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CONTROL OF BLACK FLIES IN THE ATHABASCA RIVER

TECHNICAL REPORT

An Interdisciplinary Study For The Chemical Control Of *Simulium arcticum* Malloch in Relation To The Bionomics Of Biting Flies In The Protection Of Human, Animal, And Industrial Resources And Its Impact On The Aquatic Environment

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FOREWORD

This report was prepared on behalf of the Alberta Black Fly Coordinating Committee for the Pollution Control Division of Alberta Environment to consolidate the results of research on black flies and their control in the County of Athabasca and Improvement District 18.

The research program was outlined, organized, and approved 19 December 1973 as Agriculture Canada Research Branch Program 14.2.6. It was conducted by the Agriculture Canada Research Station, Lethbridge, the Veterinary Services Division of Alberta Agriculture, the Pesticide Chemicals Branch of Alberta Environment, the Fish and Wildlife Division of Alberta Lands and Forests, the Earth Sciences Branch of the Alberta Research Council, the Freshwater Institute of Environment Canada, Winnipeg, and the Agriculture Canada Research Station, Saskatoon. The program was adopted by the Alberta Black Fly Coordinating Committee on 8 January 1974 with subsequent financial support from the Government of Alberta.

The Alberta Black Fly Coordinating Committee coordinated the support of the Agriculture Canada Research Branch; Alberta Agriculture; Alberta Environment; Alberta Research Council; the County of Athabasca; and Environment Canada Freshwater Institute, Winnipeg.

Numerous individuals associated with the participating agencies, but not mentioned by name, have contributed substantially in facilitating various administrative and operational aspects of the program. The support of all these individuals is gratefully acknowledged.

A further publication 'Control of Black Flies in the Athabasca River: Evaluation and Recommendations' is based on this document.

REPORT ACCEPTED BY THE

ALBERTA BLACK FLY COORDINATING COMMITTEE*

ALBERTA ENVIRONMENT

28 November 1979

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* Appointed by Deputy Minister, Alberta Environment, 31 December 1975

† Alternates for 1979.

TERMS OF REFERENCE OF COMMITTEE

30 January 1976

In view of:

i) various *ad hoc* committees that have met since 1964 and the formation of the present committee in 1973;

ii) the plan for the period 1974-76 to develop 3 years of comparable data, including experimental larviciding of the Athabasca river with methoxychlor through cooperative efforts of the various agencies and experts involved;

iii) and the need to develop a scientific basis for the technical solution of the black fly problem in the Athabasca and other northern areas important to economic and industrial development;

And:

i) in accordance with the objectives and activities since 1963 in response to the need for solution of problems of black flies;

ii) and in recognition that, although research into black fly control and livestock protection has been conducted in Alberta and throughout Canada over past decades, a concentrated coordinated multi-disciplinary interagency approach to programs is required;

It is recommended that terms of reference for the Alberta Black Fly Coordinating Committee to achieve the objective of solving problems of black flies are:

(1) to assess and define problems of black flies and to advise on priorities for actions;

(2) To prepare program proposals on research and control procedures and to present them to appropriate agencies in the Government of Alberta;

(3) To provide liaison, advice, and coordination in planning and operations between levels of government and between agencies concerned;

(4) And to review on-going programs on a regular basis and to provide progress reports and recommendations on solutions of problems to the Government of Alberta.

HISTORICAL REVIEW OF BLACK FLY PROBLEMS, 1962-1972

Biting flies, and especially black flies, have been a long-standing prevailing problem for farmers in the Athabasca region of Alberta. Although they were always particularly troublesome to man, they were accepted as a natural hazard in the early development of agriculture in the area.

At that time, agricultural enterprises were primarily based on cropping practices. Under cultivation, however, most soils in the area were found to be low in organic matter so that rotations were necessary to include up to 60% of cropping in the form of forage production. This requirement, in addition to the uncertainty of cereal grain crops maturing during short frost-free periods, was a major incentive for the establishment and expansion of livestock production as an increasingly important agricultural enterprise for farmers. Furthermore, cattle raising had economic potential in utilizing native roughages on river slopes, ridges, muskegs, lake shores, and meadows between mixed conifers and deciduous bluffs as a pasture resource in addition to cultivated pastures and crops.

Expansion of the livestock industry emphasized the economic importance of black flies in northern Alberta as a serious problem of both man and animals. A severe outbreak in 1962 caused complaints from farmers and residents in Athabasca County to district agriculturists and agricultural fieldmen. The problem was recognized with some initiatives by Alberta Agriculture in 1963. Limited surveys and preliminary field studies were conducted by representatives of various agencies in 1963-1967. The first surveys concerned with identification and distribution of species in rivers and streams were initiated by J. B. Gurba, Alberta Agriculture, and F. J. H. Fredeen, Agriculture Canada, in 1964. It was considered in 1965 that DDT treatments as developed for the South Saskatchewan River could not be justified at that time and meetings were held with representatives of the Alberta Fish and Wildlife Division, the Zoology and Entomology Departments of the University of Alberta, and Alberta Agriculture to plan and coordinate further research. Surveys of the Pembina, La Biche, and Wandering Rivers were continued by these agencies through 1965-1966.

Some of the field surveys were assisted by 16 cooperating farmers who supplied some 33,000 specimens of black flies for identification of the pest species attacking cattle in Athabasca County and Improvement District 18.

The early surveys to identify pest species and their distribution in association with recorded outbreaks and reports of damage in northern Alberta have been described in more detail by Fredeen (1969). Preliminary studies on the control of infestations were initiated in 1966 with some field tests of efficacy and safety of DDT, chlorpyrifos, methoxychlor, and temephos as larvicides in small streams such as Flat Creek and Pine Creek.

Since initial investigations were of insufficient depth to solve the problem, assistance was formally sought in 1967 from the National Research Council, Agriculture Canada, and the University of Alberta in a request through the Canadian Agricultural Services Coordinating Committee. The Agriculture Canada Research Station at Lethbridge initiated studies in the Athabasca area in 1968 with the appointment of K. R. Depner to identify and document the breeding sources of black fly infestations in conjunction with continued sampling of small streams and testing of pesticides by L. K. Peterson in Alberta Agriculture. Tests of techniques and pesticides for protection of cattle from flies on farms were also initiated by M. A. Khan and J. A. Shemanchuk in 1971, as possible alternatives to control of larvae in streams.

By 1971, public concern in the Athabasca and other areas of Canada began to focus more attention on biting flies as a national problem. A symposium on Biting Fly Control and Environmental Quality was organized in 1972 by the University of Alberta and the Advisory Committee on Entomological Research to the Defence Research Board to assess the state of knowledge of biting fly control. It was followed later in the same year by a work-planning meeting on 'Biting Flies and Their Control', which was organized by Agriculture Canada to consider research requirements and to establish priorities for programs in major problem areas such as those in northern Alberta and Saskatchewan. As a result of these and other reviews, the Government of Canada agreed that Agriculture Canada should provide the expertise and organization to undertake, lead, and coordinate a black fly research program in Canada.

During the early period of agricultural development in northern regions, it was thought that infestations of biting flies on farms were localized and originated in neighboring swamps. These impressions changed as a result of preliminary surveys. Collections of black flies on farms in Athabasca County indicated that attacks on cattle and horses were comprised on average of about 92% *Simulium arcticum*, 6% *S. venustum*, and 2% *S. vittatum*. It was apparent that some localized and temporary nuisance on farms could be attributed to the two less abundant species breeding in small streams in the vicinity of affected farms. Major persistent outbreaks, however, were caused by massive breeding of *S. arcticum* confined to the Athabasca River. Unlike other species, *S. arcticum* obviously dispersed from its breeding sites over distances up to 150 km to invade farms in Athabasca County and Improvement District 18. On the basis of these observations, the problem had to be considered as a complex one on a large scale with important environmental implications for control programs.

Black fly attacks on cattle became severe in 1971 and persisted from late spring until early fall. They were followed by one of the worst outbreaks on record in 1972. As a result of the severity of the attacks developing in 1972, about 150 livestock owners of the Athabasca, Grassland, and Wandering River areas held an emergency meeting in Grassland on 13 July to consider actions to combat the outbreak and related livestock losses. A committee of livestock owners was formed to request immediate action by the Federal and Provincial Governments to alleviate the problem. The committee action included a report of the problems with an assessment of losses and damages and a petition by the farmers to both governments through local representatives of Parliament and the Legislative Assembly of Alberta.

Information had been generally insufficient for an accurate analysis and quantitative assessment of the economic impact of black flies on livestock production in affected areas. The brief of the committee of livestock owners in 1972, however, provided a general survey of the scope and severity of the problem and an appreciation of its importance in livestock operations. In a survey area of 53,290 ha containing 13,008 cows, they reported previous losses up to 1971 to have been 973 dead animals and 38 sterile bulls. The most extensive loss, the reduced gain in weight of animals on pasture, was estimated to be about 45 kg/animal, which was then valued at $390,000. Loss of production in unbred cows was over $90,000. These losses, in addition to inefficiency of operations with interrupted calving schedules, sterile bulls, and dead animals, amounted to an immediate estimated annual monetary loss of about $600,000 for the survey area or of about $46/cow-calf unit for the cattle population enumerated in the assessment.

When the survey was conducted in 1972, another serious outbreak was occurring and livestock owners had already reported 449 dead animals, mostly among calves, and 588 unbred cows for the same area.

Estimated direct monetary losses excluded labor expended and time lost by farmers providing emergency relief to cattle in housing, moving them to other pastures, preparing smudges, and applying spray treatments. Much of the land that was suitable only for cattle production remained idle or underutilized. It was estimated on the basis of the area surveyed that the cattle population had increased nearly 50% within the previous 5 yr and that a further increase of 150% was feasible if infestations of black flies could be controlled. It was emphasized in the brief from the livestock owners that, as a result of factors of time and labor in cattle raising, black fly infestations restricted production to small enterprises at a time when larger herds were necessary for an economically viable livestock industry. It was also noted that hogs were seriously affected by black flies. Sows remained barren and suffered from infected udders during fly outbreaks. Intensive care was required to save pure-bred boars introduced to the area. The brief indicated the need for complete and more extensive surveys to assess the total impact of black flies, including not only the effects and losses among cattle but also those related to other livestock operations and to the general efficiency of agricultural operations in the area.

Alberta Agriculture surveyed 157 farmers in six Divisions of the County of Athabasca by interview and questionnaire on the effects of infestations in 1972. The survey generally confirmed the assessment for 1971 of the livestock owners' committee. Financial losses were generally attributed to cattle deaths during severe black fly attack, reduced gain in weight and failure of cattle to utilize pastures during the fly season, reduction in breeding efficiency and conception rate, low weaning weight in calves, and reduced milk production in dairy herds.

The brief and petition presented by livestock owners in 1972 strongly emphasized that black fly outbreaks were more widespread and of considerably more consequence to livestock production in affected areas than previously appreciated. In March 1973, Alberta Agriculture organized an Alberta Black Fly Coordinating Committee on an *ad hoc* basis with representives of various agencies to promote more effective intergovernment cooperation on the problem. Through a series of work-planning meetings, the committee encouraged the development of a feasibility study to be completed the same year for an appropriate interdisciplinary research program.

The feasibility study was conducted by the Agriculture Canada Research Station at Lethbridge, in cooperation with Alberta Agriculture and Alberta Fish and Wildlife Division. Interrelated field studies were carried out to determine a more detailed design for a 4- to 5-year research program in which essential disciplinary inputs would be assigned to responsible cooperating agencies.

Three options to alleviate the difficulties of livestock producers were assessed. Of these, control of larval production of *S. arcticum*, the most prolific pest and the major cause of losses and damage, with a favorable cost/benefit ratio for the large area affected became the major immediate objective. Of the others, changing livestock management practices in the area was neither practical nor economically acceptable for a viable livestock industry, and methods of on-farm protection of animals, while potentially effective for the broad spectrum of biting flies, involved development over a longer term at greater expense for practical application.

The potential effectiveness of the first option and a need for an economically viable and environmentally acceptable solu-

tion of the problem were major considerations in outlining a broad research program. With the involvement of the large Athabasca River drainage system, the compromise between economic and environmental implications of alternative pest control strategies required substantial resolution in terms of complete studies of the aquatic ecosystem and river hydrology.

As a result of the feasibility study and the more extensive environmental implications of larvicidal treatments in the Athabasca River during the early stages of the experimental program, the Alberta Black Fly Coordinating Committee was formally reorganized in December 1975, with direct responsibility to the Alberta Minister of Environment. It maintained the essential terms of reference of the original *ad hoc* committee as an advisory and coordinating inter-agency body for the completion of the research program with the additional responsibility of reviewing both annual operations and the final consolidated research report.

References

In addition to minutes of various *ad hoc* committees and work-planning meetings sponsored by Alberta Agriculture, the following documents are sources for further details of the history of black fly epidemics in the Athabasca area and related activities of organizations concerned with black fly control in 1962-1972.

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INTRODUCTION

OVERVIEW OF THE PROBLEM

Severe outbreaks of black flies have been recognized as a problem for livestock producers in the Athabasca area of Alberta since 1962. For many years, extension authorities of the Alberta Department of Agriculture and the County of Athabasca have reported serious farm losses associated with reduction of weight gains and milk production in animals on pasture, death of newborn calves, and disability and death of breeding stock, especially among newly introduced purebred animals.

Preliminary surveys (Fredeen 1956, 1969, 1977) identified pest species of black flies and their relative abundance in the region. These preliminary surveys and later more detailed studies in 1968-1972 (Depner 1978) established that *Simulium arcticum* Malloch was the primary pest in severe outbreaks contributing to the major losses in livestock production. They also identified the Athabasca River as the exclusive breeding source of *S. arcticum* infesting the adjacent farming areas in the region, most notably Athabasca County and Improvement District No. 18.

A feasibilty study was conducted on the Athabasca River in 1973 to define the extent of the breeding sources, to relate breeding sources to affected farming areas, to determine prospects of chemical control of pests, to identify interdisciplinary studies essential to an estimate of environmental acceptability of control methods, and to assess practical alternatives for abatement programs. Feasibility studies were also designed to establish preliminary baselines for non-target organisms and the quality of the aquatic environment in the Athabasca River. The results of these studies indicated that an interdisciplinary experimental program was required for a minimum period of 3 yr to intensively develop and evaluate practical methods of controlling outbreaks of *S. arcticum* in the Athabasca region. They culminated in the outline of an interagency research program sponsored by Alberta Environment. The research program was initiated in 1974 and completed with a post-treatment baseline study in 1977.

THE PROGRAM

The program was designed from feasibility studies to develop and evaluate chemical control of *S. arcticum* in the Athabasca River. This appeared to be the most immediately achievable and economically practical approach to prevention of severe pest outbreaks and to reduction of farm losses in livestock production. Projects and interagency participation were outlined within six objectives:

1. To identify and characterize the breeding sources of the black fly *S. arcticum* in the Athabasca River and to develop methods of treating the river with a pesticide to reduce the production of the pest in a selected area;

2. To determine the level and extent of reduction in breeding sources required in

abatement operations to provide economic reductions of infestations in contiguous agricultural areas;

3. To estimate infiltration rates for populations of the pest reinfesting agricultural areas from sources outside the area of the abatement operation;

4. To develop methods of monitoring an abatement operation for deleterious effects of treatments on aquatic non-target organisms and the river environment;

5. To develop criteria for acceptable impact on the river environment in conjunction with specifications for pesticidal treatment of river systems; and

6. To assess the impact of infestations of *S. arcticum* and other related biting flies and the effect of abatement procedures on the productivity of livestock and development of livestock enterprises, and to evaluate the benefits of animal protection in the area.

Primary emphasis in these studies has been placed on *S. arcticum* as the pest incriminated in severe outbreaks of biting flies affecting livestock enterprises in Athabasca County and Improvement District No. 18. The program has been designed to embrace the more extensive problems of biting flies in agriculture, and concomitantly to provide information necessary for management of problems of black flies that occur during the development of resource and recreational industries in northern Alberta.

RELATED RESOURCE DEVELOPMENT

Studies in the program were focussed on the downstream section of the Athabasca River between a point 65 km above the town of Athabasca and the delta at Lake Athabasca (Fig. 1, UL and LL). They embrace areas that are at present identified with the development of agricultural and other resources in the Athabasca Basin. Agriculture and the livestock industry are primarily established in Athabasca County and Improvement District No. 18 adjacent to the Athabasca River in the upstream section of the study area.

As indicated above, the study area includes the downstream part of the drainage basin that is characterized by an overlay of organic soils. Future expansion of agricultural areas may be expected to exploit these soil conditions. Since climate limits cereal and specialty crops at this latitude, emphasis is likely to be on forage crops and livestock production. The agricultural potential for the area as a base for future resource and for industrial and recreational development depends considerably on the management of severe problems of biting flies and the protection of man and animals in future economic expansion in the lower Athabasca drainage basin. Conditions of terrain, soil, and abundant moisture and supplies of fresh water are highly favorable, not only for economic development of various resources in the area but also for perpetual production of heavy infestations of biting flies. They emphasize the importance of effective methods of controlling biting flies within very large areas of potential human activity and enterprise beginning in a wilderness environment.

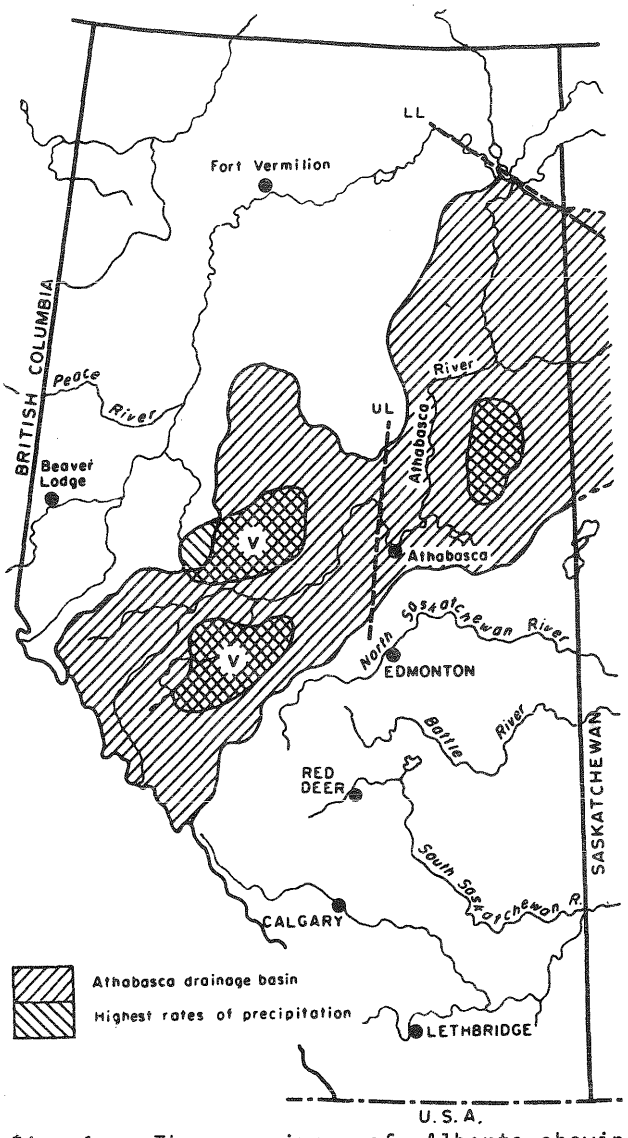


Fig. 1. The province of Alberta showing the Athabasca River Drainage System with the upper (UL) and lower (LL) limits of the study area and areas within the province having the highest rates of precipitation (Mean precipitation >560 mm/yr; days with precipitation >120/yr) and least annual variation (V) in precipitation (<25%).

THE STUDY AREA

General Description

The research program was organized as an interdisciplinary study of chemical

treatment of the Athabasca River, with all its environmental implications, for the control of black flies.

The Athabasca is one of the largest rivers in Canada and drains an extensive watershed representing about one-quarter of the area of Alberta, or an area of about 155,000 km^2 (Fig. 1).

Head waters rise due west of Red Deer on the eastern slope of the Great Divide, the river flows northwesterly along the divide for more than 100 km, and is then joined by large tributaries over a northeasterly course from Jasper to Lake Athabasca at the north-east corner of the province. The total course of the river exceeds 1,150 km. In addition to numerous small streams and rivers, it is joined by large tributaries such as the McLeod, Pembina, Lesser Slave, and Clearwater Rivers, all of which are fed by large drainage areas. As a result of the extensive drainage areas contributing to the flow, the discharge of the Athabasca River is characterized by frequent large fluctuations after heavy precipitation in one or more of the large drainage basins during spring and summer (Fig. 2).

The annual minimum discharge in winter along the river course at Athabasca, downstream from the confluence of major tributaries, varies between 10 and 25% of the annual mean. Maximum intermittent flood discharges throughout spring and summer range up to eight times the annual mean and to more than 60 times the annual minimum. Except for a few very short reaches in which the river bed widens, the flow is relatively rapid and turbulent even at low rates of discharge. High velocity of flow, frequent flooding with extreme fluctuations during spring and summer, and the relatively confined channel of the river combine in maintaining an intensively scoured river bed throughout most of the river course above Fort McMurray. All of these conditions provide a highly favorable river bed substrate and a relatively uninterrupted aquatic environment for the rapid and prolific development of *S. arcticum*, the prominent species in major outbreaks of black flies in the Athabasca area.

The terrain of the Athabasca River lies within the boreal forest (Taiga) which also provides a favorable environment for the adult activities and reproduction of a large variety of biting flies. Vegetation ranges from primarily aspen poplar and aspen ecotone association to pure stands of spruce. Much of the area, especially in the downstream parts of the watershed, is muskeg covered by sphagnum moss or sphagnum moss and black spruce. The terrain and the vegetation throughout the major part of the whole drainage area provide optimum habitats for the breeding, activity, and production of heavy infestations of various species of black flies, mosquitoes, tabanids, and ceratopogonids in addition to the potential for *S. arcticum* in the Athabasca River.

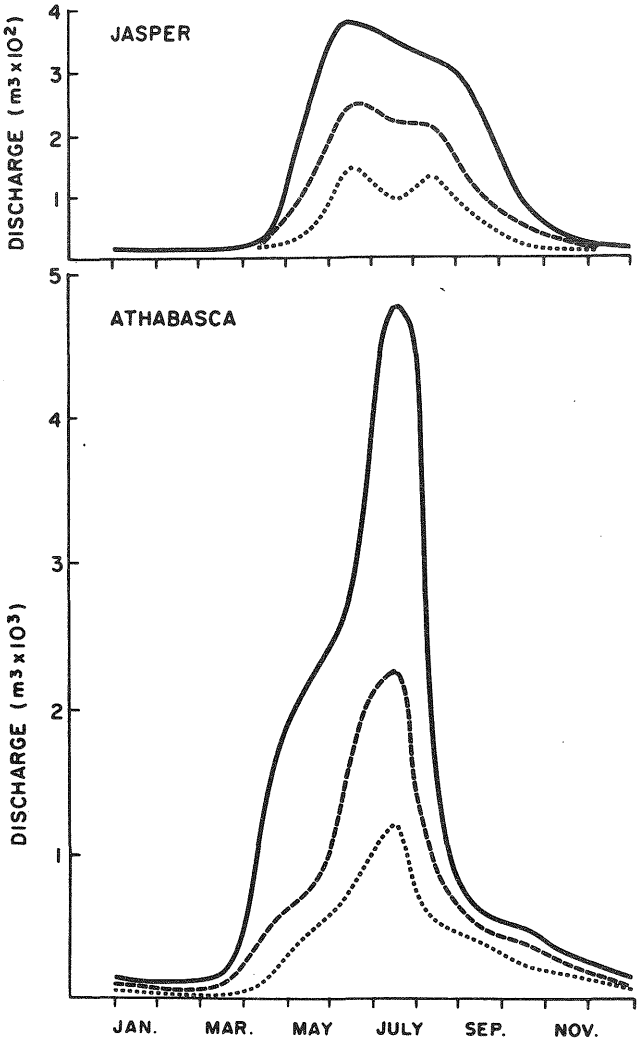


Fig. 2. Monthly variation in discharge of the Athabasca River as represented by the maximum (——), mean (---), and minimum (...) for the headwaters at Jasper (Station 07AA002) and for Athabasca (Station 07BE001 of Water Survey of Canada).

Of the drainage area, about 75,000 km^2 including Athabasca County and the downstream part of the Athabasca basin is covered by organic soils. These soils are highly favorable to the breeding of northern species of biting flies and they are characteristic of the most heavily infested regions of subarctic Canada. Immature black flies attach themselves to suitable scoured rocky surfaces in the river bed and, as filter feeders, depend on a supply of suspended organic materials in flowing water for their development. The potential of the Athabasca River for production of *S. arcticum* in the lower part of the watershed is reflected in the high concentration of organic carbon constituents in the water. Organic carbon constituents range from 2-30 mg/liter at Fort McMurray and 7-26 mg/liter

at Athabasca in the Athabasca River as compared with 1.5-15 mg/liter at Edmonton and 1-8 mg/liter at Lloydminster on the North Saskatchewan River. The trophic potential for larval feeding coupled with extensive reaches of turbulent water flowing at high velocities over scoured river beds is conducive to heavy production of *S. arcticum* larvae especially in the course of the Athabasca River between the town of Athabasca and Fort McMurray.

The trophic potential for larval feeding and the favorable physical characteristics of the water flow and river bed are significantly enhanced by climate in supporting frequent severe outbreaks of *S. arcticum* and other biting flies in the Athabasca basin. The Athabasca drainage system embraces those areas with the heaviest average amount of precipitation in Western Canada east of the Divide. It includes all three areas in the province in which precipitation exceeds 560 mm/yr with some of it falling on an average of more than 120 days/yr (Fig. 1). Two of these three areas have the lowest annual variation (<25%) in annual precipitation in the province. These climatic conditions probably explain the magnitude and frequency of severe outbreaks of *S. arcticum* in the Athabasca River. The climatic pattern for precipitation provides year-to-year stability in minimum river flow for uninterrupted development of black fly larvae at population levels that are capable of producing an outbreak whenever climate and weather are favorable for extended periods of adult activity and reproduction.

Available climatic records indicate that the phenology of environmentally related events in the Athabasca River drainage system may vary within a range of about 5 wk. The earliest break-up of river ice at Athabasca was recorded on 2 April and the latest on 9 May with average clearance of ice occurring on 23 April. Since annual development of most subarctic biting flies is closely related to clearance of ice from aquatic habitats, considerable variation may be expected in annual occurrance of infestations in the area.

Hydrometric Conditions Related to Experimental Years

From the longitudinal profile of the Athabasca River (modified from Kellerhals et al. and as shown by Beltaos fig. 6, see p. 102), the slope of the river increases from 0.26 m/km at the Athabasca townsite to a slope ranging from 0.71 to 0.98 in the reach of the river about 1.42 and 258 km respectively, downstream of Athabasca (Table 1).

IDENTIFICATION OF SAMPLING SITES

The most intensively studied area covered the reach from 60 km upstream from the town of Athabasca to about 240 km downstream. Figure 3 shows an outline of the river reach with the individual 1:50,000 map sheets (Alberta Energy and Natural Resources) that can be used to obtain more detail.

Table 1. Locations and water surface elevations at low stage of river profile (Kellerhals et al. 1972) of sample sites

Location	Distance from Athabasca Bridge (km)	Water surface elevation[a] (m)	Aerial photo (see Fig.5)
U_2	-42.90	525.8	A
U_1	-20.00	518.0	B
Athabasca Bridge	0.00	508.4	C
D_2	21.47	505.6	G
D_3	39.01	499.7	I
Calling River	77.00	492.5	J
D_4	81.47	489.9	K
D_5	120.00	476.1	M
D_6	160.00	452.0	P
Pelican Cabin	178.00	437.9	R
D_7	199.09	421.6	S
D_8	244.29	392.5	T
D_9	276.12	359.8	U
D_{10}	326.10	310.5	V
Fort McMurray Bridge	395.65	238.0	W
Lake Athabasca	698.90	208.6	-

[a] Low stage from profile.

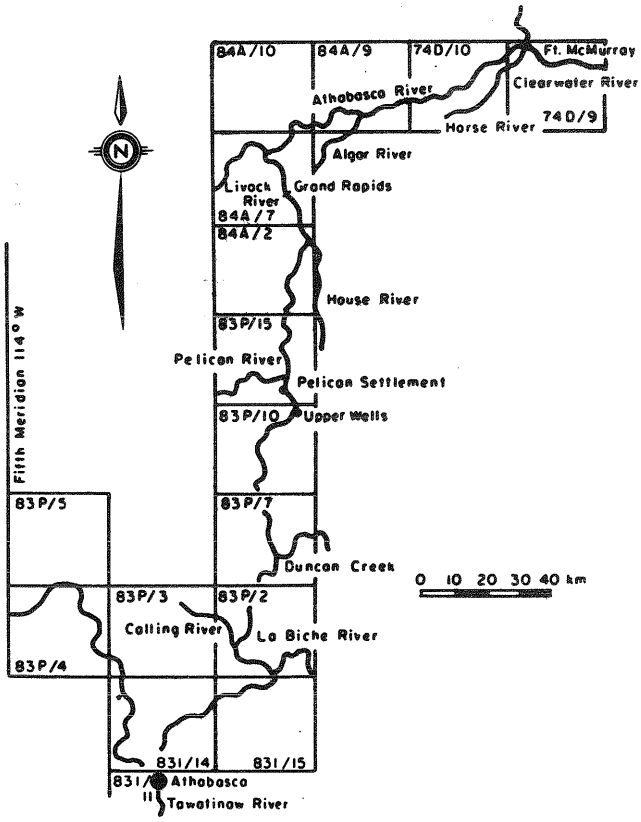
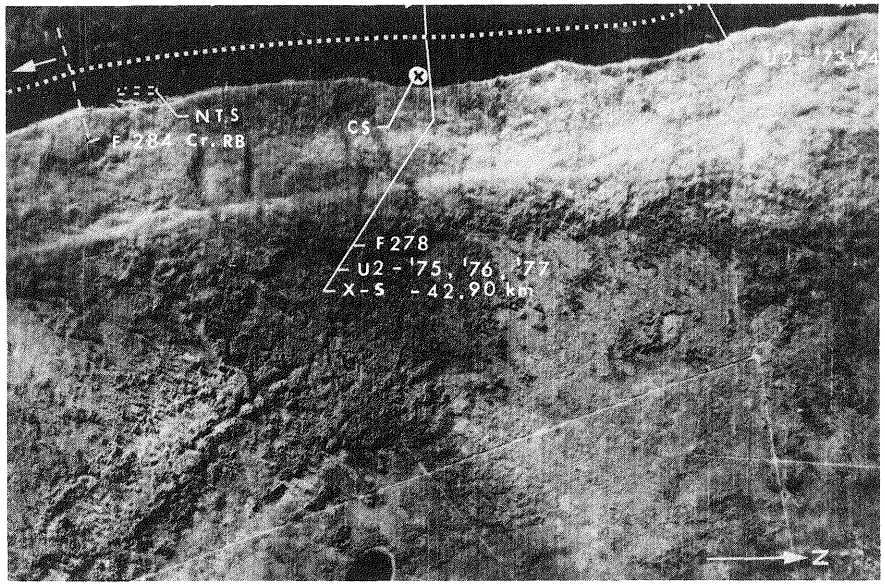


Fig. 3. Study reach of the Athabasca River showing 1:50,000 map sheets from which more detail can be obtained.

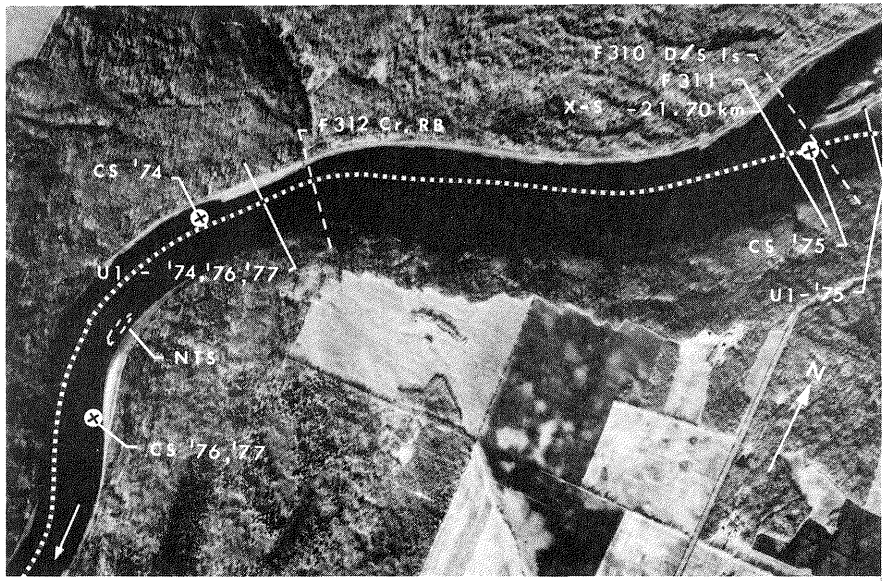
Fig. 4. Aerial photographs of the Athabasca River showing sampling sites and locations of cross sections (see Fig. 5).

Legend:

Scale 1 cm	=	0.2 km
F 278	=	Thalweg fix no. 278
U2	=	Upstream site 2
D1	=	Downstream site 1
Cr	=	Creek
RB	=	Right bank (looking downstream)
LB	=	Left bank (looking downstream)
CS	=	Cone sampling site
NTS	=	Non-target insect sampling site
X-S	=	Cross section



a



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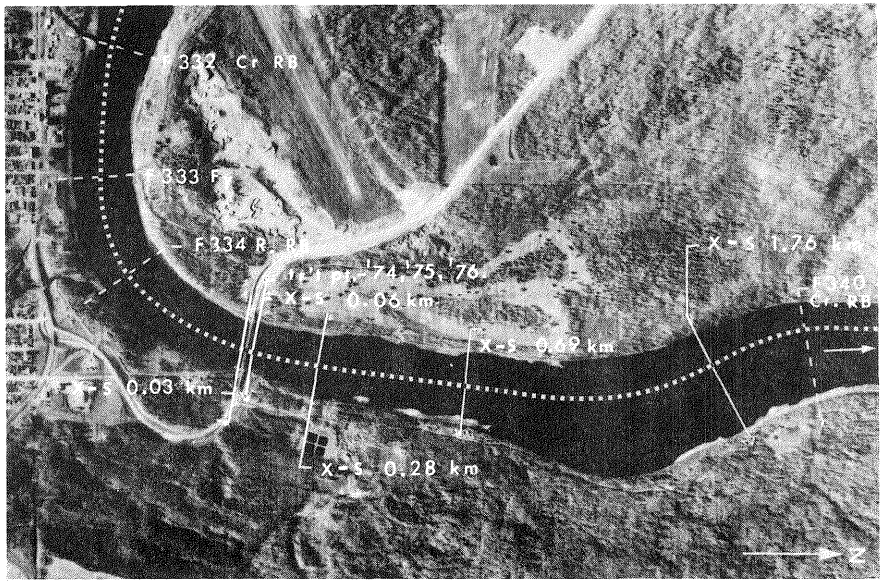
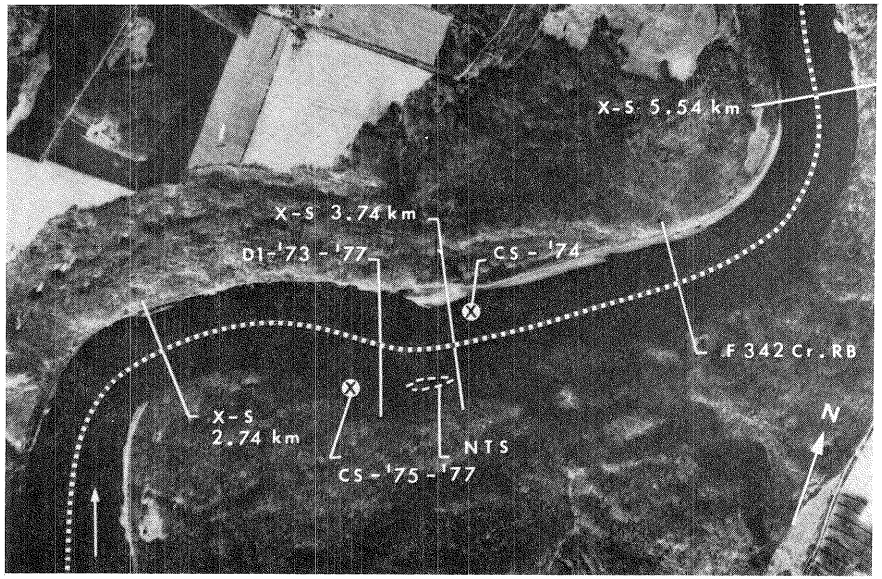
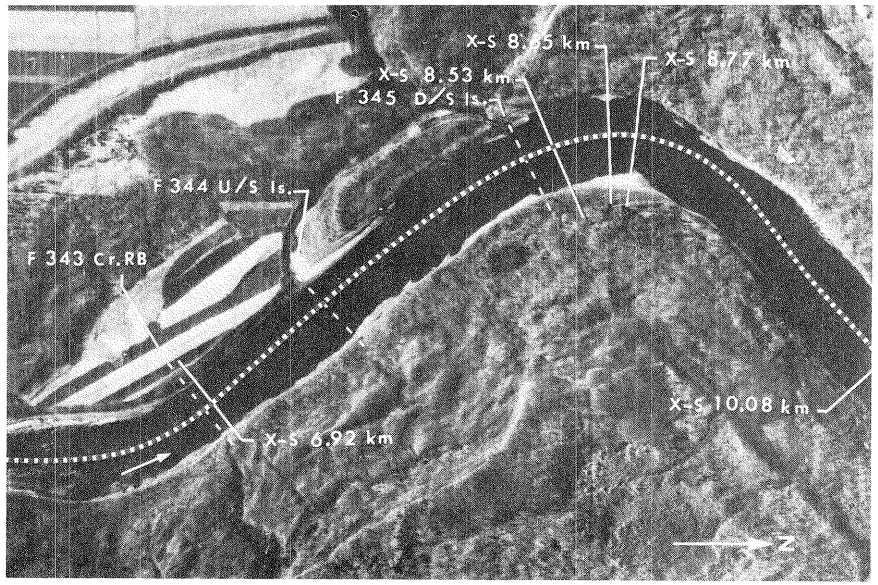


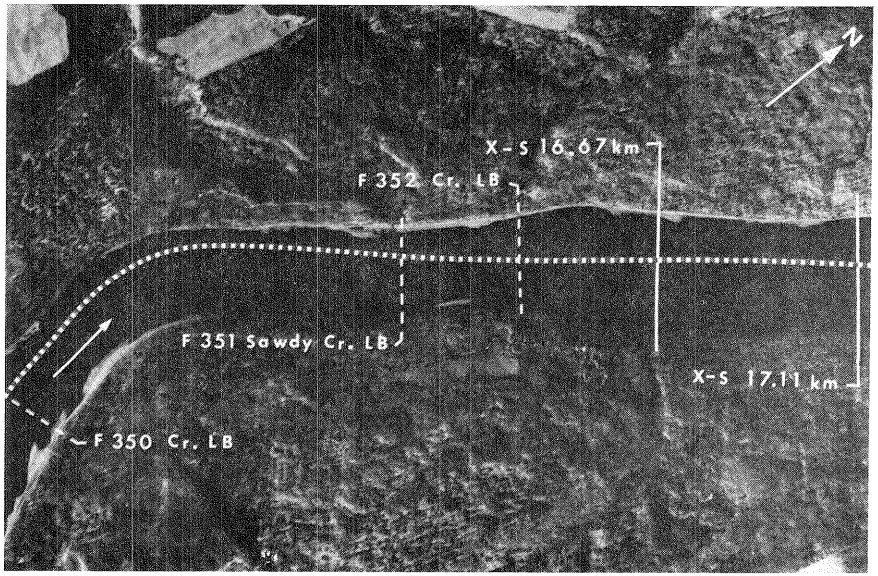
c


X-S 5.54 km
X-S 3.74 km
D1-'73 - '77
CS - '74
F 342 Cr. RB
X-S
2.74 km
CS - '75 - '77
NTS
N

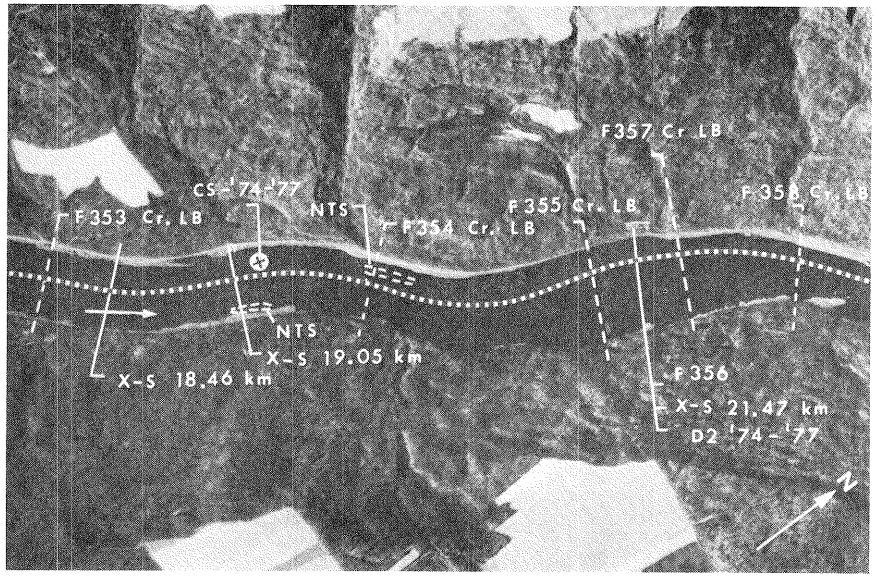
d


X-S 8.85 km
X-S 8.77 km
X-S 8.53 km
F 345 D/S Is.
F 344 U/S Is.
F 343 Cr.RB
X-S 10.08 km
X-S 6.92 km
N

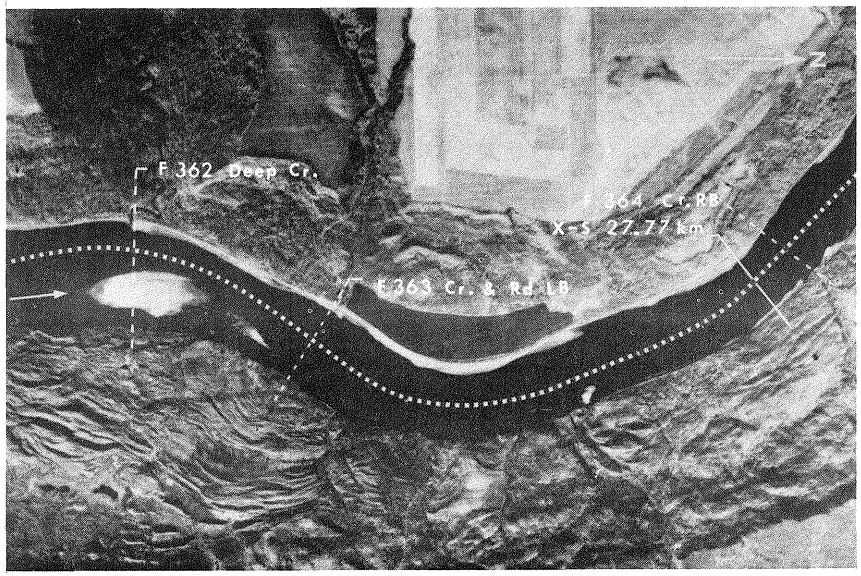
e


X-S 16.67 km
F 352 Cr. LB
F 351 Sawdy Cr. LB
X-S 17.11 km
F 350 Cr. LB
N

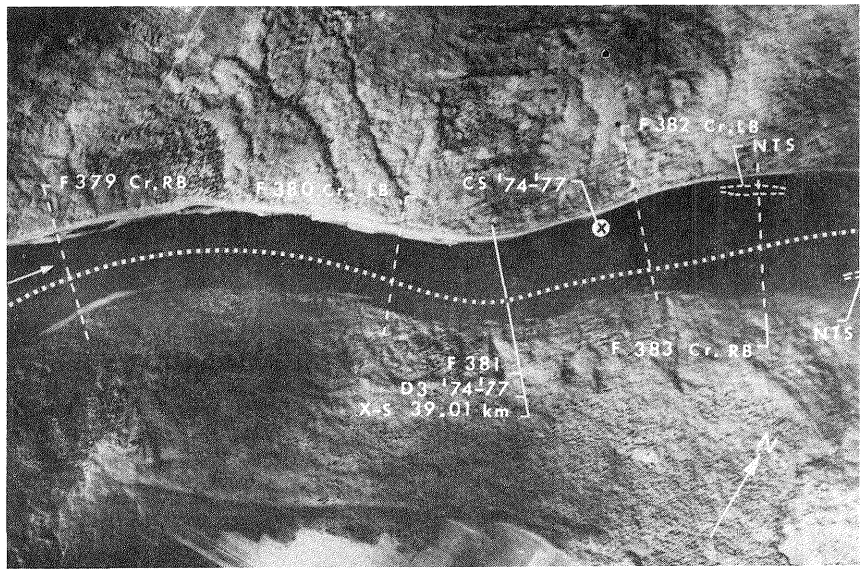
f


F357 Cr LB
CS-'74-'77
NTS
F 355 Cr. LB
F 358 Cr. LB
F 353 Cr. LB
F 354 Cr. LB
NTS
X-S 19.05 km
X-S 18.46 km
F 356
X-S 21.47 km
D2 '74 - '77
N

