant exposure point of view. The main problem is in winter when natural sediment load drops considerably, contaminant loading remains high and flocculation comes into play.*

Yunker: *It is outside of the FRAP mandate, but we should keep in mind what the impact of the Fraser is on the Straight of Georgia.*

Group: *(no comment)*

Data Gaps/Recommendations

- Studies in estuarine regions; effects of salinity and tides on sediment behaviour.
- New sediment transport algorithm may be incorporated in far-field food chain/bioaccumulation and near-field plume interaction models.
- Interpretation of 1994 bed sediment data continuing; analyses of 1995 samples not yet complete.
- Very fine sediment not included in studies, and organic particles have not been separated, identified or analyzed.
- More sampling stations to obtain higher resolution within the Fraser and Thompson rivers.
- Toxicological implication of contaminants associated with suspended sediments.
- Guidelines/criteria for contaminants associated with suspended sediments; site-specific objectives for the Fraser River.
- Tributary input information.
- More data on contaminant phase partitioning under variable field conditions.

Session 3:
Urban Issues

Chair: K. Hall

General Conclusions

Only one project in this session dealt with point source pollution (Chamber's work on P, N nutrient contributions by direct discharges). The remaining projects are concerned with non-point sources.
Review of projects:

- Kooi:
  - urban status report reviewing runoff and currently active pollution abatement activities.
  - a review of a number of projects, e.g., Urban Runoff Contaminants Project (completed), reveals lack of data on local loading of pollutants as well as need to establish how quality conditions change over storm events, etc. All the data has been collected, and data analyses are in progress. Recommendations are in the near future.
  - combined sewer outflow is concern in Burrard Inlet.
  - numerical documentation of CSO locations exists, as well as GVRD report on CSO volumes.
  - stormwater is a problem and needs to be subtracted out of CSO component to avoid double count for total loadings.
  - stormwater discharge inventory documents 257 discharges in Fraser area with photo records.
  - an initial look at contaminants coming from golf courses.
  - all chemicals from car/truck washes enter stormwaters.
- Chambers:
  - project complete.
  - look at nutrient loadings from primarily pulp mills and municipal STPs; data is limited and variable as P/N monitoring is not a licensing requirement.
  - anthropogenic sources are a small fraction of total nutrient load, but can result in ecological changes due to the high proportion of bioavailable forms of P and N in the effluents.
  - some seasonal segregation of data shows dilution effects, especially for TDP and TDN during high flow periods.
- Farrell:
  - antisapstain (DDAC and IPBC) toxicity studies; (LC 0, 50, 100) on fish and invertebrates of various life stages.
  - work completed with DDAC: white sturgeon are most sensitive; starry flounder and *Neomysis* found to be least sensitive and therefore may not be the most relevant or useful test species.
  - inspite of some uncertainties, present regulatory level for DDAC (700 ppb), suspected to be non-protective for sensitive aquatic species.
- Richardson:
  - looked at urban/agricultural contaminant effects on benthic invertebrate and fish communities of streams plus some microcosm studies relating to stormwaters (looking at impact of metals on invertebrates). Fish assemblages are distinctly different (associated with water quality variability) between sites considered "pristine" and those affected by contaminants.