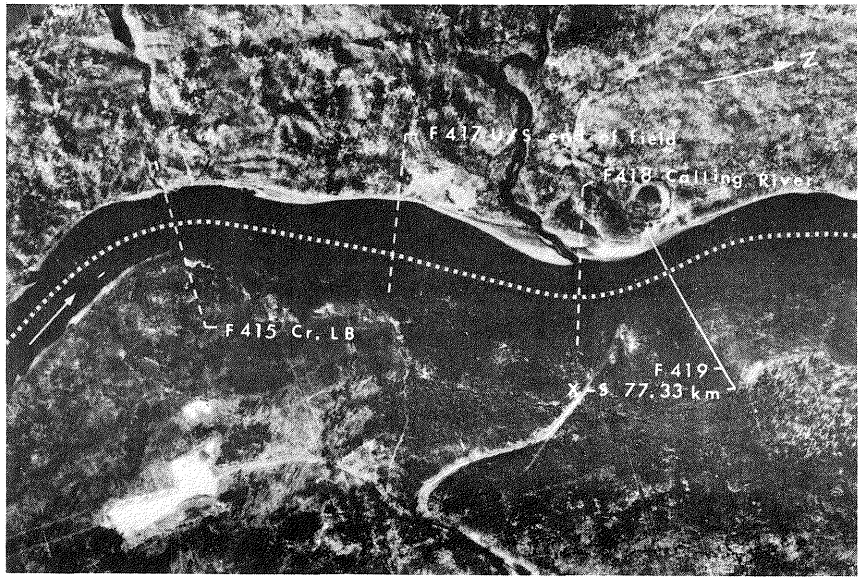
g


F 362 Deep Cr.
F 364 Cr. RB
X-S 27.77 km
F 363 Cr. & Rd LB

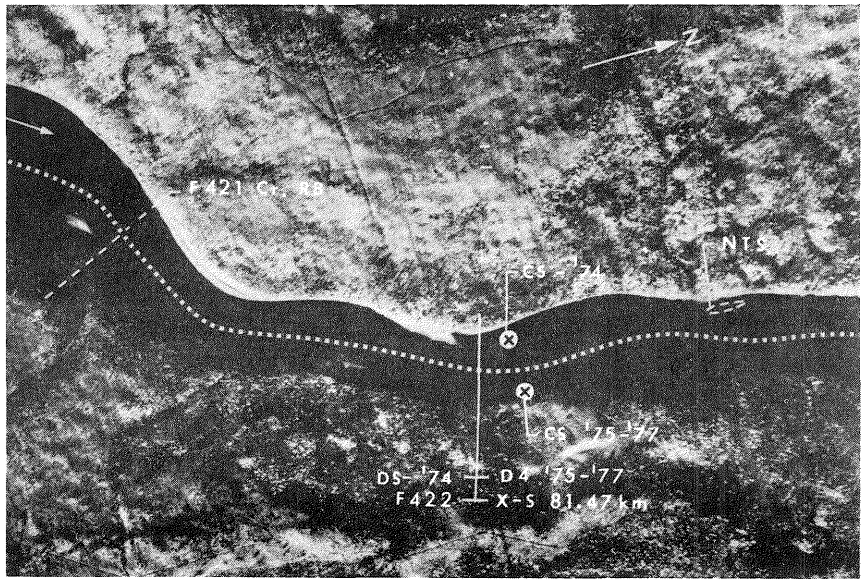
h


F 379 Cr. RB
F 380 Cr. LB
CS '74-'77
F 382 Cr. LB
NIS
F 381
DS '74-'77
X-S 39.01 km
F 383 Cr. RB
NIS

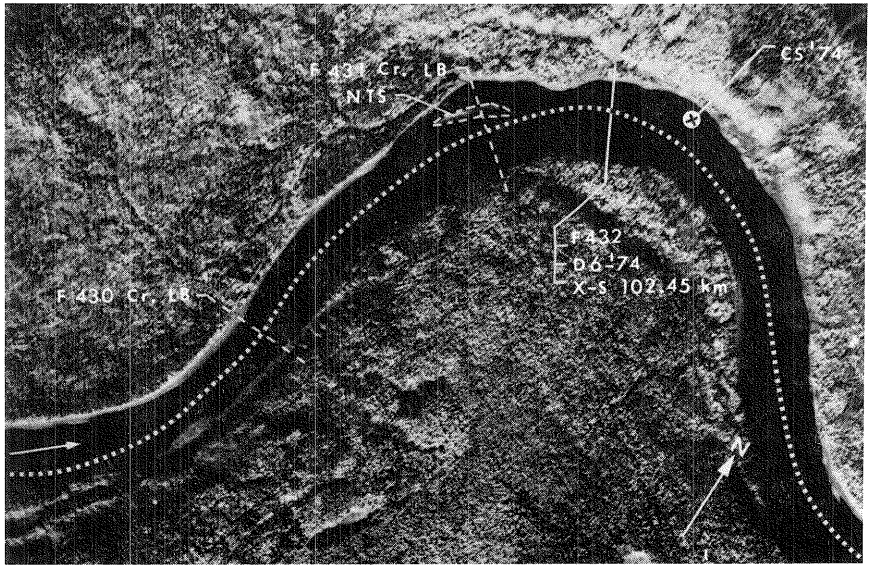
i


F 417 U/S end of field
F 418 Calling River
F 415 Cr. LB
F 419
X-S 77.33 km

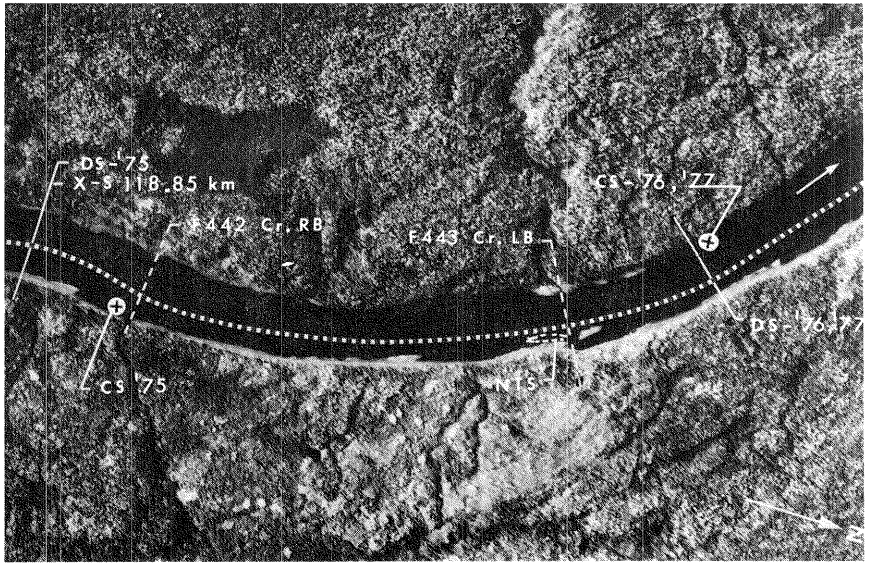
i


F 421 Cr. RB
NIS
CS '74
CS '75-'77
DS-'74 — D4 '75-'77
F 422 — X-S 81.47 km

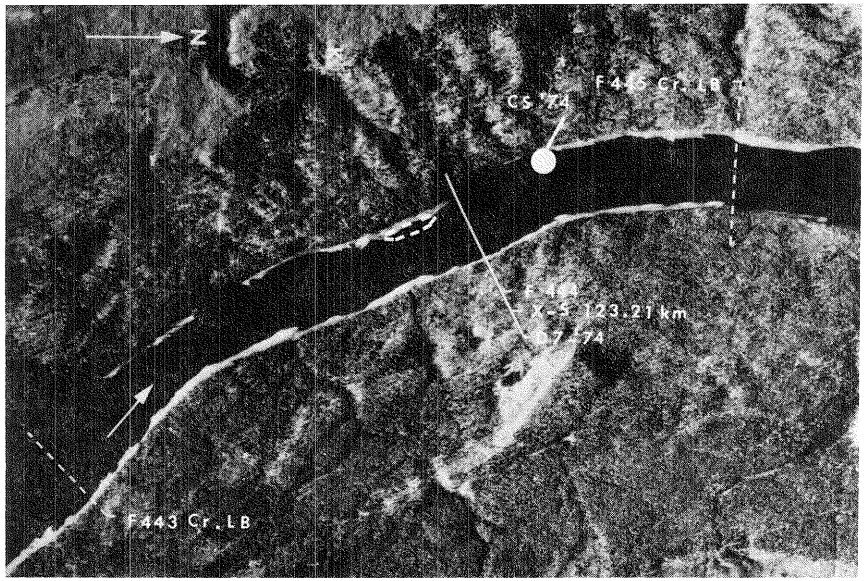
k


F 431 Cr. LB
NTS
CS '74
F 432
DB-'74
X-S 102.45 km
F 430 Cr. LB
N

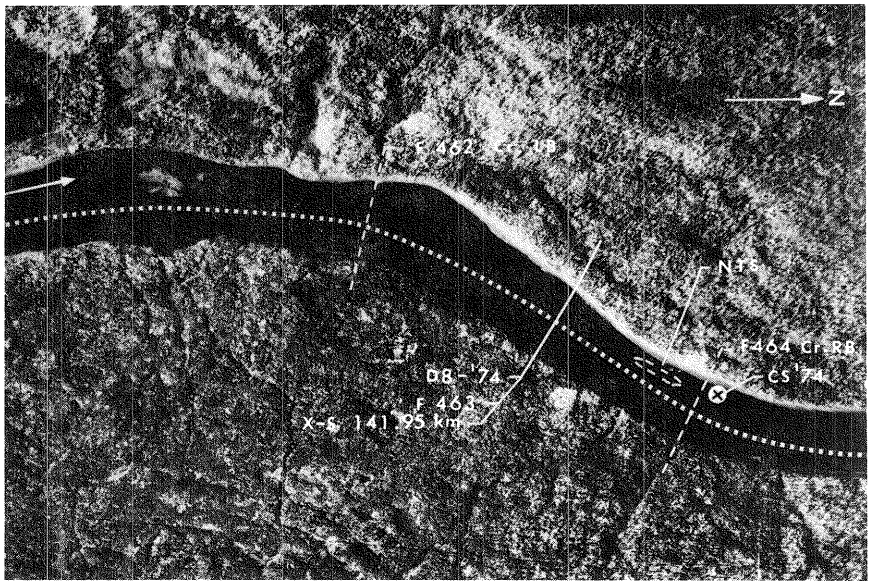
l


DS-'75
X-S 118.85 km
F 442 Cr. RB
F 443 Cr. LB
CS-'76, '77
DS-'76-'77
CS '75
NTS

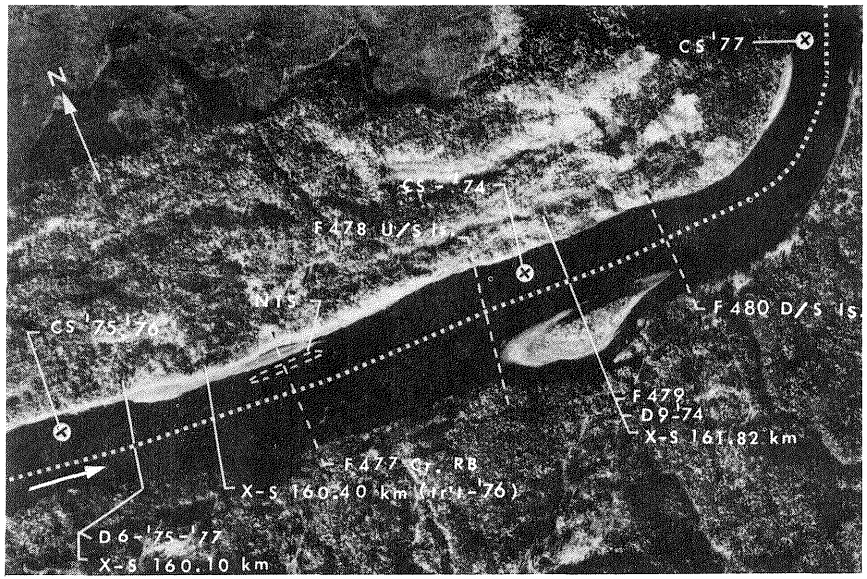
m


Z
CS '74
F 445 Cr. LB
F 444
X-S 123.21 km
DB-'74
F 443 Cr. LB

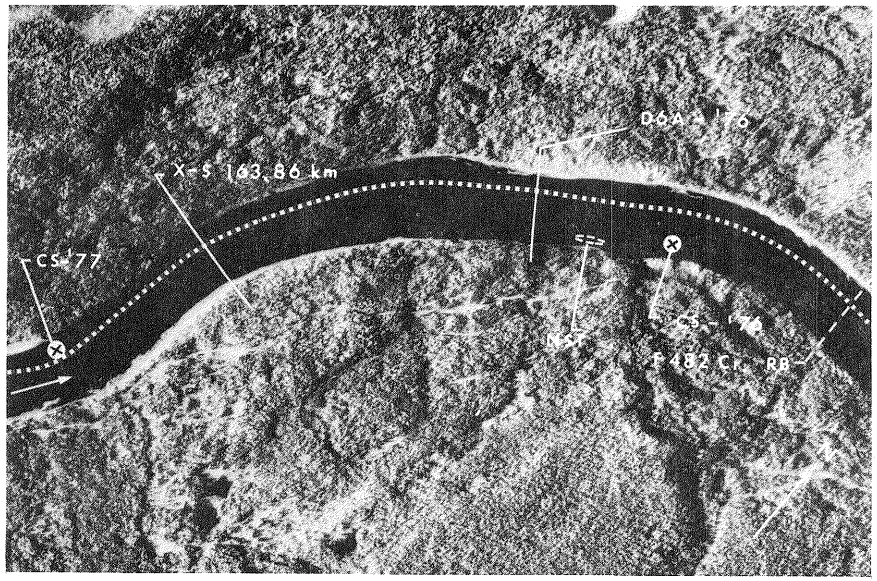
n


Z
F 462 Cr. RB
NTS
F 464 Cr. RB
CS '74
DB-'74
F 463
X-S 141.95 km

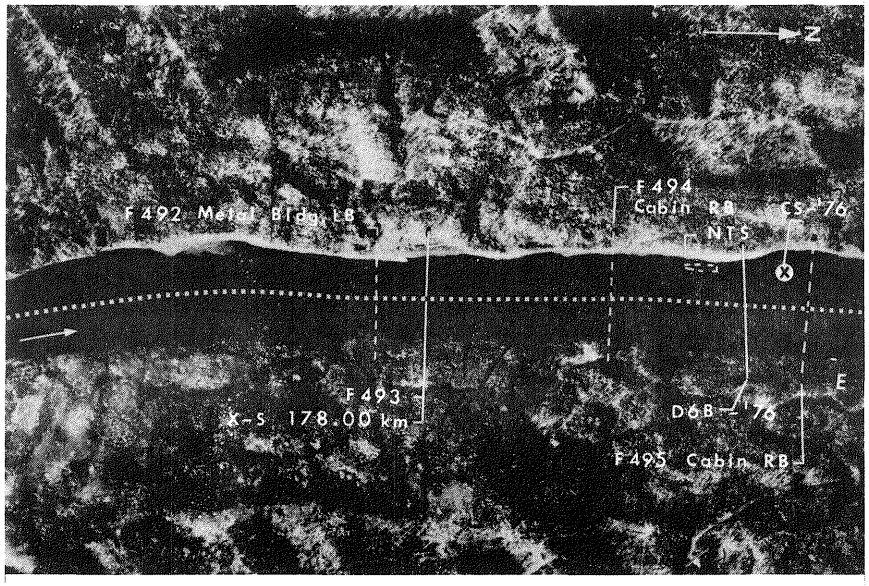
o


N
CS '77
CS - '74
F 478 U/S Cr.
NTS
CS '75 - '76
F 480 D/S Is.
F 479
D9-74
X-S 161.82 km
F 477 Cr. RB
X-S 160.40 km (Fr'r - '76)
D6 - '75 - '77
X-S 160.10 km

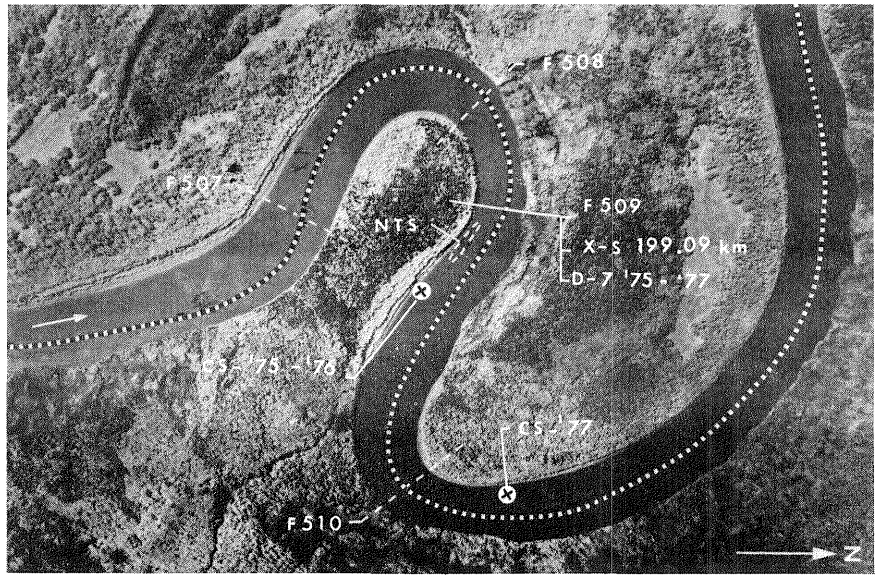
p


D6A - '76
X-S 163.86 km
CS - '77
NTS
CS - '74
F 482 Cr. RB

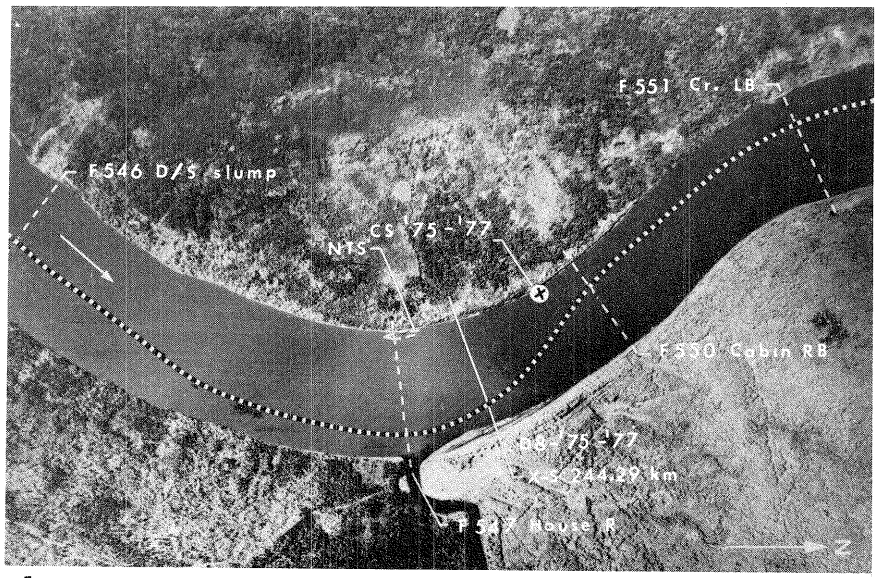
q


E
F 494
Cabin RB
NTS
CS - '76
F 492 Metal Bldg. LB
F 493
X-S 178.00 km
D6B - '76
F 495 Cabin RB

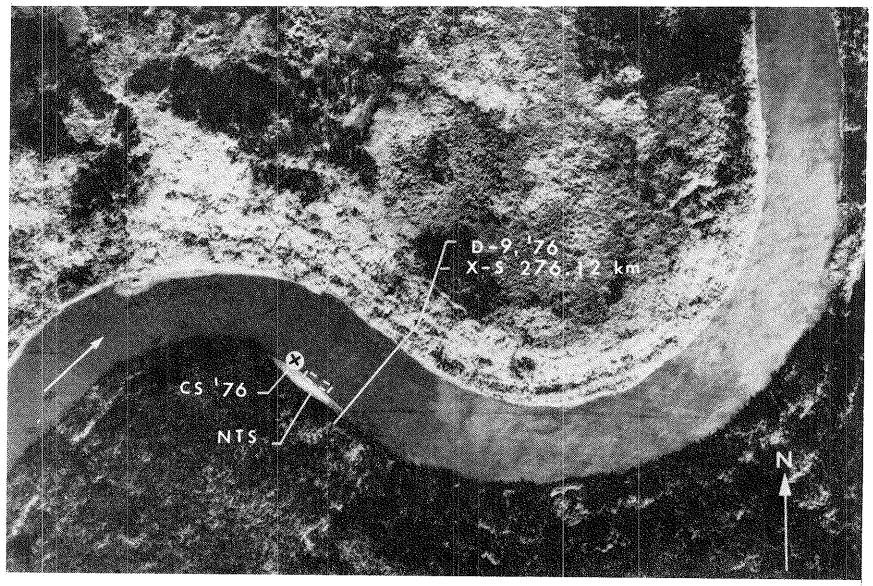
r


F 508
F 507
NTS
F 509
X-S 199.09 km
D-7 '75 - '77
CS - '75 - '76
CS - '77
F 510

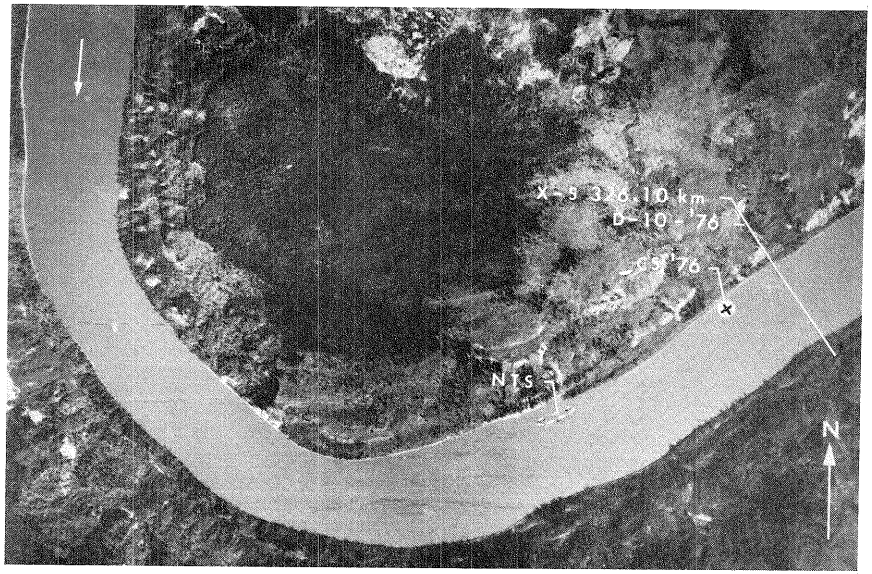
s


F 551 Cr. LB
F 546 D/S slump
NTS
CS '75 - '77
F 550 Cabin RB
D-10 '75 - '77
X-S 244.29 km
F 549 House R.
Z

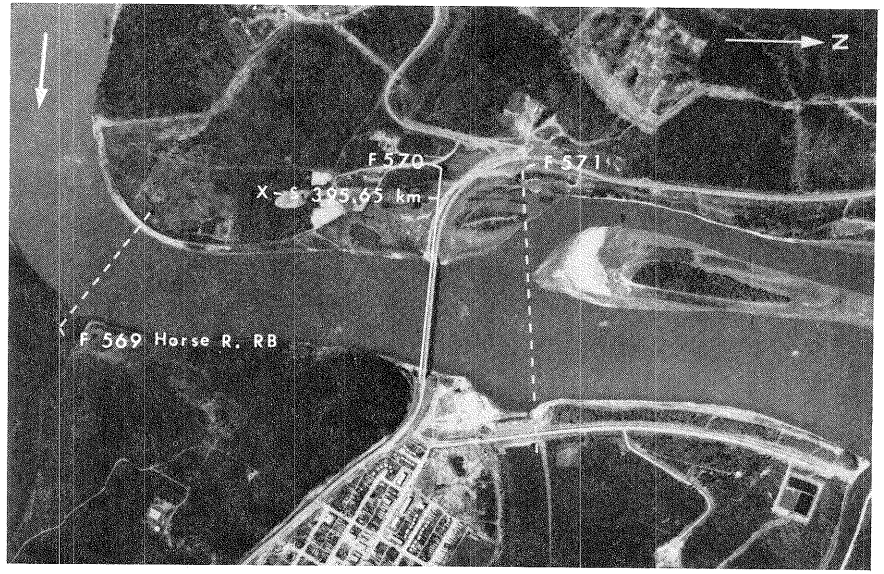
t


D-9 '76
X-S 276.12 km
CS '76
NTS
N

U


X-S 326.10 km
D-10 '76
CS '76
NTS
N

V


Z
F 570
X-S 395.65 km
F 571
F 569 Horse R. RB

W

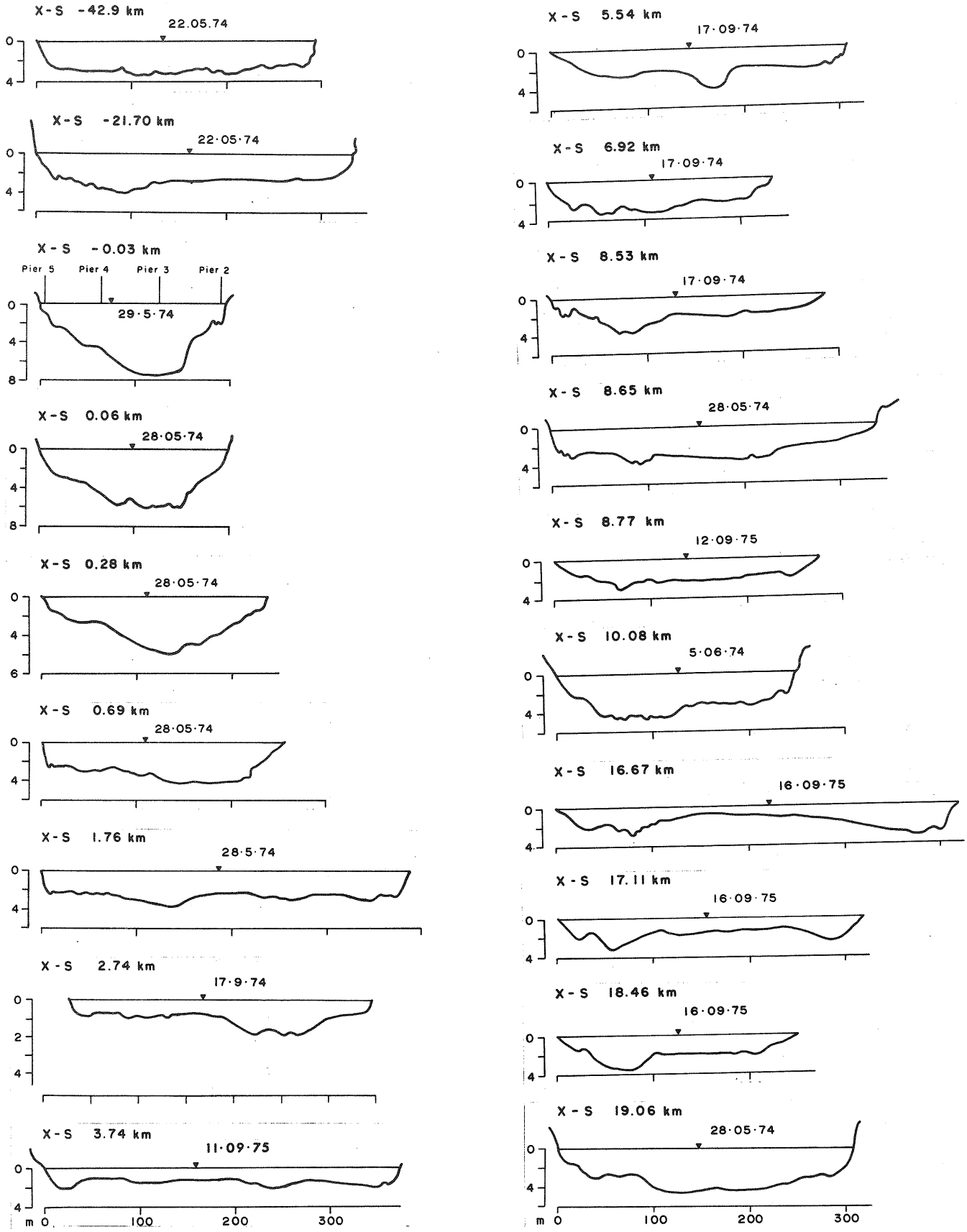
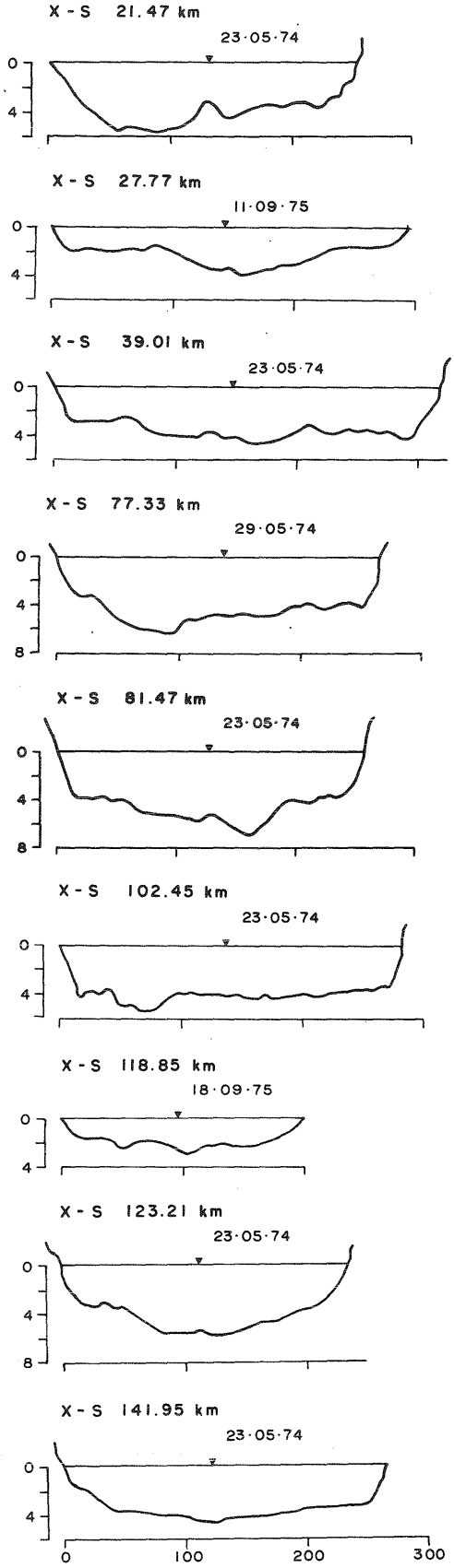
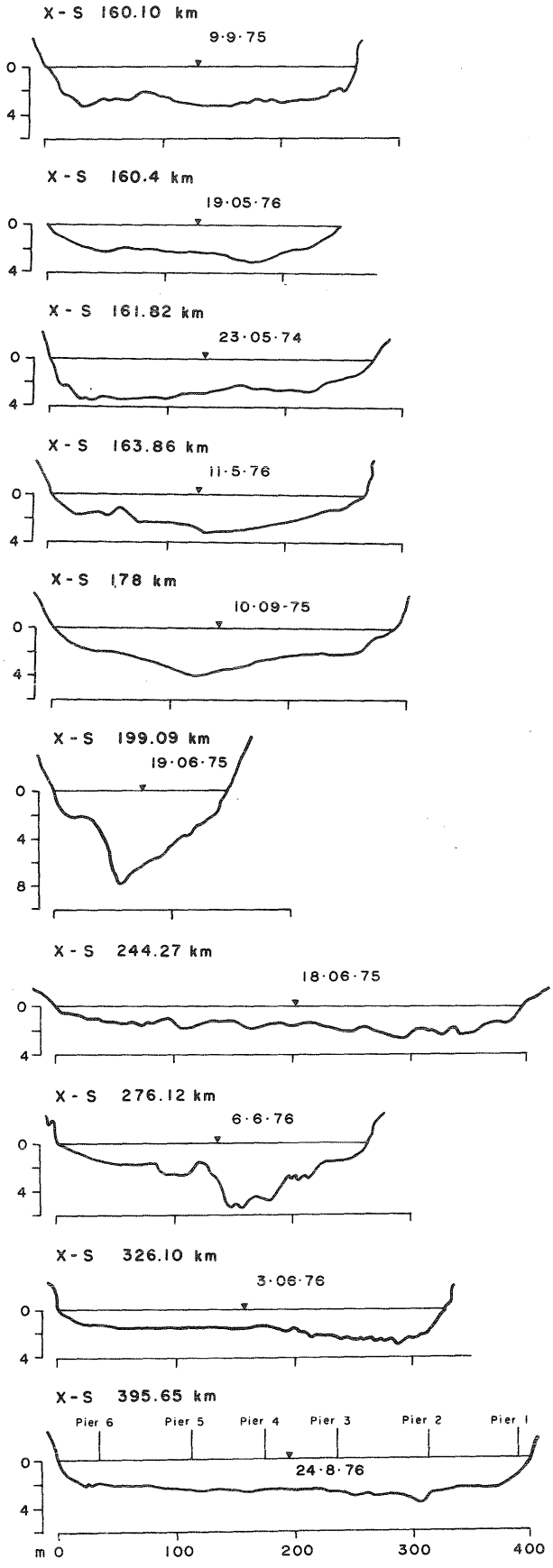


Fig. 5. Cross-sections of the Athabasca at 38 sites (for locations see Fig. 4).


X - S 21.47 km
23·05·74
X - S 27.77 km
11·09·75
X - S 39.01 km
23·05·74
X - S 77.33 km
29·05·74
X - S 81.47 km
23·05·74
X - S 102.45 km
23·05·74
X - S 118.85 km
18·09·75
X - S 123.21 km
23·05·74
X - S 141.95 km
23·05·74
0
100
200
300


X - S 160.10 km
9·9·75
X - S 160.4 km
19·05·76
X - S 161.82 km
23·05·74
X - S 163.86 km
11·5·76
X - S 178 km
10·09·75
X - S 199.09 km
19·06·75
X - S 244.27 km
18·06·75
X - S 276.12 km
6·6·76
X - S 326.10 km
3·06·76
X - S 395.65 km
Pier 6
Pier 5
Pier 4
Pier 3
Pier 2
Pier 1
24·8·76
m 0
100
200
300
400

The exact location of study areas and cross-sections and various survey parameters are shown in Fig. 4 in the series of 23 aerial photographs. All experimental sites for the three treatment years (1974-1976) are indicated on these aerial photographs together with sampling locations used by Agriculture Canada Lethbridge for non-target insect collections and cone sites for monitoring larval populations. In addition, survey fix locations mentioned by Beltaos (pp. 102-103) and the estimated river thalwag are also marked on the photographs.

The surveyed cross-sections as determined by echo soundings are shown in Fig. 5. These 38 cross-sections give a very clear picture of the changing hydrological functions of the river. It is evident that the river is not a static tube. The depth and the width of the river change drastically. These variations present the major difficulty in selecting sampling locations and in positioning of sampling equipment. In addition to the varying physical factors, the daily discharge of the river varies significantly as can be seen in Fig. 6 for the years 1973-1976 respectively. When the mean monthly and annual discharge rates for the two gauge stations at Athabasca and Fort McMurray are summarized for the years 1966-1977 (Table 2), the variation in water flow is dramatic. This variation in discharge rates plays an important role in the sampling procedure and at times limits the operation.

BACKGROUND ON WATER QUALITY

In a study of this nature and magnitude, it is important to monitor factors that may indicate any changes in the quality of the aquatic environment. The monitoring of water quality is of prime importance even though the correlation and interpretation of such data with methoxychlor residues is without precedent.

Environment Canada, Water Quality Division, has maintained sampling stations at Athabasca townsite and immediately downstream of the town of Fort McMurray (about 400 km downstream of Athabasca townsite) for many years. The water quality data obtained from these two stations for the period 1961-1973 indicate the very large range of values over the years (Appendix I).

As part of the Athabasca black fly program, water quality data were obtained by W. A. Charnetski for 1973, 1974, and 1976. They show that there was considerable variation within years (Appendix II) as well as between years.

There was no apparent significant effect of the methoxychlor treatments on the various water quality parameters measured.

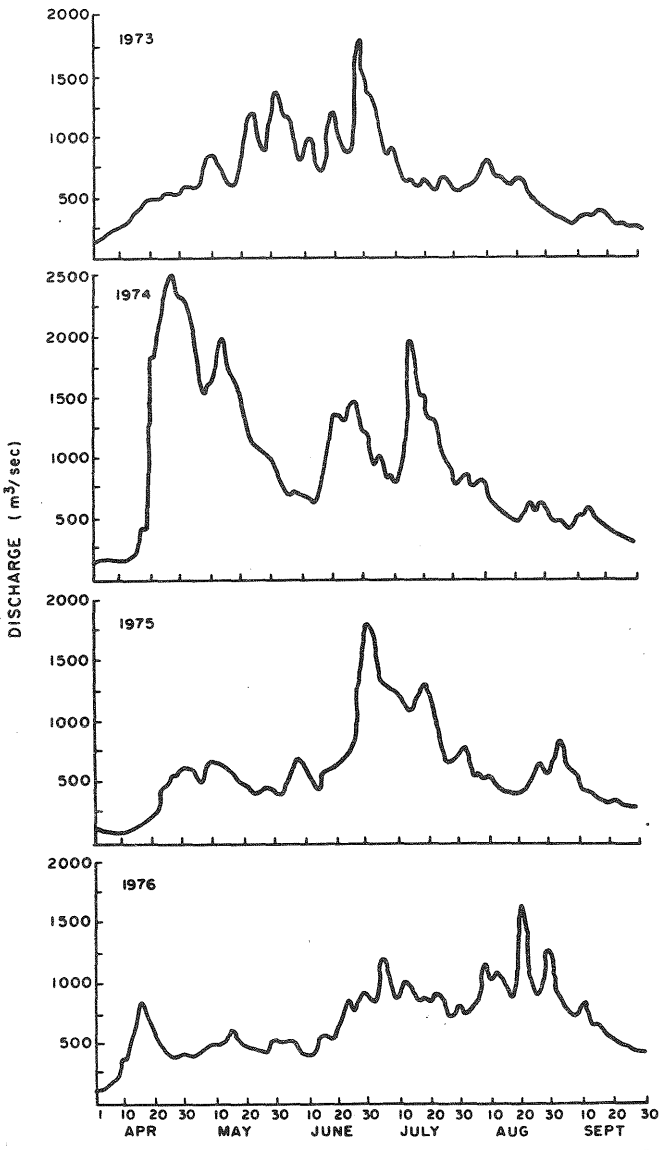


Fig. 6. Daily discharge of the Athabasca river at Athabasca (gauge station 07BE001) for the periods 1 Apr. - 30 Sep. in 1973-76.

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FREDEEN, F. J. H. 1956. Black flies (Diptera:Simuliidae) of the agricultural areas of Manitoba, Saskatchewan, and Alberta. Proc. 10 Int. Congr. Entomol., Montreal 3:819-823.

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KELLERHALS, R., NEILL, C.R. and BRAY, D. I. 1972. Hydraulic and geomorphic characteristics of rivers in Alberta. Alta. Res. Counc., River Eng. Surface Hydrol., Rep. 72-1.

Table 2. Monthly and annual mean discharges (10^3 x ft^3/sec) of the Athabasca River at two locations. Adapted from Historic Streamflow Data, Fisheries and Environment Canada.

Year	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Mean
				At Athabasca (Station 07BE001)					
1966	3.32	7.55	30.00	32.10	34.80	33.80	22.30	11.50	16.60
1967	3.42	7.58	24.60	41.60	26.40	19.40	12.80	8.75	13.40
1968	3.30	4.57	13.40	26.90	30.00	24.20	14.80	8.65	11.50
1969	2.26	14.00	16.90	23.10	25.00	35.20	18.50	12.70	13.60
1970	2.84	12.70	18.20	31.00	28.90	17.40	10.30	7.41	11.90
1971	2.73	15.60	23.40	54.30	75.40	28.00	16.00	13.20	20.60
1972	3.56	13.10	37.40	57.90	39.90	25.70	16.60	15.70	19.10
1973	4.10	13.30	30.60	38.30	27.70	22.50	12.70	12.00	15.10
1974	3.68	34.30	54.60	35.70	41.50	23.50	17.10	11.40	20.20
1975	3.73	8.30	18.70	23.80	39.30	18.90	16.00	8.95	13.10
1976	3.44	15.00	17.10	21.20	31.40	36.30	22.70	12.00	14.80
				Below Fort McMurray (Station 07DA001)					
1966	7.28	13.80	41.20	52.30	45.50	42.10	36.50	20.20	24.70
1967	5.50	11.30	47.90	51.40	38.10	30.30	18.80	13.10	20.40
1968	5.70	10.00	19.50	34.10	38.40	31.10	23.10	18.10	17.10
1969	4.16	-	35.90	35.10	32.50	40.70	29.50	26.30	-
1970	5.38	20.80	32.10	42.70	66.80	32.50	25.20	19.90	22.80
1971	5.09	24.40	37.90	61.70	96.70	38.80	22.80	19.50	28.00
1972	6.88	18.60	60.20	65.80	51.90	32.30	21.30	20.80	25.80
1973	6.03	15.70	39.40	66.60	47.30	43.10	27.70	27.90	26.20
1974	6.69	31.90	73.60	53.50	63.20	46.00	29.10	22.60	30.50
1975	7.21	13.50	34.80	34.50	61.20	36.20	37.80	23.80	24.10
1976	6.34	30.10	24.90	29.10	46.30	48.80	43.50	24.90	24.00

APPENDIX I. Summary of water quality data for Athabasca River at Athabasca (Guage 07BE001) and Fort McMurray (Guage 07DA001), 1961-1973

Analysis[a]	Method	Measurement Basis	Measurement Units	Athabasca Samples analyzed	Athabasca Results Range	Athabasca Results Avg	Fort McMurray Samples analyzed	Fort McMurray Results Range	Fort McMurray Results Avg
pH	10301S		pH	6	7.4-8.7	8.1	3	7.2-8.8	7.9
pH	10301L		pH	164	7.2-8.6	7.9	61	7.6-8.6	8.1
Alkalinity									
Total	10101L	$CaCO_3$	mg/liter	163	70-181	126	60	64-200	119
Phenolphthaline	10151L	$CaCO_3$	mg/liter	161	0-2	0	55	0-0	0
Color - apparent	02011L		Rel. units	163	<5-200	31	60	5-100	39
Turbidity	02073L		JTU	164	<0.1-1100	36	62	1.0-650	42
Saturation (calc)	00210L	Index	pH	152	-0.7-1.1	0.2	59	-0.4-1.2	0.3
Stability (calc)	00211L	Index	pH	152	6.4-8.5	7.5	59	6.1-8.7	7.5
Specific conduct.	02041S		us/cm	5	160-300	240	3	220-267	249
Specific conduct.	02041L		us/cm	165	112-448	304	62	193-476	296
Hardness - total	10603L		mg/liter	95	78-214	147	61	73.4-221	136
Residue									
Nonfilterable	10401L		mg/liter	40	<1-1618	144	21	3-865	223
Nonfilt. - fixed	10501L		mg/liter	40	<1-1508	127	22	<1-810	199
Filterable	10451L		mg/liter	32	120-283	198	1	212-212	212
Filt. - fixed	10551L		mg/liter	32	18-241	123	1	177-177	177
Carbon									
Total organic	06001L	C	mg/liter	12	7.0-26.0	11.2	10	2-30.0	13.9
Total inorganic	06051L	C	mg/liter	12	10.0-33.0	22.3		16.0-35.0	22.1
Bicarbonate (calc)	06201L	HCO_3	mg/liter	159	85-221	153	55	78-228	141
Carbonate (calc)	06301L	CO_3	mg/liter	159	0-2	0	55	0-0	0
Free CO_2 (calc)	06401L	CO_2	mg/liter	162	0.8-12.0	3.3	60	0.8-7.0	2.2
Phenolic material	06531P	Phenol	µg/liter	1	-	<2	2	<2-1717	9
Oxygen									
Diss. (DO)	08101S	O_2	mg/liter	5	7.0-9.0	8.0			
Total COD	08301L	O_2	mg/liter	8	<10-62	33			
Consumed	08401L	O_2	mg/liter	41	1.1-23.7	6.2	5	3.4-12.1	6.0
Nitrogen									
Total (calc)	07602L	N	mg/liter	3	0.5-0.59	0.53	1	0.63-0.63	0.63
Total (Kjeldahl)	07001L	N	mg/liter	3	0.5-0.5	0.5	1	0.6-0.6	0.6
Diss. NO_3 and NO_2	07105L	N	µg/liter	104	<1-429	58	55	<5-371	73
Diss. nitrate	07308L	N	µg/liter	54	0-678	131			
Diss. ammonia	07551L	N	mg/liter		<0.1-1.0	0.1	12	<0.1-0.4	0.2
Sodium - diss.	11103L	Na	mg/liter	157	2.2-14.2	7.7	61	3.6-20.8	9.8
Silica - reactive	14101L	SiO_2	mg/liter	156	2.4-10.0	5.1	62	0.3-8.0	4.9
Phosphate - total	15413L	P	µg/liter	40	<5-9898	14	6	10-33	21
Sulphate - diss.	16303L	SO_4	mg/liter	149	12.5-58.0	31.2	51	8.8-55.6	30.2
Chloride - diss.	17203L	Cl	mg/liter	156	0.2-9.1	3.2	61	0.6-40.5	4.6
Potassium - diss.	19103L	K	mg/liter	156	0.5-5.1	1.5	60	0.6-4.0	1.4
Calcium - diss.	20101L	Ca	mg/liter	156	25.4-64.5	42.0	60	21.2-67.2	40.5
Iron[a]									
Diss.	26102L	Fe	µg/liter	54	<1-38	50	19	<1-340	94
Extractable	26302L	Fe	mg/liter	6	0.08-1.30	0.55			
Extractable	26302P	Fe	mg/liter	14	0.08-13.4	2.6	2	0.82-1.40	1.11

a Sampling period at Athabasca, Jan. 1961-Nov. 1973 (except for iron, Mar. 1961-Oct. 1973) and at Fort McMurray, Oct. 1967-Dec. 1973.

Source: Water quality data, Fisheries and Environment Canada.