  - field sampling and lab sorting of organisms complete; continuing the process of identification and numerification of benthic invertebrates, and analyses of data.
  - the information will be combined with Hall's water quality data (Sumas, Brunette, Salmon systems) to look at how benthic invertebrates and fish are affected.
- Belzer:
  - dry and wet deposition of metals and PAHs.
  - study area = west end of Burnaby L; study began Dec. '94 through '95.
  - 30 PAHs identified (Persistent Organic Pollutants on the Priority Substances List); deposition values appear consistent in amounts relative to each other.
  - 22 heavy metals (HMs) identified including Pb, Hg and Cd.
  - chemical analyses of inhalable particulates shows the presence of POPs and Hms.
  - ambient NOx and VOC measurements dominated by motor vehicle emissions.
  - atmospheric data compliments Hall's work and may be useful for loading calculations (trace metals).
  - data collection complete, some analysis remaining (dry deposition).
- Hall:
  - monitoring both ambient conditions as well as stormwater in Brunette system; need to isolate ambient runoff pollutants resulting from direct discharges getting into the system.
  - considerable sediment sampling done, both spatially as well as a temporal relationship over past 20 years.
  - sediment HC data.
  - stormwater runoff can contain high levels of metals and HCs; contaminants are associated with particles.
  - contaminant levels entering waterways are related to impervious land areas and vehicle numbers.
  - source control works (e.g., Pb, CHCs).
  - data is in database; currently analyzing in context of sediment and water quality criteria.
  - work 80% complete, then work on getting out some scientific/technical reports.

Discussion

Gray: *You talked about sediment control to stop toxins from getting into the system. What about dissolved toxins?*

Hall: *A real problem. Need to have regulations.*

Gray: *What kind of indicator would you like to see in Brunette system?*

Hall: *Fish. Cutthroat trout in Still Creek. Get fecal coliform down and promote green space.*

Farrell: *How about **B**est **A**vailable **E**vidence = BAE rather than BAT (Best Available Technology). This is relevant to my study, as there is a definite problem on the Fraser with DDAC (possibly not IPAC). Juvenile sturgeon cannot survive there (because of contaminants), so you would not expect them to be found, but their absence does not mean it is valid to say that my study's results are not relevant. Also, I believe oxygen to probably be the most significant limiting factor to biota, so any toxicity tests considering anthropogenic loading (specifically, for example, in the case of Burnaby Lake) must be related to seasonal hypoxic or anoxic conditions.*

Richardson: *There are communities of organisms in Salmon River Basin and Northshore sites which can be used as references, and there are large predictable deviations (in water chemistry) being found; but the associations between these scenarios is still unclear. I am fairly optimistic that Lower Mainland stream fish/*

invertebrate community structures can be interpreted in the context of land use alterations and water chemistry (i.e., integrate with Ken Hall's work). On a good note, streams of Brunette and Salmon River watersheds still have fair bit of biodiversity.

Belzer: *There is definite atmospheric deposition and it probably contributes to what's showing up in Ken Hall's stream data. How do we interpret data with respect to toxicology; is it useful? Is what we're seeing toxic over brief rainfall periods? What happens over the long term, with flushing-out of watersheds? Are there cumulative effects? PAH source appears primarily to be traffic component; rest of data still needs to be analyzed.*

Chambers: *Most of the point source nutrient load is from pulp mills (as opposed to industry). Absolute contribution small (~ 10%), but not insignificant as anthropogenic sources have high concentrations of bioavailable forms. As for anthropogenic non-point source nutrient loading (forestry, land use changes, agriculture), it's less well understood.*

Kooi: *Monitoring is problematic for urban runoff; it's unpredictable and site-specific. This makes measuring success rate of any abatement programs difficult. In past we've developed guideline documents but we don't know how or where we're going to download all the information; municipalities don't want it as they can't enforce regulations. In future, strong, working partnerships between different levels of government will be required to implement any abatement strategies.*

Hall: *First, related to stormwater monitoring, need to recognize that the system is incredibly physically dynamic with rapid flow changes over few minutes. Think about this when relating types of organisms in systems (John Richardson's work) to contaminant effects. Perhaps this could lead to controlling toxicity by controlling flow. Second, how to communicate science to regulatory agencies? Hold workshops to present data summaries, and to address what policies government should create, and what personal choices must we all make for better ecosystem.*

For myself, I am currently working on synthesis reports (water quality, hydrocarbon, and sediment data). In context of the Brunette system, a BMP and stormwater report is in progress,. Also a working group coordinated by GVRD, (phase II of Liquid Waste Management Plan) to determine goals and actions to be achieved in Brunette watershed. Hans Schreier and I are working on hypertext document putting together three watershed projects, making information accessible to everyone. It will give some "what-if" scenarios, making it more interactive.

Chambers: *What kind of world do we want? With regard to licensing, do we regulate on accepted BAT or acceptable ecological responses? Also an issue is what do we consider as acceptable nutrient conditions in our rivers? What endpoints do we regulate on, e.g., are rivers indeed polluted, or are we just "fertilizing" them to enhance salmon production?*

Gray: *Are urban runoff impact studies done in lower Fraser easily transferable to Kamloops and Prince George regions?*

Hall: *Each watershed is unique as there are seasonal and storm-event differences. Only at gross level can data be transferred; you need to get site-specific.*

Gray: *Were non-point source contaminant fall-out figures from E.P.A.?*

Kooi: *That was just one source, the inventory includes GVRD data as well.*

Hall: *These were Stanley Engineering reports?...To come up with loading values, they use same concentration parameters (e.g., hydrocarbon concentrations) for both residential and industrial/commercial and distinguish between the two by using different runoff coefficients for summer and winter (in winter soils more saturated so they get higher percent runoff).*

MacDonald: *First, Ken Hall's point on water hydrology is very important. The public must be aware that we're losing our river. This had to do with channeling rivers, changing permeability, diverting flow through galvanized pipes (Zn source). There is a natural hydrology and these activities are changing/detracting from it. We have to take steps to protect stream systems. Second, there seems to be lots of PAH measurements being made. I think we need complete suite of PAH measurements, including the parent PAHs (which are usually otherwise put together & added up by EPA toxicity approach). This kind of information is crucial to understand sources and fate of PAHs. Third, what about silver? It is an excellent tracer for sewage.*

Bendell-Young: *From Farrell's study, we know anti-sapstain toxicity to sturgeon is in the parts per billion range. Can we regulate at these low levels; and if not, is industry going to start generating other anti-sapstains to replace what's taken off the market? If this happens, we'll just be doing endless toxicity studies rather than pushing towards drying wood by kiln? Is this a realistic direction we're heading in?*

Mah: *In the case of pentachlorophenol, it took 9 years to take it off the market.*

Farrell: *TCMTB was taken off in a shorter time....*

Mah: *...because of health reasons, not environmental effects...*

Farrell: *I disagree, there was a definite undercurrent of environmental effects. Besides, regardless of species, there is a common mechanism of action on respiratory membranes. In response to Leah (Bendell-Young), let's get off the treadmill by moving away from BAT — it's not the answer. We need to question what we want, what is acceptable for new technology in the long term.*

Data Gaps/Recommendations

- A number of urban runoff projects lack local loading data and how water quality conditions change over storm events.
- No data for biologically active P (SRP) for point sources.
- Nutrient data for tributaries limited to infrequent TP samples (with exception of Nechako and Thompson R.).
- Mandate P/N monitoring as requisite in license issue/renewal for point sources (mills and STPs).
- Possible role of sediments in modulating toxicity of anti-sapstain chemicals.
- Need to establish relevance of testing sturgeon larvae versus other species, i.e., are sturgeon larvae even exposed to the chemicals?
- Stream benthos ordination and cluster analyses data gaps.
- Fish, benthos and mesocosm experimental data consolidated for a publication.
- In order for stream ecosystems data to be useful as baseline reference, need further studies estimating the degree of variation attributable to several different contaminant sources.
- Compare experimental data with field community structure of lower Fraser streams to test predictions that biological patterns may be based on type of environmental perturbation, or channel/catchment characteristics.
- Water quality data needs to be interpreted within the context of toxicity to organisms over both short-term (brief rainfall) and long-term (flushing out of watersheds) weather events.
- An integrated summary report (air, biota, and urban runoff) is recommended for management decisions.
- Successful runoff management requires strong working partnerships between different levels of government.
- Management strategies to remove suspended solids in stormwater will help to control contaminants in urban streams.