Analysis	Method	Measurement Basis	Measurement Units	0 km	21 km	40 km	77 km	161 km	176 km	200 km	240 km	320 km	396 km
Number of samples				7	8	6	7	1	10	6	8	8	3
pH	10301L		pH	8.3	8.3	8.4	8.3	8.3	8.5	8.1	8.2	8.3	7.8
Alkalinity Total	10101L	$CaCO_3$	mg/liter	124	124	122	121	117	123	120	124	122	126
Color													
T_1 - apparent	02000L		Rel. Units	98	98	97	98		89	66	86	98	99
T_2 - apparent	02000L		Rel. Units	97	98	96	97		88	65	85	97	98
T_3 - apparent	02000L		Rel. Units	94	95	94	94		85	63	83	94	94
Turbidity	02073L		JTU	12	10	7	9		8		5	7	
Specific conduct.	02041L		us/cm	244	243	249	244	225	244	233	234	244	230
Hardness - total	10604L	$CaCO_3$	mg/liter	133	123	125	130	106	126	120	119	120	114
Residues													
Nonfilterable	10401L		mg/liter		43	50	42	91	73	69	106	65	131
Nonfilt. - fixed	10503L		mg/liter		5	15	17	60	23	44	46	22	110
Total	10471L		mg/liter	226	204	231	210	228	225	254	227	247	286
Total - fixed	10571L		mg/liter	149	138	149	141	224	157	200	157	173	223
Carbon													
Total	06000L		mg/liter	35	35	35	35	36	35	35	34	35	36
Total organic	06001L		mg/liter	19	19	19	19	19	19	18	18	19	19
Total inorganic	06051L		mg/liter	16	16	17	17	17	16	17	16	17	17
Bicarbonate	06201L	HCO_3	mg/liter	148	149	147	143	143	146	147	139	146	153
Carbonate	06301L	CO_3	mg/liter	<5	<5	<5	<5		<5	<5	6	<5	
Phenolic material	065327	Phenol	µg/liter	1	1	1	1	5	1	3	2	1	3
Oxygen													
Total COD	08301L	O_2	mg/liter	14.0	12.7	14.6	16.7	21.0	18.6	16.0	22.5	15.6	21.5
Demand BOD	08201L	O_2	mg/liter	1.1	1.1	0.8	0.5	1.0	0.4	1.0	0.7	0.6	1.1
Nitrogen													
Total - Kjeldahl	07003L	N	mg/liter	0.30	0.28	0.32	0.37	0.28	0.33	0.47	0.41	0.33	0.58
Diss. NO_3 and NO_2	07105L	N	mg/liter	<0.1	<0.1	0.4	<0.1	<0.1	0.2	0.2	0.2	0.1	<0.1
Diss. nitrate	07205L	N	mg/liter	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Diss. ammonia	07555L	N	mg/liter	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Sodium	11102L	Na	mg/liter	5.9	5.8	6.0	5.9	5.0	5.9	5.0	5.6	5.4	6.0
Phosphate	15407L	P	mg/liter	0.09	0.10	0.12	0.14	0.21	0.80	0.19	0.37	0.16	0.27
Sulphate - diss.	16306L	SO_4	mg/liter	20	16	14	20	<10	26	13	19	19	<10
Sulfide	16101L	S	µg/liter	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Chloride - diss.	17203L	Cl	mg/liter	<1	<1	2	<1	<1	<1	<1	<1	<1	<1
Potassium - diss.	19102L	K	mg/liter	1.1	1.4	2.8	1.1	1.1	1.6	1.5	1.4	1.9	1.0
Calcium - diss.	20105L	Ca	mg/liter	38.3	33.8	37.0	34.4	29.0	37.1	33.3	33.1	33.6	34.3
Iron extractable	26302L	Fe	mg/liter	0.3	0.3	0.2	0.3	0.4	0.3	0.3	0.2	0.2	0.3
Tannin and Lignin	06551L		mg/liter	0.5	0.4	0.5	0.4		0.5	0.3	0.3	0.5	0.4
Total diss. solid	00205L		mg/liter	150	140	142	147	125	154	136	144	143	135
Odor	02001L		ton					<1	<1	<1	<1		
Magnesium - diss.	12102L		mg/liter	9.0	9.5	7.8	10.7	8.0	8.4	8.7	8.6	8.6	6.7
Fluorine	09107L	F	µg/liter	180	170	170	180	90	150	160	160	170	200

APPENDIX II — B: 1974 Continued

Analysis	Method	Measurement Basis	Measurement Units	Month	-60 km	-40 km	-20 km	0 km	5 km	20 km	40 km	60 km	80 km	100 km	120 km	140 km	160 km
Chloride - diss.	17203L	Cl	mg/liter	June	1	1	1		3	4	1	1	1	1	1	1	3
				Aug.	1	6	1	3	4	4	4	4	4	3	2	4	4
				Sep.	4	4	2	4	3	2	1	1	1	4	3		
				Avg.	2	3	2	3	3	3	2	2	2	2	2	2	3
Potassium - diss.	19102L	K	mg/liter	May	1.5	1.5	1.3	1.6	2.2	2.0	2.1	1.8	2.2	2.4	2.2	2.2	2.2
				June	1.6	1.6	1.7		1.3	1.5	1.7	1.6	1.9	1.9	1.9	1.8	1.8
				Aug.	1.2	1.3	1.2	0.9	1.2	0.9	0.9	1.1	1.1	1.1	1.4	1.0	1.2
				Sep.	1.0	1.0	0.8	0.9	0.9	0.9	1.2	1.2	1.2	0.9	0.8		
				Avg.	1.3	1.3	1.3	1.1	1.4	1.3	1.5	1.4	1.6	1.6	1.6	1.7	1.7
Calcium -diss.	20105L	Ca	mg/liter	May	31.7	34.7	33.3	32.0	29.7	28.3	27.3	31.0	19.0	22.3	23.3	24.7	30.7
				June	32.3	24.3	26.7		36.0	39.7	27.7	28.5	28.3	26.7	27.7	27.0	29.0
				Aug.	25.7	27.3	27.7	33.0	34.3	32.0	37.3	30.3	40.3	26.0	38.3	34.0	26.3
				Sep.	29.0	36.3	45.3	29.0	32.3	31.3	26.0	26.7	27.3	38.3	55.0		
				Avg.	29.7	30.7	33.3	31.0	33.1	32.8	29.6	29.2	28.8	28.3	36.1	28.6	28.7
Iron - extractable	26302L	Fe	mg/liter	May	0.7	0.7	0.2	0.3	2.9	2.6	2.4	2.4	2.4	2.0	2.3	2.7	2.0
				June	1.8	1.5	1.6		0.2	0.5	1.8	0.9	1.4	2.0	1.8	1.8	2.1
				Aug.	1.4	1.6	1.6	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.4	0.2	0.2
				Sep.	0.1	0.1	0.1	0.1	0.2	0.2	0.5	0.6	0.4	0.1	0.1		
				Avg.	1.0	1.0	0.9	0.2	0.9	0.9	1.3	1.0	1.1	1.1	1.2	1.6	1.4
Total dissolved solids (TDS)	00203L	mg/liter		May	126	126	118	121	127	126	126	115	107	116	109	117	124
				June	139	126	128		142	151	129	134	129	130	133	134	133
				Aug.	114	118	118	125	129	129	132	132	148	104	141	127	111
				Sep.	120	140	155	127	128	128	121	119	121	134	173		
				Avg.	125	127	130	125	132	133	127	124	126	121	139	126	123
Odor	02001L		ton	Sep.									1				
Magnesium - diss.	12102L	Mg	mg/liter	May	5.3	5.0	4.0	5.3	7.3	7.7	7.3	6.0	10.7	9.3	7.7	8.3	7.3
				June	9.7	9.0	8.7		7.0	8.0	9.0	9.0	9.0	9.0	9.0	9.3	8.3
				Aug.	8.0	8.0	8.0	6.0	6.0	6.0	5.3	6.0	6.7	6.0	6.3	6.0	7.0
				Sep.	7.0	6.7	6.0	7.0	6.3	7.0	8.0	8.0	7.7	5.0	4.7		
				Avg.	7.5	7.2	6.7	6.1	6.7	7.2	7.4	7.1	8.5	7.3	6.9	7.9	7.6
Fluorine	09105L	F	mg/liter	May	0.12	0.08	0.09	0.11	0.08	0.10	0.08	<0.05	0.07	0.12	0.14	<0.05	0.12
				June	0.08	0.11	0.14		0.15	0.28	0.11	0.16	0.11	0.11	0.14	0.16	0.13
				Aug.	0.13	<0.05	0.11	0.15	0.15	0.12	<0.05	0.12	<0.05	0.09	0.09	<0.05	0.08
				Sep.	0.08	0.08	0.17	0.24	0.14	0.13	0.14	0.11	0.12	0.10	0.12		
				Avg.	0.10	0.08	0.13	0.17	0.13	0.16	0.09	0.10	0.09	0.10	0.12	0.09	0.11

APPENDIX II — B: 1974 continued

Analysis	Method	Measurement Basis	Measurement Units	Month	-60 km	-40 km	-20 km	0 km	5 km	20 km	40 km	60 km	80 km	100 km	120 km	140 km	160 km
Specific conduct.	02041L		us/cm	Aug.	207	208	207	213	208	210	212	205	205	200	205	205	205
				Sep.	225	230	230	227	225	226	217	215	217	230	233		
				Avg.	218	217	218	214	221	221	220	212	212	215	216	210	213
Hardness - total	10604L	$CaCO_3$	mg/liter	May	103	108	102	103	106	104	102	103	93	95	92	98	109
				June	122	103	105		120	133	108	111	110	106	109	107	110
				Aug.	99	101	103	110	112	107	117	105	129	93	125	113	97
				Sep.	103	121	137	103	109	108	102	103	102	117	159		
				Avg.	107	108	112	105	112	113	107	105	108	103	121	106	105
Bicarbonate (calc)	06201L	HCO_3	mg/liter	May	96	92	101	92	128	129	130	124	123	124	118	119	121
				June	135	128	130		111	116	125	138	128	128	129	135	138
				Aug.	114	109	115	96	95	97	107	96	108	101	107	112	112
				Sep.	106	119	115	94	106	95	122	116	124	118	125		
				Avg.	113	112	115	94	110	109	121	117	121	118	120	122	120
Carbonate (calc)	06301L	CO_3	mg/liter	May	5	6	5	6									
				June	5	5	5		6	6	5	5	5	5	5	5	5
				Aug.			5	5	6	6		5		6			
				Sep.	5	5	5	6	6	6	5	5	5		6		
				Avg.	5	6	5	6	6	6	5	5	5	5	6	5	5
Nitrogen Diss. NO_3 and NO_2	07107L	N	mg/liter	May	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
				June	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
				Aug.	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
				Sep.	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	0.2		
				Avg.	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nitrogen Diss. nitrate	07206L	N	mg/liter	May	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
				June	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
				Aug.	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
				Sep.	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1		
				Avg.	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sodium - diss.	11102L	Na	mg/liter	May	5.0	4.3	4.0	5.3	5.0	4.7	5.0	3.7	5.0	5.0	5.0	5.0	5.0
				June	5.0	5.0	5.3		5.7	4.0	5.0	5.0	4.7	5.3	5.7	5.3	5.0
				Aug.	3.0	3.0	3.0	4.3	4.0	3.7	3.7	4.0	3.3	2.3	3.3	2.7	3.7
				Sep.	4.3	4.7	3.0	5.0	4.7	4.7	4.0	4.3	4.3	3.3	3.0		
				Avg.	4.3	4.3	3.8	4.9	4.8	4.3	4.4	4.2	4.3	4.0	4.3	4.3	4.6
Sulphate - diss.	16302L	SO_4	mg/liter	May	25	25	19	22	14	14	15	12	11	13	11	13	15
				June	16	16	16		26	28	15	17	17	17	16	17	16
				Aug.	15	15	16	24	24	30	28	35	37	12	33	21	12
				Sep.	19	27	35	28	24	29	17	15	14	22	39		
				Avg.	19	21	21	25	22	25	19	20	20	16	25	17	14
Chloride - diss.	17203L	Cl	mg/liter	May	2	2	2	2	1	1	1	1	1	1	1	1	1

APPENDIX II. A: 1973 continued

Analysis	Method	Measurement Basis	Measurement Units	Month	-65 km	-45 km	-35 km	-20 km	0 km	5 km	20 km	35 km	50 km	65 km	90 km	100 km	115 km	125 km
Chloride - diss.	17203L	Cl	mg/liter	June	1.5	1.5	1.5	2.0	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5	2.0	2.0
				July	2.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0	2.0	1.5	2.0	2.0	2.0	1.0
				Sep.	2.0	2.0	2.0	1.5	1.0	1.0	1.0	1.0	1.0	1.5	1.0	1.0	1.0	1.0
				Avg.	1.8	1.5	1.5	1.5	1.7	1.7	1.7	1.7	1.7	1.5	1.5	1.5	1.7	1.4
Potassium - diss.	19103L	K	mg/liter	June	1.0	1.0	0.9	0.9	1.1	1.1	1.0	1.0	1.1	1.1	1.2	1.2	1.1	1.1
				July	1.0	0.9	0.9	0.9	1.0	0.9	0.9	1.0	0.9	1.0	1.0	1.0	0.9	0.9
				Sep.	1.1	1.2	1.2	1.1	1.1	1.2	1.2	1.1	1.2	1.4	1.3	1.3	1.3	1.3
				Avg.	1.0	1.0	1.0	1.0	1.0	1.1	1.0	1.0	1.1	1.1	1.2	1.1	1.1	1.1
Calcium - diss.	20101L	Ca	mg/liter	June	33.5	33.0	37.0	35.5	33.0	36.5	34.0	34.0	36.0	36.0	39.5	36.0	38.5	37.0
				July	34.5	33.5	33.5	32.0	35.5	35.5	35.5	35.0	34.0	34.0	33.5	36.5	36.5	35.0
				Sep.	4.0	4.0	4.0	4.2	4.2	4.1	4.2	4.0	4.3	4.2	4.1	4.1	4.1	4.1
				Avg.	24.0	23.5	24.8	23.9	24.2	25.4	23.9	24.0	24.8	24.7	25.7	25.5	26.4	23.4
Temp.	02061L		^{o}C	June	24.1	24.5	24.3	24.1	23.8	24.0	24.0	24.2	24.1	24.2	24.2	24.3	24.1	24.3
				July	25.9	25.8	25.3	25.9	23.9	23.7	23.7	24.0	24.2	23.7	24.5	24.4	23.0	24.3
				Sep.	22.0	22.0	21.8	21.9	21.5	21.6	21.7	21.7	21.8	22.1	21.9	22.1	21.7	21.7
				Avg.	24.0	24.1	23.8	23.9	23.1	23.1	23.1	23.3	23.3	23.3	23.5	23.6	23.2	23.3

APPENDIX II — B: 1974

Analysis	Method	Measurement Basis	Measurement Units	Month	-60 km	-40 km	-20 km	0 km	5 km	20 km	40 km	60 km	80 km	100 km	120 km	140 km	160 km
pH	10301L		pH	May	8.5	8.6	8.5	8.5	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.3
				June	8.4	8.4	8.2		8.6	8.7	8.5	8.3	8.4	8.4	8.5	8.5	8.4
				Aug.	8.3	8.3	8.3	8.4	8.5	8.4	8.2	8.3	8.3	8.3	8.3	8.3	8.3
				Sep.	8.4	8.3	8.3	8.4	8.5	8.5	8.3	5.8	8.3	8.2	8.4		
				Avg.	8.4	8.4	8.3	8.4	8.4	8.5	8.3	7.6	8.3	8.3	8.3	8.3	8.3
Alkalinity - total	10101L	$CaCO_3$	mg/liter	May	86	85	89	85	104	105	106	101	100	101	96	97	99
				June	117	107	108		101	105	110	115	108	108	112	113	108
				Aug.	93	89	96	86	88	83	88	80	88	86	87	92	91
				Sep.	92	98	99	84	93	84	101	98	103	96	126		
				Avg.	97	95	98	85	97	94	101	97	100	98	106	101	99
Turbidity	02073L		JTU	Sep.									14	12			
Specific conduct.	02041L		us/cm	May	203	201	200	203	212	207	208	198	197	202	197	195	202
				June	237	230	237		241	241	242	240	230	230	230	230	232

APPENDIX II. Summary of water quality data taken at Athabasca Black Fly sampling locations during 1973

A: 1973

Analysis	Method	Measurement Basis	Measurement Units	Month	-65 km	-45 km	-35 km	-20 km	0 km	5 km	20 km	35 km	50 km	65 km	90 km	100 km	115 km	125 km
pH	10301L		pH	June	8.2	8.1	8.1	8.2	8.2	8.0	8.0	8.0	8.2	8.1	8.2	8.2	8.2	8.2
				July	8.1	8.0	8.0	8.0	8.5	8.6	8.6	8.7	8.4	7.9	7.9	7.9	8.0	8.0
				Sep.	8.0	8.0	8.0	8.1	7.8	7.8	8.1	7.7	7.7	7.8	7.9	7.9	7.9	8.1
				Avg.	8.1	8.0	8.0	8.1	8.1	8.1	8.2	8.1	8.1	7.9	8.0	8.0	8.0	8.1
Alkalinity - total	10101L	$CaCO_3$	mg/liter	June	91	93	94	96	93	99	96	98	100	95	96	97	93	95
				July	95	95	94	95	100	97	95	98	99	97	99	99	98	98
				Sep.	110	112	112	113	114	119	118	117	118	118	115	116	116	115
				Avg.	99	100	100	101	102	105	103	104	106	102	103	104	102	104
Color - apparent	02011L		Rel. units	June	63	58	65	60	58	58	55	58	58	85	78	80	85	90
				July	30	28	30	28	35	28	28	28	28	35	35	35	43	40
				Sep.	20	25	20	30	25	20	30	25	25	35	30	25	30	30
				Avg.	38	37	38	39	39	35	38	37	37	52	48	47	53	56
Turbidity	02073L		JTU	June	76	82	78	81	85	85	87	81	86	84	106	109	119	108
				July	23	24	31	24	27	24	25	27	21	28	27	32	26	30
				Sep.	42	48	45	54	35	30	53	49	38	43	35	20	55	69
				Avg.	47	51	51	53	49	46	55	52	48	51	56	54	67	76
Specific conduct.	02041L		us/cm	June	209	211	214	217	214	228	223	225	228	209	224	227	223	223
				July	228	227	225	235	238	230	231	232	237	235	235	240	236	235
				Sep.	264	264	264	263	265	270	268	269	271	264	266	263	263	260
				Avg.	233	234	234	238	239	243	241	242	245	236	241	243	241	240
Hardness - total	10603L	$CaCO_3$	mg/liter	June	104	103	104	107	106	112	110	114	111	106	111	112	110	111
				July	112	111	110	111	115	114	113	116	117	115	116	118	117	117
				Sep.	135	132	130	134	124	140	134	132	132	133	133	130	130	131
				Avg.	117	115	115	117	115	122	119	121	120	118	120	120	119	120
Residue - nonfilt.	1040L		mg/liter	July	33	57	77	63	67	41	44	64	36	72	72	69	46	94
Res. nonfilt. - fixed	1050L		mg/liter	July	27	48	65	53	54	32	34	53	28	60	61	58	36	83
Sodium - diss.	11103L	Na	mg/liter	June	1.8	4.9	5.3	5.4	5.4	5.4	5.3	5.3	5.4	5.1	5,3	5.4	5.4	5.3
				July	4.9	4.8	4.8	4.7	5.0	4.6	4.2	5.0	4.8	4.9	5.0	5.1	4.0	5.1
				Sep.	5.5	5.7	5.8	5.7	6.0	6.3	6.3	6.2	6.4	6.7	6.8	6.4	6.4	6.3
				Avg.	4.0	5.1	5.3	5.3	5.5	5.4	5.2	5.5	5.5	5.6	5.6	5.6	5.3	5.7
Silica - reactive	14102L	SiO_2	mg/liter	June	6.1	6.0	6.0	6.0	6.8	6.0	5.9	6.0	6.2	5.9	5.8	5.7	5.7	5.6
				July	4.6	4.4	4.2	4.2	4.0	4.0	3.9	4.2	4.4	4.4	4.5	4.5	4.6	4.6
				Avg.	5.3	5.2	5.1	5.1	5.4	5.0	4.9	5.0	5.3	5.1	5.1	5.1	5.1	5.1
Sulphate - diss.	16304L	SO_4	mg/liter	June	21	20	22	23	16	17	18	16	15	15	15	23	26	24
				July	19	19	20	19	20	20	20	21	21	21	21	21	21	21
				Sep.	29	28	28	27	31	30	29	29	26	24	27	25	27	26
				Avg.	19	22	23	23	22	22	22	22	20	20	21	23	25	24

POPULATION REDUCTION OF THE BLACK FLY SIMULIUM ARCTICUM AT BREEDING SITES IN THE ATHABASCA RIVER

K. R. DEPNER, W. A. CHARNETSKI

AND W. O. HAUFE

INTRODUCTION

The problem of black flies, *Simulium arcticum*, attacking livestock in the County of Athabasca and in the neighboring Improvement District No. 18 has been a recurring one for as long as livestock have been in the area. Because of this problem, we undertook, in 1967, to study the biology of the pest. This study, from 1968 to 1972, led to the conclusion that the breeding areas of *S. arcticum* related to the problem were confined to the Athabasca River. The highest populations of larvae were found in reaches of the river between the towns of Athabasca and Fort McMurray. A multidisciplinary feasibility study was conducted in 1973 to provide base-line data on (a) black fly breeding sites in the river, (b) background chemical residues in fish, invertebrates, water, and mud, and (c) distribution, numbers, and identity of food-chain organisms.

In 1974, a multidisciplinary control program was designed to reduce populations of *S. arcticum* developing in the Athabasca River with chemical larvicides. This report describes a 3-yr control program in selected reaches of the Athabasca River. Monitoring was continued for 1 yr after the final river treatment to determine the effects on populations of the pest and on the non-target invertebrates of the river ecosystem.

METHODS

The area selected for study extended upstream from the town of Athabasca for 50 km and downstream for up to 320 km. Yearly details are shown in Table 1. In every year, stations upstream were untreated controls while treated stations were downstream.

Table 1. Location and designation of sampling stations

Distance from Athabasca (km)	Year			
	1974	1975	1976	1977
	Upstream			
60	U3	-	-	-
40	U2	U2	U2	U2
20	U1	U1	U1	U1
	Downstream			
4.7	D1	D1	D1	D1
20	D2	D2	D2	D2
40	D3	D3	D3	D3
60	D4	-	-	-
80	D5	D4	D4	D4
100	D6	-	-	-
120	D7	D5	D5	D5
140	D8	-	-	-
160	D9	D6	D6	D6
165	-	-	D6A	-
180	-	-	D6B	-
200	-	D7	D7	D7
240	-	D8	D8	D8
280	-	-	D9	-
320	-	-	D10	-

S. arcticum Larval Sampling

Black fly larvae were sampled by using plastic cones as artificial substrates for larval attachment. These cones had a basal diameter of 10 cm, a height of 17.5 cm, and an area of 353.6 cm^2 each. Two of these cones were attached by a 24-cm leader and snap to rings tied into a 20-m long polypropylene line at points 1 and 10 m from the top. When this line was set into the river in about 3 m depths of water, the cones were suspended at 0.3 and 1.5 m depths below the surface. The lines were anchored in place by 11-kg weights at the lower end and tied to a 4.5-liter plastic bottle at the top as a float. Each of these units was called a set and three sets were placed at each sampling station. Cones were left in the water for 7 days and then fresh cones were attached.

All cones were placed and retrieved by boat. Sets were assembled in the boat, three for each sampling station. All operations were made with the boat pointing upstream and with both motors adjusted to maintain just enough headway to hold against the current. Suitable locations for sets were chosen at sampling stations according to depth (2-3 m), substantial current velocity (1-1.5 m/sec), and protection from the main flow of surface debris.

When cones were retrieved and replaced, sets were approached from downstream, and a fresh approach was required for each set. At least two persons were required to accomplish successful replacement - one to pick up sets and the other to drive the power boat. As the boat passed alongside the float, it was picked up, and with it the upper plastic cone. Pick up was in one smooth uninterrupted movement to prevent the cone from dipping back below the surface and thereby losing a proportion of the attached larvae. When the cone was picked up, it was unsnapped from the ring in the line and set into a 2-liter polyethylene beaker containing about 250 ml of alcohol. Before the ring was released, a fresh unused cone was snapped into place on the line which was then gradually passed backward through the hands of the operator until the second cone was reached. In the process of moving forward, the float and the newly replaced upper cone had been allowed to drop back into the water. The second cone was lifted in the same manner as the first and also placed in a beaker containing alcohol after which a fresh cone was snapped into place and the line released to move back into postion.

When cones at all three sets at the sampling station had been replaced, the retrieved cones were immediately processed to remove the larvae.

Cone processing

1. Larvae were washed from cones carefully to avoid damage, using plastic gloved fingers and wash bottles.

2. The larvae were then separated from the wash alcohol by pouring through a 9-cm diam, 100-mesh cloth screen that was held in a metal and rubber ring. This assembly was held in a 14-cm diam plastic funnel that had a 100-mesh brass screen in its outlet.

3. When all larvae had been deposited on the cloth screen, it was removed from its holder, folded, and placed in a 40-ml screw-cap vial together with an identifying label and alcohol.

4. The vial was then sealed and stored for return to the laboratory.

At the laboratory, each vial was carefully emptied into a 9-cm diameter petri dish, and the black fly larvae were carefully removed from the cloth filter. All larvae were identified to species, measured to determine stage of development, and counted under a stereoscopic binocular microscope at magnifications of 10-50 times. Careful and complete records were kept for all stages of the operation.

Determination of Treatment Time

Monitoring of *S. arcticum* larval numbers and development began in the 1st wk in May in most years. In each week, the numbers of larvae and the proportion in each instar were recorded. As the weeks passed, the proportion of larvae in the later stages increased. Treatment was scheduled to coincide with the period in which a significant number of larvae had reached the seventh instar but before any significant number of mature larvae had pupated. It was important to time this operation carefully, since both eggs and pupae are unaffected by the treatment. Delaying treatment until just before pupation ensured that as many larvae as possible had hatched from the eggs and were susceptible to the pesticide.

Larviciding Treatments

1974

The river was treated on 4 June with methoxychlor applied from the bridge over the Athabasca River located at the town of Athabasca. River discharge at this time was 759.0 m^3/sec and required 795.5 liters of 24% emulsifiable concentrate of methoxychlor to maintain a concentration of 0.3 ppm of active ingredient during an injection period of 15 min. Insecticide was applied from steel drums lined up along the railing of the bridge. Rate of flow of larvicide was controlled by an orifice drilled into the bottom end of a 3-m long drop tube designed to empty the 114-liter steel drum in 15 min (Fig. 1).

Black fly larval samples were obtained at all sampling stations in the week before and again immediately after treatment. The posttreatment sample was taken as soon as the last of the treated water had passed each sampling station. Population reduction

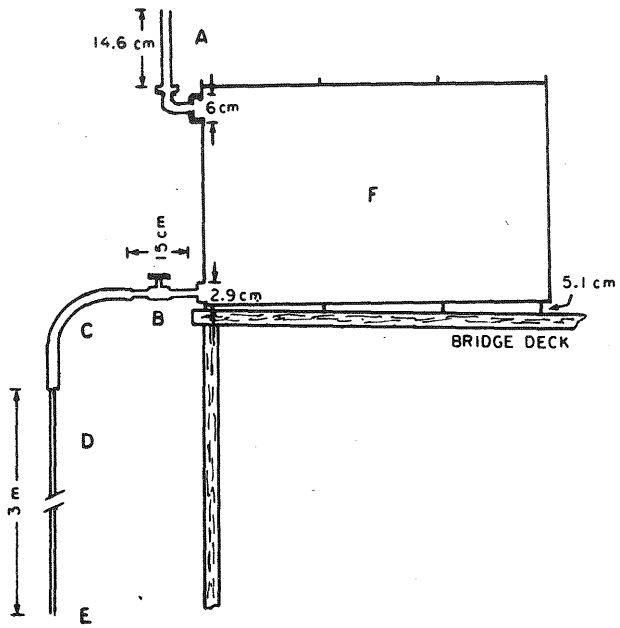

Fig. 1. Larvicide injection apparatus, 1974. A - air inlet; B - outlet faucet; C - 40-cm length of neoprene hose; D - 3-m length of 1.6-cm ID pipe; E - drilled orifice; and F - 114-liter insecticide drum.

of *S. arcticum* larvae was determined at each station from these samples. Larval sampling continued until September.

1975

The river was treated on 4 June at a river discharge of 477.2 m^3/sec. Concentration of active ingredient was 0.3 ppm but injection time was reduced to 7.5 min. Pesticide was applied from three boats with racks to hold the larvicide drums (Fig. 2).

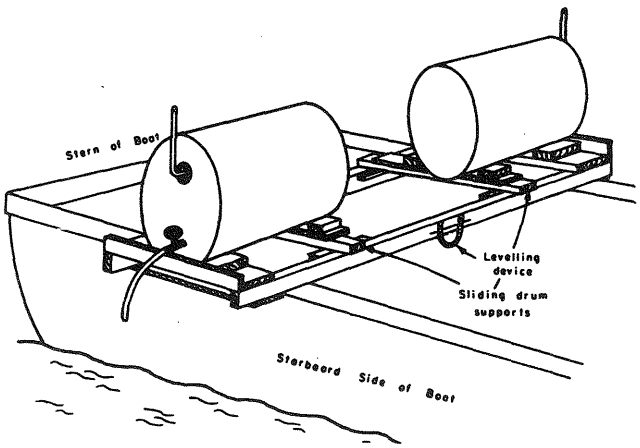

Fig. 2. Larvicide drum rack for boat.

Rate of application of larvicide to the river was regulated by a constant flow apparatus developed for this purpose. This apparatus used the principle of a Mariott flask modified to use Bernouli's Principle to obtain a constant flow rate (Fig. 3). To make the injection of material, the boats moved synchronously within channels marked to contain measured percentages of total river flow. Boat no. 1 delivered 44.4% of the total larvicide in a channel extending from the edge of flow on the left bank facing upstream to a marker placed at the correct position in the river to the right. Boat no. 2 delivered 33.3% of the larvicide in a channel to the right of the previous one and boat no. 3 delivered 22.3% in a channel that covered the remaining portion of the river. Each boat moved from its left channel marker to the right in 2.5 min, back to its left marker in another 2.5 min, and then back to the right again in 2.5 min, for a total time of 7.5 min. This was half of the time of application used in 1974 and therefore used only half of the larvicide used in 1974. To move between markers, boats maintained only enough headway to hold against the current.

Larval sampling techniques were improved in 1975 and double sets were put into the water at each sampling station. Pretreatment samples were taken immediately before the treated slug of water reached each station, and posttreatment samples were taken immediately after the treated slug of water had passed.

1976

A double treatment was made in this year to give a total of three replicates of the 7.5-min injection time, and to test the

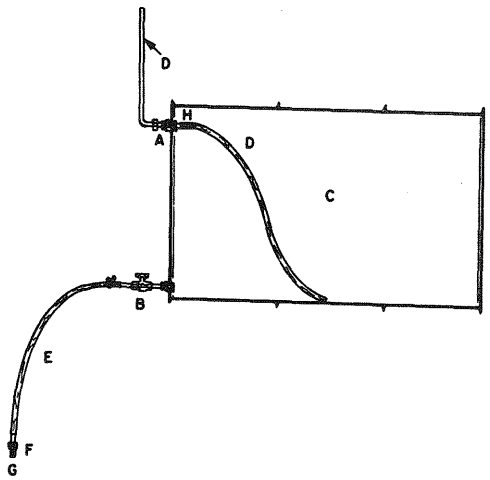

Fig. 3. Larvicide delivery apparatus, 1975 and 1976. A - air inlet seal arrangement; B - outlet faucet; C - 114-liter drum; D - 0.95-cm ID copper tubing; E - 1.6 cm ID neoprene tubing; F - thin wall conduit and reducer to hold drilled orifice; G - Drilled orifice; and H - 1.27-cm ID tygon tubing.

portability of the newly developed technique of treatment by boat. The first treatment was made on 20 May at a point 364 m below the 160-km downstream sampling station (D6). This area duplicated the area lying between 0 and 160 km downstream from the Athabasca treatment point in terms of distances between sampling stations. Rate of river discharge this time, as measured by personnel of the Alberta Research Council, was 566.4 m^3/sec. Treatment was by boat as in 1975 and pre- and post-treatment samples were taken as in 1975. Sampling stations D9 at 280 km, and D10 at 320 km were inaccessible by boat and required servicing by helicopter.

On 25 May, the second half of the double treatment was made at a point 50 m downstream from the bridge at Athabasca at a river discharge rate of 416.3 m^3/sec. Larvicide application was by boat as in the first half of the 1976 operation. Pre- and post-treatment sampling were as in previous years.

1977

No treatment of the river was made in this year in order to have 1 yr in which to determine the effect of 3 yr of larviciding. Sampling began in early May, as in other years, and continued into September. Sampling stations were the same as in 1975.

S. arcticum Adult Sampling

An adult sampling technique usable on large rivers was developed in the period before 1973 and was used in the period of the expanded study after 1973. In this sampling method, a long handled insect net with a 0.3-m^2 opening was held as close as possible to the river surface while moving along in a boat at planing speeds. These speeds varied from 40 to 60 km/hr depending on the power boat used, and on the direction of travel on the river. In practice, the net was held well out to one side of the boat above undisturbed water and therefore sampled undisturbed above-surface fly activity. Sweeping with the net was done for 1.6 km every 8 km and on every passage up and down the river during sampling operations. First sweeps in spring were made shortly before the first expected appearance of adult black flies, and continued until river operations were suspended in the fall. Adult black flies captured in this way were transferred to screw-cap vials, labelled, and preserved in alcohol. These flies were returned to the laboratory at Athabasca where they were identified, counted, and their physiological state noted.

River Equipment

The distances involved in servicing the sampling stations set up each year extended to 240 km downstream of the town of Athabasca and up to 60 km upstream. These stations were serviced each week starting near the beginning of May in each year, and continuing through to September. This meant that a total of about 600 km of river was travelled every week under all weather and river conditions. Travelling such distances required fast and reliable power boats.

Boat no. 1 - This boat (length 5.7 m, beam 1.8 m) was powered by two 115 hp outboard motors in which water-jet propulsion units replaced the regular propellor drive. It had fuel tanks designed to give it a range of 320 km and had a cruising speed of 60 km/hr.

Boat no. 2 -This boat (length 5.8 m, beam 1.6 m) was powered by two 65 hp outboard motors equipped with jet propulsion units. Its basic range was about 200 km at a cruising speed of 40 km/hr.

Boat no. 3 - This was a larger, heavier boat, length 7.1 m, equipped with a large inboard marine engine that drove a jet propulsion unit. Cruising speed was about 35 km/hr. This boat was used primarily as a back-up emergency unit except at treatment time when it became one of the treatment boats. It was also used to transport supplies and personnel.

Miscellaneous Boats - These boats were hired as needed to perform various tasks at treatment time and were usually 3.7-m length, aluminum, and equipped with small outboard motors.

RESULTS

Black fly larval populations are discussed in relation to sampling stations and are expressed on an average per cone basis.

Control Stations

At both control stations, larval averages decreased through the summer reaching near 0 in the 3rd wk of August.

U2-40 km upstream - Average numbers of *S. arcticum* larvae in all years between 1973 and 1977 were low. The highest average numbers of larvae in May, June, and July were 74 in 1974, 95 in 1974, and 89 in 1973, respectively (Fig. 4, Appendix I).

U1 - 20 km upstream - This station also showed low average numbers; the highest was 101 in June 1974 (Appendix I).

Treated Stations

D1 - 5 km downstream - Average larval numbers were low in all years both before and after larvicide treatment although post-treatment averages approached 0. In general, levels of larval numbers at this station were lower than at the two control stations upstream. The highest per cone average recorded was 103 *S. arcticum* larvae in the 2nd wk of June 1974 (Appendix I).

Table 2. Highest number of S. arcticum adults swept per 1.6 km, 1969-1977

Year	Upstream reaches (km)						Downstream reaches (km)													
	>80	80-64	64-48	48-32	32-16	16-0	0-16	16-32	32-48	48-64	64-80	80-96	96-112	112-128	128-144	144-160	160-176	176-192	192-208	208-224	224-240
June																					
1969											94	100									
1970				17	8	40	77	41	5	37	10	15	34								
1971				26	30	26	59	235	70	26	780	396	750								
1972					18	10	32	39	210	306	1196	273	180								
1973		1	3	10	14	5	-	36	-	-	-	38	195	44							
1974			1	0	-	-	10	17	21	13	6	14	9	15	-	3	2				
1975				3	5	3	2	6	3	5	9	39	215	39	58	30	43	58	144	738	126
1976				0	0	1	0	1	2	14	1	7	5	3	1	2	15	10	21	12	10
1977				3	6	5	22	52	96	131	87	168	288	348	189	107	2051	2172	2124	100	258
July																					
1969						12	8	163													
1970	2	3	0	4	5																
1973	9	11	42	25	3	12	7	95	178	169	21	49	32	108	125	157					
1974			1	1	4	2	3	4	4	20	21	25	15	27	34	12					
1975				1	0	2	2	2	6	46	140	43	82	35	133	47	28	9	16	30	5
1976				0	0	0	18	46	46	23	26	7	19	12	8	12	35	41	48	8	9
1977				11	14	4	14	33	106	223	316	157	142	121	71	25	505	254	45	15	95
August																					
1969						0	-	4	1.6	1											
1970					4	13	8	6	122	5	168	464	105	15							
1971							8	910	520	14	124	909	12								
1973		20	44	6	1	1	6	26	11	9	34	84	56	24	31	18	15	5			
1974			55	1	3	4	31	47	429	180	42	125	187	68	36	91					
1975				2	0	7	16	24	89	29	192	95	168	240	88	57	100	46	61	552	30
1976				33	23	20	36	80	1033	129	517	514	107	203	202	28	32	3	6	5	2
1977				9	8	7	951	324	3752	1024	509	128	156	70	96	97	25	88	33	70	23
September																					
1973		20	7	0	0	1	1	8	1	2	1	3	12	0							
1974			1	0	0																
1975				0	0	0	0	1	27	12	26	12	10	5	3	8	8	2	4	34	46
1976				0	0	0	0	0	1	0	0	1	1	0	1	0	1	1	1	0	2
1977				24	6	5	10	4	67	20	247	150	121	168	50	18	86	156	7	3	7

- Not sampled.

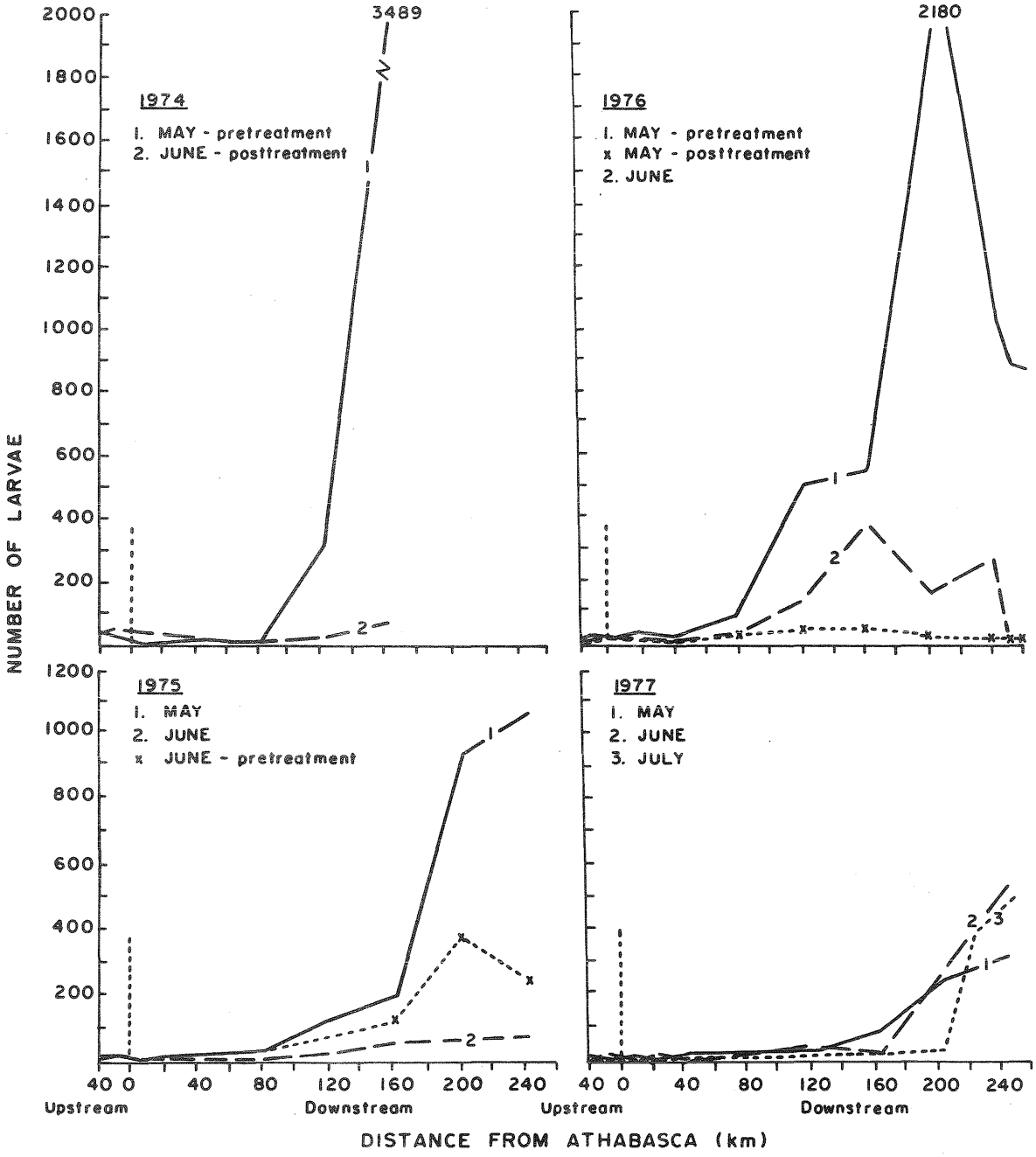

Fig. 4. *S. arcticum:* average larval populations plotted against distance from Athabasca, 1974-1977.

D2 - 20 km downstream - Per cone averages of *S. arcticum* larvae at this station were much the same as D1 during the 5 yr of sampling (Fig. 4, Appendix I).

D3 - 40 km downstream - The numbers of black fly larvae here were much the same as D1 and D2 (Fig. 4).

D4 - 80 km downstream - S. arcticum larvae were more numerous at this station than at any station further upstream, particularly in May and early June (Fig. 4). The highest per cone average recorded was 135 in July 1973 (Appendix I). This figure was higher than numbers for the corresponding date in other years.

D5 - 120 km downstream - S. arcticum larval averages here were consistently higher than at any station further upstream. The highest number recorded here was 931 in May 1976 (Appendix I).

D6 - 160 km downstream - Per cone averages of *S. arcticum* larvae at this station in the 4 yr in which it was sampled were generally higher than at D5. The highest average recorded was 3,490 in late May 1974 (Appendix I).

D7 - 200 km downstream - This station was usually somewhat higher in per cone averages than D6 although the differences were not great. The highest average recorded was 3,176 in May 1976 when the value for D6 was 1,085 larvae (Appendix I).

D8 - 240 km downstream - Larval numbers of *S. arcticum* were high and were comparable to D6 and D7. In 1977, the larval averages at D7 and D8 were low in May compared to other years but the numbers increased gradually to a peak in late June and early July. Numbers remained higher than in any previous recorded year until mid-August when they approached 0 as in previous years (Fig. 4).

D9 and D10 - 280 and 320 km downstream - These stations were monitored only in May 1976 to complete the downstream half of the double larviciding treatment. Rapids above and below these two stations are not navigable by boat and required that sampling crews be flown in and out by helicopter. Consequently these two stations were not used longer than was absolutely necessary. Pre- and post-treatment larval samples, however, indicated that *S. arcticum* larval numbers were similar to D7 and D8 (Fig. 4).

To sum up, *Simulium arcticum* larval numbers in the Athabasca River upstream from the town of Athabasca, and downstream to about 80 km, were usually relatively low. Beyond this point, larval numbers increased to 160 km after which they appear to level off. This section of the river also corresponds to an increased current velocity due to an increased slope in the river bed.

Hatching of *S. arcticum* Larvae

Sampling of the Athabasca River from 1973 to 1977 has indicated that there is a pattern of hatch that follows in most years (Fig. 5, Appendix II). Highest hatches normally occur in late April and early May (Fig. 6). This is followed by a gradual decrease through May and early June to a second, but lower, peak in late spring and early summer. This second peak is not long-lasting and normally drops to near 0 by early August. Some years, however, do not follow this pattern and 1977 was such a year (Fig. 6). In this year, early spring hatches were very low at all stations. Hatches gradually increased as the season progressed, particularly at D6, D7, and D8, and reached a peak in the 1st wk of July (Fig. 5, 1977). After this, hatches at the downstream stations continued at relatively high levels until the end of July with significant numbers hatching at D7 and D8 until the 1st wk of August.

Effect of Larvicide Treatment

1974

In this year, the Athabasca River was treated on 4 June from the bridge that crosses it at the town of Athabasca. Results can be seen in Appendix III which

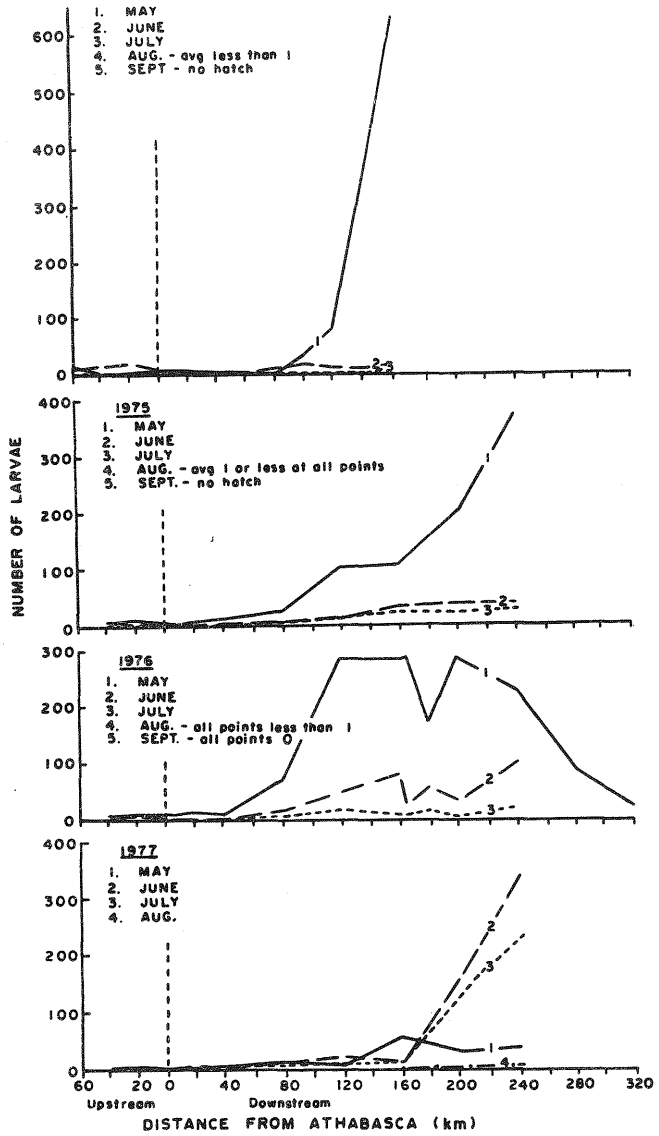

Fig. 5. *S. arcticum:* average hatch (first and second instars) plotted against distance from Athabasca, 1974-1977.

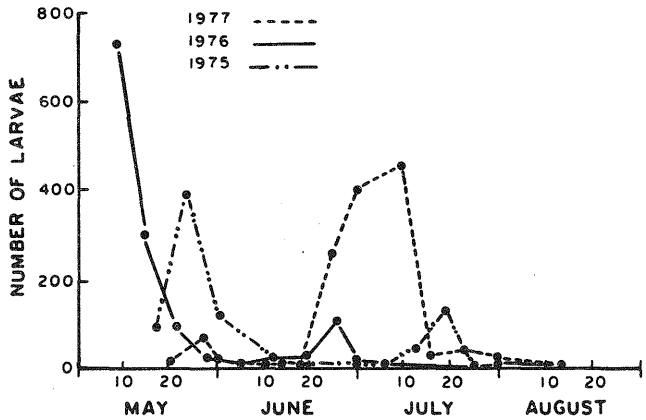

Fig. 6. *S. arcticum:* seasonal larval hatch at 200 km downstream from Athabasca, 1975-1977.

shows a corrected *S. arcticum* larval population reduction of 99.94% at a distance of 160 km downstream from the point of application of the larvicide. As a result of a posttreatment hatch of eggs in the middle of June, numbers of larvae increased slightly but dropped again very quickly to very low numbers in late June, and for the rest of the summer (Appendix I).

1975

Treatment in this year was from boats at a point 50 m downstream from the Athabasca bridge on 4 June. Population reduction of *S. arcticum* larvae was less than in 1974 and dropped from 93.5% at 5 km downstream to 36.3% at 120 km, with no reduction beyond this point. River discharge levels through May and June were lower than in 1974 (Fig. 7), and posttreatment hatches of larvae were insignificant until mid-July when for 1 wk numbers increased at D6, D7, and D8 (Appendix II). River levels at this time were also higher than previously (Fig. 7).

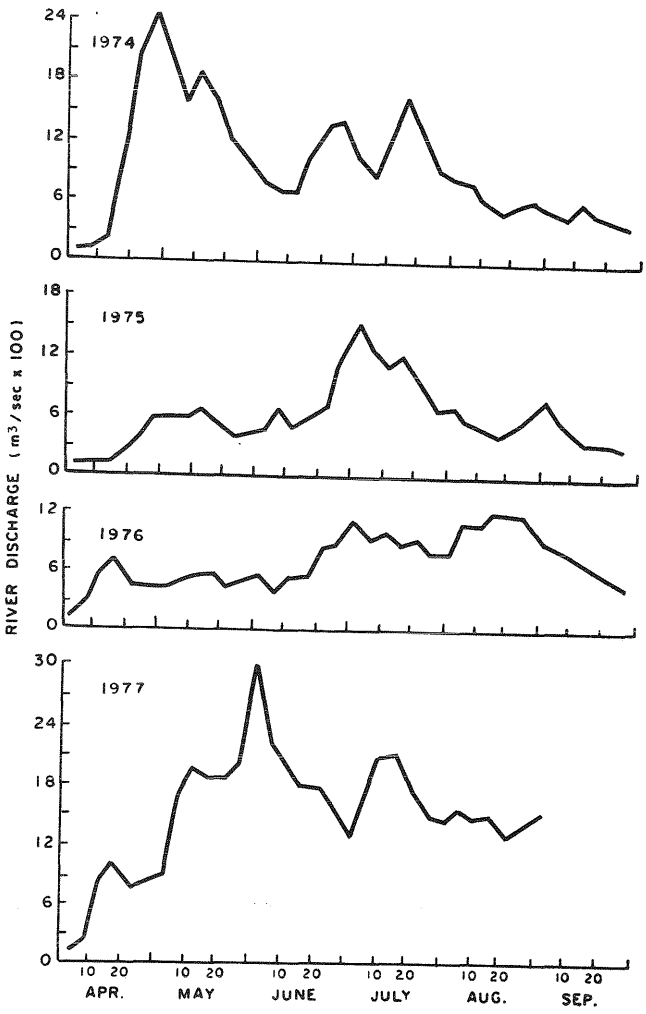

Fig. 7 Seasonal river discharge, 1974-1977.

1976

As described previously, a double treatment of the river was made. The first part of the treatment was at D6 (160 km) on 20 May since larval monitoring indicated that this was the most advantageous date. Pretreatment larval numbers at all stations downstream from D5 at 120 km showed high numbers of larvae in May (Appendix I). Larval population reductions in part one of the double treatment were excellent, ranging from 98.8% at 5 km below the injection point (165 km downstream) to 99.1% at 160 km (320 km downstream). Part two of the treatment was less effective than part one with *S. arcticum* larval reductions ranging from 99.7% at 5 km to 38.9% at 160 km downstream. River discharge levels were lower during the second part of the treatment than in the first and, since average velocity also decreased, silt loads carried by the river were lower.

1977

No river treatment was scheduled in this year but sampling was continued to determine the effect, if any, of 3 yr of larvicide treatments on black fly larval populations. Monitoring of larvae began in early May as in other years. Per cone averages of *S. arcticum* larvae at all sampling stations were low in May and continued at low and decreasing levels until mid-June (Fig. 4) when larval numbers suddenly began to increase at all stations including the upstream control stations. This increase reached its highest levels at D8 and D7 in the last week in June and the 1st wk in July respectively (Appendix I). After this, larval numbers at the far downstream stations remained higher than in other years until the end of July. By the 1st wk in August, larval numbers were not significantly higher than for corresponding periods in previous years.

S. arcticum Adults

1974

First adults were caught in flight near the river surface on 19 June. Numbers were low in all monitored reaches of the river. The number of flies swept in 1.6 km remained below 100 in all areas until 13 August when 187 flies were taken at 102 km downstream. Numbers over 100 were taken four times in areas between 40 and 96 km downstream on 21 August. The highest of these was 429 adults, taken at 40 km downstream. After this date, the numbers of flies taken per sweep dropped in all areas with only one sweep of over 100 recorded. By the 3rd wk in August, adult levels approached 0 in most sweeps with one high of 29 flies at 99 km.

1975

First adults taken were on 12 June and the first sweeps of over 100 flies occurred on 25 June at downstream reaches of the river and at six locations between 64 and

132 km. Two of these sweeps had over 200 flies and one was over 700. After this, numbers of flies remained relatively low and sweeps of over 100 were taken only nine times to the end of the summer. Only two of these were over 200 and only one was over 500. By 1 September, levels were below 25 adult flies in all areas and approached 0 by 30 September.

1976

First adults were taken on 15 June and numbers remained low (below 50 flies/sweep) until 3 August. On this date, very high numbers of flies were taken in sweeps between 32 and 128 km downstream. The highest single 1.6-km sweep in this period contained 1,033 flies at 32 km. On the same day, six sweeps caught 100-200 flies, four sweeps were 200-300, two sweeps were 500-600, and one sweep was 800-900. In the next week, on 10 August, only one sweep had over 100 flies and was at 80 km downstream. After this date, fly numbers dropped sharply and remained low for the remainder of the season.

1977

The adult *S. arcticum* picture in 1977 was as unusual as the larval picture described earlier. First adults were swept on 24 May, i.e. about 3 wk earlier than in 1976. Numbers of flies swept remained low until 8 June when high numbers of adults suddenly appeared in the reach of the river lying between 160 and 241 km. On this day, four sweeps yielded between 100 and 200 flies, one sweep was between 200 and 300, one sweep was between 1,000 and 2,000, and four sweeps had over 2,000 adult flies. In the next week, sweeps containing over 100 flies were taken at 12 places between 88 and 210 km downstream. On 29 June, sweeps over 100 had moved upstream somewhat and appeared at three places lying between 48 and 105 km downstream. It is apparent that there was a general movement of adult flies upstream during this period (Table 2). The weeks after 29 June showed low levels of flies swept at all locations until 20 and 21 June when numbers over 100 were taken in four sweeps between 90 and 178 km downstream. The highest of these was 505 flies swept at 170 km. Two sweeps of 100 to 200 and one of 254 flies were also taken. After this, high numbers of flies again moved gradually upstream and appeared between 0 km and 50 km downstream on 3 August. From this date until the end of the summer, the highest numbers of flies swept were in the area between 1 km upstream from the town of Athabasca and 104 km downstream. High numbers persisted until 21 September when the last sweep was made. The highest number of adults of *S. arcticum* taken in a 1.6-km sweep in the years 1973-1977 was taken on 30 August 1977, when 3,752 flies were swept at 40 km downstream. In the weeks between 3 August and 30 September 1977, highest numbers taken were: 100-200 in 14 sweeps, 200-300 in four sweeps, 300-400 in four sweeps, 400-500 in two sweeps, 500-1,000 in six sweeps, and over 1,000 flies in two sweeps.

INTERPRETATION AND DISCUSSION

Larval Populations of *S. arcticum* as Related to Adult Populations

In the years 1971 and 1972, no accurate monitoring of the Athabasca River was made. High numbers of adults appeared along the river in June of both years. At the same time, the number of flies attacking cattle on farms in the area was very high. Imperfect sampling of the larvae at this time indicated a not excessively high larval population level. In 1973, the first reliable larval sampling was accomplished. Larval numbers in spring were low and so were adults later in the season. In this period, very little problem was experienced by livestock owners in the area. Larval sampling in 1974 showed a remarkable increase in numbers on cones over those found in 1973. This should have lead to high numbers of adults near the river during the season. This year, however, was the 1st yr of the larviciding operations in which a very successful reduction of *S. arcticum* larval populations was accomplished. The expected high numbers of adults therefore did not materialize, and attacks on livestock were brought down to acceptable limits. In 1974, high numbers of adults did not appear near the river until August and these flies presumably, as shown by upstream movement of populations, came from areas downstream of the monitored area which, in this year, extended to 160 km. This upstream movement from areas near Fort McMurray required 2 mo to reach the vicinity of Athabasca.

In 1975, larval numbers in spring (expressed as per cone averages) were much lower, less than one-tenth, at 160 km than in 1974. Monitoring was extended downstream for another 80 km and showed higher levels of larvae at these downstream sampling stations (D7 and D8). Even here, spring peak numbers in 1975 were about half of those at 160 km in the previous year. The second larviciding treatment was carried out on 4 June of this year. Larval population reduction by this treatment was far less than in 1974 and had an effective level of only 36.3% at 160 km beyond which there was no reduction. In other words, effective population reduction was in an area of low larval numbers and insignificant in areas of higher larval numbers. In spite of this, numbers of adults in all areas near the river remained relatively low for almost the entire summer with only a few sweeps of high numbers being taken in far downstream reaches in 1 wk of June and again in 1 wk of August.

It is interesting to note at this point that, although average reductions corrected for natural variations dropped to zero beyond 160 km, the uncorrected reduction was greater in all areas. A simultaneous sharp reduction at control stations indicated that some unknown factor in the river was responsible for a substantial reduction in larval numbers at all stations.

The final year of treatment of the Athabasca River under the experimental timetable laid down in 1974 was 1976. In this year, a double control was attempted due to the increased mobility brought about by the development of a more versatile, boat injection, method of larvicide application. In this year, one application was made at 160 km and succeeded in reducing larval populations by 98.8% at 165 km and 99.1% at 320 km. The second half of the control attempt was made 5 days after the first at a lower river discharge rate than the first and succeeded in reducing larval populations by 99.7% at 5 km below point of injection and 80.6% at 120 km. Beyond this point, reduction decreased to 38.9% leaving about 40 km of the river in which control was ineffective. To sum up, the 1976 treatment gave an effective population reduction of *S. arcticum* larvae to 320 km with the exception of one short section of 40 km in the middle. As a result of this degree of control, it was expected that spring levels of *S. arcticum* adults would be low. This proved to be the case and populations of adults along the river remained low except for 1 wk in August when several sweeps yielding high numbers of adults were taken. Analysis of data since then has shown that, in 1976, posttreatment hatches of *S. arcticum* larvae were substantial at all stations below 120 km from mid-June to mid-July, and could easily account for the flies present in August.

These increases in hatch of eggs seemed to follow an increase in river discharge levels that began in mid-June and continued for over 1 mo (Fig. 7).

Efficacy of Larviciding

In the experiments described here, 0.3 ppm concentration of methoxychlor was used in each of the 3 yr. The treatment in 1974 was at a river discharge level of 759.0 m^3/sec and had a duration of 15 min of injection time. It was successful for the entire 160 km distance monitored. Concentration of methoxychlor used in 1975 was still 0.3 ppm but duration of injection time was reduced to 7.5 min. This treatment was successful for only 80 km or about half of the distance of the 1974 treatment. River discharge levels at this time were lower than the previous year and amounted to 477.1 m^3/sec. This decrease in volume of flow results in a reduction in average current velocity. At the town of Athabasca, the reduction was from 1.07 m/sec to 0.79 m/sec or about 0.28 m/sec. This decrease in current velocity decreased silt transport and therefore lowered the amount of silt available for the adsorption of larvicide. This resulted in a lower amount of material available for ingestion by black fly larvae.

In 1976, injection times were kept to 7.5 min for each part of the double treatment. The first or downstream portion of the treatment was made at a river discharge rate of 566.4 m^3/sec in a section of river where velocities are higher than near Athabasca. This portion of the treatment was very successful and removed virtually all of the hatched *S. arcticum* larvae from the entire distance monitored (160 km). The second portion of the treatment, which was made at Athabasca 5 days later, was not as successful as the first and left a portion of the river in which from 20-60% of larvae survived. The reasons for this are now obvious. The treatment was in a section of river in which current velocities were lower at uniform discharge rates. In addition to reduced current velocities, a reduction in discharge rate to the lowest of any treatment further reduced current velocity to an estimated 0.72 m/sec.

To sum up, it can be expected that, when discharge rates in the Athabasca River at Athabasca are above 560 m^3/sec, a 7.5-min injection of 0.3 ppm concentration of methoxychlor larvicide can be expected to give effective control of *S. arcticum* larvae for a distance of at least 160 km. This is particularly true if injection is made at a point 120 km downstream from the town of Athabsca. If river discharge rates are below 560 m^3/sec, effective control is reduced to less than 120 km, and an effective abatement to reduce *S. arcticum* larval numbers must be repeated about every 100 km of river. An alternative would be to increase injection time, preferrably to 15 min.

CONCLUSIONS

1. An abatement operation, as described here, can be effective in reducing populations of the livestock pest *Simulium arcticum* that breeds in the Athabasca River.

2. Adult populations can be reduced to economically acceptable levels at least until late summer.

3. The need for treatment and the time of treatment can be determined by sampling the larval populations at monitoring stations set up immediately after spring break-up at points below 100 km downstream from the town of Athabasca. When larval numbers in May average less than 500 per cone at 100 km downstream and beyond, larviciding is not required.

4. If late spring hatches of larvae are high, a later-than-normal treatment may be required.

5. Three years of larviciding had no lasting effect on *S. arcticum* population build-up beyond the year in which treatment was carried out.

6. Larviciding operations were most effectively accomplished by boat.

7. Precision of application of larvicide, and portability of the operation were increased by the use of powered river boats.

8. Abatement operations, e.g. larvicide concentration, distance between treatments, and duration of injection times, must be determined by river discharge rates at the point of larvicide injection.

9. Successful abatement operations require a highly trained crew led by a person who has had biological training and an understanding of the local situation.

QUESTIONS REQUIRING FURTHER STUDY

In the 5 yr between the feasibility study and the end of the program, many previously unanswerable questions have been answered. However, each answer leads to further questions. Now that we can sample large-river larval black fly populations satisfactorily, and can determine such things as hatching of eggs throughout the season, the question arises: what factors are responsible for the hatching of black fly eggs? Why are hatches so variable in terms of time of year and numbers? Further work has a good chance of answering these questions. Some of this will need to be done under field conditions and some in the laboratory.

Further work is required on the relationship between larval numbers at the source and the adults as they appear on farms at various distances and directions. This work would involve factors affecting the movement of adult flies in response to stimuli resulting in dispersal from the river to the host for blood meals, and back to the river again. We need to know the life span of adult *S. arcticum*, how fast they move, why they move, and what percentage survive to lay eggs again? What percentage survival is needed to maintain a population as opposed to the percentage survival leading to an outbreak?

We now have the capability of answering questions dealing with the severity of attack of *S. arcticum* on livestock in various parts of Alberta. One of the goals of Alberta Agriculture for the future should be to determine actual and potential outbreak areas on the various major rivers of the province from the Peace in the north to the South Saskatchewan in the south.

Although there is now an acceptable method of population control using chemical larvicide, work on other means of control should be undertaken. It may include biological control of larvae and adults. It requires more studies of the phenology of the pest to identify weaknesses in the life cycle that might be used as points of attack.

More work could be done on the protection of livestock through the use of repellents applied to the animals or of bait or behavior traps to sweep an area free of adults.

Appendix I. Per cone average for S. arcticum larvae, May-August 1973-1977

Site	Year	May					June				July					August			
		29-5	6-12	13-19	20-26	27-2	3-9	10-16	17-23	24-30	1-7	8-14	15-21	22-28	29-4	5-11	12-18	19-25	26-1
U2	1973			3.1				33.3				89.3	-			7.0	1.7		
	1974			7.0	39.8	74.0	26.0	95.3	25.5	1.8						2.0	0.8	0.8	0.0
	1975			5.5	14.3	10.8	22.8	10.5	6.7	8.2	0.0	1.8	2.5	1.0	2.0	1.0	1.2	0.6	0.0
	1976	3.5	21.2	10.3	9.5	Pre-treatment													
	1976		Posttreatment		8.0	11.2	8.0	7.7	5.7	2.3	10.7	1.0	0.5	0.5	0.5	0.0	0.2	0.2	-
	1977		-	3.8	8.5	8.8	1.2	16.0	15.0	43.2	5.2	1.8	2.5	17.7	4.2	2.0	0.3	0.3	-
U1	1973			2.2				31.5				14.0	-			3.5	1.7		
	1974			-	25.0	40.5	58.8	101.0	48.3	0.5						3.5	1.3	0.5	0.0
	1975			2.2	29.4	15.3	25.0	3.0	6.5	9.0	0.8	2.0	2.3	0.0	1.5	0.3	0.8	0.5	0.0
	1976	6.8	30.3	13.0	12.5	Pre-treatment													
	1976		Post-treatment		15.8	23.3	11.3	10.3	5.3	3.8	1.7	5.0	0.3	0.3	0.2	0.6	0.3	0.0	0.3
	1977		-	0.0	3.8	5.6	1.2	11.0	23.0	31.2	-	3.8	2.2	6.8	2.3	1.5	0.5	0.0	-
D1	1973			11.4				40.3				52.5	43.2			3.5	-		
	1974			2.3	5.5	25.2	13.0	102.8	62.5	0.8						3.0	1.5	0.5	0.0
	1975			4.0	9.6	5.3	16.2	Pre-treatment											
	1975				Post-treatment		0.3	13.3	7.3	6.2	0.0	3.5	2.8	0.5	1.7	0.3	0.7	0.8	0.0
	1976	9.2	24.2	7.3	8.3	Pre-treatment													
	1976		Post-treatment		0.3	13.7	29.0	10.2	7.4	1.6	3.3	3.5	3.7	0.05	0.5	0.0	0.0	-	0.0
	1977		0.3	1.0	7.8	2.5	1.8	19.0	15.8	19.5	16.8	3.8	4.0	17.0	3.5	0.8	0.8	0.0	-
D2	1973							38.5				35.0	24.5			1.8	0.0		
	1974			0.4	8.5	21.0	9.5	91.8	-	0.5						2.5	0.0	0.0	0.0
	1975			12.2	14.0	8.0	17.3	Pre-treatment											
	1975			Post-treatment			0.5	2.5	7.8	2.0	0.0	2.0	5.7	1.2	0.7	1.2	0.0	0.3	0.0
	1976	32.2	47.8	12.8	20.0	Pre-treatment													
	1976		Post-treatment		0.3	17.5	25.8	19.5	4.0	1.2	2.5	2.3	0.8	0.0	0.2	0.0	0.2	0.0	0.0
	1977		-	1.2	5.3	5.2	1.0	8.0	4.2	13.7	17.0	6.0	2.4	1.2	1.8	0.7	0.0	0.2	-
D3	1973			5.25				15.8	-			35.0	7.0			3.5	0.0		
	1974			-	0.5	24.5	2.2	44.3	45.8	1.2						1.0	0.0	0.0	0.0
	1975			9.0	14.3	20.0	11.7	Pre-treatment											
	1975			Post-treatment			0.3	3.8	5.0	2.7	0.0	1.5	1.5	0.8	0.0	0.5	0.3	0.0	0.0
	1976	19.8	20.3	14.8	7.0	Pre-treatment													
	1976	Pre-treatment			0.17	6.8	12.3	5.7	3.7	5.2	0.8	2.3	1.2	1.3	0.0	0.2	0.3	0.2	0.0
	1977		7.0	1.7	3.3	7.0	3.0	4.0	3.2	15.3	23.5	2.7	0.6	4.3	1.0	0.2	0.4	0.2	-
D4	1973			18.8				96.8				134.8	72.3			3.5	6.1		
	1974			1.6	6.3	3.3	0.3	34.0	-	2.8					3.7	0.8	0.2	0.0	0.2
	1975			59.3	13.2	12.2	22.0	Pre-treatment											
	1975				Post-treatment		2.7	4.2	7.7	12.0	0.0	21.3	34.2	6.3	1.7	1.5	0.3	0.8	0.3
	1976	123.5	118.3	39.2	52.5	Pre-treatment													
	1976		Post-treatment		4.7	25.3	63.0	19.5	15.5	1.4	2.3	17.3	9.0	3.7	0.7	0.0	0.3	0.0	0.0
	1977		1.2	14.8	32.8	-	3.3	8.5	6.0	39.5	19.2	19.5	4.7	6.0	1.2	0.3	0.3	0.3	
D5	1973			98.0				45.5				105.0	117.3			5.3	-		
	1974			-	-	305.2	0.5	42.2	-	-					7.0	3.3	0.2	0.0	0.3

Appendix I continued

		May					June				July					August			
Site	Year	29-5	6-12	13-19	20-26	27-2	3-9	10-16	17-23	24-30	1-7	8-14	15-21	22-28	29-4	5-11	12-18	19-25	26-1
D5	1975			233.5	98.7	45.4	31.7	Pre-treatment											
	1975				Post-treatment		5.8	9.7	24.8	31.7	0.0	30.2	69.8	5.2	8.2	2.3	1.2	0.3	0.7
	1976	711.8	931.0	249.2	83.5	Pre-treatment													
	1976		Post-treatment		17.5	67.2	178.3	217.3	128.3	18.3	10.5	46.5	17.3	2.0	5.7	1.8	3.2	0.7	0.8
	1977		7.8	19.0	28.0	40.0	5.0	18.0	26.0	87.2	36.5	15.2	14.3	11.3	2.5	2.3	1.2	1.0	-
D6	1974			-	-	3489.7	2.2	44.0	-	184.9					24.5	11.3	3.8	1.5	0.2
	1975			140.2	284.0	155.7	122.0	Pre-treatment											
	1975				Post-treatment		51.5	4.2	72.2	111.3	2.0	171.7	211.7	21.8	31.5	10.8	2.0	2.3	2.2
	1976	658.8	1084.5	313.0	118.8	Pre-treatment													
	1976		Post-treatment		78.5	14.8	159.2	823.5	467.7	36.3	51.3	36.3	18.3	8.8	2.8	1.0	0.3	0.3	2.0
	1977		-		93.2	-	2.0	10.7	29.8	46.5	68.7	8.0	11.7	49.0	4.8	2.2	0.8	0.5	-
D7	1975			103.7	1561	1148	381.2	Pre-treatment											
	1975				Post-treatment		213.8	13.7	8.2	38.0	0.0	70.0	421.0	105.0	81.5	23.2	6.0	1.7	1.7
	1976	2424	3176	759.3	Pre-treatment														
	1976	Post-treatment		3.7	32.3	7.0	62.3	234.2	229.0	92.0	82.8	-	29.8	32.2	9.3	1.5	0.7	-	2.3
	1977		-	386.5	209.3	162.3	1.5	98.7	437.7	620.8	1098.2	296.0	106.8	85.5	76.7	31.8	5.7	2.2	0.0
D8	1975			589.3	1575	1027	255.8	Pre-treatment											
	1975				Post-treatment		200.3	26.3	14.8	69.2	8.0	106.0	421.0	98.2	116.7	26.6	10.5	4.2	0.7
	1976	1327	1376	488.8	Pre-treatment														
	1976	Post-treatment		2.0	25.2	10.3	37.3.	213.8	629.0	186.3	265.0	149.0	37.5	24.3	7.3	1.8	3.5	0.3	0.0
	1977		519.8	421.5	242.0	159.8	15.0	151.1	363.4	1674.3	810.5	690.5	177.0	312.3	149.5	40.3	9.3	0.5	1.0
D9	1976	-	1182	594.5	Pre-treatment														
	1976	Post-treatment		9.0	12.3	0.7													
D10	1976	-	1497	226.7	Pre-treatment														
	1976	Post-treatment		2.2	4.2	0.0													

Appendix II. Average hatch of *S. arcticum* (1st and 2nd instars)

(a) May 1974-1977

Site			May 1974			May 1975			May 1976				May 1977			
km	1974	1976	12-18	19-25	26-31	11-17	18-24	25-31	2-8	9-15	16-22	23-29	8-14	15-21	22-28	29-31
60	U3			5.5	9.0											
40	U2	U2	3.5	12.0	21.7	4.3	10.0	5.3	3.2	10.3	5.7	4.8	-	2.0	6.5	5.0
20	U1	U1			17.1	2.0	18.4	9.0	6.2	12.2	7.5	7.7	-	0.0	2.8	1.3
4.8	D1	D1	1.66	2.1	4.0	4.0	6.0	2.2	9.0	14.7	4.7	5.5	0.3	0.8	6.5	0.6
20	D2	D2	0.39	3.5	0.5	12.0	9.8	4.7	29.3	18.8	4.3	1.8	-	0.8	3.8	2.2
40	D3	D3		0.3	5.9	9.0	12.3	13.7	19.3	10.2	6.5	1.8	5.0	0.8	2.8	3.7
60	D4	D4	1.55	4.5	1.3											
80	D5	D4	1.9	1.5	1.0	57.7	11.3	11.0	122.7	84.5	27.7	42.7	0.3	11.3	27.8	
100	D6		7.6	21.5	72.7											
120	D7	D5	0.0	-	81.7	230.0	57.5	23.0	653.7	317.3	118.5	51.3	2.5	12.5	16.3	1.3
140	D8		15.2	22.8	53.7											
160	D9	D6			628.0	117.7	152.2	50.3	518.7	466.5	87.8	63.8	-	-	55.8	
165		D6A							836.7	221.3	85.8	6.2				
180		D6B							292.3	262.8	75.2	53.5				
200		D7				82.5	393.5	112.7	728.7	293.0	94.0	25.8	-	16.5	66.8	18.3
240		D8				512.2	500.7	106.0	521.3	227.0	150.0	18.3	30.3	81.7	33.2	14.2
280		D9								146.6	116.0	1.0				
320		D10								42.0	17.2	1.8				
TOTALS			31.8	73.7	896.6	1031	1172	337.9	3741	2126	800.9	285.3	38.4	126.4	222.3	46.6

(b) June 1974-1977

Site			June 1974				June 1975				June 1976					June 1977			
km	1974	1976	2-8	9-15	16-22	23-29	1-7	8-14	15-21	22-28	1-5	6-12	13-19	20-26	27-30	5-11	12-18	19-25	26-30
60	U3		12.8	22.5	1.5														
40	U2	U2	2.3	13.2	3.0	0.25	12.8	3.8	2.8	8.2	3.0	1.8	0.8	2.3	1.5	0.5	2.5	5.3	26.7
20	U1	U1	5.2	14.0	1.5	0.0	11.2	0.0	3.2	4.5	6.8	2.5	1.8	2.8	1.2	0.2	3.2	4.3	18.5
4.8	D1	D1	4.8	9.7	7.0	0.5	8.2	3.6	0.7	2.0	4.2	14.7	0.1	2.3	1.2	0.5	2.8	3.5	10.0
20	D2	D2	1.3	17.7	-	0.0	7.0	1.8	5.3	1.0	6.5	8.8	1.8	1.5	0.5	0.0	1.2	2.3	8.2
40	D3	D3	1.2	9.5	7.3	0.25	7.5	2.8	2.8	1.0	3.2	2.2	1.6	2.0	3.3	1.0	0.5	0.7	9.0
60	D4		0.0	7.3	-	0.0													
80	D5	D4	0.0	28.0	3.5	1.8	13.5	3.8	6.0	6.5	24.0	36.2	8.8	9.8	0.2	2.2	4.8	4.5	36.0
100	D6																		
120	D7	D5	0.2	34.4	-	-	13.3	9.5	22.2	9.7	62.8	61.7	59.7	51.0	9.8	1.6	5.2	9.3	77.8
140	D8		0.0	21.7															
160	D9	D6	0.0	37.8	-	8.5	50.5	3.8	6.5	32.2	10.0	70.3	119.7	188.8	16.2	0.0	0.6	19.2	36.0
165		D6A									4.0	30.3	18.0	54.2	23.5				
180		D6B									18.3	45.3	35.8	159.0	31.7				
200		D7					62.5	4.8	6.5	9.2	4.2	20.3	20.7	109.3	18.6	0.0	6.5	253.7	398.8
240		D8					56.5	12.3	11.2	23.5	7.7	4.8	90.5	330.2	72.5	3.0	10.5	205.2	1163
280		D9									0.0								
320		D10									0.0								
Totals			28.8	245.3	23.8	11.3	243.0	46.2	67.2	92.8	154.7	298.9	359.3	913.2	180.2	9.0	37.8	508.0	1748

Appendix II continued

(c) July 1974-1977

Site			July 1974		July 1975					July 1976				July 1977			
km	1974	1976	21-27	28-31	1-5	6-12	13-19	20-26	27-31	4-10	11-17	18-24	25-31	3-9	10-16	17-23	24-30
60	U3			1.0													
40	U2	U2	0.0	0.7	0.0	0.7	0.8	0.5	0.3	2.0	0.3	0.0	0.0	2.0	1.3	1.0	4.3
20	U1	U1		0.2	0.0	1.2	1.7	-	0.3	0.6	2.2	0.0	0.2	-	1.8	1.5	1.7
4.8	D1	D1		0.0	0.0	2.8	1.5	0.5	0.8	1.2	1.7	2.2	0.0	7.8	2.0	1.8	4.0
20	D2	D2		0.5	0.0	1.3	3.3	0.7	0.0	0.8	1.2	0.0	0.0	12.2	3.8	0.7	0.2
40	D3	D3		1.0	0.0	1.2	0.5	0.3	0.0	0.2	1.7	0.5	0.8	17.3	1.3	0.3	1.3
60	D4			1.1													
80	D5	D4	2.0	0.0	0.0	10.8	19.5	3.0	1.0	2.3	7.7	5.8	2.5	16.3	17.8	3.7	1.0
100	D6			0.2													
120	D7	D5		0.8	0.0	21.8	39.3	2.2	5.0	3.5	23.3	8.7	0.0	26.3	15.0	10.0	3.3
140	D8			0.8													
160	D9	D6		8.7	0.8	69.0	78.5	7.5	3.5	19.0	7.2	6.5	4.0	42.0	3.0	6.5	7.8
165		D6A								6.3	21.0	4.5	1.0				
180		D6B								9.0	32.7	8.2	10.3				
200		D7			0.0	38.0	126.5	9.7	3.8	6.0	-	6.8	2.5	448.8	28.5	35.3	21.3
240		D8			2.0	39.2	123.3	14.5	8.3	51.0	19.7	8.8	7.5	430.8	300.3	71.0	129.5
280		D9															
320		D10															
Totals			2.0	15.0	2.8	186.0	394.9	38.9	23.0	101.9	118.7	52.0	28.8	1003	374.8	131.8	174.4

(d) August 1974-1977

Site			August 1974				August 1975				August 1976					August 1977			
km	1974	1976	4-10	11-17	18-24	25-31	3-9	10-16	17-23	24-30	1-7	8-14	15-21	22-28	29-31	1-6	7-13	14-20	21-27
60	U3		0.2	0.0	0.0	0.0													
40	U2	U2	0.0	0.3	0.0	0.0	1.0	0.2	0.5	0.0	0.3	0.0	0.0	0.2	0.0	2.1	1.5	0.2	0.0
20	U1	U1	0.0	0.0	0.3	0.0	0.3	0.3	0.2	0.0	0.0	0.0	0.3	0.0	0.0	0.8	0.3	0.0	0.0
4.8	D1	D1	0.0	0.2	0.0	0.0	0.2	0.0	0.2	0.0	0.2	0.0	0.0	-	0.0	0.5	0.3	0.3	0.0
20	D2	D2	0.0	0.0	0.0	0.0	0.6	0.0	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.2	0.0	0.0
40	D3	D3	0.2	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.7	0.0	0.0	0.0
60	D4		0.0	0.0	0.0	0.2													
80	D5	D4	0.7	0.0	0.0	0.0	1.3	0.2	0.3	0.0	0.2	0.0	0.3	0.0	0.0	0.5	0.3	0.3	0.2
100	D6		0.3	0.0	0.2	0.0													
120	D7	D5	0.3	0.0	0.0	0.2	1.6	0.8	0.2	0.7	3.3	0.8	2.5	0.2	0.7	0.5	0.8	0.7	0.7
140	D8		0.0	0.2	0.0	0.3													
160	D9	D6	1.0	0.5	1.0	0.0	8.0	0.8	0.8	0.7	1.0	0.2	0.2	0.3	1.8	1.2	0.7	0.3	0.3
165		D6A									2.3	0.6	0.2	0.3	0.3				
180		D6B									2.5	0.8	0.2	0.0	0.5				
200		D7					5.3	0.5	0.0	0.0	0.8	0.2	0.0	-	2.0	13.7	1.2	0.5	0.3
240		D8					5.7	1.5	0.7	0.0	0.7	0.5	3.3	0.2	0.0	27.3	3.3	0.7	0.3
280		D9									-	-	-	-	-				
320		D10									-	-	-	-	-				

Appendix II continued

(e) September 1974-1976

Site				Sep. 1974	Sep. 1975		Sep. 1976	
km	1974	1975	1976	15-21	1-6	7-13	5-11	12-18
60	U3			0.0				
40	U2	U2	U2	0.0	0.0	0.0	0.0	0.2
20	U1	U1	U1	0.0	0.0	0.0	0.0	0.0
4.8	D1	D1	D1	0.0	0.0	0.0	0.0	0.0
20	D2	D2	D2	0.0	0.0	0.0	0.0	0.0
40	D3	D3	D3	0.0	0.0	0.0	0.0	0.0
60	D4			0.0				
80	D5	D4	D4	0.0	0.0	0.0	0.8	0.2
100	D6			0.0				
120	D7	D5	D5	0.0	0.0	0.0	2.0	0.0
140	D8			-				
160	D9	D6	D6	-	0.2	0.0	0.5	0.0
165			D6A				0.3	0.0
180			D6B				1.7	0.3
200		D7	D7		0.0	0.0	2.0	0.2
240		D8	D8		0.0	0.0	1.8	0.7
280		D9					-	-
320			D10				-	-
		TOTALS		0.0	0.2	0.0	9.1	1.6

Appendix III. Effect of 0.3 ppm methoxychlor on per cone averages of larvae of S. arcticum

Site				1974				1975				1976			
				Treatment[a]		% Reduction		Treatment[a]		% Reduction		Treatment[a]		% Reduction	
km	1974	1975	1976	Pre-	Post-	Raw	Corrected[b]	Pre-	Post-	Raw	Corrected[b]	Pre-	Post-	Raw	Corrected[b]
60	U3			42.3	73.8	-74.5									
40	U2	U2	U2	74.0	26.0	68.8		22.8	10.5	54.0		9.5	8.0	15.8	
20	U1	U1	U1	40.5	58.8	-45.2		25.0	3.0	88.0		12.5	15.8	-26.4	
Control	Total			156.8	158.6	-1.2		47.0	13.5	73.4		22.0	23.8	-8.2	
4.8	D1	D1	D1	25.5	13.0	49.0	49.60	16.2	0.3	98.2	93.55	8.3	0.3	96.4	99.67
20	D2	D2	D2	21.0	9.5	54.8	55.27	17.3	0.5	97.1	89.94	20.0	0.3	98.5	98.61
40	D3	D3	D3	24.0	2.2	90.8	90.94	11.7	0.3	97.4	91.07	7.0	0.2	97.1	97.75
60	D4			3.3	0.3	90.9	91.01								
80	D5	D4	D4	8.8	0.5	94.3	94.38	22.0	2.7	87.7	57.27	52.2	4.7	91.6	91.88
100	D6			449.7	1.5	99.7	99.67								
120	D7	D5	D5	305.2	0.5	99.8	99.84	31.7	5.8	81.7	36.30	83.5	17.5	79.0	80.63
140	D8			296.2	1.5	99.5	99.50								
160	D9	D6	D6	3489.7	2.2	99.9	99.94	122.0	51.5	57.8	0.00	118.8	78.5	33.9	38.92
165			D6A									186.2	2.3	98.8	98.86
180			D6B									496.2	1.7	99.7	99.68
200		D7	D7					381.2	213.8	43.9	0.00	759.3	3.7	99.5	99.55
240		D8	D8					255.8	200.3	21.7	0.00	488.8	2.0	99.6	99.62
280			D9									594.5	9.0	98.5	98.60
320			D10									226.7	2.2	99.0	99.10

a Pretreatment (untreated) refers to time of sampling.

b By Abbot's transformation, where P = 100[1 - (TA/TB)(CB/CA)].

DISTRIBUTION AND PERSISTENCE OF METHOXYCHLOR IN ATHABASCA RIVER WATER

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INTRODUCTION

Adult populations of black flies in northern Alberta can reach outbreak proportions and have caused extensive losses to cattle production through death of newborn calves, death of nonindigenous cattle, weight losses and reduced milk production. It was established that *Simulium arcticum* was the major problem of any of the black flies in the Athabasca area and that this black fly breeds in the Athabasca River. On the basis of preliminary work by Depner in 1968-1973, larval breeding sites in the river were identified.

Feasible approaches to the problem of black fly abatement (specifically *S. arcticum*) were defined in 1973, and an integrated multidisciplinary research program was established (see Introduction, p. 1-2).

The senior author was originally charged with the responsibility of coordinating the methoxychlor residue program and, in the case of water, bedload, and mud, of preparing sampling protocols, taking the samples, and making the chemical analyses. To discuss the results of the residue program in view of the various hydraulic functions of the river, Dr. R. Gerard and subsequently Dr. S. Beltaos were asked to establish the hydraulic parameters of the Athabasca River within the study area. In addition, Beltaos was asked to identify those processes that could influence insecticide mixing and movement. These engineering data, with data collected by other cooperators, led to the development of the working hypothesis for our analytical model described by Beltaos (pp. 97-122).

The objectives of the study reported herein were to identify the actual and estimated levels of methoxychlor through quantitative analysis of water and associated washload, to describe the time-concentration curves, and the movement and distribution of methoxychlor as it related to water in the Athabasca River ecosystem. In addition, the methoxychlor concentrations were correlated to *S. arcticum* control as established by Depner et al. (pp. 21-37).

Recommendations for further research are also given in this paper.

MATERIALS AND METHODS

Site Description

The overall description of the study area has been given in the Introduction (pp. 2-13).

Sampling Locations and Sites

In late 1973, water samples were taken randomly along the length of the river to identify any compounds that would interfere with methoxyclor analysis.

There were one to five sampling sites at each sampling location. Site 1 was designated as being near the right bank (R/B, looking downstream), site 2 at 25% of the width from the right bank, site 3 at the

center of the river, site 4 at 75% of the width of the river from the right bank, and site 5 near the left bank (L/B).

In 1974, surface (immediately below) sample locations were established at 0.34, 0.72, 1.9, 3.8, 8.8, 21, 28, and 396 km downstream (D/S) from the Athabasca bridge for the collection of water samples. In addition, subsurface samples were collected by pumping stations at 21, 40, 77, and 176 km downstream. Sample site designations were the same as for 1973, described above.

In 1975, the water-sampling program was greatly enlarged to better describe the movement of methoxychlor in the Athabasca River. Surface sample locations were established at 1.9, 3.8, 8.8, 17, 21, 40, 77, 120, and 176 km D/S, and locations for separator sampling (described later) were established at 1.9, 17, 40, 77, 120, 176, 240, 396, and 418 km D/S. In addition, point samples were taken at 21 km D/S at three sites across the river and at three depths at each site. Sample site designations were the same as described for 1973.

In 1976, surface sample locations were established 5.0, 16, 40, 80, 160, and 236 km D/S of the point of the first treatment which was 160 km D/S of the Athabasca River Bridge. In addition, six surface sampling locations were established at 5, 21, 40, 77, 176, and 320 km D/S of the Athabasca River Bridge; the point of the second treatment. Separator sampling stations were established 1.9 km D/S of the point of application for each treatment. Sample site designations were the same as described for 1973.

Sampling

Sampling times at all locations were determined on the basis of information provided by Gerard in (1974) and Beltaos in (1975 and 1976) on the various river engineering parameters required to estimate the times of arrival and departure of the methoxychlor at any one location. A safety factor was introduced both before and after the estimated duration of the 'slug'. The number of samples taken at each location for each site was limited to 25, spaced equally over the total calculated sampling time.

Sample Containers

In 1973, it was established that only glass containers could safely be used to collect and retain water samples until they could be analyzed for methoxychlor content. The glass containers were commercial bottles of various sizes, 0.5-4.5 liters. The smaller containers were used for samples at locations close to the point of injection while the larger containers were for samples from locations further D/S from the point of methoxychlor injection.

Gas chromatographic analysis (described later) of n-hexane rinses of the sample bottles indicated that contaminants were present that would interfere with the detection of methoxychlor. Therefore, an exhaustive procedure involving soap-and-water and chromic acid washes, and hexane and acetone rinses with a final baking at 500°C for at least 4 hr was implemented. These 'clean' bottles were again rinsed with pesticide-grade n-hexane which was then analyzed by the gas chromatographic procedure. Any bottles that still showed the presence of contaminant were destroyed.

The 'clean' bottles were topped with a piece of glass-distilled (Pesticide grade) hexane-rinsed aluminum foil and capped with a Teflon-lined metal screw cap. All bottles were appropriately labelled in the field.

Sampling Techniques

Surface water samples - Surface water samples were taken by sharply submerging the glass sample bottle below the water surface but away from the boat wash. Where a boat could not be used, sample bottles were secured in a pole-holder arranged to obtain the samples.

In 1976, the water sampling program was consolidated in terms of number of locations. However, it was substantially improved because every location was equipped with a boat so that the surface sampling stations could be established for at least three sites at each location.

Sub-surface water samples - Subsurface sampling with pumping stations was used because it was the only convenient method of sampling from shore without the use of boats. Water was continually pumped (Fig. 1) through submerged 1.25-cm diam. copper lines and sampled at predetermined intervals. The copper lines had been heated to a high temperature and subsequently rinsed with hexane and acetone. These lines (3.7 and 11 m long) with 20 cm risers were moored along the river bottom from the shore and attached to electric- or gasoline-powered pumps.

Water collected by this technique was shown to contain no materials that would interfere with methoxychlor detection. Subsurface pumped sampling was essentially discontinued in 1976.

Point water samples - Point samples were taken with a standard point-integrating sampler equipped with a 450-ml glass bottle. Three sites were established at the sample location and, at each site, samples were taken at about 30 cm below the surface, 30 cm above the bottom, and at a point half way between.

Separator samples - A silt separator (Fig. 2) was designed and constructed to remove the greater part of the washload from the water. It was estimated that its maximum efficiency would be about 95%. This separator was operated with a head pressure of 0.56 kg/cm^2 utilizing a gasoline-powered unit to pump the water from the desired

Fig. 1. Pumping apparatus for subsurface water sampling.

location to shore into a boat where the apparatus was being used. Three different types of water samples were obtained from this device: natural water, before being subjected to the separator; filtered water that had most of the larger suspended particles removed; and silted water that contained an increased concentration of suspended particles.

Sample Handling

Samples collected in the field were stored at each location in a cool dark place until transfer to base camp within 2 days. Samples were then transferred to the Lethbridge Research Station where they were held in darkness at 0.5-1°C until analyzed.

Analytical Procedures

The initial procedure used in 1973 was established for qualitative analysis only. This procedure was modified twice for the quantitative analysis of samples collected in 1974-1976. These modifications were made to improve lab efficiency and therefore did not affect the determination of methoxychlor and the comparability of data between years.

Fig. 2. Separator for obtaining natural, filtered, and sediment-laden water samples.

Chemicals

The following is a list of reagents used for the analytical procedures:

1. Hexane -- glass - distilled (Pesticide Grade) n-hexane.

2. Acetone -- glass - distilled (Pesticide Grade) acetone.

3. Na_2SO_4 -- anhydrous, ACS-grade sodium-sulphate; washed three times with glass-distilled acetone and n-hexane and dried for 48 hr in an oven at 130°C.

4. Al_2O_3 -- aluminum oxide, Woelm Basic, activity II for 1973 and activity III for 1974-1976 samples.

1973 procedure

For water samples collected in 1973, a measured amount of water (1000 ml) was transfered to a 2-liter separatory funnel, and extracted three times, each with 80 ml of hexane. The combined hexane extracts were dried over 8 g Na_2SO_4 and concentrated to about 5 ml.

The hexane concentrate was quantitatively transferred to the top of a hexane-prerinsed (65 ml) chromatographic column of 10 g Al_2O_3 with a 10-g layer of Na_2SO_4 on top. Two 50-ml rinses of the sample flask were subsequently eluted through the column with an additional 200 ml hexane. The hexane eluant was collected in a round-bottom flask and concentrated on a rotary evaporator. This concentrate was quantitatively transferred to a volumetric flask and made up to volume with hexane for analysis by gas-liquid chromatography.

A subsample of this extract was analyzed by gas-liquid chromatography equipped with an electron-capture detector (tritiated foil); carrier gas, nitrogen at 60 ml/min; 48 cm x 3 mm OD (1.8 mm ID) borosilicate glass column, packed with QF-1(5%)/SE-30 (4%) on 60/80 mesh Chromosorb W,

A/W; injector, 190°C; oven and detector, 180°C.

1974 procedure

For water samples collected in 1974, the total sample volume was measured and the water was quantitatively transferred to a separatory funnel of adequate size. The sample container was rinsed twice, each with 50 ml hexane. The rinses were added to the water sample. This mixture was shaken then allowed to settle, and the hexane phase collected. The aqueous phase was extracted twice, each with 100 ml hexane. The combined hexane extracts were dried over 10 g of Na_2SO_4 and concentrated to about 5 ml on a rotary evaporator.

The concentrated hexane extract was quantitatively transferred to the top of 10 g of prerinsed (50 ml) Al_2O_3 in a chromatographic column. The extract flask was rinsed twice with 50 ml hexane and the rinses eluted through the column followed by an additional 200 ml hexane. The hexane eluate was concentrated on a rotary evaporator, quantitatively transferred to a volumetric flask, and brought up to volume with hexane.

A subsample of this extract was analyzed by gas-liquid chromatography as described for 1973.

1975-1976 procedure

For water samples collected in 1975 and 1976, the total sample volume was measured and the water was quantitatively transferred to a separatory funnel of adequate size. The sample container was rinsed first with 50 ml acetone and then twice with 50 ml of hexane, all rinses were added to the separatory funnel. This mixture was shaken vigorously then allowed to settle, and the hexane phase collected. The aqueous phase was extracted twice, each with 100 ml hexane. The combined hexane phases were dried over 10 g of Na_2SO_4, quantitatively transferred to a round-bottom flask, and concentrated on a rotary evaporator. This hexane concentrate was then quantitatively transferred to a volumetric flask and made up to volume with hexane.

A subsample of this extract was analyzed by gas-liquid chromatography utilizing an electron capture detector (N-63, pulse modulated); carrier gas 5% methane: argon, 60 ml/min; 1 m x 6 mm OD (4 mm ID) borosilicate column packed with 10% OV-1 on 80/100-mesh Chromosorb G-HP; injector, 250°C; oven, 250°C; detector, 300°C.

Methoxychlor Application

On June 4 1974, the Athabasca River was treated with 796 liters of 25% emulsifiable concentrate (EC) methoxychlor (Stan Chem 25 EC, PCP reg. no. 11617) from the highway bridge crossing the river at the town of Athabasca by a technique developed by Depner and Fredeen (unpublished). The water temperature was 14°C and the river discharge was 759 m^3/sec at an average velocity of 1.07 m/sec. This application was calculated to give a source concentration of 300 ppb for 15 min at the point of injection. Methoxychlor movement was monitored through residue analysis of water samples taken at various time and space intervals in the 160-km D/S study area.

This technique of application lacked the flexibility necessary for large river larviciding because of its dependence on existing man-made structures. Depner et al. (see pp.) therefore, devised an improved procedure whereby the application could be made from several boats, thus permitting the introduction of the chemical at any location along a river without contamination of the adjacent terrestrial habitat.