Session 4: Agricultural Issues

Chair: H. Schreier

General Conclusions

- Impact of agriculture on stream water quality:
  - excess of nutrients a major problem.
  - stocking density far exceeds absorption capacity of the soils.
  - at certain times of the year, dissolved O_2 depression problematic.
  - ammonia toxicity found in several agricultural streams.
  - Sumas R: impact of agriculture intensification on water quality is leading to extensive stream deterioration in the fall in areas where river is fed by rainwater inputs; in areas of river where groundwater inputs dominate, contamination is highest in August when groundwater inputs are greatest.
  - high nitrate values (above health standards) particularly for unconfined groundwater aquifers.
  - eutrophication: excess P is building up everywhere. When there are stormwater runoffs, sediments get into streams and this leads to eutrophication.
  - in terms of metals, agriculture contributes Zn, and some Cu — pig operations use these as dietary supplements, and as prophylactics.
  - pesticides do have effect on bird life — but limited studies have been done.
- Implications and approaches useful to management:
  - pest management practices.
  - EPS - an index of manure management for farmers.
  - continued efforts to improve on farming practices, but no real solutions. Farmers are fixed in tradition and do not realize they have intensified their practices; need to convince farmers of the value of BMPs.
  - community involvement in setting objectives and monitoring efforts.
  - simulation modeling to forecast into the future.

Discussion

Vadas: *The citizen monitoring programs need to be tested. Some of the organisms are too small.*

Schreier: *The whole area of citizen participation is difficult.*

Johnstone: *How can we start to feed the results to the community before all the papers are completed? How can we do this on an ongoing basis? Is this a reasonable expectation?*

Schreier: *Initially, communities were not interested. But a constant feed of information to them helps. In Langley, they are now working with the community management. Langley is setting bylaws based on these studies.*

Hall: *Cooperation with Burnaby is now building; both with stormwater management and flood control.*

Chambers: *What are typical P, N application rates in the area?*

Schreier: *The surplus is in the range of 50 - 150 kg/ha. Application rates are 25 - 30 kg/ha for fertilizer, but it's mostly animal stuff that's the excess.*

Chambers: *What percent of application (not the excess) of fertilizer/manure do you estimate is lost to receiving waterbodies?*

Schreier: *We use coefficients: 0.3 for N, 0.2 for P. These values are for the excess, not the applied.*

Compared to the Prairies (<1 - 5% for both N, P), the application rates are much higher in the lower Fraser Valley, and about 1/3 of the nutrients are from fertilizer, rest from manure.

Landucci: *Are wood chips used in hobby farms, and the potential for leaching into streams and ditches, a problem?*

Schreier: *Probably. We haven't examined the wood chip issue, but we did wind-shield survey and located each hobby farm by bicycle — we found most of them to be small lots on poor agricultural land and poorly managed. This leads to very high concentrations along buffer zones to the river. This is particularly problematic to the Salmon watershed as most of the middle of the Salmon is unconfined groundwater aquifer, coarse gravel, so inputs directly affect the river.*

Farrell: *Your model is commendable, but in the long term, might it be misused? The computer predictions and computer-generated delivery decisions mean that you've set some thresholds and/or created the environment in which we can expand, based on what the model assumes to be okay. So we test your model, but then this leaves room for violating the 5% population growth scenario permitted by the model. How can you protect against this?*

Schreier: *Our model isn't static, it changes with more information. We get managers' feedback and make necessary modifications. This just requires educating people that this technology is useful, but that it must be used with caution. We need to look further into the future and create "what-if" scenarios that can work as shock-tactics (like the 5% population growth) by presenting several scenarios from the conservative to the extreme, with the likely reality somewhere in between.*

Farrell: *You do have a rate limiting factor like the 2.5 stocking density. The model needs this kind of warning measure, check, built in for various other aspects.*

Schreier: *The only other thing is you can use multiple indices. For example, look at N, water use, stocking density, impervious areas, etc., to make people see that they are all inter-related: that one index can serve to warn for the others.*