On 4 June 1975, the Athabasca River was treated 100 m D/S of the Athabasca bridge with 291 liters of methoxychor (Stan Chem 25 EC from 1974, analyzed as 21%) applied by boat. The water temperature was 15°C and the river discharge was 477 m^3/sec at an average velocity of 0.79 m/sec. This application was calculated to give a source concentration of methoxychlor of 300 ppb for 7.5 min at the point of injection. Methoxychlor movement was monitored through residue analysis of river water samples taken at various time and space intervals within a 240-km D/S study area as well as at 396, 410, and 580 km D/S.

On 20 May 1976, the Athabasca River was treated about 160 km D/S of the Athabasca townsite with 213 liters of methoxychlor (Methoxol 25% EC, PCP reg. no. 6763) at a river discharge rate of 566 m^3/sec. On 25 May 1976, the Athabasca River was treated a second time at the Athabasca bridge with 227 liters of methoxychlor (25% EC) at a river discharge rate of 416 m^3/sec at an average velocity of 0.72 m/sec. Both treatments were also applied from three boats and were calculated to give a mean source concentration of 300 ppb for 7.5 min.

RESULTS

Because of time and man-power limitations not all of the 4,500 samples collected between 1974 and 1976 could be analyzed. However, about 2,800 determinations were completed by gas-liquid chromatography and the discussion presented here is based on these results.

Time-concentration curves for all the sampling locations and sites are given in Appendix I (Fig. 10-54). The distribution of the curves by year and sampling method is shown in Table 1.

DISCUSSION

Background Pesticide Residues

Background pesticide and Aroclor residue levels in water were available

Table 1. Figure numbers for time-concentration curves in Appendix I by year and sampling method

Year	Surface	Depth integrator	Separator	
			Surface	Sub-surface
1974	10-17	-	-	18-21
1975	22-30	40	31	32-39
1976				
-1	42-47	-	41	-
-2	49-54	-	48	-

(Table 2) for the Athabasca River for the period September 1971-June 1973. All levels were below the detectable levels of the residue laboratory conducting the analyses.

Nevertheless, a program was established to identify any compounds that would interfere with the determination of methoxychlor. No interferring materials were found in water samples taken late in 1973 and pretreatment in 1974.

Table 2. Summary[a] of pesticide residues for Athabasca River at Athabasca (gauge 07BE001) between September 1971 and June 1973

Analysis	Samples anal.	Conc (ppb)	
		Range	Median
p,p'-DDT	7	<4-<4	<4
p,p'-DDD	7	<2-<2	<2
p,p'-DDE	7	<1-<1	<1
p,p'-methoxychlor	7	<12-<12	<12
hepachlor	7	<1-<1	<1
heptachlor-epoxide	7	<2-<2	<2
α-endosulphan	7	<1-<1	<1
β-endosulphan	7	<3-<3	<3
γ-BHC	7	<1-<1	<1
aldrin	7	<1-<1	<1
dieldrin	7	<2-<2	<2
aroclor 1254	4	<24-<32	<28
aroclor 1248	4	<24-<32	<28
aroclor 1260	3	<55-<55	<55
2,4-D	4	0-10	0
2,4-D[b]	2	0-0	0
2,4-DB	5	<10-<10	<10
3,4-DP	5	0-30	0
2,4,5-T	2	0-<10	0
2,4,5-T[b]	2	0-0	0
MCPA	4	<200-<200	<200

[a] Summarized from Water Quality Data - Alberta (Environment Canada 1975).

[b] Methyl ester.

Methoxychlor Dispersion in Surface Water

Factors determining the lateral, vertical, and transverse distribution of an exogenous material in a flowing aquatic system have been well documented. Originally, it was intended that, as well as the methoxychlor, Rhodamine WT dye would be injected into the river. Rhodamine dye is classified as a neutral tracer and is easily detected in water at very low concentrations. Methoxychlor can not be classified as a neutral tracer because it is known to adsorb onto particulate material and is relatively insoluble in water. Thus any difference in behavior of Rhodamine and methoxychlor would clearly illustrate the differences between the dispersion of a neutral tracer and methoxychlor. Establishment of these differences under identical conditions would have provided data required for the evaluation of future larvicides that had properties different from those of methoxychlor. However, some members of the research team felt that the addition of the dye to the river might have deleterious effects on portions of the ecosystem, thereby compounding the difficulty of interpretating the effects of methoxychlor. Therefore, separate dye tests were conducted by Beltaos in September 1974 and February 1975; the results and the implications of these tests are reported by Beltaos (pp. 106-107).

The rate of loss of methoxychlor will ultimately be estimated by calculating the rate of assimilation by channel boundaries. However, this paper discusses the dispersion of methoxychlor in water and the washload component. The results for methoxychlor on bedload are further discussed in the paper by Charnetski et al. (pp. 63-73).

Methoxychlor Residues - 1974

The time of first detection of methoxychlor together with the maximum measured methoxychlor concentration, the maximum estimated methoxychlor concentration, and the duration of the methoxychlor slug as it passed locations of sampling in 1974 are summarized in Table 3.

The application technique in 1974 was essentially equivalent to seven point applications of methoxychlor along the cross-section of the river with the intention of achieving a 300-ppb concentration in the total mass of water for 15 min. The methoxychlor dropped from the measured orifices of the application devices to the surface of the water.

At 0.34 and 0.72 km D/S of application at five sites at each cross-section, the maximum measured methoxychlor concentration was very variable (Table 3) and the duration of the 'slug' could not be measured because of incomplete detection of the total slug of methoxychlor.

At 1.9 and 3.8 km, it would appear that the methoxychlor had layered and had dropped below the surface of the water and therefore very low values, averaging 0.5 and 0.1 ppb for the two cross-sections respectively, were recorded. However, at 8.8 km, the range was substantially narrowed with an average estimated concentration of 111 ppb. The duration of the 'slug' of methoxychlor at this location was estimated as 3.5 hr.

Table 3. Summary of methoxychlor (MeOCl) concentrations (ppb) in surface[a] water and associated washload from the Athabasca River immediately after treatment from 0512 and 0527 on 4 June 1974

Site	Init. MeOCl (hr)[b]	Max. MeOCl Meas.	Max. MeOCl Est.	Elapsed time[c] I	Elapsed time[c] II
		0.34 km D/S			
1	0.25	211.8			-
2	0.25	379.6			>0.06
3	0.23	145.9			>0.28
4	0.21	52.5			>0.20
5	0.18	415.0			>0.20
Avg	0.22	240.9			>0.19
		0.72 km D/S			
1	0.20	727.8			>0.27
2	0.35	131.2			>0.16
3	0.33	348.5			>0.18
4	0.31	91.6	116.6		>0.19
5	0.32	52.7			>0.13
Avg	0.30	270.4	116.6		>0.19
		1.9 km D/S			
1	1.93	0.1			>0.90
2	1.92	0.4			>0.90
3	1.92	0.4			>0.90
4	1.90	0.8			>0.90
5	1.88	0.9			>0.90
Avg	1.91	0.5			>0.90
		3.8 km D/S			
1	1.50	0.1			>0.35
3	1.50	0.1			>0.35
5	1.50	0.1			>2.00
Avg	1.50	0.1			>0.90
		8.8 km D S			
1	2.06	112.0	112.0	1.75	>4.56
3	1.92	124.5	124.5	0.63	3.00
5	1.88	84.0	96.4	0.76	3.00
Avg	1.95	107.5	111.0	1.05	>3.52
		21.0 km D/S			
1	4.08	48.5	59.0	4.1	>4.4
3	4.08	105.2	110.0	4.3	>4.4
5	4.33	14.5	14.5	>4.4	>4.4
Avg	4.16	56.1	61.2	>4.3	>4.4
		28.0 km D/S			
1	6.52	39.6	67.5	3.8	>6.2
3	6.50	53.3	53.3	3.3	>6.1
5	6.48	33.0	46.5	4.9	>6.1
Avg	6.50	41.9	55.8	4.0	>6.2
		396 km D/S			
5	49.83	0.4	0.5	>55.5	>55.5

[a] Dip samples taken immediately below surface.

[b] Time from start of treatment to first detection of methoxychlor (see Figs. 10-17).

[c] Total elapsed time (hr) when methoxychlor concentrations was (I) above 2% of maximum estimated concentrations or (II) at measurable levels (>0.01 ppb).

Complete mixing had not been achieved at this point because, at 21 km D/S from treatment, complete peaks were identified at only three sites. At site 1, the range of values varied significantly and the time-concentration curve is, at best, an approximation of the concentration (Appendix I, Fig. 15). In contrast, the curves for sites 3 and 5 were complete and apparently normal except that site 5 was substantially lower than site 3.

Better mixing was achieved by 28 km where the range of measured maxima was 33.0-53.3 ppb and of estimated maxima was 46.5-67.5 ppb, respectively. At 396 km D/S of treatment at one site, a complete time-concentration function was described with a measured maximum concentration of 0.4 ppb when the estimated maximum was 0.5 ppb.

Beltaos (p. 106) calculated the distance required to obtain 90, 95, and 98% mixing as 1.5, 19, and 48 km from the Athabasca bridge respectively using the data obtained from the fluorescent dye studies. These calculations, however, apply to the mixing of the dosage and not necessarily to the mixing of peak concentrations.

Methoxychlor Residues - 1975

In 1975, the application technique was modified so that the methoxychlor was injected at the surface of the water in three bands to achieve an ultimate concentration of 300 ppb for 7.5 min. It is important to note that the concentration of methoxychlor was the same as for 1974; however, the application period was only half. This would not change the initial concentration of the methoxychlor in the water but would substantially decrease the exposure time for about the first 10-15 km for biological organisms because the 'slug' of methoxychlor would be much shorter. In addition, the shorter period decreases the amount of material in the water for adsorption onto the washload particles.

The time of initial detection of methoxychlor together with the maximum measured and estimated methoxychlor concentrations, and the duration of the slug of methoxychlor for residue analyses of samples collected in 1975 are given in Table 4. Clearly, the new technique for injection of methoxychlor achieved better mixing at least as far as the surface water samples are concerned.

At 1.9 and 3.8 km D/S, the variation in residue values at three sites at each location was substantially less than in 1974 and the average measured maximum methoxychlor concentrations were 263 and 351 ppb respectively, compared to the estimated values of 335 and 453 ppb. The high estimated values indicate that complete mixing was not achieved by these sites.

When one considers the 8.8-km D/S site, the average measured maximum methoxychlor

Table 4. Summary of methoxychlor (MeOCl) concentration (ppb) in surface[a] water and associated washload from the Athabasca River immediately after treatment from 0700 and 0707:30 on 4 June 1975

Site	Init. MeOCl (hr)[b]	Max. MeOCl Meas.	Max. MeOCl Est.	Elapsed time[c] I	Elapsed time[c] II
		1.9 km D/S			
2	0.37	377.3	377.3	0.27	0.71
3	0.40	324.3	324.3	0.26	0.72
4	0.35	87.1	302.0	0.23	>0.92
Avg	0.37	262.9	334.5	0.25	>0.78
		3.8 km D/S			
2	0.82	565.6	635.0	0.25	>1.58
3	0.83	170.8	270.0	0.37	>1.53
4	0.85	313.9	455.0	0.30	>1.55
Avg	0.83	350.1	453.3	0.31	>1.55
		8.8 km D/S			
1	2.43	66.9	74.0	2.04	>4.00
2	2.15	139.0	139.0	0.50	>3.95
3	2.03	113.7	129.0	0.58	3.25
4	1.83	85.3	99.0	1.50	>4.43
5	2.22	78.7	87.0	2.20	>4.05
Avg	2.04	96.7	105.6	1.36	>3.94
		16.9 km D/S			
1	5.22	26.0	40.0	3.75	>5.17
2	4.35	86.4	98.7	1.10	5.93
3	4.53	61.0	80.0	1.30	>5.78
4	4.55	59.4	76.0	1.20	>5.80
5	4.57	30.3	64.7	3.08	>5.50
Avg	4.64	52.6	71.9	1.95	>5.64
		21.0 km D/S			
2	6.42	51.1	65.0	1.3	3.7
3	6.10	56.9	72.0	1.7	4.4
4	6.20	26.2	72.0	1.8	>6.0
Avg	6.24	44.7	72.0	1.6	>4.7
		40.0 km D/S			
1	10.33	4.5	4.7	14.2	>14.5
		77.0 km D/S			
1	23.05	1.1	1.3	23.0	28.0
		120 km D/S			
5	34.97	1.3	1.5	29.5	>32.0
		176 km D/S			
1	49.00	0.3	0.5	56.0	56.0

[a] Dip samples taken immediately below surface.

[b] Time from start of treatment to first detection of methoxychlor (see Figs. 22-30).

[c] Total elapsed time (hr) when methoxychlor concentration was (I) above 2% of maximum estimated concentration or (II) at measurable levels (>0.01 ppb).

concentration of 97 ppb and the estimated maximum methoxychlor concentration of 106 ppb, suggest that more complete mixing had taken place. With increasing distance from application, the maximum measured methoxychlor concentration decreases as does the maximum estimated value (Table 4). Also, the time for the methoxychlor 'slug' to pass any single sample location increases. The phenomenon of dispersion mentioned earlier describes this function clearly. At 176 km D/S, the maximum measured methoxychlor concentration was 0.3 ppb and the maximum estimated methoxychlor concentration was 0.5 ppb.

Initially, the concentration of methoxychlor in the surface water and associated washload decreased relatively rapidly to a location 21 km D/S of application. There after, with increasing distances, the decreased loss of methoxychlor from the water and its associated washload decreased substantially.

Methoxychlor Residues - 1976

In 1976, two treatments of the river were applied, both similar to that carried out in 1975.

The first treatment was carried out 160 km D/S of the 1975 application and the sampling locations were in reaches of the river that had a higher velocity than those established for treatments in 1975 and the second treatment in 1976. The program was modified to permit three sampling sites at each location and to reduce the number of sample locations close to treatment. This latter change was made because reliable data from sites close to the application site were difficult to obtain due to very brief durations and incomplete mixing.

At 5 and 16 km D/S, average measured methoxychlor concentrations were 262 and 294 ppb respectively and the maximum estimated values were 275 and 383 ppb (Table 5). The lack of complete mixing was still apparent at 16 km because the estimated maximum methoxychlor concentration was higher than the initial application level. Between 16 and 40 km, however, the concentration of methoxychlor was substantially reduced. At 236 km, both the maximum measured and maximum estimated methoxychlor concentrations were only one-third the values at 80 km D/S. It is again evident that, with increasing distance downstream, the concentration of methoxychlor was reduced while the duration of methoxychlor slug was increased.

The second treatment in 1976 took place at the Athabasca townsite. The levels of methoxychlor in the samples from this treatment were substantially lower (Table 6) than those reported for the first 1976 treatment (Table 5) or for the initial sites in the 1975 treatment (Table 4) for methoxychlor applied at essentially the same rate. The values for methoxychlor from 40-176 km do not vary significantly between the treatment in 1975 and the second treatment in 1976. However, both differ significantly from those for the first treatment in 1976. This difference occurred because the water velocity, and therefore the washload

Table 5. Summary of methoxychlor (MeOCl) concentrations (ppb) in surface[a] water and associated washload from the Athabasca River immediately after treatment on 20 May 1976

Site	Init. MeOCl (hr)[b]	Max. MeOCl Meas.	Max. MeOCl Est.	Elapsed time[c] I	Elapsed time[c] II
		5.0 (165) km[d]			
3	0.40	262.0	275.0	>0.29	>0.39
		16.0 (176) km			
2	3.25	346.3	366.0	>1.30	>1.65
3	3.17	238.0	300.0	1.20	>1.70
4	3.20	298.9	349.0	1.40	>1.65
Avg	3.21	294.4	338.3	>1.30	>1.67
		40.0 (200) km			
2	7.90	12.6	16.3	4.2	4.8
3	7.52	13.4	19.0	4.3	4.6
4	7.90	8.8	14.4	4.9	5.8
Avg	7.77	11.6	16.5	4.5	5.1
		80.0 (240) km			
2	16.75	6.6	6.6	7.3	9.5
3	16.78	5.8	7.6	7.4	10.5
4	16.78	5.3	7.4	7.5	9.8
Avg	16.77	5.9	7.2	7.4	9.9
		160.0 (320) km			
2	38.00	1.7	3.2	14.5	17.0
3	38.00	2.5	2.8	12.5	13.0
4	38.00	2.4	2.5	13.0	15.0
Avg	38.00	2.2	2.8	13.3	15.0
		236.0 (396) km			
2	39.00	2.0	3.7	>25.0	>39.5
3	38.85	1.5	2.3	>25.0	>39.7
5	38.75	1.5	2.4	>25.0	>39.8
Avg	38.87	1.7	2.8	>25.0	>39.6

[a] Dip samples taken immediately below surface.

[b] Time from start of treatment to first detection of methoxychlor (see Figs. 42-47).

[c] Total elapsed time (hr) when methoxychlor concentration was (I) above 2% of maximum estimated concentration or II at measurable levels (>0.01 ppb)

[d] Distances from treatment with distances from Athabasca in parenthesis.

Table 6. Summary of methoxychlor (MeOCl) concentrations (ppb) surface[a] water and associated washload of the Athabasca River immediately after treatment on 25 May 1976

Site	Init. MeOCl (hr)[b]	Max. MeOCl Meas.	Max. MeOCl Est.	Elapsed time[c] I	Elapsed time[c] II
		5.0 km D/S			
3	1.20	90.1	107.0	>1.0	>1.0
		21.0 km D/S			
2	5.98	18.9	22.2	2.0	4.0
3	6.02	23.7	31.5	1.5	2.3
4	6.03	10.4	18.0	1.4	2.2
Avg	6.01	17.7	23.9	1.6	2.8
		40.0 km D/S			
2	12.33	2.7	5.9	6.3	6.4
3	12.37	3.0	6.1	6.0	6.2
4	12.40	4.3	6.0	7.9	9.0
Avg	12.36	3.3	6.0	6.7	7.2
		77.0 km D/S			
2	25.33	1.9	2.4	15.5	22.0
3	25.25	2.3	2.8	14.8	23.2
4	25.17	3.7	4.3	9.5	>23.3
Avg	25.25	2.6	3.2	13.3	>22.8
		176 km D/S			
2	52.55	0.7	0.8	22.0	24.8
3	52.50	0.7	0.7	18.8	30.0
4	52.45	0.7	0.7	22.0	23.0
Avg	52.50	0.7	0.7	20.9	25.9
		320.0 km D/S			
2	84.00	0.3			>14.0
3	84.00	0.3			>14.0
4	84.00	0.3			>14.0
Avg	84.00	0.3			>14.0

[a] Dip samples taken immediately below surface.

[b] Time from start of treatment to first detection of methoxychlor (see Figs. 49-54)

[c] Total elapsed time (hr) when methoxychlor concentration was (I) above 2% of maximum estimated concentration or (II) at measurable levels (>0.01 ppb).

capacity, were higher in the first 1976 treatment and therefore loss of methoxychlor to the moving and static bed of the river was decreased. This fact is shown later to be important in the ultimate goal of the program, i.e., the control of black fly larvae.

In all four treatments, it is very obvious that, with increasing distance downstream of the application of methoxychlor, both the maximum measured and estimated methoxychlor concentrations decreased. At the same time, the length of the methoxychlor 'slug' increased with increasing distance from application. Even though Tables 3-6 appear to show an increase followed by a decrease in the duration of the 'slug', this occured because the analytical techniques were sensitive only to a level 0.01 ppb and therefore, at the more distant points downstream, it was impossible to detect the low levels of methoxychlor at both the leading and tailing edges of the 'slug'.

Methoxychlor Dispersion in Sub-surface Water

Because of program constraints in 1974, surface water samples could not be taken more than 28 km D/S and therefore a series of pumping stations (see Materials and Methods) was established to take water samples 20 cm above the static bed of the

river at 3.7 and 11 m from one bank at four locations. Table 7 summarizes the time of initial detection of methoxychlor together with the maximum measured and estimated methoxychlor concentrations.

At 21 km D/S, sampling was stopped before the slug of methoxychlor had totally passed the location and therefore the concentration-time curve can not be completely described. The concentration of methoxychlor at the remaining three locations shows the expected steady decline with increasing distance and the increasing duration of the methoxychlor 'slug'.

Methoxychlor Distribution in a River Profile

In 1975, nine sample sites were established at 21 km where a point integrating sampler was used. Because of the establishment of known depths of the sample locations at three sites along the cross-section, it was felt that the amount of water accumulated in the sampler between the top of the river and the actual point of sampling would not significantly affect the residues measured. It is felt that this profile is significant.

Table 7. Summary of methoxychlor (MeOCl) concentrations (ppb) in sub-surface water and associated washload from the Athabasca River immediately after treatment from 0512 and 0527 on 4 June 1974

Type[a]	Init. MeOCl (hr)[b]	Max. MeOCl Meas.	Max. MeOCl Est.	Elapsed time[c] I	Elapsed time[c] II
		21.0 km D/S (Site 5)			
A	5.42	9.5			>3.0
B	6.92	14.4			>4.0
Avg					>3.5
		40.0 km D/S (Site 1)			
A	9.63	9.1	11.6	8.8	14.0
B	9.63	10.1	11.9	7.5	>16.6
Avg	9.63	9.6	11.8	8.1	>15.0
		77.0 km D/S (Site 1)			
A	19.83	3.6	4.3	11.5	15.7
B	19.83	4.6	4.8	11.7	>25.8
Avg	19.83	4.1	4.5	11.6	>20.8
		176 km D/S (Site 5)			
A	37.83	1.2	1.5	31.8	>60.0
B	37.83	1.7	2.0	22.8	>62.0
Avg	37.83	1.5	1.8	27.3	>61.0

[a] Samples taken by pumping 20 cm above the static river bed; where A is 3.7 m and B is 11 m from shore.

[b] Time from start of treatment to first detection of methoxychlor (see Figs. 18-21)

[c] Total elapsed time (hr) when methoxychlor concentration was (I) above 2% of maximum estimated concentration or (II) at measurable levels (>0.01 ppb).

The time of the initial methoxychlor determination varied significantly among the nine sample sites (Table 8). More importantly, the maximum measured and estimated methoxychlor concentrations also varied significantly among the nine sample locations. The samples taken at site 2 (25% of the width of the river from the right bank) were substantially higher than those at the other two sites. However, by calculating the area under the respective time-concentration curves (Appendix I, Fig. 40), the overall dosage concentration can be established in parts per billion hours (ppb•hr). These do not show the same wide spread as the measured or estimated maxima but do show the same trend (Fig. 3).

This phenomenon is influenced by many factors but most probably occurred because site 2 was influenced by a curve in the thalweg causing the methoxychlor-laden particles to follow the faster current, i.e. the outside of the curve. Graf (1974) has alluded to this type of diffential hydraulic activity. These data clearly indicate that it is possible to have varying concentrations of methoxychlor no matter what the degree of mixing (based on dosage) because of the influence of river geometry and hydraulics. This varying concentration is not significant as long as the lower concentration of methoxychlor is above the level that would give greater than 90% control of black fly larvae, but is significant at lower levels; therefore, the location of

Table 8. Summary of methoxychlor (MeOCl) concentration (ppb) in sub-surface water and associated washload of the Athabasca River at 21 km D/S immediately after treatment from 0700 - 0707:30 on 4 June 1975

Site[a]	Init. MeOCl (hr)[b]	Max. MeOCl Meas.	Max. MeOCl Est.	Elapsed time[c] I	Elapsed time[c] II
2A	6.00	62.1	75.0	1.4	2.5
B	6.02	64.4	74.5	1.6	2.8
C	5.70	65.3	70.5	2.1	3.2
3A	5.75	66.1	66.0	1.7	4.9
B	6.13	45.0	45.0	1.6	2.3
C	6.17	55.7	56.0	2.0	2.5
4A	6.22	23.3	33.0	2.9	3.3
B	6.25	19.5	34.0	3.3	3.7
C	6.27	26.6	35.0	2.8	2.9
Avg	6.05	35.6	54.0	2.2	3.2

[a] Samples taken by a point sampler where A is 30 cm below surface, B is mid depth, and C is 30 cm above bottom (see Fig. 3).

[b] Time from start of treatment to first detection of methoxychlor (see Fig. 40).

[c] Total elapsed time (hr) when methoxychlor concentration was (I) above 2% of maximum estimated concentration or (II) at measurable levels (>0.01 ppb).

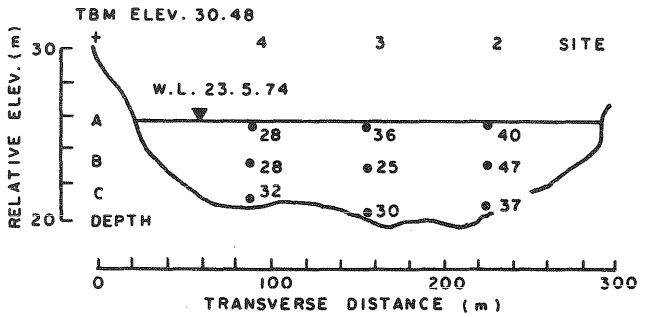

Fig. 3. Cross-sectional profile of the Athabasca River at 21 km D/S of treatment in 1975 showing maximum methoxychlor dose, DMtc (ppb·hr), at nine sampling locations.

sampling sites and the reported effect of methoxychlor on biological organisms could be strongly influenced. Clearly, a sampling location on the outside of a curve could show a large effect on the biota whereas one on the inside would show a substantially reduced effect. These phonomena must therefore be considered when control and effect on biological organisms is discussed.

Adsorption Phenomena

In 1975 and 1976, a system using the separator (see Materials and Methods) was used in an attempt to show the difference in methoxychlor levels in natural water as opposed to filtered water.

From the samples collected at 1.9 km D/S in the three treatments, the methoxychlor was clearly concentrated by the separator into the filtered water (Table 9 and 10). This suggests that, at this point in the river, the methoxychlor is still associated with the emulsifier and not adsorbed on particulates and therefore, because of the design of the separator, concentrated in the filtered water sample. These samples were collected in mid-stream about 60 cm below the water surface at 1.9 km D/S. In 1975, at 16.9 km D/S, this phenomenon was reversed and the concentration of methoxychlor in the filtered sample was substantially less than that in the natural sample (Table 9). At 16.9 km D/S, the level in the silted sample was higher than that in the natural water.

Because the number of analyses that could be made was restricted, only natural and filtered samples were analyzed at the remaining six sites in 1975. It was felt that any difference in methoxychlor concentration between natural and filtered water would be on the silt and therefore it was not necessary to analyze the silted water samples. The methoxychlor was obviously associated with the silt fraction as the natural water samples had higher methoxychlor loads at all remaining sites except at 396 km. The higher levels of methoxychlor in filtered samples at 396 km are not explainable at present.

Table 9. Summary of methoxychlor (MeOCl) concentration (ppb) in three fractions of subsurface water and associated collected through a separator immediately after treatment from 0700 - 0707:30 on 4 June 1975

Type[a]	Init. MeOCl (hr)[b]	Max. MeOCl Meas.	Max. MeOCl Est.	Elapsed time[c] I	Elapsed time[c] II
		1.9 km D/S (Site 3)[d]			
N	0.35	87.1	302.0	0.23	>0.92
F	0.35	160.1	306.0	0.26	>0.92
S	0.35	55.9	116.0	0.25	>0.92
		16.9 km D/S (Site 3)			
N	4.25	55.5	68.5	1.25	>5.50
F	4.25	36.2	58.5	1.10	>6.17
S	4.25	55.5	76.0	1.59	5.67
		40.0 km D/S (Site 1)			
N	10.3	3.5	4.0	5.1	>15.3
F	8.3	2.6	2.6	13.0	>14.0
		77.0 km D/S (Site 1)			
N	23.00	1.8	1.8	3.3	>30.3
F	25.67	1.2	1.2	11.5	>11.5
		120 km D/S (Site 5)			
N	34.97	1.1	1.3	33.5	>34.0
F	28.97	1.0	1.0	36.0	>37.0
		176 km D/S (Site 1)			
N	40.00	0.6	0.7	48.0	51.0
F	52.00	0.3	0.5	59.5	60.0
		240 km D/S (Site 1)			
N	62.00	0.8	0.8	60.0	60.0
F	70.00	0.2	0.2	36.0	47.0
		396 km D/S (Site 1)			
N	70.30	0.1	0.2	>97.0	>97.0
F	70.30	0.2	0.2	50.0	50.0

[a] N = natural, i.e., non-separated water; F = filtered, i.e., water with most of the suspended material removed; and S = silted, i.e., water with a concentration of suspended material.

[b] Time from start of treatment to first detection of methoxychlor (see Figs. 31-38)

[c] Total elapsed time (hr) when methoxychlor concentration was (I) above 2% of maximum estimated concentration or (II) at measurable levels (>0.01 ppb).

[d] Surface sample.

Total Methoxychlor Recovery

The total methoxychlor dose (DMtc) can be expressed in terms of a time-concentration (ppb·hr) function. This value for methoxychlor dose is given by the area under the concentration-time curve, and was calculated for each site at each location for the four treatments of methoxychlor in the Athabasca River from the curves shown in Appendix I (Figs. 10-54).

Table 10. Summary of methoxychlor (MeOCl) concentration (ppb) in two fractions of Athabasca River surface water and associated washload collected through a separator immediately after treatments on 20 and 25 May 1976 at 1.9 km (Site 3) D/S of treatment

Type[a]	Init. MeOCl (hr)[b]	Max. MeOCl Meas.	Max. MeOCl Est.	Elapsed time[c] I	Elapsed time[c] II
	Treatment 1 (20 May 1976)				
N	0.30	264.6	321.4	0.20	0.28
F	0.23	355.4	376.6	0.20	0.27
	Treatment 2 (25 May 1976)				
N	0.37	195.6	263.0	0.21	>0.65
F	0.47	262.1	324.0	0.20	>0.54

a N = natural, i.e., non-separated water; and F = filtered, i.e., water with most of the suspended material removed.

b Time from start of treatment to first detection of methoxychlor (see Figs. 41 and 48)

c Total elapsed time (hr) when methoxychlor concentration was (I) above 2% of maximum estimated concentration or (II) at measurable levels (>0.01 ppb).

The 1974 treatment provided a very high dose of methoxychlor compared to the other three treatments to about 100 km D/S from which point it was lower than the 1976-first treatment level (Fig. 4). The curves for the 1975 and 1976-second treatments are very similar and show a rapid decrease in dosage to about 80 km D/S with subsequent levelling out and a substantially reduced loss of methoxychlor. The dose curve for the 1976-first treatment is much higher and begins levelling out at about 60 km at a much higher level than the preceding two curves. This relatively high dosage is attributable to the fact that this treatment was made at 160 km D/S in a reach where the river had higher velocity than the other three treatments. This high velocity continued through the sampled reach of the river.

On the basis of the DMtc data and the river discharge, a second methoxychlor dose function (DMai) can be calculated giving the total weight of active ingredient passing through a location. Figure 5 shows the average dose (active ingredient) or DMai per location as a function of distance downstream from treatment. Here again, for the 1974 treatment, the excessive amount of methoxychlor to about 120 km D/S is very obvious. Again the curves describing the total DMai in the 1975 and 1976-second treatments are similar to each other. After the initial loss of methoxychlor, all curves show about the same rate of decrease of methoxychlor, illustrating that, after an initial stabilization period, the functions effecting the loss of methoxychlor are the same and are independent of velocity and characteristics of the static bed.

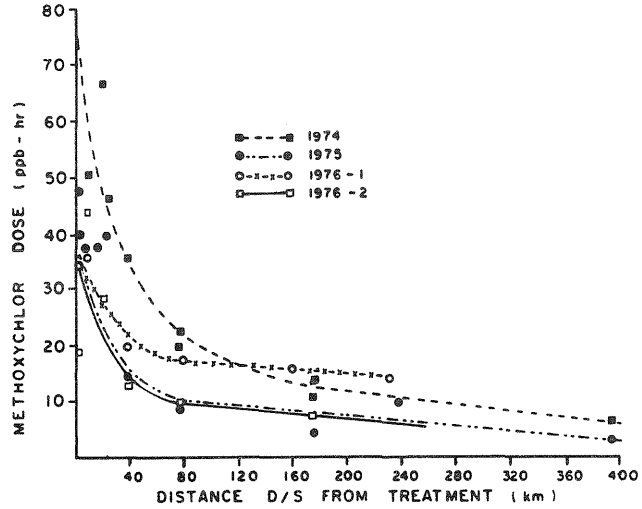

Fig. 4. Average measured methoxychlor dose, DMtc (ppb·hr), in water and associated washload against distance from treatment in the Athabasca River, 1974-1976.

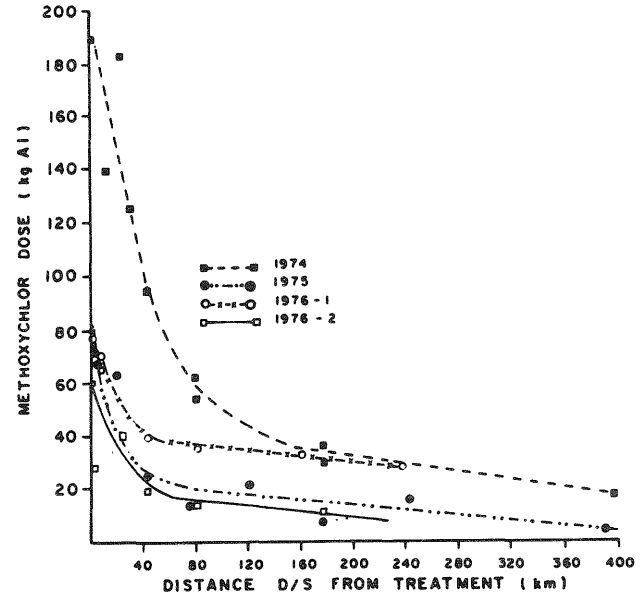

Fig. 5. Average measured methoxychlor dose, DMai (kg, active ingredient), in water and associated washload against distance from treatment in the Athabasca River, 1974-1976.

To describe the overall loss of methoxychlor at locations downstream from the application, the term 'recovery ratio' can be used to describe the functional loss of methoxychlor (i.e., to the static and moving bed) with distance. The recovery ratio is calculated on the basis of the total amount of methoxychlor recovered at a location divided by the total amount of methoxychlor injected into the river. The curves describing this function for the 1974, 1975, and 1976-second treatments are

very similar and, because of the variability of concentration, are thought to be the same (Fig. 6). However, the curve for the 1976-first treatment is substantially higher. This is again a reflection of the higher velocity and the fact that, at a higher velocity, the river can carry a higher washload thereby keeping more of the methoxychlor-laden silt particles in suspension.

The total amount of methoxychlor recovered and the total amount of methoxychlor actually available at each location are very important with respect to control. Methoxychlor below a lethal concentration is known to have a disruptive effect on small stream larvae causing them to detach and drift in the current until such time that they can reattach in an environment that contains a level of methoxychlor below the disruption level. Because of this effect, methoxychlor is very valuable for larval control as the treatment can be 'tailored' to those species of black fly that require water velocities above a certain level. They will then be flushed out of their natural habitat into an area where they would not complete development and subsequently die. Thus methoxychlor may operate in two completely different ways - one as a true insecticide and the other as a means of reducing the population and forcing it to an abnormal death.

Relationship of Methoxychlor Levels in Water to Black Fly Control

The effectiveness of the four methoxychlor treatments for control of *S. arcticum* in the Athabasca river is reported by Depner et al. (pp. 21-37). Graphical representation of the uncorrected (raw) and corrected data (Fig. 7) show no significant difference between the two sets of data except for the treatment in 1975. The raw data were corrected using the modified Abbott's formula:

$$\% \text{ control} = 100[1 - (TA/TB)(CB/CA)]$$

Where CB = control before treatment; CA = control after treatments; TB = treated area before treatment; and TA = treated area after treatment.

Shortly before treatment in 1975, a noticable decrease in river turbidity (i.e., washload) was recorded at the Athabasca townsite with no significant change in river velocity. The change in water quality and the presence of some exogenous materials was shown by a significant reduction of black fly larvae upstream of the townsite and subsequently by residue analysis. Because of this reduction of larval populations in the control (untreated) reach of the river, treatment of the 1975 data by Abbott's formula shows a substantially reduced control of larvae. The effect of this phonemenon is thought not to continue very far downstream because comparison of the curves for larval control for 1975 (uncorrected) with those for the 1976-second

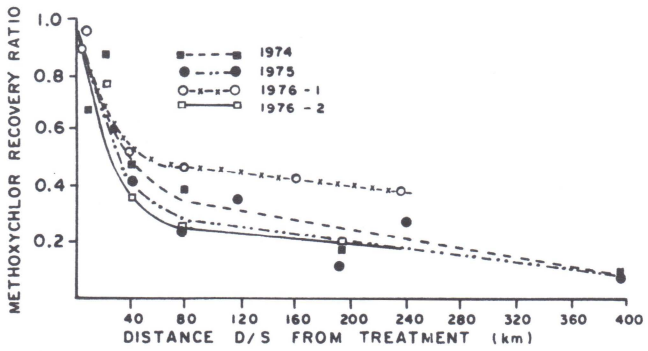

Fig. 6. Average measured methoxychlor recovery ratio (RR) in water and associated washload against distance from treatment in the Athabasca River, 1974-1976.

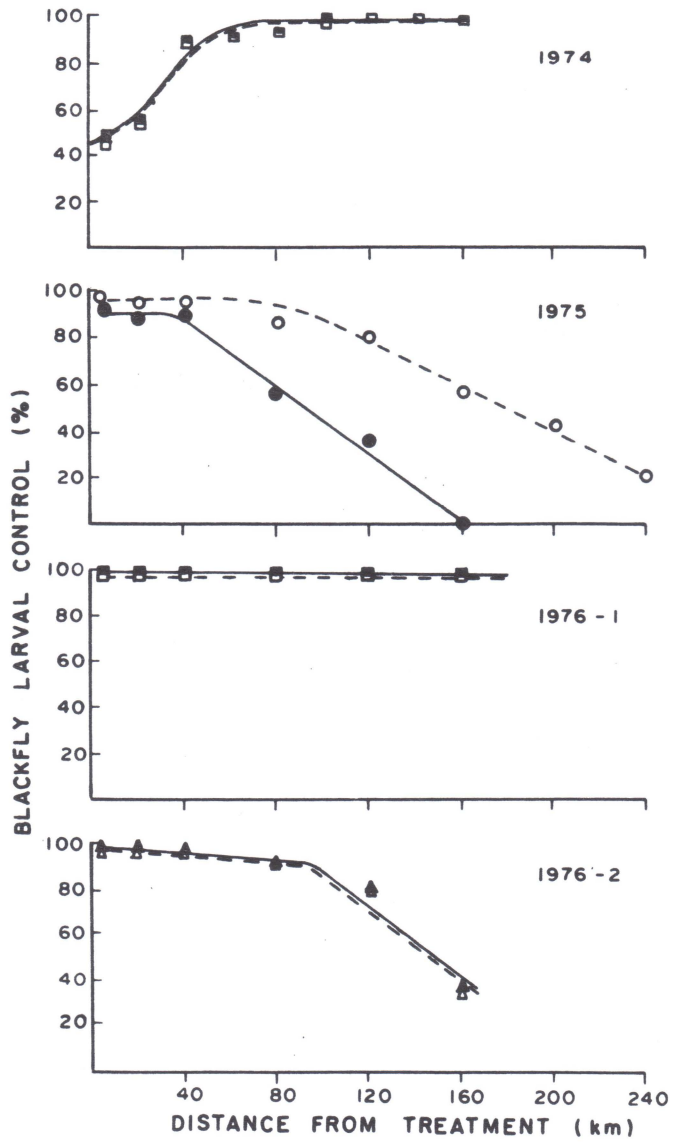

Fig. 7. Variation in black fly control with distance using uncorrected data (——) and data corrected (---) through a modification of Abbott's formula.

treatment (corrected and uncorrected) show only a slight difference (Fig. 7). Therefore, the discussion that follows deals with corrected larval control data for 1974 and 1976 treatments and both corrected and uncorrected data for the 1975 treatment.

Ultimately, it is necessary to relate methoxychlor dosage-DMtc (ppb·hr which is equivalent to µg hr/liter) and dose-DMai (total kg active ingredient) to percent larval control. It is well known that methoxychlor kills black fly larvae, however, at sub-lethal concentrations, methoxychlor causes the larvae to detach and drift. This latter function is as important as killing, especially in the case of the reach of the Athabasca River under consideration. The 'flushing' of larvae results in moving a portion of the population into areas where emergent adults are economically unimportant or into areas where the larvae cannot complete their development and therefore suffer 'ecological death'. This situation describes the fate of the larvae that are flushed into the reach downstream of Fort McMurray where, because of the low river velocity and lack of attachment sites *S. arcticum* cannot survive.

The three effects of methoxychlor on blackfly larvae are clearly evident by relating the methoxychlor dosage (DMtc) to larval mortality (Fig. 8). In the 1975 and 1976-second treatments, mortality is lower at the lower methoxychlor dose (Fig. 8A). The first effect undoubtedly results in some mortality, but the reduced population is probably due largely to detachment resulting from irritation by low methoxychlor concentrations. In addition, there is an effect of change in water quality. This is not due to a difference in river velocities since they were 0.79 and 0.72 m/sec for the 1975 and the 1976-second treatments respectively. However, as shown in Fig. 7 and discussed above, using the uncorrected 1975 data, a curve (Fig. 8A) similar to the 1976-second treatment is described. These two curves establish an LD_{90} (lethal methoxychlor dose to kill 90% of the population) of 10.7 and 9.6 ppb·hr respectively; hardly a significant difference. Based on the corrected data, the LD_{90} would be 18 ppb·hr. The similarity of the 1976-second and 1975 curves is not surprising because the concentration profiles (Fig. 4) for the same treatments were similar.

The dose-mortality curve (Fig. 8B) for the 1976-first treatment is described by a straight line at 98% control. This conforms to the upper portion of the curve for the 1976-second treatment and describes the mortality-release effect of methoxychlor.

The third effect of methoxychlor, that of mortality without release, is descirbed by Fig. 8C for the 1974 treatment. In this year, methoxychlor was applied at 300 ppb for 15 min (subsequent treatments were at 300 ppb for 75 min). As shown earlier (Figs. 4 and 5), this resulted in excessive amounts of methoxychlor immediately downstream of treatment. Also, because the larvicide and its emulsifier probably do not adsorb as rapidly onto the particulate matter of the washload, ingestion of the insecticide would be reduced. It is therefore hypothesized that, at these high methoxychlor dosages, and lower river velocities, the larvae are killed, but do not release from the sampling cones. If this were the case, then the three points in Fig. 8C above 30 ppb·hr do not reflect complete actual mortality.

Similarly, when the second dose-mortality relationship (Fig. 9) is considered, the three effects of methoxychlor and the similarity of the curves for the 1976-second and 1975 (uncorrected) treatment are apparent. Calculating dose-mortality on the basis of DMai (total kilograms of active ingredient) versus larval control, it is evident that about 16.5 kg of methoxychlor, evenly dispersed, was required to achieve 90% control (LD_{90}).

The dose-mortality curve for the 1974 treatment (Fig. 9C) further accentuates the

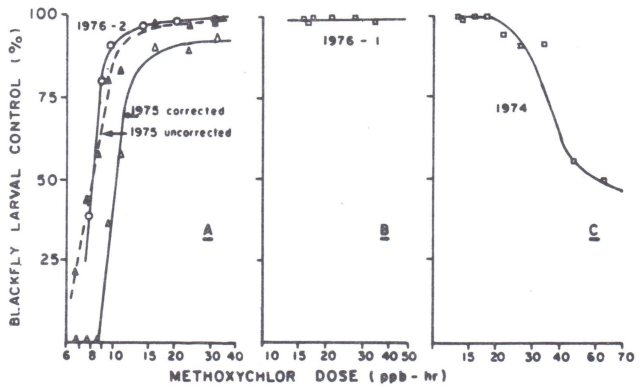

Fig. 8. Relationship of estimated methoxychlor dose, DMtc (ppb·hr), to percent black fly control for four treatments of the Athabasca River, 1974-1976.

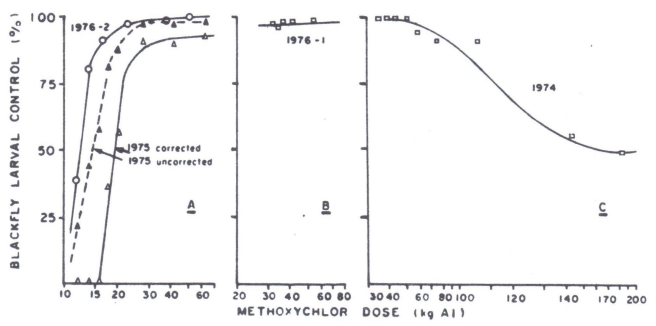

Fig. 9. Relationship of estimated methoxychlor dose, DMai (kg, active ingredient) to percent black fly control for four treatments of the Athabasca River, 1974-1976.

excess methoxychlor at the earlier sampling sites.

SUMMARY AND CONCLUSIONS

Methoxychlor concentrations in the water varied substantially between various sites at the same location and certainly between locations within years and between years at the same location. Cross-sectional profiles of methoxychlor concentration show that methoxychlor can apparently be concentrated on one side of the river and this is strictly a function of well known hydraulic phenomena in river hydrology.

Through the use of separators, we have shown that methoxychlor remains in emulsion close to the treatment but, as dispersion processes reduce the concentration of the formulated methoxychlor, adsorption takes place and a greater amount of methoxychlor is carried by the suspended particulate material known as washload. With increasing adsorption, more material is lost to the moving or static bed of the river (see Charnetski et al. p. 63); this results in a smaller amount of methoxychlor in the water and its associated washload.

Calculation of the recovery of methoxychlor shows that the higher velocity of the river for the 1976-first treatment resulted in a substantially larger amount of methoxychlor being retained in the water and washload. In addition, it is clear that a rather excessive amount of methoxychlor was in the water at locations up to 80 km in the 1974 treatment when the initial concentration of 300 ppb was established for 15 min rather than for 7.5 min. Calculation of recovery ratios, however, shows that the 1974, 1975, and the 1976-second treatments are described by similar curves and therefore the phenomena affecting the rate of loss of methoxychlor are the same, regardless of the total amount of methoxychlor available in the system.

The relationship of methoxychlor dosage to percent larval control appears to show a trimodal distribution. It is hypothesized that methoxychlor achieves control through mortality but also, at a lower concentration, it acts as a disturbing agent leading to detachment of the black fly larvae thus causing them to move downstream. Whereas at very high concentrations, larvae are killed but do not detach from the sampling cones thereby accounting for an apparent lack of control.

Because of the nature of the sampling regime established by Depner for evaluating mortality or rather reduction of the black fly population, it is felt that the data reported here for methoxychlor concentration in water and its associated washload are the only functions that can be correlated to control. Because of the particle size range on which these black fly larvae are feeding, most of the material in the bedload would be unavailable to the black fly larvae. Thus the methoxychlor in the bedload is immaterial as far as population control is concerned. However, the methoxychlor in bedload is truly of environmental importance.