Krishnappan: *Did you make estimates of effects of improvements in farming practices?*

Schreier: *No, we're not there yet. This is something Pat Brisbane and George Derksen looked at in their BMPs model.*

Krishnappan: *This should be done with your model — given management practice improvements, how will the scenarios change.*

Schreier: *I agree.*

Data Gaps/Recommendations

- BMPs. Nutrient modeling shows it is possible to improve on the excess with better management. Manure processing: improve storage and timing of application, reduce fertilizer use, develop buffer zones.
- Effects of agricultural pollutants on amphibians; proposed study March 1996 - 1998.
- Ecosystem objective-setting should be done with active community participation, e.g., Salmon R. watershed.

- Citizens can and should be involved in active monitoring of the biota. This is possible without compromising scientific rigour, and still appeasing the public.
- The impact of agricultural pesticides on bird mortality needs further study to resolve any associations.
- Concentration of livestock is a problem, and manure application must be addressed.
- Need greater efforts in public education. Integrated watersheds projects in hypertext format to display and communicate research results to public.

Session 5:
Biological Indicators

Chair: T. Tuominen

General Conclusions

- Work that has been completed:
  - compiled data on various resident fish species of Fraser Basin; good source of background data on fish populations that were not previously available.
  - survey of the status of terrestrial and aquatic ecosystem components within Salmon and Nicola rivers, relative to different riparian vegetation characteristics and products are known:
    1. Fish database available electronically; and,
    2. Aquatic and riparian ecosystem information can be used to develop indicators for ecosystem objectives.
- Ongoing studies:

A. Objective of studies is to investigate resident fish as indicators of contaminant exposure and effects.

Findings thus far:

- differences in tissue contaminant levels in peamouth chub and mountain whitefish.
- differences in contaminant levels among different areas within the basin.
- differences between liver and muscle levels in whitefish and chub.
- in general, contaminant levels very low.
  - HAI (Health Assessment Index), indicated differences in fish condition throughout the basin.
  - Factors other than contaminants appear to account for the variability in HAI.
- whitefish is one fish considered as an indicator species, but some potential confounding factors exist including its variable range of movement, and potentially different genetic populations in tributaries.
- other resident fish (redside shiner, squawfish) may have less movement and thus may be good indicator species.

B. Toxaphene levels in burbot liver are being measured in six lakes in the Fraser system - levels of toxaphene in burbot liver are higher than current consumption guideline, for five Fraser Basin lakes (same lakes as those in Rob MacDonald’s work on sediment cores).

- predictive capabilities of benthic macroinvertebrate community structure program utilising reference condition approach still going through testing period.

End products of projects include:

- status report of resident fish condition and contaminants assessment.
- management software package or model utilising benthic macroinvertebrate reference condition concept which will flag disturbances to the aquatic ecosystem.
- database and knowledge of current status of benthic community in relation to the various physical, geographical and chemical factors.

Discussion

Elner: *Where will studies on fish indicators lead?*

Tuominen: *I expect in the future we will use a collection of indicators. Fish give good exposure indications; this helps understand both ecosystem and human health.*

Elner: *Vadas' work suggests we don't have the ecology-work background we need before setting up indicators.*

Tuominen: *We don't understand all the causes of the stress, but it does indicate stress and gives us a baseline. It is a tool! It's not something (this indicator monitoring) that you have to use every year.*

In the monitoring, we are looking at undisturbed areas to provide a reference for comparing with disturbed areas.