RECOMMENDATIONS

A series of problems have been identified through the work reported in this paper. If answers were available to these problems, the practicality of controlling black fly larvae through use of an emulsifiable concentrate formulation of methoxychlor could be established. The problems are:

1. Establishment of the particle size and the nature of the particles in the washload of the water;

2. Determination of the exact habitat of the black fly larvae and the relation of this habitat to the moving bed;

3. Establishment of the adsorption/desorption time functions for methoxychlor on washload and moving bed material particles;

4. Establishment of the concentration-time function relationship as it relates to control through mortality and detachment of black fly larvae; and

5. Development of a particulate formulation of methoxychlor.

ACKNOWLEDGEMENTS

This portion of the program could not have been accomplished without the technical and analytical capabilities of D. Inaba, K. Au, and S.-M. Mak together with the assistance of R. Jackson, M. Qually, J. Carson, R. Johnson, M. Lowings, S. Graveland, C. Hulstein, and a large number of summer students too numerous to name. Their dedication, accurate sample handling, analysis, and reporting is truly appreciated. Thanks are also extended to M. Anderson, G. Childs, G. Putz, and H. Schultz of the Alberta Research Council for their dedication to this essentailly biological problem and their unselfish cooperation.

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Appendix I. Changes in methoxychlor residues with time at various locations and by various sampling methods after treatment of the Athabasca River in 1974, 1975, and 1976.

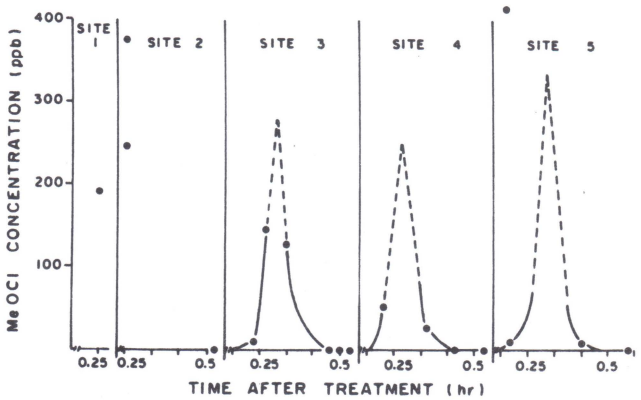

Fig. 10. Methoxychlor (MeOCl) residues in surface water samples taken at 0.34 km D/S from treatment, 1974.

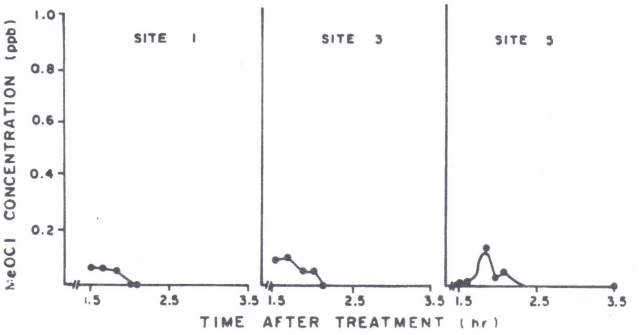

Fig. 13. Methoxychlor (MeOCl) residues in surface water samples taken at 3.8 km D/S from treatment, 1974.

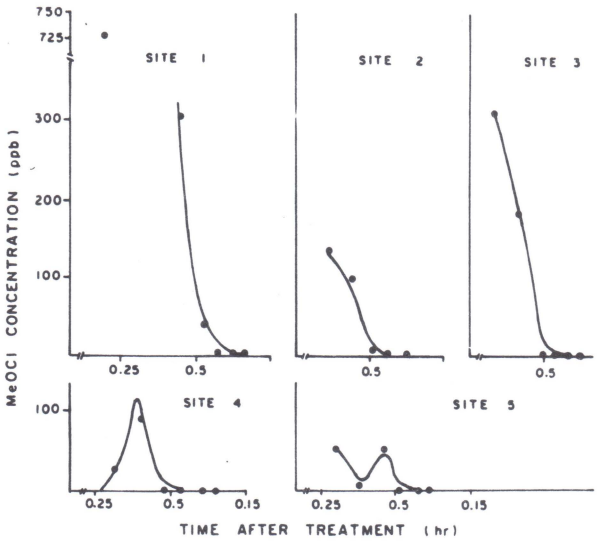

Fig. 11. Methoxychlor (MeOCl) residues in surface water samples taken at 0.72 km D/S from treatment, 1974.

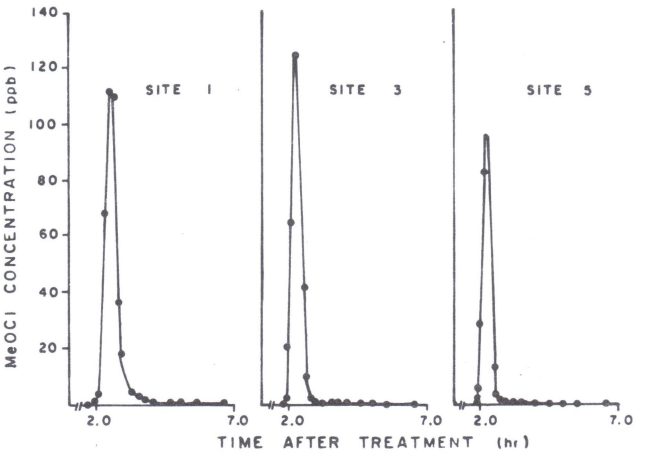

Fig. 14. Methoxychlor (MeOCl) residues in surface water samples taken at 8.8 km D/S from treatment, 1974.

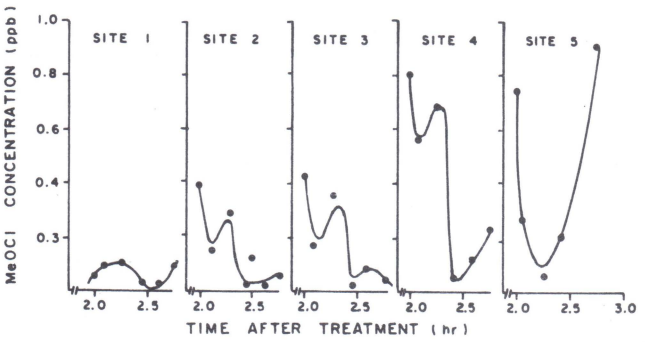

Fig. 12. Methoxychlor (MeOCl) residues in surface water samples taken at 1.9 km D/S from treatment, 1974.

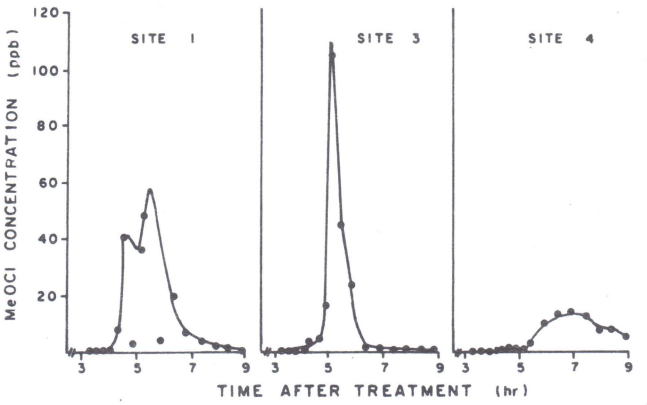

Fig. 15. Methoxychlor (MeOCl) residues in surface water samples taken at 21 km D/S from treatment, 1974.

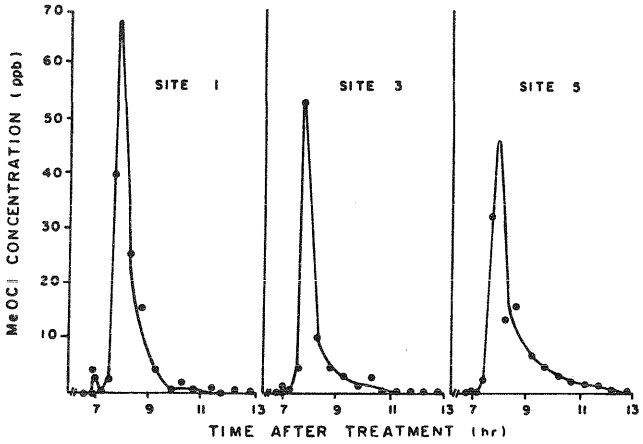

Fig. 16. Methoxychlor (MeOCl) residues in surface water samples taken at 28 km D/S from treatment, 1974.

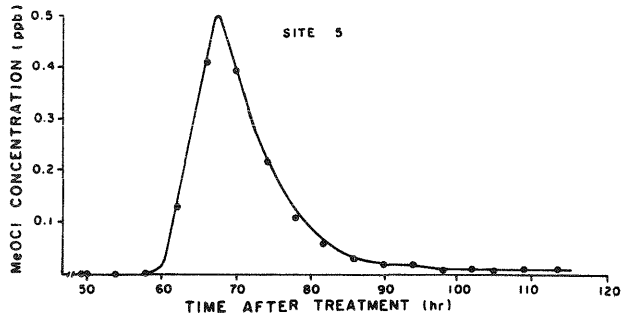

Fig. 17. Methoxychlor (MeOCl) residues in surface water samples taken at 396 km D/S from treatment, 1974.

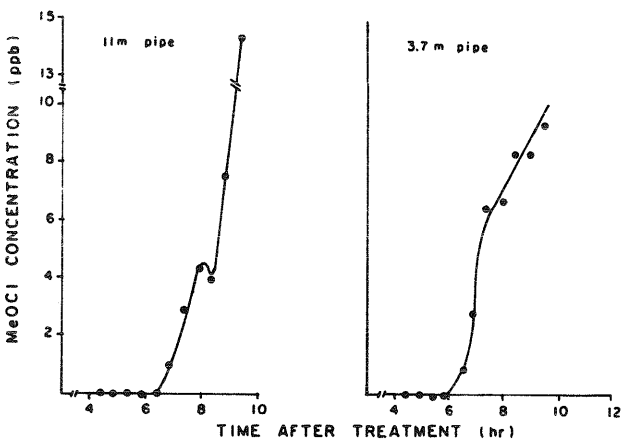

Fig. 18. Methoxychlor (MeOCl) residues in subsurface water samples taken at 11 m and 3.7 m from shore at site 5 21 km D/S from treatment, 1974.

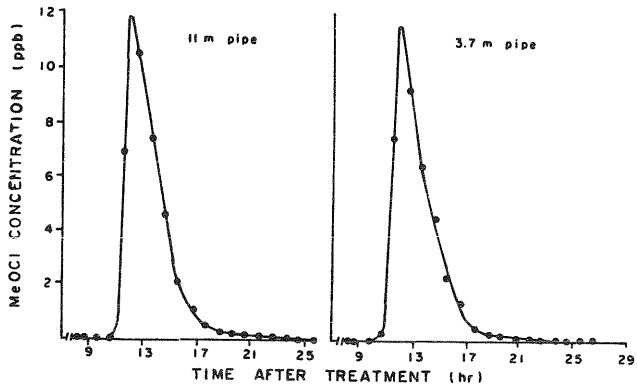

Fig. 19. Methoxychlor (MeOCl) residues in subsurface water samples taken at 11 m and 3.7 m from shore at site 1 40 km D/S from treatment, 1974.

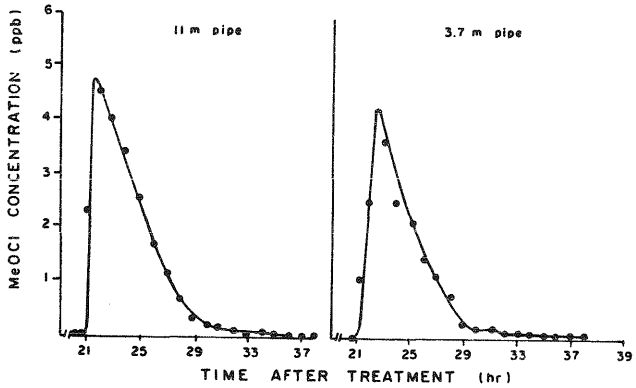

Fig. 20. Methoxychlor (MeOCl) residues in subsurface water samples taken at 11 m and 3.7 m from shore at site 1 77 km D/S from treatment, 1974.

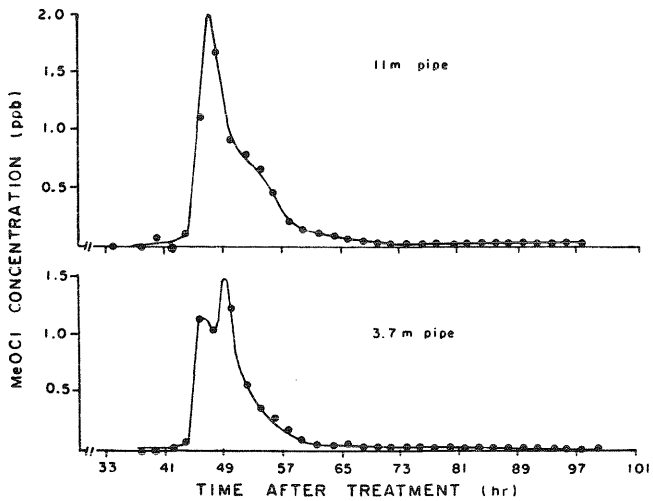

Fig. 21. Methoxychlor (MeOCl) residues in subsurface water samples taken at 11 m and 3.7 m from shore at site 1 176 km D/S from treatment, 1974.

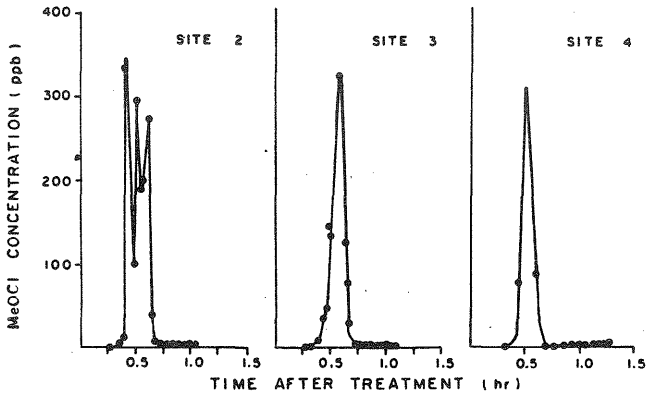

Fig. 22. Methoxychlor (MeOCl) residues in surface water samples taken at 1.9 km D/S from treatment, 1975.

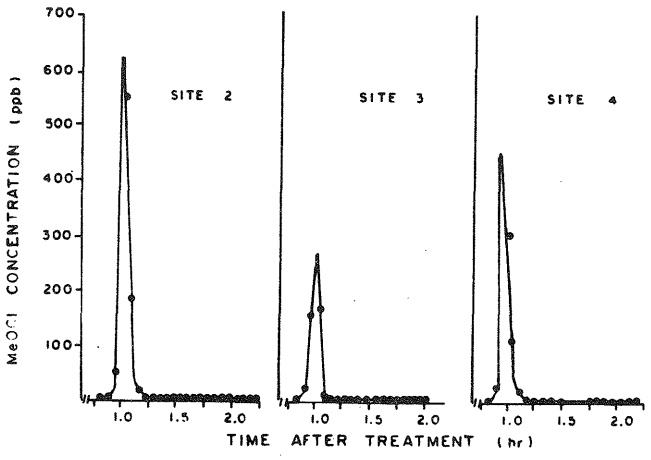

Fig. 23. Methoxychlor (MeOCl) residues in surface water samples taken at 3.8 km D/S from treatment, 1975.

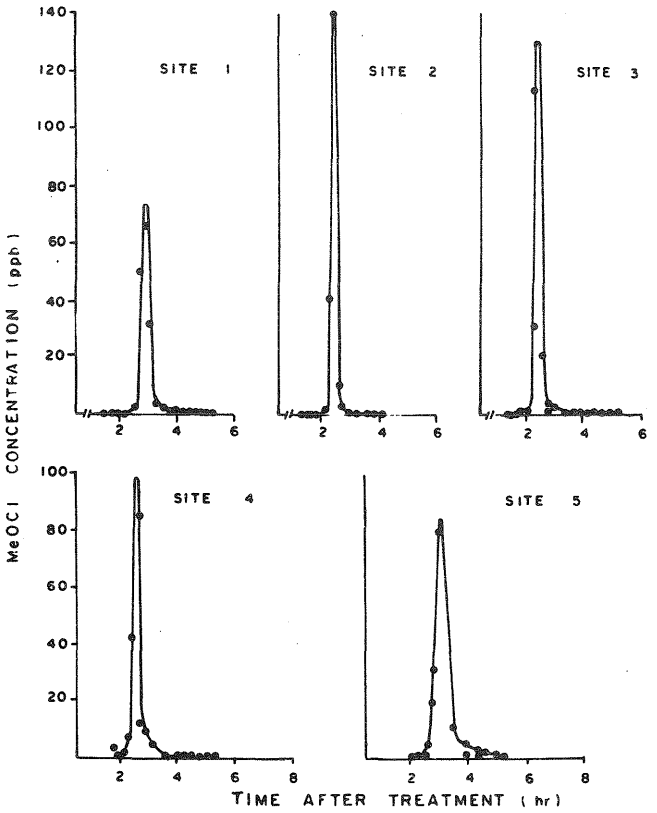

Fig. 24. Methoxychlor (MeOCl) residues in surface water samples taken at 8.8 km D/S from treatment, 1975.

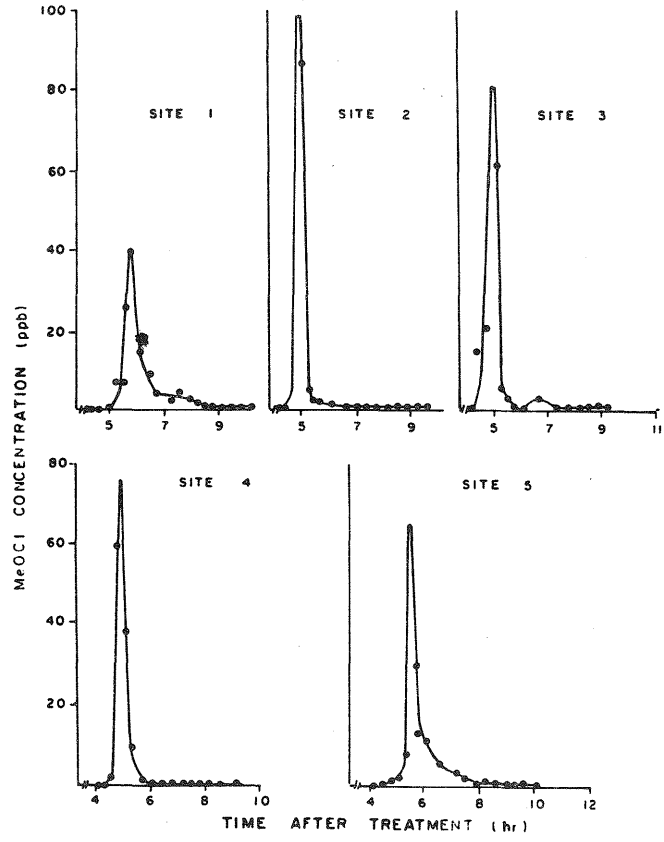

Fig. 25. Methoxychlor (MeOCl) residues in surface water samples taken at 16.9 km D/S from treatment, 1975.

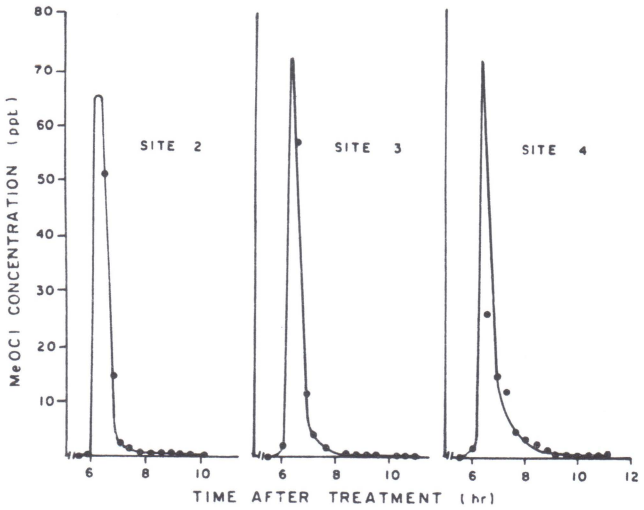

Fig. 26. Methoxychlor (MeOCl) residues in surface water samples taken at 21 km D/S from treatment, 1975.

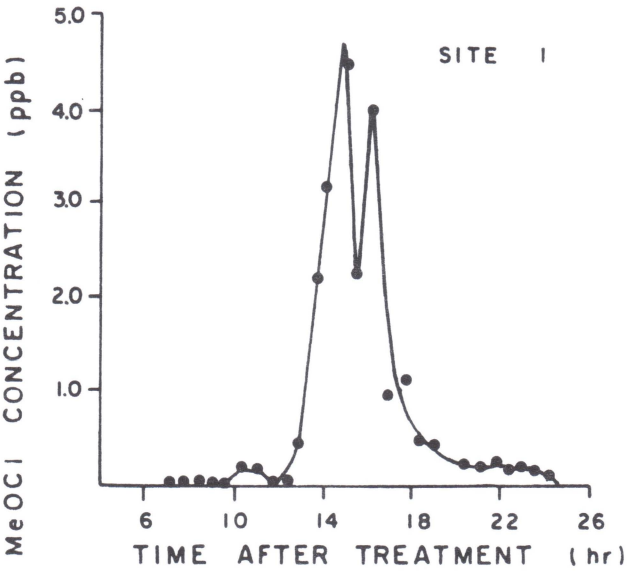

Fig. 27. Methoxychlor (MeOCl) residues in surface water samples taken at 40 km D/S from treatment, 1975.

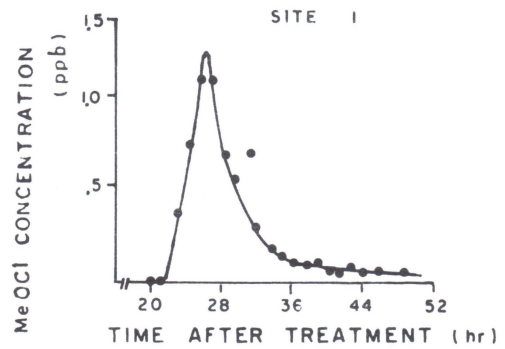

Fig. 28. Methoxychlor (MeOCl) residues in surface water samples taken at 77 km D/S from treatment, 1975.

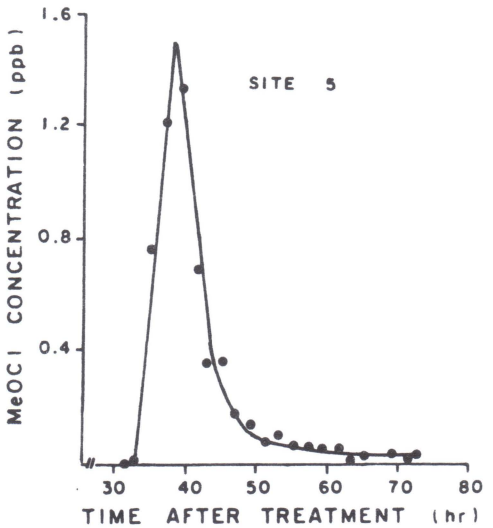

Fig. 29. Methoxychlor (MeOCl) residues in surface water samples taken at 120 km D/S from treatment, 1975.

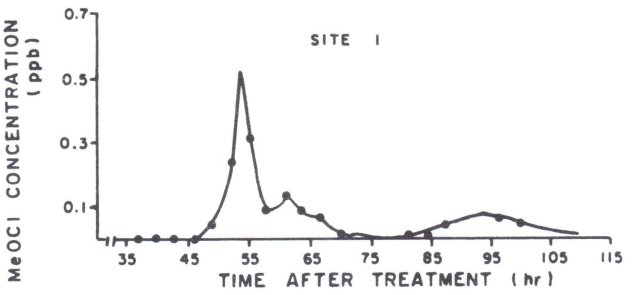

Fig. 30. Methoxychlor (MeOCl) residues in surface water samples taken at 176 km D/S from treatment, 1975.

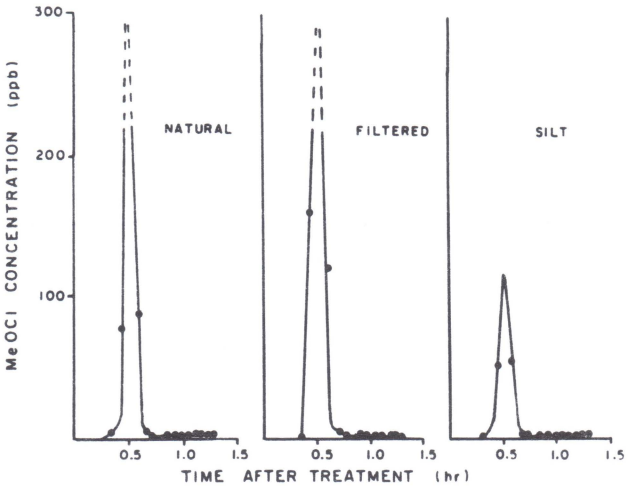

Fig. 31. Methoxychlor (MeOCl) residues in natural, filtered, and silt fractions of surface water samples taken at site 3 1.9 km from treatment, 1975.

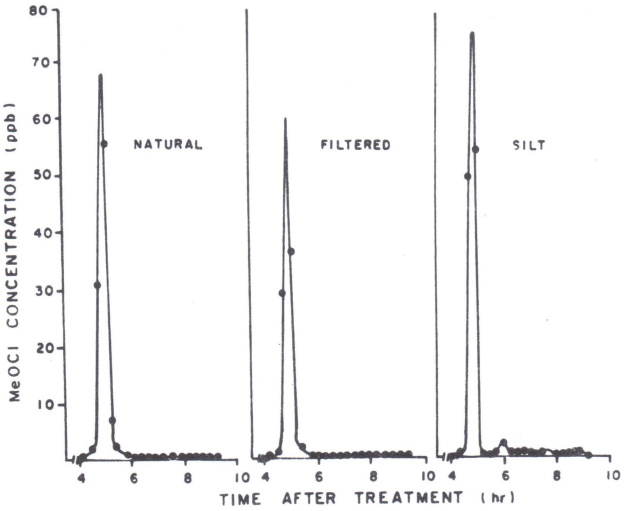

Fig. 32. Methoxychlor (MeOCl) residues in natural, filtered, and silt fractions of subsurface water samples taken at site 3 16.9 km D/S after treatment, 1975.

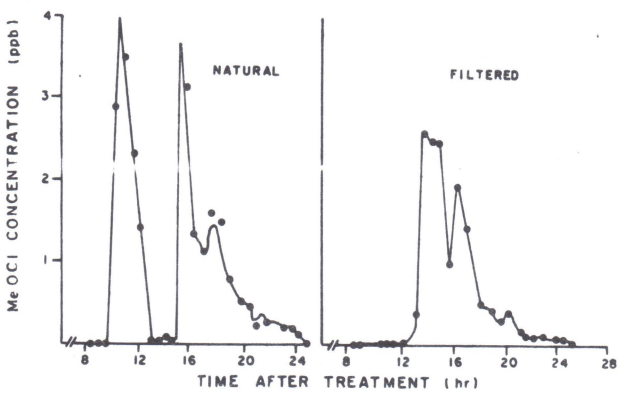

Fig. 33. Methoxychlor (MeOCl) residues in natural and filtered fractions of subsurface water samples taken at site 1 40 km D/S from treatment, 1975.

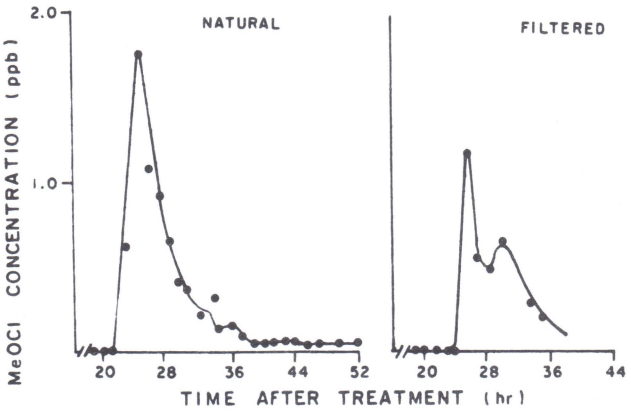

Fig. 34. Methoxychlor (MeOCl) residues in natural and filtered fractions of subsurface water samples taken at site 1 77 km D/S from treatment,1975.

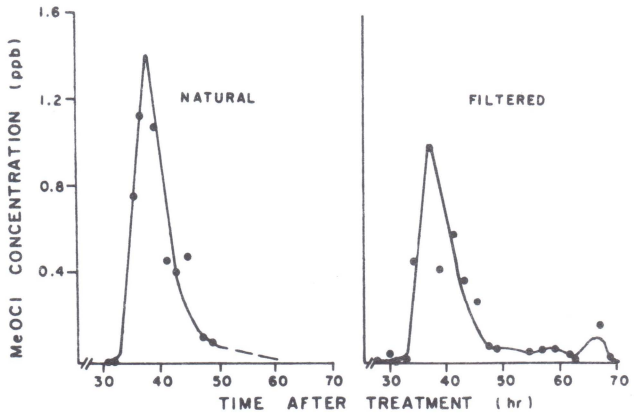

Fig. 35. Methoxychlor (MeOCl) residues in natural and filtered fractions of subsurface water samples taken at site 1 120 km D/S from treatment, 1975.

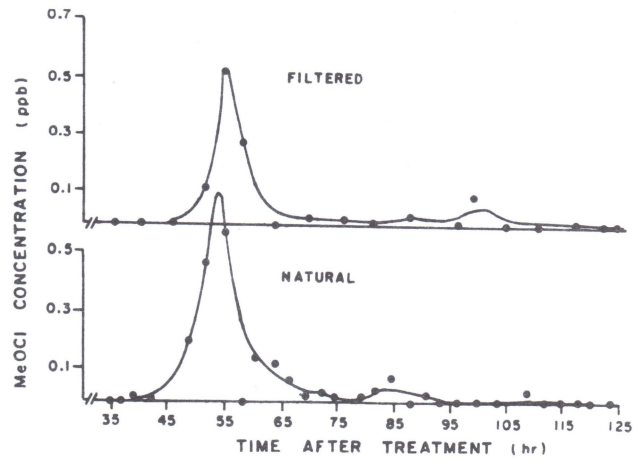

Fig. 36. Methoxychlor (MeOCl) residues in natural and filtered fractions of subsurface water samples taken at site 1 176 km D/S from treatment, 1975.

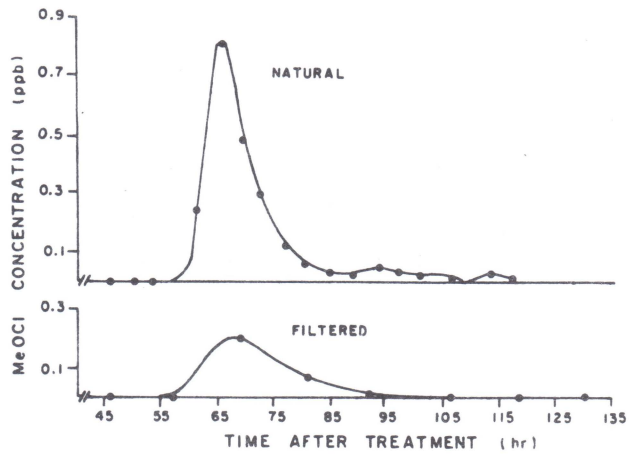

Fig. 37. Methoxychlor (MeOCl) residues in natural and filtered fractions of subsurface water samples taken at site 5 240 km D/S from treatment, 1975.

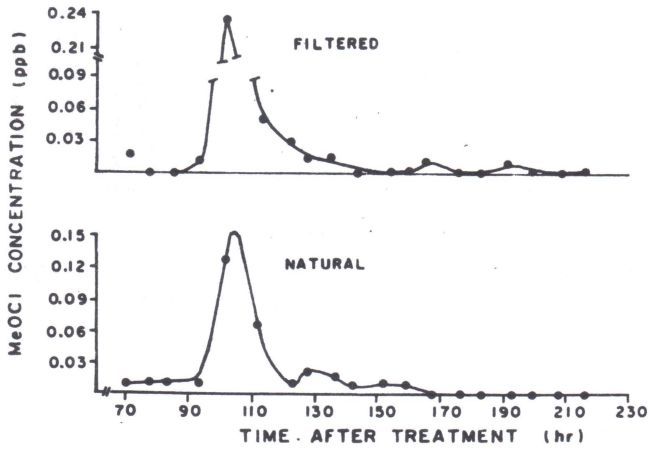

Fig. 38. Methoxychlor (MeOCl) residues in natural and filtered fractions of subsurface water samples taken at site 5 396 km D/S from treatment, 1975.

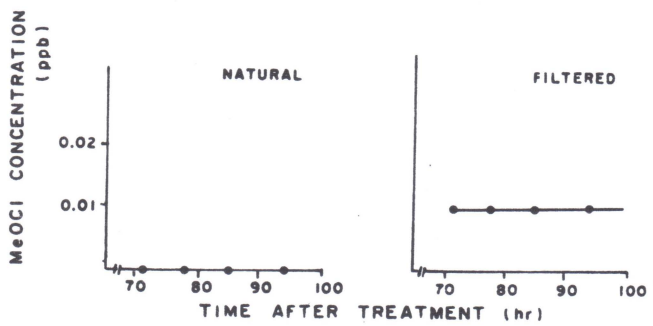

Fig. 39. Methoxychlor (MeOCl) residues in natural and filtered fractions of subsurface water samples taken at site 1 418 km from treatment, 1975.

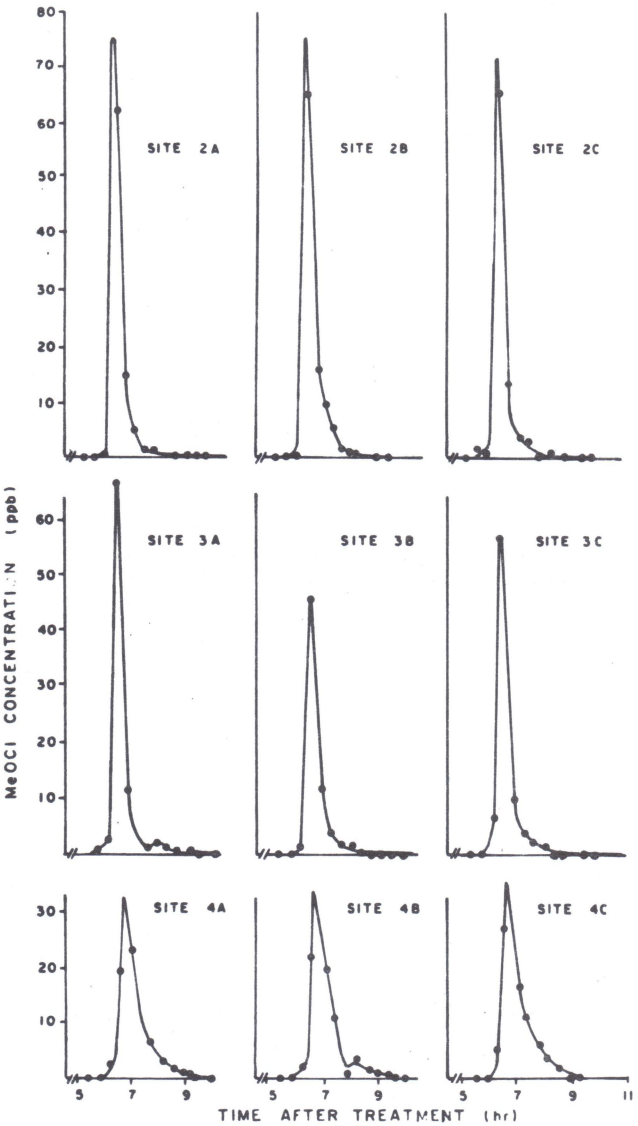

Fig. 40. Methoxychlor (MeOCl) residues in depth integrated water samples taken at 21 km D/S from treatment, 1975.

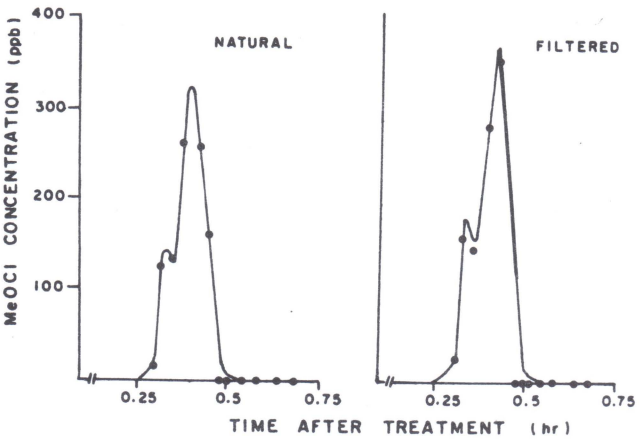

Fig. 41. Methoxychlor (MeOCl) residues in natural and filtered fractions of surface water samples taken at site 3 1.9 km D/S from first treatment, 1976.

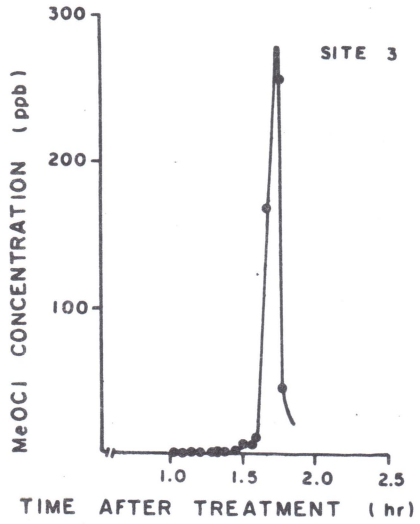

Fig. 42. Methoxychlor (MeOCl) residues in surface water samples taken at 5 km D/S from first treatment, 1976.

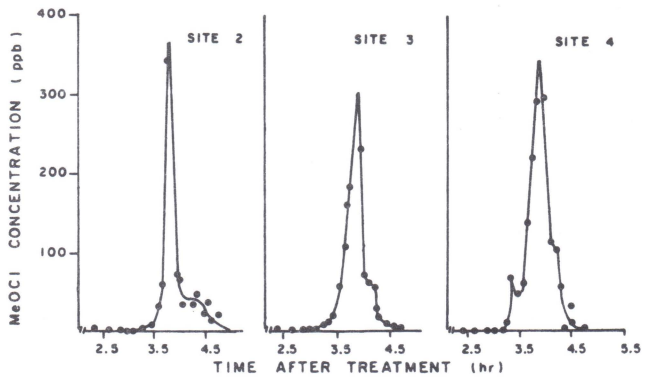

Fig. 43. Methoxychlor (MeOCl) residues in surface water samples taken at 16 km D/S from first treatment, 1976.

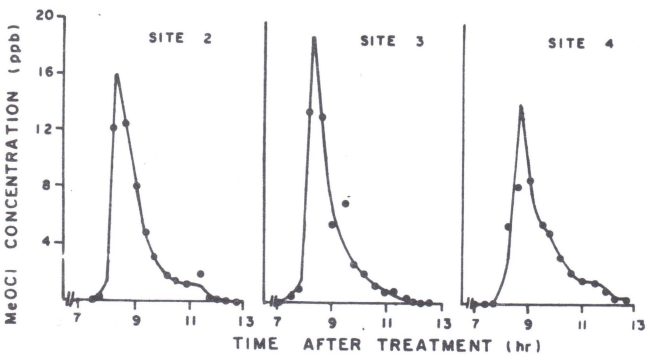

Fig. 44. Methoxychlor (MeOCl) residues in surface water samples taken at 40 km from first treatment, 1976.

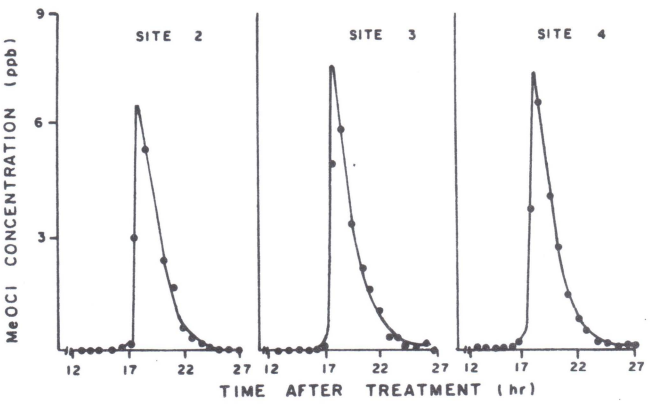

Fig. 45. Methoxychlor (MeOCl) residues in surface water samples taken at 80 km D/S from first treatment, 1976.

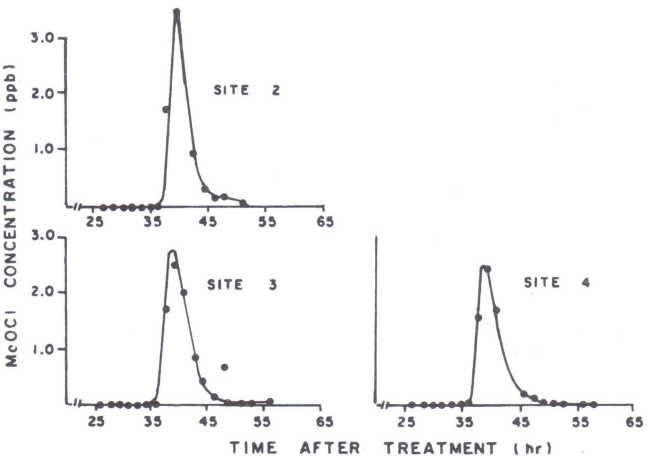

Fig. 46. Methoxychlor (MeOCl) residues in surface water samples taken at 160 km D/S from first treatment, 1976.

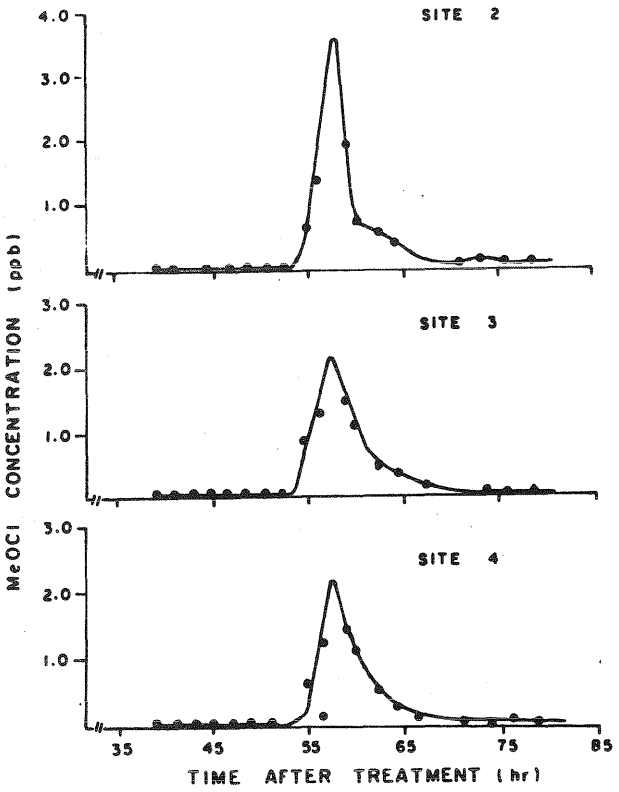

Fig. 47. Methoxychlor (MeOCl) residues in surface water samples taken at 236 km D/S from first treatment, 1976.

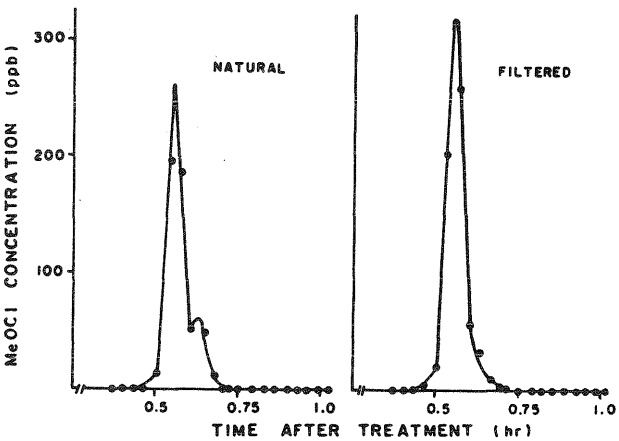

Fig. 48. Methoxychlor (MeOCl) residues in natural and filtered fractions of surface water samples at site 3 1.9 km D/S from second treatment, 1976.

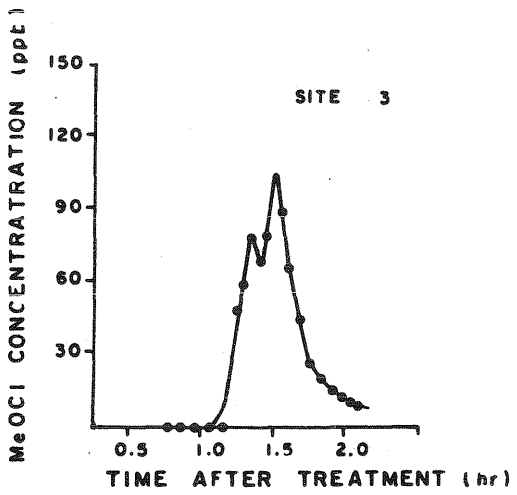

Fig. 49. Methoxychlor (MeOCl) residues in surface water samples taken at site 3 5 km D/S from second treatment, 1976.

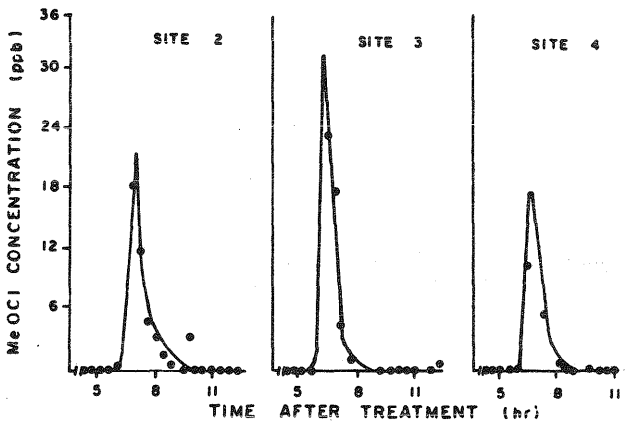

Fig. 50. Methoxychlor (MeOCl) residues in surface water samples taken at 21 km D/S from second treatment, 1976.

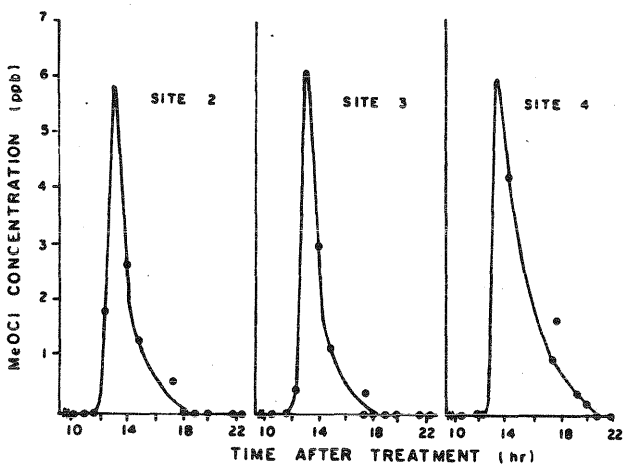

Fig. 51. Methoxychlor (MeOCl) residues in surface water samples taken at 40 km D/S from second treatment, 1976.