Data Gaps/Recommendations

- Use resident fish condition and contaminants assessment data in Environmental Effects Monitoring Program for pulp and paper mills on Fraser R.
- Identify contaminant sources, non-toxic levels in fish for guidelines information, and migratory patterns/life histories of fish.
- Expand contaminant classes to include non-ionic surfactants.
- Elucidate relationships between HAI and other stressors.
- Confirmation and QA work on histology and HAI components required.
- Suggest further exploration of burbot study findings: reasons for north-south distribution of levels (i.e., north has higher levels); and the role of the food-chain in the differences in contaminant levels.
- Analyse for other contaminants in burbot that were collected from the basin lakes.
- Assessment of human impacts on aquatic and riparian ecosystems through further examinations of several biological parameters.
- Establishment of biological indicators may be improved by increasing spatio-temporal replication.
- Further refinement of benthic macroinvertebrate reference condition model; inclusion of data collection along impairment gradients such as logging, mining and agriculture.
- Adoption of model by province and other agencies for test period with relevant practitioners.
- Investigate the geographic relevance of model, i.e., how applicable is it to other areas in province with similar geographic and ecological attributes.

Session 6:
Estuary Issues

Chair: P. Harrison

Study started in mid-1994 through 1995 (only full year's data) and continues through fall 1996.

Study looked at three sites:

1. Iona; A0 = specific point contaminated site.
2. Mouth of the Fraser R., A14 = reference site.
3. Fraser Estuary Mudflat (Sturgeon Bank, Roberts Bank and Boundary Bay).

- Work covers new data on nutrient cycling, primary production, formation of nutrients, pore-waters, cohort analyses for secondary production, pollutant transfer from sediments to invertebrates to birds, and bird predation on invertebrates; no rate measurements have been made.
- By combining current data from the various estuary studies with historical data from the literature, it will be possible to get some idea of Iona recovery.
- We need more work to better understand the ecology of the mudflat.

1. Iona

- In 1988 sewage input into mudflat halted — a unique opportunity to follow the response/recovery.
- Silver (Ag) is a good tracer of sewage.
- Zn and Hg are still high, especially Hg, is very high.
- Previously anoxic and azoic A0 site is recovering as indicated by nutrients, chl a, primary and secondary production, and fish.
- Benthic invertebrate populations in intertidal mudflats are dynamic and this could have some implications for monitoring programs (i.e., the size of the program, budget and sampling sizes).
- Dunlin may be good indicator species as they overwinter in the area, have sustainable populations, and their toxic loads are good indicators of estuary health.
- Year 3 (1996) will involve more sampling around A0.

2. Mouth of Fraser

- Metal concentrations indicate broader, low levels of pollution.
- Need good baseline data for site A14, before Annacis and Lulu Island convert to secondary STPs.

3. Fraser Estuary Mudflat (Sturgeon Bank, Roberts Bank and Boundary Bay)

- Boundary Bay relatively pristine (with regard to metals) and may serve as good reference site.
- High stress area (MacDonald Slough, airport, coal port ferry terminal, housing developments).
- Need a better understanding of basic ecology of mudflat and how pollutants affect the area.

Deliverables:

1) Pollutant Status:
   - metals (Hg, Pb, Cd, Zn)
   - sewage tracer - Ag
   - organics - PAHs, OCs

2) Abundance and Distribution:
   a) Dominant Primary Producers
      – benthic algae
      – marsh grasses
   b) Infaunal Macro/Invertebrates (e.g., *Macoma, Corophium*)
   c) Fish
   d) Birds - overwintering dunlin
3) Estuarine Rate Processes - Influence of pollutants on:
   a) Nutrient Cycling
   b) Primary Productivity
   c) Secondary Productivity
   d) Bird Predation on Benthic Invertebrates
   e) Pollutant Transfer from Sediment to Invertebrates to Birds
4) Recovery of Iona Island Site (Present vs. Past Azoic Site) - review chapter - overview of recovery
5) Baseline Data for A14 (Mouth of Fraser River) - before Annacis and Lulu Island convert to secondary treatment
6) Increased understanding of ecology of mudflat and its biochemical processes

Year 3 - Additional Measurements

1) More sampling around A0 to map horizontal and vertical extent of pollution (silver as a sewage tracer).
2) Analyze archived benthic invertebrate samples at A14 (mouth of Fraser River).
3) Measure PAHs and possibly OCs.