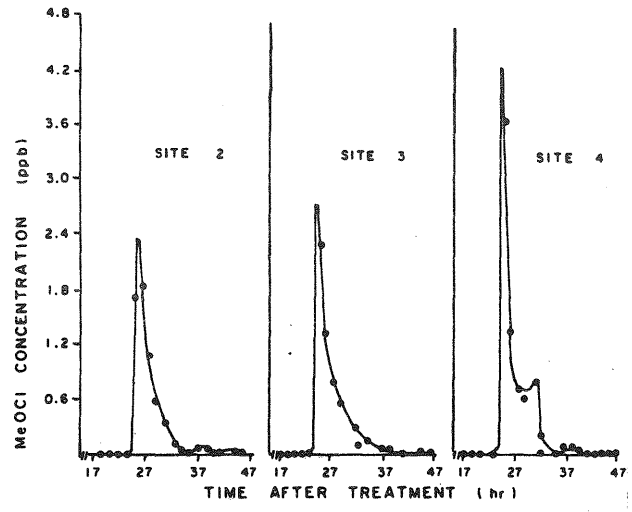

Fig. 52. Methoxychlor (MeOCl) residues in surface water samples taken at 77 km D/S from second treatment, 1976.

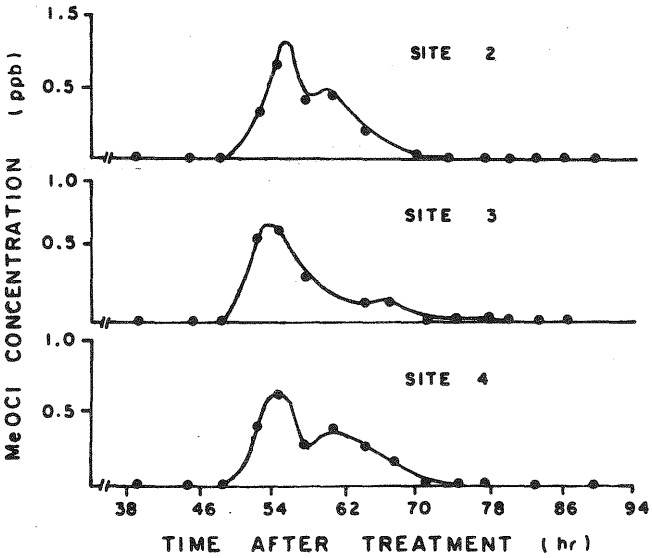

Fig. 53. Methoxychlor (MeOCl) residues in surface water samples taken at 176 km D/S from second treatment, 1976.

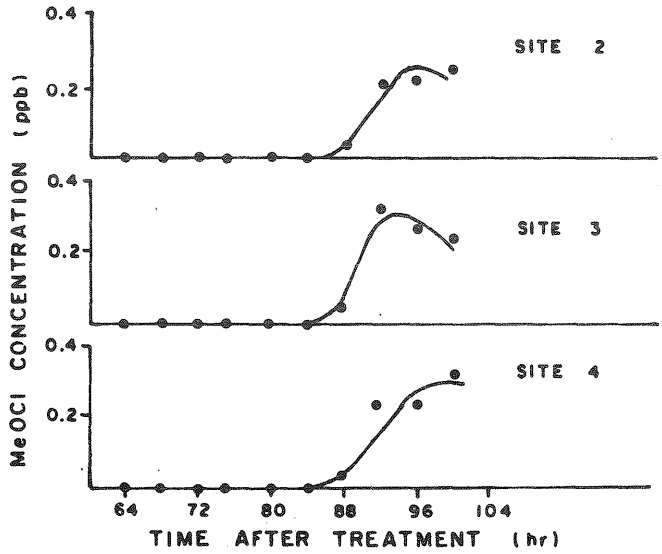

Fig. 54. Methoxychlor (MeOCl) residues in surface water samples taken at 320 km D/S from second treatment, 1976.

DISTRIBUTION AND PERSISTENCE OF METHOXYCHLOR IN ATHABASCA RIVER MUD AND BEDLOAD

W. A. CHARNETSKI AND K. R. DEPNER

INTRODUCTION

Detailed levels of methoxychlor in the sediments of the Athabasca River are necessary to provide the data that can be correlated to the environmental impact of the larvicidal application of methoxychlor.

Methoxychlor is an organochlorine insecticide and as such is very hydrophobic. Solubility in water is 12 ppb but varies with the amount and type of dissolved salts (Charnetski, unpublished). Therefore, methoxychlor adsorbs onto organic matter, clay, and inorganic particles in an aqueous environment. Methoxychlor can be lost from water to two major components: the washload of the river and the moving bedload material.

The washload is composed of the finer sediment particles held in suspension by the water. The amount and the maximum size of the particles depends directly on the velocity of the flow. Methoxychlor adsorbed onto these particles is discussed by Charnetski et al. (pp. 45-46).

This paper deals, in part, with the dynamics of methoxychlor on the second major component: the bedload material. For the most part, this is coarser material moving along the static bed of the river and may in fact be composed of particle sizes found in appreciable quantities in the shifting portions of the bed. This material, retained in our sampling devices, is termed bedload.

This paper also deals with methoxychlor adsorbtion to that portion of the river bed that results directly from a significantly reduced water velocity and results in sedimentation of particles. This material is referred to as mud. Predominantly, this material was collected from shorelines, sand bars, and beds of backwaters.

MATERIALS AND METHODS

Site Description

A general site description is presented in the Introduction (pp. 2-13). Included in this description are aerial photographs detailing sampling locations within the study area.

Methoxychlor Application

In 1974, the first application of methoxychlor larvicide was carried out from the highway bridge crossing the river at the town of Athabasca by an unpublished technique developed by Depner and Fredeen.

On 4 June 1974, the Athabasca River was treated with 796 liters of 25% emulsifiable concentrate (EC) methoxychlor (Stan Chem 25 EC, PCP reg. no. 11617). The water temperature was 14°C and the river discharge was 759 m^3/sec at an average velocity of 1.07 m/sec. The dose was calculated to give a source concentration of 300 ppb for 15 min at the point of injection. Methoxychlor

movement was monitored through residue analysis of water samples taken at various time and space intervals in the 160-km downstream (D/S) study area.

This technique of application lacked the flexibility necessary for large river larviciding because of its dependance on existing man-made structures. Depner et al. (see p. 23), therefore devised an improved procedure whereby the application could be carried out from several boats. This permits the introduction of the chemical at any location along a river and eliminates the chance of contamination of the adjacent terrestrial habitat.

On 4 June 1975, the Athabasca River was treated at Athabasca with 291 liters of methoxychlor (Stan Chem 25 EC from 1974, analyzed as 21% EC) applied by boat. The water temperature was 15°C and the river discharge was 477 m^3/sec at an average velocity of 0.79 m/sec. This application was calculated to give a source concentration of methoxychlor of 300 ppb for 7.5 min at the point of injection. Methoxychlor movement was monitored through residue analysis of river water samples taken at various time and space intervals within a 240-km D/S study area as well as at 396, 410, and 580 km D/S.

On May 1976, the Athabasca River was treated about 160 km D/S of the Athabasca townsite with 213 liters of methoxychlor (Methoxol 25% EC, PCP reg. no. 6763) at a river discharge rate of 566 m^3/sec. On 25 May 1976, the Athabasca River was treated a second time at the Athabasca bridge with 227 liters of methoxychlor (25% EC) at a river discharge rate of 416 m^3/sec at an average velocity of 0.72 m/sec. Both treatments were also applied from three boats and were calculated to give a mean source concentration of 300 ppb for 7.5 min.

Bedload Sampling.

A modified Bogardi bedload sampler (Fig. 1) was used to obtain all the bedload samples. In 1974 and 1975, samplers were left in the river for about 24 hr, whereas in 1976 the samplers were in the river for periods of about 8 hr.

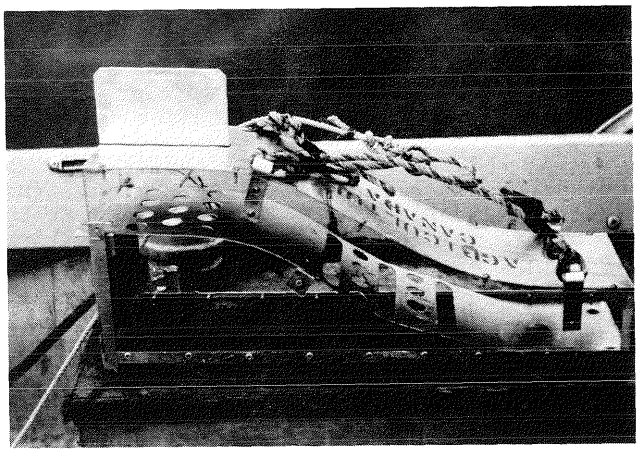

Fig. 1. Modified Bogardi sampler for collecting bedload.

Samplers were positioned at up to five sites across any specific cross-section with site 1 being near the right bank (looking D/S) in 2.5 m of water, site 2 was 25% of the distance across the river, site 3 was positioned at the middle of the river, site 4 was 75% of the distance across from the right bank, and site 5 was close, in about 2.5 m of water, to the left bank looking D/S. It was not possible in every case to place samplers at the specified points because of excessive water velocities, etc. In some cases, samplers were lost due to drifting debris or entanglement in submerged materials.

Mud Sampling

Mud samples were collected from areas of obvious sedimentation, primarily shorelines, levees, sand bars, and back waters. The samples were taken in up to 1 m of water at high water levels and in up to 0.7 m of water at low water levels in areas where obvious sedimentation had taken place since the time of treatment. Samples were taken at random with the idea of getting sample material from areas of high methoxychlor-laden sediment.

A Ponar grab sampler and an Eckman dredge were both tried in 1973 and 1974; however, they were found to be unsatisfactory to obtain samples for residue analysis in a river ecosystem such as that of the Athabasca. Therefore, an uncomplicated sampler was fabricated from a metal juice container flattened on one side and attached to a pole. This enabled the operator to scrape the surface to a depth of 2.5-5.0 cm and collect the resultant scrapings in the can. In 1974, 1975, and 1976, this procedure was used exclusively and found to be most satisfactory.

In 1977, in an attempt to obtain samples that might have been deposited from any of the four treatments in the Athabasca River, a 7.5-cm core device was used to take samples up to 15 cm deep from areas varying from above shoreline to water of about 0.7 m deep. This sampler was found to be effective and easy to operate and to decontaminate.

Sample Handling

Samples of mud and bedload were placed in plastic bags, labelled, and kept in a cool, dark place (at times up to 48 hr) until frozen at the base camp. These frozen samples were then transported to the Agriculture Canada Research Station in Lethbridge and stored at -20 and -30°C until analyzed.

Methoxychlor Analysis

Samples collected in 1974, 1976, and 1977 were analyzed at the Agriculture Canada Research Station in Lethbridge whereas most of the 1975 samples were analyzed by the Pollution Control Division Laboratory of Alberta Environment in Edmonton.

Analytical Procedure

Both the Agriculture Canada and the Alberta Environment labs used the same procedure for extraction, clean up, and identification of methoxychlor in mud and bedload samples. All solvents used in the procedure were glass distilled (pesticide grade).

Samples were thawed and mixed to obtain a homogeneous subsample of about 500 g from which free water was removed using a Buchner funnel with a vacuum receiver. The sample was then mixed again and four 100-g samples were weighed out: one sample for moisture analysis, one sample for spiking with methoxychlor, and two samples for methoxychlor determination.

Samples were extracted using a mechanical shaker under the following regime. To each 100-g sample, 100 ml of acetone were added; the mixture was shaken for 2 hr, then centifuged, and the supernatant decanted. To the solid portion, 100 ml of acetone plus n-hexane (1:1) was added and the mixture shaken overnight. It was then allowed to settle and the supernatant decanted. The solid portion was again suspended in 100 ml of acetone plus n-hexane (1:1) and shaken for 2 hr. After the liquid had cleared, the supernatant was decanted and 25 ml n-hexane were added to the solid portion. The mixture was again shaken, for 15 min, and the supernatant decanted and the solid discarded. All the supernatant solutions were combined into one separatory funnel together with 400 ml of 2% NaCl solution and shaken vigorously. This liquid extraction procedure resulted in the n-hexane phase separating from the aqueous-acetone phase. The aqueous phase was collected in a flask and the n-hexane phase was collected in a separate flask. The aqueous phase was transferred back to the separatory funnel and extracted two more times with 85-ml portions of n-hexane. The combined n-hexane phases were then dried with 10 g of Na_2SO_4 (anhydrous), and finally evaporated and concentrated to about 5 ml.

Individual sample extract concentrates were subjected to a column 'clean up' procedure where 10 g of 0.4% carbon/99.6% $Al_2O_3 \cdot 6\% H_2O$ in 50 ml n-hexane were added to a Chromaflex chromatographic column (250 x 20 mm) with a glass wool plug at the bottom. This mixture was agitated in the column to remove air bubbles and then allowed to settle. A small plug of glass wool was placed over the surface of the packing to prevent any disruption of the surface when liquids were added to the column. The excess n-hexane was drained from the column to a level just above the carbon-aluminum oxide packing and discarded. The 5-ml extract of mud or bedload was quantitatively transferred to the column with flask rinsings to a total of 75 ml n-hexane. This 75-ml of n-hexane was drained from the column so that again the level of liquid was level with the top of the carbon-aluminum oxide bed. The column was then eluted with 425 ml of 25% ethyl ether/n-hexane. The first 75 ml of the eluant were discarded and the remainder was collected in a round-bottom flask, evaporated on a rotary vacuum evaporator, and quantitatively transferred to a volumetric flask preparatory to gas-liquid chromatographic analysis.

This concentrated eluant was analyzed with a gas-liquid chromatograph equipped with an electron capture detector (Ni-63, pulse-modulated); carrier gas 5% methane/-argon (70 ml/min); 0.8 m x 6 mm OD (4 mm ID) borosilicate glass column, QF-1(5%)/SE-30(4%) on Chromosorb W (80-100 mesh); injector 200°C, oven 190°C, and detector 300°C.

The levels of methoxychlor were corrected for moisture content so that the analyses were based on the dry weight of mud or bedload materials.

RESULTS AND DISCUSSION

Methoxychlor in Bedload and Mud, 1974

In 1974, 124 bedload samples and 88 mud samples were analyzed for levels of methoxychlor.

The average methoxychlor residues in the bedload samples from the Athabasca River collected in 1974 are summarized in Table 1. The analyses of samples collected at the injection site and upstream for the entire year show no detectable methoxychlor residues. In addition, all except one sample collected below the treatment site but before treatment showed no detectable methoxychlor. After treatment, however, extremely high methoxychlor residue levels, 5,050 and 4,850 ppb, were found at 5 km D/S on 4 and 5 June respectively. By 6 June, these levels had dropped to 885 ppb and by 8 June to 27 ppb. Such high levels were not found at any other site. At 20 km D/S on 4 June, the methoxychlor level was only 27 ppb and on 5 June 338 ppb. The values for methoxychlor rose with increasing distance on 5 June at 75 km D/S to 252 ppb and on 6 June at 140 km D/S to 575 ppb. Of samples taken after 7 June, the residue levels were relatively low with the highest value being 57.4 at 140 km D/S on 7 June. By 30-31 July, only samples taken at 5 and 140 km D/S had detectable levels of methoxychlor. By 20 August, at nine sampling locations, no samples had detectable levels of methoxychlor.

The average methoxychlor residues in mud from the Athabasca River in 1974 are summarized in Table 2. As in bedload samples, methoxychlor was not detectable in

Table 1. Summary of average methoxychlor (MeOCl) residue concentrations of Athabasca River bedload at various distances above and below the point of treatment (300 ppb between 0512 and 0527 hr on 4 June 1974)

Dist. (km) from treat.	Avg. MeOCl[a] (ppb, dry weight)									
	May	June							July	Aug.
	24-27	3	4	5	6	7	8	9	30-31	22
-20	ND(6/6)									
-1.6							ND(1/1)	ND(2/1)		
0.0	ND(2/2)									ND(1/1)
1.6						ND(1/1)				
5.0		ND(2/2)	5050(4/4)	4850(1/1)	885(2/2)		26.7(2/2)	55.4(2/1)	90.8(1/1)	ND(1/1)
14								15.4(4/2)		
17								22.7(4/4)		
19								24.4(3/3)		
20	ND(1/1)	ND(1/1)	27.0(2/2)	337.6(2/2)	35.3(2/2)	12.0(2/2)	21.8(2/2)	15.4(2/2)	ND(1/1)	ND(1/1)
26								6.0(4/3)		
35				ND(1/1)						
40		ND(1/1)	ND(1/1)	115(3/2)	34.1(3/2)	24.2(2/2)	21.6(2/2)			ND(1/1)
60	ND(1/1)	13.2(2/2)	ND(1/1)	6.2(3/2)	21.3(2/2)	15.4(2/2)	19.8(3/2)		ND(1/1)	ND(1/1)
77				252(4/2)	82.8(1/1)	38.8(2/2)				ND(1/1)
100				13.3(2/2)	97.2(1/1)	50.3(1/1)	28.2(1/1)		ND(1/1)	
120				205(1/1)	14.4(1/1)	44.5(1/1)	43.1(1/1)			ND(1/1)
140				ND(1/1)	575(1/1)	57.4(1/1)	30.4(1/1)		9.1(1/1)	ND(1/1)
160				ND(1/1)	678(1/1)	8.6(1/1)	49.0(1/1)		ND(1/1)	ND(1/1)

a Average of samples taken across the river; values in parenthesis are--numerator = number of analyses, and denominator = number of individual samples; ND = not determined.

Table 2. Summary of average methoxychlor residue concentrations of Athabasca River mud at various distances above and below the point of treatment (300 ppb between 0512 and 0527 hr, 4 June 1974)

Distance (km) from treatment	Avg. MeOCl[a] (ppb, dry weight)							
	May		June				July	Aug.
	24	26	3	7	8	9	31	21
-60	ND(1/1)							
5		ND(1/1)						
10		ND(1/1)				177(3/2)		
14						9.4(1/1)		
20				ND(1/1)				ND(2/2)
27						ND(4/2)		
35						ND(2/1)		
40		ND(2/2)				ND(2/1)	ND(1/1)	5.4(1/1)
44						22.7(4/2)		
47						25.8(6/3)		
48						56.8(6/3)		
51						ND(2/1)		
53						320(6/3)		
60					ND(1/1)			2.2(2/2)
65					5.7(1/1)			
69				ND(1/1)	14.0(1/1)			
71						ND(4/2)		
77				10.7(2/2)			ND(1/1)	30.4(1/1)
85				39.5(1/1)				
88				47.9(2/1)				
96					44.0(4/3)			
100			ND(1/1)	ND(1/1)			ND(1/1)	
104				ND(1/1)				
120				ND(2/2)				
140				26.1(2/1)				
156				165(3/2)				
159				32.9(8/4)				

a Average of samples taken across the river; values in parenthesis are--numerator = number of analyses, and denominator = number of individual samples; ND = methoxychlor not detected.

mud above the treatment site or below the treatment site before treatment. After treatment, no location gave levels as high as those for bedload; however, high residues were found 7 June at 156 km D/S, 9 June at 10 km D/S, and 9 June at 53 km D/S. The striking difference is that the overall residue level in mud on 9 June at any sampling site was higher than those in bedload although we believe that these values are not significantly different. On 31 July, three sites showed no detectable residue levels but, on 21 August, methoxychlor was evident at 40, 60, and 77 km D/S.

Methoxychlor in Bedload and Mud, 1975

The average methoxyclor residues in bedload samples taken in 1975 are summarised in Table 3. Before treatment in 1975, an abnormality appeared 2 days before treatment; the washload level decreased significantly and the water became quite clear for 3-4 days. The reason for this abnormality is not known. No apparent hydrological phenomena could be correlated to give such an affect.

Evidently, an unknown quantity/material was detected in 1975 (Table 3). The same analytical techniques did not show the presence of this material in 1974 or later in 1975. From the samples taken at -20 and -40 km, a component that had similar detection characteristics to methoxychlor was evident and, over the year, an average background level of 17 ppm was calculated in 15 samples. Although no samples were taken before treatment, the levels registered would have reflected some level of this unknown material.

Overall, no extremely high levels of methoxychlor were evident in the 1975 results as were apparent in 1974. On 6 June, the highest average was 286 ppb; on 7 June, it was 50 ppb; on 8 June, 73 ppb; and on 9 June, 64 ppb. On 10 June, however, an average level of 636 ppb was calculated for two samples taken at 120 km D/S. This result may be erroneous as it is made up of the average of two samples - one registering 1,257 ppb and the other 16 ppb; the high value was vastly different from any other sample analyzed in 1975.

Considering the levels of methoxychlor in samples collected below the treatment sites over the entire reach of the river, those collected between 4 and 13 June gave an average methoxychlor level of 40 ppb (average of 95 samples), whereas those collected between 8 July and 21 August gave an average of 7 ppb (average of 32 samples), much below the background of 17 ppb registered in the samples collected above the site of treatment. In considering those samples collected between 0 and 176 km D/S between 4 and 13 June, the mean rises to 46 ppb (81 samples) and taking the mean for the

Table 3. Summary of average methoxychlor (MeOCl) residue concentrations in 1975 Athabasca River bedload samples taken at various distances above and below the point of treatment (300 ppb between 0500 and 0507:30 hr, 4 June 1975)

Distance (km) from treatment	Avg. MeOCl[a] (ppb, dry weight)										
	June							July		Aug.	
	4	6	7	8	9	10	11-13	8-10	22-24	4-7	19-21
-40	24.9(1)[b]							4.1(2)	4.1(2)	3.2(2)	26.5(1)
-20								2.9(1)	2.0(3)	13.4(2)	1.8(1)
1.9		1.4(1)									
2.8						3.2(1)					
3.8					1.4(1)						
4.7				2.4(1)			1.8(1)	2.1(2)	2.1(1)	6.4(2)	9.4(2)
8.8		27.4(1)				4.7(1)	1.8(1)				
11				38.7(1)	12.7(1)						
17		25.8(1)		72.5(3)	14.8(1)	2.6(3)	17.2(2)				
20		286(2)	8.1(1)	18.4(1)			ND(1)	10.1(2)	2.8(1)	3.7(1)	4.5(1)
40	9.7(1)	5.7(1)		14.4(2)	14.5(2)	33.1(2)	11.3(2)	3.2(1)	4.6(1)	4.3(1)	17.9(2)
77		63.7(3)	17.0(3)	50.1(3)	64.0(3)	15.2(2)	12.9(2)	7.7(1)	19.3(1)		15.1(2)
120	16.5(3)		45.2(2)		31.1(2)	636(2)	44.4(2)	3.4(1)		3.8(2)	5.6(2)
160	9.0(2)	21.4(3)	9.1(1)		64.7(1)	15.3(1)	15.9(1)		2.8(2)	4.0(1)	
176	21.6(3)		49.6(1)		9.1(1)	14.6(1)	4.6(3)		12.9(2)	7.3(1)	2.7(1)
200			5.5(1)								
240					9.7(1)		11.2(1)				
396			6.0(2)		ND(1)	6.2(1)	6.3(3)				
410		ND(1)	2.7(1)								
Embarass						ND(1)	ND(1)				

a Average of samples taken across the river; values in parenthesis are numbers of individual samples analyzed.

b Sample taken 27 May.

samples collected between 11 and 176 km D/S for the same period, it rises to 51 ppb (for 73 samples). For the same period, the means for those samples collected between 0 and 8.8 km D/S, and between 200 km D/S and Embarass were 5.5 ppb (eight samples) and 3.8 ppb (14 samples), respectively. These two values are again well below the background level of 17 ppb for samples collected above the treatment site.

The average methoxychlor residues from mud in 1975 are summarized in Table 4. As with the bedload samples, the background level for above the treatment site was 3.6 ppb (six analyses) and was 4.1 ppb (23 analyses) for below the treatment site but before treatment. It is evident that the levels recorded above and below the treatment site do not differ and it can therefore be interpreted that the material was not methoxychlor.

The highest single value from 19 samples taken between 4 June and 7 August was 771 ppb at 48 km D/S. However, the overall average was 19 ppb for the 19 samples. Comparing levels of methoxychlor in the samples for 4-10 June with those for 20 June - 7 Aug. (avg. of 31 ppb from 9 samples vs. 8 ppb from 10 samples), it is evident that the methoxychlor resident levels were being reduced.

Methoxychlor in Bedload Samples, 1976

In 1976, it was decided to concentrate entirely on the residues of methoxychlor in bedload and therefore no samples of mud were taken. In an attempt to better define the dynamics of methoxychlor in bedload, the sampling procedure was modified from 1974 and 1975 so that, in 1976, bedload samplers were removed every 8 hr instead of every 24.

The average methoxychlor residues (with standard errors) in bedload samples taken at various sites along the cross-section at 16, 40, 80, and 160 km D/S of the first 1976 treatment are shown in Figs. 2-5. At 16 km, the highest average methoxychlor level, 123 ppb, was from the sample taken 6 hr after treatment. At 40 km, the average of the highest sampling period was 3,020 ppb. Subsequent samplings at 40 km indicate average values between 50 and 100 ppb. At 80 km, the maximum average was just under 300 ppb whereas at 160 km an extremely high average, 1,328 ppb, was recorded for one sample period.

It is also evident from Figs. 2-5 that the methoxychlor levels taper off fairly rapidly after the peak and the length of time seems to be consistent between sample locations independent of the distance downstream of the treatment.

For the second treatment in 1976, the methoxychlor concentration at various sites along cross-sections at 21, 40, 76, 77, 176, and 320 km D/S are shown in Figs. 6-11. The residue levels at sites at equivalent distances downstream of the first and second treatments in 1976 do not have comparable residue levels. The explanation for this phenomenon is not known.

The low levels between -20 and 50 hr (Fig. 10) at 176 km from the second treatment (i.e., 16 km downstream from the

Table 4. Summary of average methoxychlor (MeOCl) residue concentrations in 1975 Athabasca River mud at various distances above and below the point of treatment (300 ppb between 0500 and 0507:30 hr 4 June 1975)

Distance (km) from treatment	Avg. MeOCl[a] (ppb, dry weight)								
	May				June		July		Aug.
	4-13	14-20	21-27	28-29	4-10	20	7-10	22-24	7
-40	0.5								
-20	1.8	ND	14.6				4.7		
4.7	9.7	0.9	4.0					0.5	
14					24.0				
20	5.3		6.0		0.6			14.1	
24					22.7				
27					25.4				
40	5.1		1.7		29.2			4.2	
47					40.5				
48					71.4				
77			4.2	2.7	16.5		14.4		10.5
120		0.6	3.0	12.9					
160		ND		9.4	6.3				
200	ND		3.0	9.4	50.2		9.4		
240		4.9	1.2	4.6	ND				
396				0.3		6.7			
416				0.1		2.4			

[a]Average of samples taken across the river; ND = not detected.

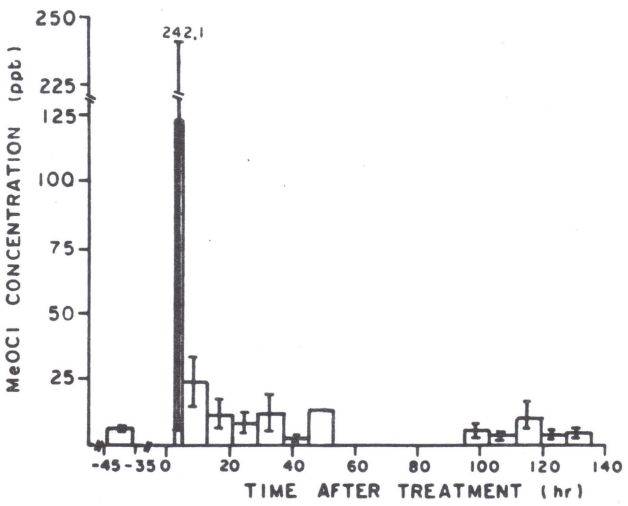

Fig. 2. Average methoxychlor (MeOCl) residues with standard errors in bedload samples taken at sites 1, 2, 3, and 4, 16 km D/S from the first treatment in 1976.

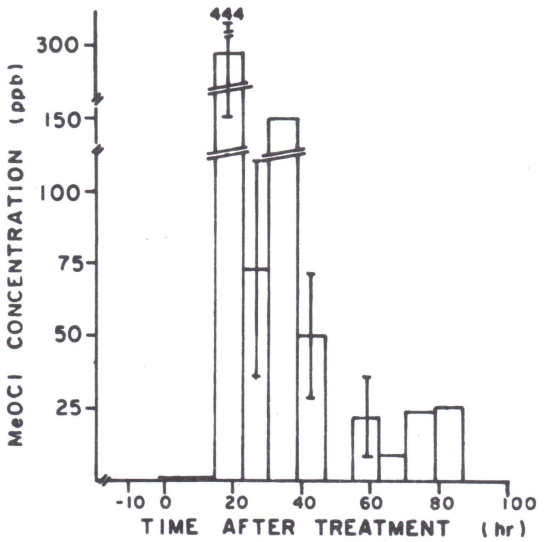

Fig. 4. Average methoxychlor (MeOCl) residues with standard errors in bedload samples taken at sites 2, 3, 4, and 5, 80 km D/S from the first treatment in 1976.

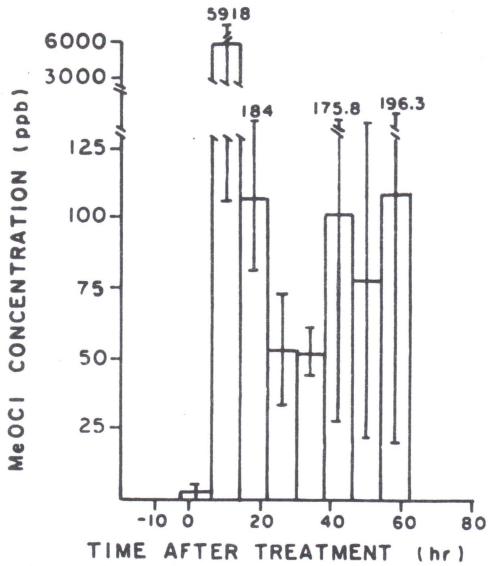

Fig. 3. Average methoxychlor (MeOCl) residues with standard errors in bedload samples taken at sites 1, 2, 4, and 5, 40 km D/S from the first treatment in 1976.

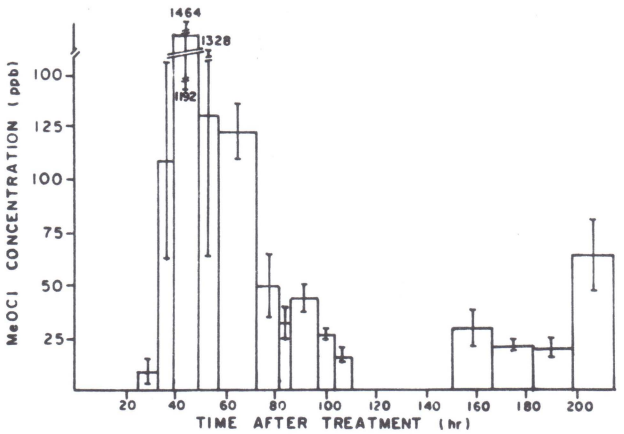

Fig. 5. Average methoxychlor (MeOCl) residues with standard errors in bedload samples taken at sites 2, 3, 4, and 5, 160 km D/S from the first treatment in 1976.

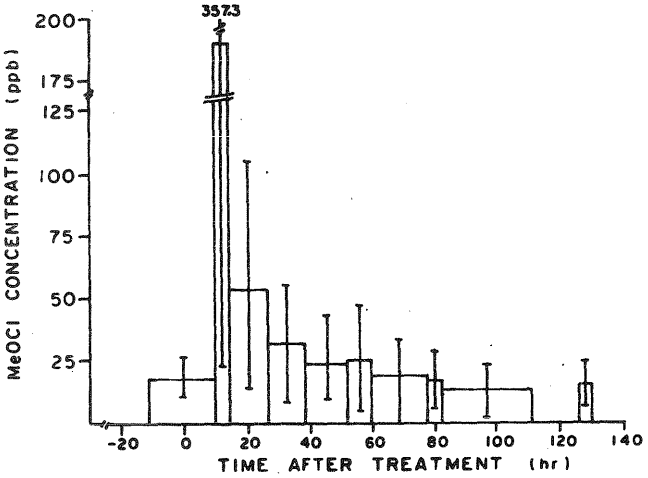

Fig. 6. Average methoxychlor (MeOCl) residues with standard errors in bedload samples taken at sites 2, 3, 4, and 5, 21 km D/S from the second treatment in 1976.

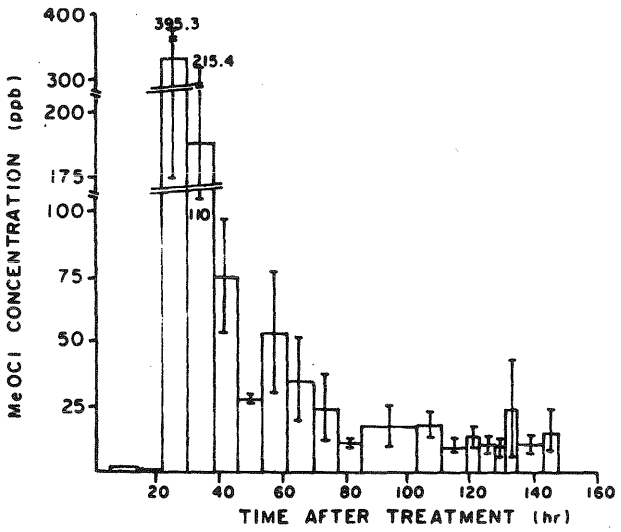

Fig. 8. Average methoxychlor (MeOCl) residues with standard errors in bedload samples taken at sites 1, 2, and 4, 76 km D/S from the second treatment in 1976.

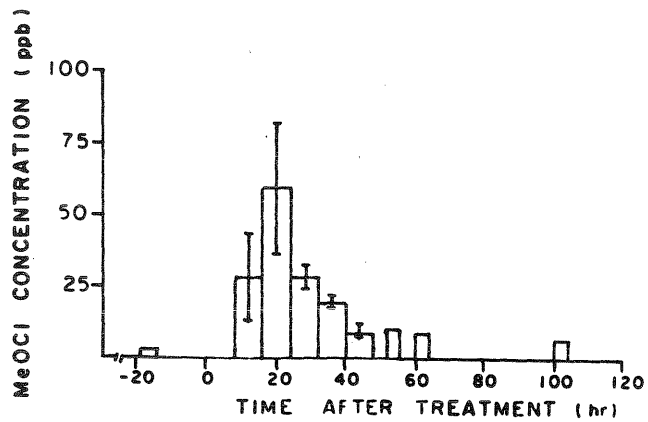

Fig. 7. Average methoxychlor (MeOCl) residues with standard errors in bedload samples taken at sites 1, 2, 3, and 4, 40 km D/S from the second treatment in 1976.

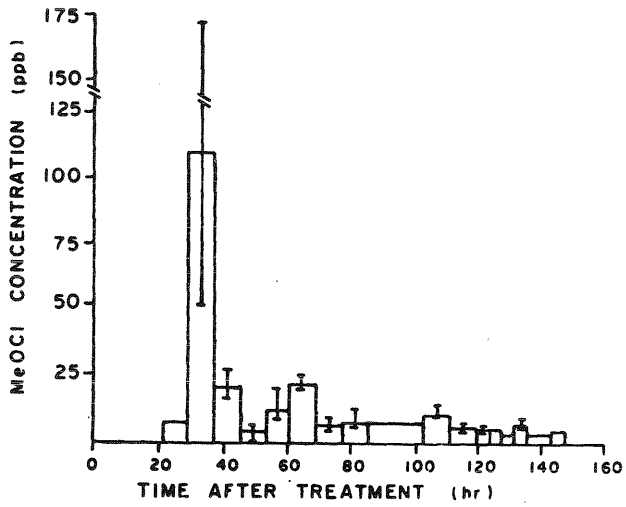

Fig. 9. Average methoxychlor (MeOCl) residues with standard errors in bedload samples taken at sites 2, 3, and 4, 77 km D/S from the second treatment in 1976.

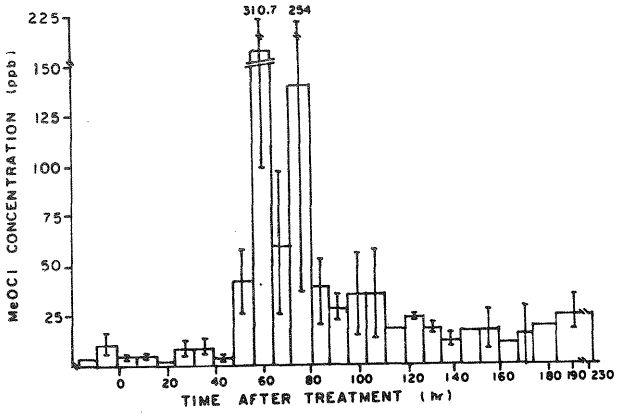

Fig. 10. Average methoxychlor (MeOCl) residues with standard errors in bedload samples taken at sites 1, 2, 3, and 4, 176 km D/S from the second treatment in 1976.

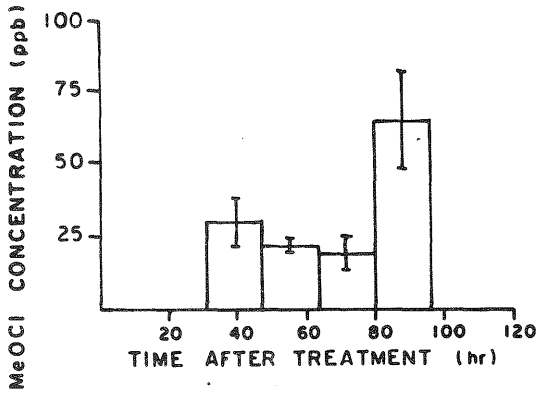

Fig. 11. Average methoxychlor (MeOCl) residues with standard errors in bedload samples taken at sites 2, 3, 4, and 5, 320 km D/S from the second treatment in 1976.

first treatment) before the major peak residues from the first treatment.

Methoxychlor in Bedload and Mud, 1977

The average levels of methoxychlor identified in 14 bedload samples and 64 mud samples taken in October 1977 are summarized in Table 5. Although these samples were taken 17 mo after the last injection of methoxychlor, they are important in registering the length of time that methoxychlor persisted in the environment. In the bedload samples, 4 of 10 samples registered an unknown material that had detection characteristics similar to methoxychlor. The levels of this questionable material could not be quantitated as they were below the detection limit for methoxychlor. Similarily, 1 of the 64 mud samples showed the same questionable peak, again in levels that could not be quantitated. We believe that these materials were not methoxychlor.

Table 5. Summary of average methoxychlor (MeOCl) residue concentration ppb of Athabasca River mud and bedload taken in October 1977 at various distances D/S of the 1974, 1975, and 1976-second treatments

	Mud		Bedload	
Distance (km) from treatment	Date	MeOCl	Date	MeOCl
20			21.9	T (1)[a]
21	20.9	ND (6)		
22	20.9	ND (6)		
34	20.9	ND (4)		
40	20.9	ND(12)	21.9	ND (3)
76	20.9	ND (6)	21.9	ND (2)
				T (2)
176	19.9	ND (9)	18.9	ND (1)
		T (1)	19.9	ND (1)
			20.9	ND (1)
240	18.9	ND(10)	21.9	ND (2)
				T (1)

[a] Value in parentheses is number of samples analyzed. T = trace (<0.1 ppb); and ND = not detected.

Dynamics of Methoxychlor Residues

As shown above, methoxychlor residues dissipated rather rapidly from the moving bed. This is further analyzed by Beltaos and Charnetski (p. 123). The bedload does not move rapidly and therefore the decrease in methoxychlor levels on successive days must be a direct result of loss to the static bed, degradation, or desorption at non-detectable levels into the water. The loss to the static bed was probably relatively little as the bed of the river is predominantly large gravel and rock. If the loss was due to degradation, we do not know whether it was chemical or biological. We strongly suspect that a certain amount of desorption is possible especially after the concentration in the water is reduced below the solubility of methoxychlor.

The decreased levels of methoxychlor in mud can certainly be attributed to biological degradation. However, a certain amount of the decrease could also be due to destruction by heat. This would apply in areas where, as the river level drops, sediment contaminated with methoxychlor is deposited on the shoreline. Laboratory evidence shows that heating the sediment to 105°C releases or degrades all the methoxychlor in that sediment. Bare soil in direct sunlight is heated to temperatures well above ambient air temperatures and could on occasion reach these elevated temperatures. Thus river sediment could be cleared of methoxychlor especially in the case of the Athabasca River where the water levels drop very significantly over the summer months (see Introduction, p. 3).

Efficiency of Bedload Sampler

The modified Bogardi bedload sampler used in this study undoubtedly was too light to sample the bedload in the deepest and fastest flowing channels in the river. However, it was generally quite satisfactory for most areas along the cross-section and for most reaches of the river. The inability to sample in the fast-flowing water was not considered a major problem because these areas generally had a rock bed with little or no bedload deposits.

However, the 24-hr sampling period used in 1974 and 1975 was far too long as the retention capacity of the sampler for sample material was frequently exceeded. It was for this reason that the sample period was shortened to 8 hr in 1976. This sampling time generally gave a large enough sample for analysis although an increased number of samples were below the 500 g required for a complete analysis and the retention capacity of the sampler was exceeded only in a few cases. Nevertheless, this shortened sampling period was far superior because it provided a more representative sample of the moving bed. The Bogardi sampler has an inherent fault--as the sampler fills, the relative retention of the different bedload particle sizes changes.

Bedload samples from six sites at 77 km following the 1976 second treatment were analyzed for particle size range (Table 6). The particle size range clearly varies considerably between the individual sites. However, 85% of the particles retained by the modified Bogardi bedload sampler are within the diameter range of 0-425 µm. Chance (1970) reported that particle sizes of less than 1 µm to about 350 µm were ingested by four species of black fly, but not *S. arcticum*, with 10-100 µm being the sizes most commonly ingested. Chance also states that the maximum dimension of measured particulate matter ingested by any simuliid larva ranges from 0.3-10,000 µm. She also suggests that the older instars can ingest larger sized particles. Thus measurement of the methoxychlor in the bedload would give a fairly accurate picture of the level that would be flowing past the black fly larvae in the Athabasca River.

Methoxychlor as a Particulate Formulation

Several authors have referred in the literature to the practicality of formulating methoxychlor as a particulate formulation. The senior author has suggested since the inception of the black fly program that this might be a preferable way to control larval black flies in large rivers. This judgement was based on the fact that methoxychlor introduced into the river as an emulsifiable concentrate quickly becomes a particulate formulation -- because of its hydrophobic nature, it binds to particulate matter in the washload and bedload of the river. It is the ingestion of these particles that leads to the population drops reported by Depner et al. (p. 21) at low water concentrations farther D/S of treatment.

When the level of methoxychlor in the bedload is compared to the distances of control, it is clear that very small amounts of methoxychlor are required to control black fly larvae and that the amounts lost to the bedload appear to be unimportant in terms of environmental impact on the general biological community of the river.

Adequacy of the Bedload Sampling Program

The adequacy of the bedload sampling program could be discussed at great length by various hydraulic engineers. Graf (1973), in his book 'Hydraulics of Sediment Transport', devotes a section to the meandering of the thalweg and its relation to the movement of water and sand particles. It is evident that even hydrologists do not agree completely on how these events affect bed movement. Nevertheless, in a program such as this one for black fly control, it is impossible to design a sampling regime that could consider all the factors that might determine the real methoxychlor level in the bedload. Because residue analysis is a very time-consuming procedure, it was

Table 6. Mean particle size of bedload samples taken at 77 km D/S of Athabasca Bridge in 1976

Site No.	Number of samples	Avg. particle size (µm)						
		>1700	1700 -1000	1000 -425	425 -250	250 -110	110 -53	<53
		% of total						
1	5	0.0	0.0	2.3	73.3	23.6	0.6	0.2
2	6	0.0	0.1	13.4	67.4	17.6	0.6	0.9
3	9	0.2	0.6	12.4	70.1	16.2	0.4	0.2
4	20	5.9	8.8	24.4	36.3	24.0	0.3	0.3
5	10	0.1	0.6	10.9	47.2	39.5	1.1	0.6
6	12	0.2	0.6	7.4	51.3	39.4	0.6	0.5
Avg		1.1	1.8	11.8	57.6	26.7	0.6	0.5

necessary to tailor the sampling program to obtain a number of samples that could approximately describe the levels of methoxychlor in the aquatic ecosystem. It was for this reason that the number of sampling sites per treatment were reduced in 1976 in favor of an increased number of samples per location.

CONCLUSION

1. The levels of methoxychlor in river bedload were higher than those measured in samples of mud taken from sedimentation sites.

2. The methoxychlor residues in bedload samples taken in 1974 reached higher maximums than those taken in 1975 and 1976.

3. The methoxychlor dissipated rapidly to a point where the levels were probably unimportant as far as their environmental impact is concerned.

4. There is a brief period shortly after methoxychlor injection when the levels of methoxychlor were very high in bedload; however, their impact on the environment, specifically the non-target invertebrates and fish, in these areas has not been measured.

5. Analysis of samples taken in 1977, 17 mo after the last treatment with methoxychlor, showed no determinable levels of methoxychlor in mud and bedload.

RECOMMENDATIONS

1. An additional study is required to clearly define the level of methoxychlor in bedload and water at one or two locations so that the influence of hydraulic phenomena could be more clearly described.

2. The concentration of methoxychlor on various particle size ranges should be identified together with the nature of these particles.

3. A detailed investigation of the particle size range ingested by various instars of *S. arcticum* larvae should be established.

4. The nature of adsorption of methoxychlor onto silt particles and the possibility and nature of desorption of methoxychlor from silt particles should be investigated.

5. The relevance of methoxychlor-levels on bedload and suspended particles in the river to the susceptibity of non-target insects and fish residing in the river should be established.

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PRETREATMENT BACKGROUND INSECTICIDE AND PCB RESIDUES AND POSTTREATMENT METHOXYCHLOR INSECTICIDE RESIDUES IN FISH FROM THE ATHABASCA RIVER

W. A. CHARNETSKI AND R. A. CURRIE

INTRODUCTION

Black flies, particularly *Simulium arcticum*, are apparently the single most limiting factor to livestock production in the Athabasca grassland area of northern Alberta. Preliminary investigations by Depner between 1969 and 1973 identified the Athabasca River as the only location in the area for larval development of this blackfly species. He also identified the reaches of river that had significant concentrations of larvae of this insect.

The research program on black fly abatement, as outlined in the Introduction (pp. 1-2) centered around a methoxychlor larvicide study. Concern over the effects of methoxychlor on the biota, other than the target black fly species, of this aquatic ecosystem was crucial to the design of this program. Fish are probably the single most important biological component of the Athabasca River.

Fish form a large part of the diet of some of the residents of the Athabasca River area, as well as being a food source for hunting and sled dogs. Also, the Athabasca River drains into Lake Athabasca, the location of a substantial commercial fishery.