General Conclusions

1) Rudimentary knowledge of Fraser estuary mudflat.
2) Focus on mouth of Fraser River for contaminant effects on ecology.
3) Boundary Bay - a reference area.
4) Interactions of large intertidal mudflat with adjacent Strait of Georgia.

Data Gaps/Recommendations

- Unfortunately missed the rapid response (1989 - 1994) due to budget constraints; data represents more mid to end-point series along time line.
- Areas deserving more research:
  – Meiofauna (<500 µm).
  – Macrophytes - role in pollutant uptake and food web transfer.
  – Identification of food web structure on the mudflats.
    * implications for alteration of food web components.
    * how important is meiofauna (< 500 µm) to bird feeding?
  – Linkages to biological effects:

    - * significance of contaminant exposure levels to sentinel species such as the dunlin; and,
    - * how are contaminants moving up the food chain.
  - – Relevance of Fraser River estuary, relative to other estuaries, with respect to potential impacts on migratory species.
  - – Relative effects of fresh water falling on mudflats or fields, and driving marine invertebrates down or terrestrial invertebrates up, and how important these effects are on birds' behaviour.
  - – Habitat loss:
    - * extent of habitat loss;
    - * implications for wildlife use and pollutant exposure;
    - * what habitat will be left for use by wildlife, now and projected; and,
    - * what will be pollutant exposure regimes, now and projected.
  - – Identify all dunlin habitats during a life cycle, and establish the nature and use of each habitat type.
  - – Samples to be collected for Rob MacDonald for PAH analyses; organochlorines also need to be looked at.
  - – Take more samples at A0 and get horizontal distribution of silver to complement vertical profiles.
  - – Benthic samples have been archived at A14 (reference site) — need to coordinate with someone else to analyze data this summer and thereby provide baseline information.
- Focus on biogeochemistry and ecology of Fraser estuary mudflat and mouth of Fraser River.
- Recovery of Iona Island Site (present vs. past azoic site) - review chapter - overview of recovery.

Discussion

Hall: *Is there any info on vertical distribution near Iona?*

Harrison: *Gordon has done some core samples.*

Hall: *Has anybody talked about the application of stable isotopes, e.g., carbon?*

Harrison: *Gordon found silver the best.*

Bendell-Young: *Is the marsh a sink for contaminants?*

Harrison: *With the little sampling we have done, I don't think we can answer that.*

Hall: *Check the FREMP research workshops.*

Unrecorded Speaker: *Will the contaminants come back to the surface?*

Harrison: *It will vary with texture. Winter storms affect this.*

Gray to Harrison: *Dependence of migratory waterfowl on estuarine system - will there be any difficulty linking information from reference sites to other sites in the estuary.*

Shepherd: *Bird movement can be tracked with radio.*

Gray: *Will we ever get the location of the prey species?*

Shepherd: *There is sediment data, but little vegetation data.*

Harrison: *Can other birds be used?*

Shepherd: *Dunlin are the most practical.*

Gray: *Comment on contaminants/nutrients from Fraser?*

Harrison: *This could be an important source of nitrogen to the Strait, i.e., the Strait feeds the mudflat. Not much nitrogen comes down the river. We would have to look at nutrients.*

Levings: *In favour of more work* - *we know little about certain species and loss of habitat.*

Harrison: *At the BC/Washington conference, habitat loss was the main issue.*

Gray: *Do mudflats act as a sink to STP metals.*

Bendell-Young: *It is acting as a sink or trap, I think.*

Gray: *It would be interesting to do a mass balance.*

Bendell-Young: *Basic ecology of these birds helps a lot with other parts of biogeochemistry.*

Unrecorded Speaker: *Is there enough manganese getting in (from gasoline) to increase manganese oxide movement in the river?*

Hall: *This has to be studied* - *both in lab and field. There was a poster paper on this at SETAC conference.*