The objectives of this study in the abatement program were to establish the level of any background organophosphorus and organochlorine insecticide residues before the treatment and the posttreatment methoxychlor residue in the common resident free-living fish species.

MATERIALS AND METHODS

Site Description

The overall description of the study area has been presented in the Introduction (pp. 2-13).

Methoxychlor Application

On 4 June 1974, the Athabasca River was treated with 796 liters of 25% emulsifiable concentrate (EC) methoxychlor (Stan Chem 25EC, PCP reg. no 11617) from the highway bridge crossing the river at the town of Athabasca by a technique developed by Depner and Fredeen (unpublished). The water temperature was 14&C and the river discharge was 759 m^3/sec at an average velocity of 1.07 m/sec. This application was calculated to give a source concentration of 300 ppb for 15 min at the point of injection. Methoxychlor movement was monitored through residue analysis of water samples taken at various time and space intervals in the 160-km downstream (D/S) study area.

This technique of application lacked the flexibility necessary for large river larviciding because of its dependance on existing man-made structures. Depner et al. (see p. 23), therefore, devised an improved procedure in which the application could be carried out from several boats. This permits the intriduction of the chemical at any location along a river and eliminates the chance of contamination of the adjacent terrestrial habitat.

On 4 June 1975, the Athabasca River was treated at Athabasca with 291 liters of methoxychlor (Stan Chem 25EC from 1974, analyzed as 21% methoxychlor) applied by boat. The water temperature was 15°C and the river discharge was 477 m^3/sec at an average velocity of 0.79 m/sec. This application was calculated to give a source concentration of methoxychlor of 300 ppb for 7.5 min at the point of injection. Methoxychlor movement was monitored through residue analysis of river water samples taken at various time and space intervals within a 240-km D/S study area as well as at 396, 410, and 580 km D/S.

On 20 May 1976, the Athabasca River was treated about 160 km D/S of the Athabasca townsite with 213 liters of methoxychlor (Methoxol 25% EC, PCP reg. no. 6763) at a river discharge rate of 566 m^3/sec. On 25 May 1976, the Athabasca River was treated a second time at the Athabasca bridge with 227 liters of methoxychlor (25% EC) at a river discharge rate of 416 m^3/sec with an average velocity of 0.72 m/sec. Both treatments were also applied from three boats and were calculated to give a mean source concentration of 300 ppb for 7.5 min.

Fish Sampling

The collection and subsampling of fish from the Athabasca River was the responsibility of personnel from Alberta Recreation, Parks and Wildlife (Fish and Wildlife Division). In 1973, D. Buckwald co-ordinated the sampling carried out by C. S. Shirvell and C. Copland, and in 1974 K. A. Zelt co-ordinated the sampling carried out by R. Potts and R. Brown. In 1975, K. A. Zelt arranged for the collection of fish samples from the Athabasca Delta Region.

In 1973, the fish were collected from the Athabasca River at 11 locations from 35 km upstream (U/S) of the Athabasca townsite to the Athabasca delta (Table 1). In 1974, fish collections were restricted to the reach of 35 km U/S to 400 km D/S of the Athabasca townsite. Within this reach, nine sample locations were established (Table 1). In late fall of 1975, 31 fish of six species were obtained for methoxychlor analysis from fishermen of the Athabasca River Delta area.

Fish Sampling Techniques

Fish collection relied primarily on gill nets; however, seine hauls and fish traps were also used. Gill net sets consisted of one to four nets, each 25-50 m long, depending on the availablity of suitable locations at or near a sample site. Mesh size of the nets used varied from 2.5 to 11.5 cm stretched mesh. Mainly, the larger meshes were used to select for larger fish most suitable for analysis. The most suitable nets for this type of work were 25 or 50 m with 10-cm mesh and 30 meshes deep. Sets were in place for only about 24 hr to minimize physiological stress and possible deterioration of residue levels in the fish.

Table 1. Location[a] of fish sampling sites, 1973 and 1974

1973		1974	
Site no.	From bridge	Site no.	From bridge
1	-34	1	-34
2	-7	2	-12
3	7	3	-7
4	25	4	9
5	62	5	26
6	77	6	47
7	97	7	62
8	108	9	396
9	444		
10	518		
11	637		

[a] Distances (km) measured from the highway bridge at Athabasca; negative numbers indicate upstream sites.

In 1973, all fish were sexed, when possible, and all fish 200 mm or longer captured after 15 July were measured to the nearest millimeter. In 1974, fish were sexed, when possible, lengths measured, and fins or scales, or both, retained for age determination.

Tissue Sampling

Large fish were dissected whereas small fish (under 200 mm) were kept whole. Dissection tools were carefully rinsed between cuttings to avoid cross-contamination.

It was intended that, from the large fish, the following parts should be retained for residue analysis: muscle, fat, liver, gonads, and stomach contents. However, subsampling was not always complete. Portions most commonly unobtainable were fat, gonads, or stomach contents mainly due to emaciation, reproductive dormancy, or not having fed recently.

Dissected tissues were placed in specially washed glass containers previously shown to be free of materials which would interfer with residue analysis. The containers were then covered with aluminum foil rinsed with glass-distilled acetone or n-hexane over which a plastic or metal screw cap lid was placed. In the field, samples were kept cool with wet or, when possible, dry ice in insulated coolers until returned to base camp where they were held at -10°C for shipment to the residue lab. at Lethbridge where they were held at -30°C until analyzed.

Analytical Techniques

All solvents used in the following procedures were pesticide grade (glass distilled).

Extraction and cleanup of muscle tissue

Muscle tissue samples were thawed and subsamples to a maximum of 25 g were weighed (weight recorded) and placed in an Omni-mixer container. Acetonitrile (100 ml) was added to the container and the mixture blended for 3 min at maximum speed. The contents of the container were filtered through a Buchner funnel with coarse fritted disks using a water-aspirator vacuum. The filtered tissue was re-extracted in the blender with 100 ml of acetonitrile plus 15 ml of water and again filtered. The combined filtrates were partitioned into petroleum ether in the normal manner. To the combined filtrates, one drop of paraffin solution was added as a keeper before evaporation. The sample was made up to 25 ml in petroleum ether after evaporation.

The petroleum ether extract was poured into a chromatographic tube (650 x 28 mm) to which 50 g Florisil (activity IIab) with a layer of 20 g Na_2SO_4 (anhydrous) had been added (Currie 1977). The sample container was quantitatively rinsed with 5 ml petroleum ether and the sides of the column rinsed with 10 ml petroleum ether. An additional 25 ml of petroleum ether was added to the column and a flow rate established at 5 ml/min. A 500-ml reservoir was placed under the chromatographic tube when the petroleum ether had drained into the Na_2SO_4 layer. The column was then eluted with 300 ml of 7% (v/v) methylene chloride in petroleum ether (fraction a). Receivers were then changed and the column eluted with 300 ml of 25% (v/v) methylene chloride in petroleum ether (fraction b). After this fraction had eluted, a third receiver was placed under the column and the column was eluted with 300 ml of 40% (v/v) ethyl acetate in petroleum ether (fraction c). Each fraction was evaporated to near dryness on a rotary evaporator at 35°C. The residue was taken up in an appropriate volume of n-hexane for gas chromatographic analysis.

The pesticides eluted by each of the three fractions are listed in Table 2 (from Currie 1977).

Fractions a and b were analyzed by gas chromatography equipped with an electron capture detector (Ni-63, pulse-modulated): carrier gas, 10% methane in argon at 50 ml/min; 1 m x 6 mm OD borosilicate glass column, 12% OV-101/QF-1 (2:3) on Gas-Chrom Q, 80-100 mesh; injector 210°C, oven 190°C, detector 350°C. The third fraction was analyzed for common lipid-soluble organo-phosphorus pesticides using a gas chromatograph equipped with an alkali flame ionization detector: carrier gas, helium at 50 ml/min, column as above except 0.6 m x 6 mm OD; injector 200°C, oven 185°C, detector 200°C. No correction was made for the methoxychlor splitting between fractions b and c.

Extraction and cleanup of liver, gonadal, and fat tissues

A weighed sample, maximum of 5 g, was added to 16 g of Florisil (5% deactivation) in a glass mortar. Using a pestle, the sample was ground into the Florisil until a free-flowing powder resulted. An additional 9 g of Florisil (5% deactivation) was then added and mixed into the sample. To a dry chromatographic column (650 x 28 mm OD), 25 g of Florisil (5% deactivation) was added and the tube tapped to settle the Florisil. With the aid of a powder funnel, the sample-Florisil mixture was added to the chromatographic tube, tapped to settle the powder, and topped with 2.5 cm of anhydrous Na_2SO_4. A 500-ml evaporator flask was placed under the column, which was then eluted with 300 ml of 50% ethyl acetate in petroleum ether. The solvent was evaporated off on a rotary evaporator at 35°C. Sample extracts containing more than an estimated 1 g of fat were partitioned between petroleum ether and acetonitrile (four times) in the usual manner to remove the bulk of the lipids. After returning the extract to petroleum ether, a drop of paraffin solution was added and the solvent completely removed. Sample residues were then taken up

Table 2. Chemicals recoverd from 50 g activity IIab Florisil column: 28 x 650 mm chromatographic tube; 300 ml fractions; all fractions eluted (in order)

Fraction A: 7% CH_2Cl_2 - petroleum ether	
aldrin	heptachlor
aroclor 1254	hexachlorobenzene
aroclor 1260	lindane
BHC, alpha	mirex
BHC, beta[a]	PCNB
chlordane, Tech.	pentachlorobenzene
chlordane	perthane
p,p'-DDD	strobane
p,p'-DDE	TCNB[a]
o,p'-DDT	toxaphene
p,p'-DDT	
Fraction B: 25% CH_2Cl_2 - petroleum ether	
BHC, beta[a]	leptophos
dieldrin	leptophos, PH analog
dursban[b]	methoxychlor[b]
endrin	ronnel
heptachlor epoxide	TCNB[a]
kelthane	thiodan I
Fraction C: 40% EtOAc - petroleum ether	
ciodrin	MCPA, Me ester
2,4-D Me ester	methoxychlor[b]
diazinon	parathion,
dursban[b]	parathion, methyl
EPN	phorate
ethlon	pichloram, Me ester
guthion	2,4,5-T, Me ester
imidan	thiodan II
malathion	
Not recovered by the above eluants	
bromacil	dimethoate
coumaphos	fenthion
dasanit	methomyl
dibrom	ruelene
dichlorvos	

[a] Elutes in both fractions A and B

[b] Elutes in both fractions B and C

in 25 ml petroleum ether preparatory to Florisil cleanup and gas chromatographic analysis as described for muscle tissue.

Postapplication study

The extraction and cleanup procedures for the postapplication study were the same as in the preapplication study with the exception that fraction b was eluted from the Florisil column using 300 ml of 30% (v/v) methylene chloride in petroleum ether to quantitatively elute methoxychlor in a single fraction. Fractions a and c were retained but not analyzed. The gas chromatographic conditions for the analysis of fraction b were the same as those described above for fractions a and b except that the column oven temperature was increased to 200°C.

RESULTS AND DISCUSSION

In 1973, 13 species of fish were collected (Table 3). Four species, the Artic greyling (*Thymallus arcticus*), the mountain whitefish (*Prosopium williamsoni*), the nine-spine stickleback (*Pungitius pungitius*), and the yellow perch (*Perca flavescenes*), were not collected although they are reported as having distributions within the study area (Paetz and Nelson 1970).

Originally, it was hoped that all species could be collected at each site. Such sampling locations, however, exist in theory only, predicated on the fact that a great diversity in substrate, current velocity, turbidity, depth, etc. would be necessary to offer a suitable habitat for all species. Sampling usually resulted in catching an abundance of one species associated with the type of habitat in which the net was set, with a paucity in both numbers and kinds of other species. Therefore, any conclusion as to the distribution of individual fish in the Athabasca River from this study were impossible.

Of the 289 individual fish captured in 1973, only the walleye, the northern pike, and longnose sucker were caught in all or most of the sites. On the basis of (a) the abundance of these three species, (b) the fact that lake whitefish are the commercial fish in Lake Athabasca, and (c) the report by Fredeen et al. (1975) that goldeye concentrated methoxychlor residues, it was decided that these five species would be considered first in the residue analytical program.

Table 3. Fish species collected in the Athabasca River, 1973

Species	Common name
Stizostedion vitreum	Walleye
Esox lucius	Northern pike
Catostomus commersoni	White sucker
Catostomus catostomus	Longnose sucker
Hiodon alosoides	Goldeye
Lota lota	Burbot
Coregonus clupeaformis	Lake whitefish
Notropis hudsonius	Spottail shiner
Notropis atherinoides	Emerald shiner
Couesius plumbeus	Lake chub
Platygobio gracilis	Flathead chub
Cottus sp.	Sculpin
Percopsis omiscomaycus	Trout perch

Although a full complement of subsamples of muscle, fat, liver, gouads, and stomach contents were taken from most fish collected in 1973, only muscle and fat were analysed from all fish. The number of samples analyzed was restricted simply by the time available for analysis. It was decided that concentrating efforts towards analyzing fewer tissues in a greater number of samples would facilitate a more generally valid interpretation of the analytical results.

In 1974, pike, walleye, whitefish, longnose sucker, and goldeye were again evaluated for insecticide residues. The selection of tissues sampled were based on those most commonly reported in the literature to be important either physiologically or as sinks for insecticides, particularly the organochlorines.

Background Residues in Fish

Residue analyses for 17 organochlorine and organophosphorus and polychlorinated biphenyls (PCBs) were carried out on 112 samples of fish muscle and fat subsampled from fish collected in 1973 and on 128 samples of fish muscle, fat, liver, and gonads taken from fish collected in 1974. The results of the 1973 analyses were summarized and then compared according to fish sex, fish age, sampling location, and sampling dates. However, only a comparison by sex for each tissue showed any significant trend that would warrant any statistical considerations. Therefore, the residue results for those compounds that showed high residue values or that were felt to be important to this study are summarized by site and sex (Appendix I; Tables 14-17).

Most significantly, in all cases the fat tissue contained significantly higher levels of residues than muscle tissue. These data are summarized in the form of averages and compared to the results of the fish sampled in 1974 in the following sections. It is important to note that, in fish caught in 1973, the levels of 'unidentified hydrocarbons' were extremely high in pike and walleye, reaching levels of 5,110 and 7,020 ppb respectively.

The term 'unidentified hydrocarbons' is used for those compounds that continually showed up through gas-liquid chromatographic analyses with electron capture detector and were not identifable as any known insecticide. The nature of these compounds is not known other than that they are chlorinated.

Unfortunately, determination of some individual compounds could not be confirmed because of apparent interferences. Rather than compromise the quality of the analyses, these analyses are reported here as 'masked'.

In pretreatment fish, no tissue subsamples showed any detectable level of methoxychlor.

The range of residue levels of individual compounds in specific tissues of the same sex of fish caught in 1973 and 1974 was very wide. Therefore, the data were not analysed statistically.

The levels of α-BHC are interesting because the relatively high levels in the fat of fish caught in 1974 were also apparent in the liver and gonadal tissues. The only source of α-BHC is thought to be a contaminant in older formulations of lindane. However, no lindane (γ-BHC) was identified; thus the source of α-BHC is unknown.

Table 4. Mean insecticide, PCB, and unidentified hydrocarbon residues in muscle and fat from male and female Pike (*Esox lucius*) collected from the Athabasca River, 1973

	Residue level (ppb, wet weight)					
	Muscle			Fat		
Residue	♂	♀	Avg	♂	♀	Avg
number analyzed	8	5	13	8	5	13
hexachlorobenzene	ND	T	T	22	21	22
α-BHC	2	T	1	119	159	139
lindane	ND	ND	ND	111	7	9
pp'-DDT	1(5)	1(4)	1(9)	29(2)	M	29(2)
op'-DDT	ND(5)	ND(4)	ND(9)	M	M	M
pp'-DDE	21	5	13	251	161	206(12)
pp'-DDD	1(5)	1(4)	1(9)	31(2)	M	31(2)
PCB (as Arochlor 1260)	56	30	43	424	243	334
methoxychlor	ND	ND	ND	ND	ND	ND
dieldrin	ND	ND	ND	9	12	11
heptachlor epoxide	ND	ND	ND	8	10	9
unidentified hydrocarbons	ND	ND	ND	2,001	2,922	2,462

a Values in parentheses are number of determinations averaged that were not masked; T = trace; ND = not detected; and M = determination masked.

Table 5. Mean insecticide, PCB, and unidentified hydrocarbon residues in muscle, fat, liver, and gonads from male and female pike (*Esox lucius*) collected from the Athabasca River, 1974

	Residue levels (ppb, wet weight basis)											
	Muscle			Fat			Liver			Gonad		
Residue	♂	♀	Avg	♂	♀	Avg	♂	♀	Avg	♂	♀	Avg
average age	8	9	9	8	9	9	8	9	9	8	9	9
number analyzed	6	8	14	6	8	14	6	8	14	6	8	14
hexachlorobenzene	T	T	T	28	31	30	5	4	4	2	3	2
α-BHC	1	2	2	133	254	198	17	17	17	4	8	6
lindane	ND	ND	ND	4	2	3	ND	ND	ND	ND	ND	ND
pp'-DDT	T	2	1	103	208	163	3	7	5	ND	7	4
op'-DDT	ND	ND	ND	25	57	43	ND	ND	ND	ND	1	1
pp'-DDE	2	2	2	291	348	324	29	32	31	7	15	11
pp'-DDD	T	2	1	104	110	107	13	17	15	1	3	2
PCB (as Arochlor 1260)	ND	ND	ND	168	1195	755	23	318	192	ND	169	97
methoxychlor	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
dieldrin	ND	ND	ND	6(5)	8(5)	7(10)	ND	ND	ND	ND	ND	ND
heptachlor epoxide	ND	ND	ND	3(5)	6(5)	5(10)	ND	ND	ND	ND	ND	ND
unidentified hydrocarbons	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

a Value in parentheses represents the number of determinations averaged that were not masked; T = trace; ND = none detected; and M = determination masked.

Pike

Significantly greater levels of insecticide, PCBs, and unidentified hydrocarbons were found in fat than in muscle of fish collected in 1973. Samples collected in 1974 exhibited a similar tendency in that significantly higher levels of insecticide and PCBs were found in fat, liver, and gonads of fish collected than in muscle (Tables 4 and 5, respectively).

The lack of detectable levels of unidentified hydrocarbons in any subsample from fish collected in 1974 is unexplainable. It cannot be attributed to sample handling or analytical procedures as these were the same as in 1973.

Residues in fat and muscle - Fat from pike collected in 1973 contained significant levels of unidentified hydrocarbons in all but one male fish, whereas no detectable residues were found in muscle tissue. Of the males with residues, the levels ranged from 930 to 5,090 ppb whereas in female fish the range was from 1,130 to 5,110 ppb.

Substantial levels of α-BHC, DDE, and PCBs were also identified in pike fat. The levels of α-BHC ranged from 21 to 172 ppb in males and from 52 to 319 ppb in females. The levels of DDE ranged from 106 to 664 ppb in males and from 61 to 289 ppb in females, whereas the levels of PCBs ranged from 105 to 1,350 ppb in males and from 88 to 410 ppb in females.

Although there were no detectable unidentified hydrocarbon residues in fat of pike collected in 1974, the levels of α-BHC, DDT, DDE, DDD, and PCBs averaged more than 100 ppb. Higher concentrations of all these compounds were identified in female fish. The levels of α-BHC ranged from 74 to 438 in females and from 70 to 242 ppb in males. The levels of DDT and its metabolites DDE and DDD ranged in females from 27 to 782, 88 to 986, and 34 to 274 ppb respectively, whereas in males, the levels ranged from 22 to 279, 124 to 556, and 32 to 285 ppb respectively. PCB levels were significant in females where the levels ranged from 0 to 5,220 ppb whereas in males only one of six fish had detectable levels (1,010 ppb).

Muscle tissue was essentially free of residues; only the levels of DDE and PCBs from fish collected in 1973 were noticeable. The levels of DDE ranged from 0 to 96 ppb in males and from 0 to 21 ppb in females, whereas the levels of PCBs ranged from 0 to 313 ppb in males and from 0 to 152 ppb in females.

Residues in liver and gonads - Analysis of liver tissue of pike collected in 1974 identified significant levels of PCBs: 597, 610, and 1,340 ppb in three females, and 23 and 136 ppb in two males. Gonadal tissue was also essentially free of residues in fish collected in 1974 with the exception of PCBs in females where the levels ranged from 180 to 527 ppb.

Longnose sucker

Compared to pike, the tissues analyzed from longnose suckers collected in 1973 and 1974 were essentially free of residues (Table 6 and 7). Most noticeable was the lack of any unidentified hydrocarbons and the low levels of DDT and its metabolites. Unfortunately, only three muscle samples of fish caught in 1974 were analyzed.

Table 6. Mean insecticide, PCB, and unidentified hydrocarbon residues in muscle and fat from male and female longnose sucker (*Catostomus catostomus*) collected from the Athabasca River, 1973

	Residue level (ppb, wet weight)					
	Muscle			Fat		
Residue	♂	♀	Avg	♂	♀	Avg
number analyzed	8	11	19	7	11	18
hexachlorobenzene	1	T	1	17	17	17
α-BHC	4	2	3	88	59	74
lindane	T	T	T	3	3	3
pp'-DDT	4(7)	2(10)	3(17)	52(4)	51(6)	52(10)
op'-DDT	ND(7)	ND(10)	ND(17)	ND(6)	ND(9)	ND(15)
pp'-DDE	4(8)	2(11)	3(19)	101(6)	74(9)	88(15)
pp'-DDD	4(7)	2(10)	3(17)	71(4)	37(6)	54(10)
PCB (as Arochlor 1260)	5(8)	1(10)	3(18)	352	229	286
methoxychlor	ND	ND	ND	ND	ND	ND
dieldrin	ND	ND	ND	ND	2	ND
heptachlor epoxide	1	ND	ND	ND	ND	ND
unidentified hydrocarbons	ND	ND	ND	ND	ND	ND

a Values in parentheses are number of determinations averaged that were not masked; T = trace; and ND = not detected.

Residues in fat and muscle - The muscle tissue did not contain any significant residues. Substantial levels of α-BHC, DDE, and PCBs were identified in fat of suckers caught in 1973. These levels ranged in males from 38 to 126, 29 to 196, and 0 to 1,370 ppb respectively, as compared in females with 0 to 111, 12 to 267, and 0 to 1,594 ppb respectively.

Residues in liver and gonads - The analysis of liver tissue from 1974 fish identified only significant levels of α-BHC (range 56 to 257 ppb) in male fish. Similarly, α-BHC was predominant in male gonadal tissue although at lower levels (21-60 ppb). In females, analysis of gonadal tissue identified two of five samples with PCBs (133 and 223 ppb) which accounted for the mean of 71 ppb.

Walleye

Residue levels in walleye were generally higher for fish caught in 1973 than in 1974

Table 7. Mean insecticide, PCB, and unidentified hydrocarbon residues in muscle, fat, liver and gonads from male and female longnose sucker (*Catostomus catostomus*) collected from the Athabasca River, 1974

	Residue levels (ppb, wet weight basis)											
	Muscle			Fat			Liver			Gonad		
Residue	♂	♀	Avg	♂	♀	Avg	♂	♀	Avg	♂	♀	Avg
average age	10	13	12	10	13	12	10	13	12	10	13	12
number analyzed	3	0	3	3	5	8	3	5	8	3	5	8
hexachlorobenzene	T	-	T	13	21	17	10	4	7	3	2	3
α-BHC	11	-	11	228	105	151	128	23	62	43	14	25
lindane	ND	-	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
pp'-DDT	3	-	3	61	54(4)	57(7)	42	24	36	13	7	9
op'-DDT	ND	-	ND	ND	4(4)	2(7)	ND	ND	ND	ND	ND	ND
pp'-DDE	2	-	2	46	57	53	20	20	20	8	8	8
pp'-DDD	3	-	3	75	66(4)	58(7)	41	23	29	18	5	10
PCB (as Arochlor 1260)	ND	-	ND	ND	597	373	ND	44	28	ND	71	45
methoxychlor	ND	-	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
dieldrin	ND	-	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
heptachlor epoxide	ND	-	ND	ND	32	20	ND	ND	ND	ND	ND	ND
unidentified hydrocarbons	ND	-	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

a Value in parentheses represents the number of determinations averaged that were not masked; T = trace; and ND = none detected.

Table 8. Mean insecticide, PCB, and unidentified hydrocarbon residues in muscle and fat from male and female walleye (*Stizostedion vitreum*) collected from the Athabasca River, 1973

	Residue level (ppb, wet weight)					
	Muscle			Fat		
Residue	♂	♀	Avg	♂	♀	Avg
number analyzed	7	8	15	7	7	14
hexachlorobenzene	ND	ND	ND	25	6	16
α-BHC	1	1	1	225	55	140
lindane	T	ND	T	22	3	13
pp'-DDT	5	1	3	19(2)	M	19(2)
op'-DDT	1	ND	1	M	M	M
pp'-DDE	5	1	3	160	159	160
pp'-DDD	5	T	3	7(2)	M	7(2)
PCB (as Arochlor 1260)	ND	T	T	364	974	669
methoxychlor	ND	ND	ND	ND	ND	ND
dieldrin	ND	ND	ND	16	16	16
heptachlor epoxide	ND	1	1	8	3	6
unidentified hydrocarbons	ND	ND	ND	3,869	3,004	3,437

a Values in parentheses are number of determinations averaged that were not masked; T = trace; ND = not detected; and M = determination masked.

(Tables 8 and 9). It is important to note that only three male and one female fish were analyzed in 1974.

Residues in fat and muscle - In fat of fish caught in 1973, significant levels of α-BHC, DDE, PCBs, and unidentifiable hydrocarbons were detected. In males, these levels ranged from 21 to 967, 47 to 268, 0 to 428, and 0 to 7,020 ppb respectively, whereas in females the levels ranged from 0 to 158, 31 to 296, 121 to 2,660, and 0 to 6,870 ppb respectively. In contrast, only levels of α-BHC and unidentifiable hydrocarbons were significant in walleye fat in 1974 fish, although the number of fish analysed was small. The levels of αBHC in males ranged from 236 to 305 ppb and for unidentifiable hydrocarbons from 0 to 8,770 ppb.

Residues in liver and gonads - Residue levels were very low in liver and gonadal tissue, with α-BHC identified at the highest average level of 23 and 14 ppb respectively.

Table 9. Mean insecticide, PCB, and unidentified hydrocarbon residues in muscle, fat, liver, and gonads from male and female walleye (*Stizostedion vitreum*) from the Athabasca River, 1974

	Residue levels (ppb, wet weight basis)											
	Muscle			Fat			Liver			Gonad		
Residue	♂	♀	Avg	♂	♀	Avg	♂	♀	Avg	♂	♀	Avg
average age	9	10	10	9	10	10	9	10	10	9	10	10
number analyzed	3	1	4	3	1	4	3	1	4	3	1	4
hexachlorobenzene	T	T	T	17	12	13	2	2	2	1	T	1
α-BHC	2	2	2	260	250	258	26	13	23	16	7	14
lindane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
pp'-DDT	1	ND	1	40	11	33	6	6	6	9	T	7
op'-DDT	ND	ND	ND	3	5	4	ND	ND	ND	ND	ND	ND
pp'-DDE	1	T	1	62	52	60	7	5	6	5	2	5
pp'-DDD	ND	T	ND	42	20	37	9	9	9	8	T	6
PCB (as Arochlor 1260)	ND	ND	ND	27	20	26	ND	ND	ND	ND	ND	ND
methoxychlor	ND	ND	ND	ND	20	ND	ND	ND	ND	ND	ND	ND
dieldrin	ND	ND	ND	ND	M	ND	ND	ND	ND	ND	ND	ND
heptachlor epoxide	ND	ND	ND	ND	M	ND	ND	ND	ND	ND	ND	ND
unidentified hydrocarbons	ND	ND	ND	2,923	M	2,190	ND	ND	ND	ND	ND	ND

a Value in parentheses represents the number of determinations averaged that were not masked; T = trace; ND = none detected; and M = determination masked.

Table 10. Mean insecticide, PCB, and unidentified hydrocarbon residues in muscle and fat from male and female goldeye (*Hiodon alosoides*) collected from the Athabasca River, 1973

	Residue level (ppb, wet weight)					
	Muscle			Fat		
Residue	♂	♀	Avg	♂	♀	Avg
number analyzed	2	7	9	2	6	8
hexachlorobenzene	2	2	2	12	13	13
α-BHC	4	6	5	72	121	97
lindane	ND	T	T	6	7	7
pp'-DDT	ND	ND	ND	43	14(5)	24(7)
op'-DDT	ND	1	T	ND	2(5)	1(7)
pp'-DDE	ND	ND	ND	116	34	80
pp'-DDD	ND	ND	ND	61	17(5)	39(7)
PCB (as Arochlor 1260)	ND	ND	ND	ND	13	7
methoxychlor	ND	ND	ND	ND	ND	ND
dieldrin	ND	ND	ND	4	ND	4
heptachlor epoxide	ND	ND	ND	ND	ND	ND
unidentified hydrocarbons	ND	ND	ND	ND	ND	ND

a Values in parentheses are number of determinations averaged that were not masked; T = trace; ND = not detected; and M = determination masked.

Table 11. Mean insecticide, PCB, and unidentified hydrocarbon residues in muscle, fat, liver, and gonads from whitefish (*Coregonus clupeaformis*) and goldeye (*Hiodon alosoides*) collected from the Athabasca River, 1974

	Residue level (ppb, wet weight basis)[a]						
	Whitefish[b]				Goldeye[c]		
Residue	Muscle	Fat	Liver	Gonad	Muscle	Fat	Liver
hexachlorobenzene	3	15	3	12	T	121	T
α-BHC	42	160	64	1240	15	307	18
lindane	3	10	3	ND	ND	ND	ND
pp'-DDT	3	10	ND	4	ND	ND	ND
op'-DDT	3	11	ND	ND	ND	ND	ND
pp'-DDE	11	40	3	4	T	25	ND
pp'-DDD	7	14	ND	4	ND	ND	ND
PCB (as Arochlor 1260)	12[d]	ND	ND	ND	ND	ND	ND
methoxychlor	ND	ND	ND	ND	ND	ND	ND
deildrin	3	9	ND	M	ND	ND	ND
heptachlor epoxide	1	6	ND	M	ND	ND	ND
unidentified hydrocarbons	ND	ND	ND	ND	ND	ND	ND

a T = trace; ND = none detected; and M = determination masked. *b* One fish (♀) aged 9 yr.

c One fish (sex not determined) aged 4 yr. *d* Measured as Arochlor 1254.

Goldeye

Residue levels in muscle tissue were insignificant in the nine goldeye collected in 1973 and one goldeye collected in 1974. In fat, however, levels of α-BHC and DDE were relatively high (Tables 10 and 11). In 1973, levels of α-BHC ranged from 102 to 126 ppb in females and from 0 to 116 ppb in males, and the single goldeye (not sexed) collected in 1974 had a level of 307 ppb. A level of 121 ppb hexachlorobenzene was also identified in the 1974 goldeye. The levels of DDE ranged from 0 to 232 ppb in males and from 15 to 81 ppb in females.

The liver was virtually free of any residues.

Whitefish

The analysis of one lake whitefish from the river showed α-BHC as the only significant residue. The levels identified were 42, 160, 64, and 1,240 ppb in muscle, fat, liver, and gonads respectively.

Methoxychlor Residues in Fish

Only fish caught after treatment in 1974, where all muscle, fat, liver, and gonadal subsamples were taken from the same individual, were analyzed for methoxychlor residues. The summary of these results by catch location, tissue analyzed, and sex are shown in Table 12. It is evident from this table that there is no correlation between the methoxychlor level and catch location within the first 74 km or between methoxychlor level and sex within the same species. Therefore, the residue data were further summarized according to species, tissue, and two general sampling locations

Table 12. Summary of methoxychlor (MeOCl) residue concentrations in four tissues of walleye, pike, and longnose sucker for fish collected from the Athabasca River between 31 July and 19 September, 1974

Loc. (km D/S)	Sex[a]	MeOCl (ppb, wet wt basis) Muscle	Fat	Liver	Gonad	Avg wt (g)	Avg age (yr)
		Walleye (*Stizostedion vitreum*)					
9	♂(11)	0	0	1	0	1177	6.5
	♀(3)	0	0	2	0	2443	8
47	♂(1)	0	0	0	0	598	5
	♀(2)	0	2	0	1	1303	10.5
77	♀(6)	0	3	0	<1	2438	8.5
396	♂(9)	<1	9	3	<1	1065	>9
	♀(3)	0	9	0	0	594	>9
		Pike (*Esox lucius*)					
9	♂(1)	0	0	0	0	2495	9
47	♀(1)	0	6	5	0	6577	9
77	♂(7)	0	3	0	2	1670	7.3
	♀(1)	0	0	0	0	3856	8
396	♂(2)	0	4	2	0	1639	7
	♀(1)	0	0	2	0	3062	7
		Longnose sucker[b] (*Catostomus catostomus*)					
9	♀(5)	0	54	0	0	803	13

[a]Number of fish analysed in brackets.

[b]Collected 26 June 1974.

Table 13. Summary of methoxychlor (MeOCl) residue concentrations in four tissues of walleye (*Stizostedion vitreum*), pike (*Esox lucius*), and longnose sucker (*Catostomus catostomus*) taken from two reaches of the Athabasca River between 31 July and 19 September, 1974

	Walleye				Pike				Longnose sucker			
		ND[a]	MeOCl (ppb)			ND	MeOCl (ppb)			ND	MeOCl (ppb)	
Tissue	No anal	MeOCl (%)	Avg	Range	No anal	MeOCl (%)	Avg	Range	No anal	MeOCl (%)	Avg	Range
					0-74 km							
Muscle	23	100	0	0	10	100	0	0	5	100	0	0
Fat	23	78	1	0-8	10	50	3	0-9	5	40	54	0-179
Liver	23	91	1	0-13	10	80	<1	0-5	5	100	0	0
Gonad	23	91	<1	0-3	10	90	1	0-14	5	100	0	0
					400 km							
Muscle	12	92	<1	0-4	3	100	0					
Fat	12	10	10	0-29	3	67	2	0-9				
Liver	12	67	2	0-9	3	33	2	0-5				
Gonad	12	82	<1	0-5	3	100	0	0				
					Overall							
Muscle	35	97	<1	0-4	13	100	0	0	5	100	0	0
Fat	35	63	4	0-29	13	54	3	0-9	5	40	54	0-179
Liver	35	83	1	0-13	13	70	1	0-5	5	100	0	0
Gonad	35	89	<1	0-5	13	92	1	0-14	5	100	0	0

[a]Percent of fish with no determinable MeOCl residue.

(Table 13). At least one tissue contained residues of methoxychlor in 49% of the walleye, 36% of the pike, and 60% of the longnose suckers. In the latter species, methoxychlor was found only in the fat.

In walleye, methoxychlor was found in 3, 37, 17, and 11% of the muscle, fat, liver, and gonadal samples, respectively. In pike, methoxychlor was found in 0, 46, 30, and 8% of the muscle, fat, liver, and gonadal samples, respectively. The single highest methoxychlor residue was 179 ppb in the longnose sucker, 29 ppb in walleye, and 9 ppb in pike, all in the fat tissue.

The percentage of walleye caught at 400 km with no determinable methoxychlor residues in the fat was lower than for those caught between 0 and 74 km. Conversely, the average methoxychlor concentration was higher. The same trends were not evident in pike. The pike, however, did show an decrease in the percent with no determinable residue in the liver. Comparable data are not available for longnose sucker.

The methoxychlor levels in the four tissues of the various fish species reported here suggest that there are no problems with high residues in fish. Furthermore, no conclusion can be drawn as to the physiological or behavioral effect on the fish. It is important to note that these levels were much lower than the background level of other organochlorine compounds identified in fish caught before the 1974 treatment.

Methoxychlor Residues in Athabasca Delta Fish

In the fall of 1975, after two river treatments, seven pike, eight longnose sucker, six walleye, three white sucker, five goldeye, and two lake whitefish were collected in the Athabasca delta area, and muscle, fat, liver, and gonadal tissue analyzed for methoxychlor residues.

No detectable levels of methoxychlor were found, clearly indicating that the treatment of the Athabasca River does not result in long-term residue accumulation in fish in the delta or Lake Athabasca.

CONCLUSIONS

Background residues in fish caught in the Athabasca River were significantly higher than methoxychlor residues as measured by gas-liquid chromatography techniques. Disregarding the background residue levels, the levels of methoxychlor were not deemed sufficiently high to pose a problem.

RECOMMENDATIONS

It was felt that dynamic bioassay studies should be conducted to correlate the residue levels in fish with the real time of exposure under field conditions.

In addition, the study of the effect of the methoxychlor treatment on the behavior of fish should be attempted when the Athabasca River is treated again. Radio-tagging of fish has been shown by Dr. Bidgood (personal communication) of the Alberta Fish and Wildlife Division to be a convenient way of watching the movement of fish in a natural environment.

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Appendix I. Average concentrations of insecticide, PCB, and unidentified hydrocarbon residues in muscle and fat tissues from male and female fish of four species collected in 1973 (Tables 14-17).

Table 14. Insecticide, PCB, and unidentified hydrocarbon residue concentrations in muscle and fat from male and female pike (*Esox lucius*) collected at various locations from the Athabasca River in 1973

			Residue levels (ppb, wet weight basis)													
Loc. (km)	Sex	No. analyzed	Hexachloro-benzene	α-BHC	Lindane	pp'-DDT	op'-DDT	pp'-DDE	pp'-DDD	PCB (as 1260	Methoxychlor	Dieldrin	Heptachlor epoxide	Unidentified hydrocarbons	Organo-phosphates
							Muscle								
-34	♂	2	ND[a]	3	ND	3	ND	7	2	ND	ND	ND	ND	ND	ND
	♀	1	ND	ND	ND	M	M	21	M	152	ND	ND	ND	ND	ND
-7	♂	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	♀	1	ND	T	ND	ND	ND	1	ND	ND	ND	ND	ND	ND	ND
62	♂	3	ND	2	ND	M	M	50	M	140	ND	ND	ND	ND	ND
	♀	1	ND	1	ND	3	ND	1	3	ND	ND	ND	ND	ND	ND
77	♂	2	ND	1	ND	M	M	2	M	15	ND	ND	ND	ND	ND
	♀	2	T	1	ND	ND	ND	1	ND	ND	ND	ND	ND	ND	ND
							Fat								
-34	♂	2	18	20	9	29	M	135	31	391	ND	9	ND	1,240	ND
-7	♀	2	9	84	ND	M	M	148	M	308	ND	10	10	3,890	ND
62	♂	3	22	150	10	M	M	178	M	553	ND	5	6	2,130	ND
	♀	1	37	319	ND	M	M	289	M	261	ND	18	11	4,200	ND
77	♂	3	34	163	12	M	M	319	M	316	ND	12	11	2,380	ND
	♀	2	25	154	18	M	M	109	M	170	ND	11	10	1,320	ND

[a]M = Determination masked by PCB; ND = None detected; T = Trace.

Table 15. Insecticide, PCB, and unidentified hydrocarbon residue concentrations in muscle and fat from male and female longnose sucker (*Catostomus catostomus*) collected at various locations from the Athabasca River in 1973

Loc. (km)	Sex	No. analyzed	Residue levels (ppb, wet weight basis)												
			Hexachloro-benzene	α-BHC	Lindane	pp'-DDT	op'-DDT	pp'-DDE	pp'-DDD	PCB (as 1260)	Methoxychlor	Dieldrin	Heptachlor epoxide	Unidentified hydrocarbons	Organo-phosphates
							Muscle								
-34	♂	2	2	1	ND	4	ND	1	4	ND	ND	ND	ND	ND	ND
	♀	2	1	1	ND	2	ND	2	3	ND	ND	ND	ND	ND	ND
-7	♂	1	T	5	ND	M	M	8	M	37	ND	T	7	ND	ND
	♀	2	T	3	1	M	M	5	M	5	ND	ND	ND	ND	ND
6.5	♂	2	T	3	T	7	ND	4	4	6	ND	ND	ND	ND	ND
	♀	1	T	2	T	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
25	♂	1	ND	T	ND	4	ND	3	4	ND	ND	ND	ND	ND	ND
	♀	2	ND	1	ND	1	ND	4	1	ND	ND	ND	ND	ND	ND
62	♂	1	2	10	2	5	ND	7	ND	ND	ND	ND	ND	ND	ND
	♀	2	1	2	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
444	♂	1	4	5	T	ND	ND	5	ND	ND	ND	ND	ND	ND	ND
	♀	2	1	3	ND	5	ND	5	5	ND	ND	ND	ND	ND	ND
							Fat								
-34	♂	2	8	67	ND	M	M	35	M	49	ND	ND	ND	ND	ND
	♀	2	11	31	ND	M	M	11	M	253	ND	ND	ND	ND	ND
-7	♂	1	23	119	ND	164	ND	102	242	ND	ND	ND	ND	ND	ND
	♀	2	15	72	3	M	M	31	M	132	ND	3	ND	ND	ND
6.5	♂	2	22	101	T	M	M	170	M	1,182	ND	ND	ND	ND	ND
	♀	1	19	67	ND	M	M	M	M	1,060	ND	ND	ND	ND	ND
25	♀	2	9	23	ND	M	M	96	M	797	ND	ND	ND	ND	ND
62	♂	1	16	105	12	42	ND	65	40	ND	ND	ND	ND	ND	ND
	♀	2	33	95	10	5	M	20	7	79	ND	6	ND	ND	ND
444	♂	1	6	54	8	T	ND	29	T	ND	ND	ND	ND	ND	ND
	♀	2	13	71	4	39	ND	174	103	ND	ND	ND	ND	ND	ND

[a] M = Determination masked by PCB; ND = None detected; T = Trace.

Table 16. Insecticide, PCB, and unidentified hydrocarbon residue concentrations in muscle and fat from male and female walleye (*Stizostedion vitreum*) collected at various locations from the Athabasca River in 1973

Site no.	Sex	No. analyzed	Residue levels (ppb, wet weight basis)												
			Hexachloro-benzene	α-BHC	Lindane	pp'-DDT	op'-DDT	pp'-DDE	pp'-DDD	PCB (as 1260)	Methoxychlor	Dieldrin	Heptachlor epoxide	Unidentified hydrocarbons	Organo-phosphates
								Muscle							
-34	♂	1	ND[a]	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	♀	4	ND	T	ND	ND	ND	1	ND	ND	ND	ND	.001	ND	ND
-7	♂	2	ND	ND	1	4	2	3	6	ND	ND	ND	ND	ND	ND
6.5	♂	1	ND	T	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	♀	2	ND	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
25	♂	1	ND	3	ND	19	ND	12	15	ND	ND	ND	ND	ND	ND
62	♂	2	ND	1	ND	3	ND	3	3	ND	ND	ND	ND	ND	ND
	♀	2	ND	1	ND	4	ND	3	1	ND	ND	ND	ND	ND	ND
								Fat							
-34	♂	2	17	22	11	19	M	69	7	535	ND	8	ND	1,590	ND
	♀	4	5	22	ND	M	M	198	M	1,564	ND	19	2	3,540	ND
-7	♂	1	84	967	97	M	M	252	M	428	ND	56	34	7,020	ND
6.5	♂	1	13	154	16	M	M	63	M	148	ND	11	7	4,590	ND
	♀	2	7	69	5	M	M	36	M	149	ND	9	1	1,530	ND
25	♂	1	12	101	ND	M	M	268	M	363	ND	11	ND	4,990	ND
62	♂	2	16	159	12	M	M	197	M	269	ND	11	9	3,660	ND
	♀	1	12	158	15	M	M	250	M	267	ND	21	12	3,800	ND

[a] M = determination masked by PCB; ND = none detected; T = trace.

Table 17. Insecticide, PCB, and unidentified hydrocarbon residue concentrations in muscle and fat from male and female goldeye (*Hiodon alosoides*) collected at various locations from the Athabasca River, 1973

Site no.	Sex	No. analyzed	Residue levels (ppb, wet weight basis)												
			Hexachloro-benzene	α-BHC	Lindane	pp'-DDT	op'-DDT	pp'-DDE	pp'-DDD	PCB (as 1260)	Methoxychlor	Dieldrin	Heptachlor epoxide	Unidentified hydrocarbons	Organo-phosphates
								Muscle							
-7	♀	2	3	6	ND[a]	ND	ND	T	ND	ND	ND	ND	ND	ND	ND
6.5	♀	1	4	3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
25	♀	1	1	3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
62	♂	1	1	4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
97	♀	2	2	9	1	ND	ND	2	ND	ND	ND	ND	ND	ND	ND
444	♀	1	1	8	1	2	ND	3	ND	ND	ND	ND	ND	ND	ND
	♂	1	3	3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
								Fat							
-7	♀	2	9	114	6	13	ND	32	25	ND	ND	ND	ND	ND	ND
25	♀	1	14	113	7	37	ND	81	25	ND	ND	ND	ND	ND	ND
62	♂	1	24	141	11	85	ND	232	122	ND	ND	7	ND	ND	ND
97	♀	2	13	135	7	3	5	16	4	ND	ND	ND	ND	ND	ND
444	♀	1	20	116	6	M	M	24	M	79	ND	ND	ND	ND	ND
	♂	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

[a] M = determination masked by PCB; ND = none detected; T = trace.

METHOXYCHLOR, ORGANOCHLORINE, AND ORGANOPHOSPHORUS INSECTICIDES AND UNIDENTIFIED HYDROCARBON RESIDUES IN BED MATERIAL OF LAKE ATHABASCA AND THE ATHABASCA DELTA

W. A. CHARNETSKI, R. A. CURRIE AND L. CALDER

The introduction of an insecticide into a large aquatic ecosystem could have a far-reaching environmental impact on the aquatic biomass of a river. To further evaluate the dynamics of methoxychlor in the Athabasca River, the study area was extended in 1977 to include Lake Athabasca and the Athabasca River delta. Although this study was carried out 17 mo after the last injection of methoxychlor, it was felt that if methoxychlor had accummulated in the bottom sediments it would be detectable.

The Athabasca River delta is important not only as an avian nesting and moulting ground but also as a major staging area of the spring and fall migrations of 15 species of ducks, four species of geese, and the whistling swan. In addition, the waters of the delta are important as spawning grounds for goldeye (*Hiodon alosoides*), walleye (*Stizostedion vitreum*), and northern pike (*Esox lucius*).

Therefore, this program was initiated to investigate the degree of environmental contamination in Lake Athabasca and the Athabasca River delta resulting from the use of methoxychlor in 1974, 1975, and 1976 to control black fly larvae about 600 km upstream.

MATERIALS AND METHODS

Site Description

Lake Athabasca is about 320 km long and straddles the Alberta-Saskatchewan border at about 60°N lat. and 110°W long. in northern Canada. This lake is one of the largest lakes in the vast Mackenzie drainage system and is important in the regulation of inflowing waters from the Athabasca and Fond du Lac Rivers.

The Athabasca River delta covers an area of about 1,970 km^2 and now extends across the end of Lake Athabasca having formed Lake Mamawi and creating the southerly and easterly shores of Lake Clare, a former bay of Lake Athabasca.

This study considered only the delta of the Athabasca River and the extreme west end of Lake Athabasca up to Bustard Island some 16 km off the delta shore. It was designed to consider only the material deposited in Lake Athabasca from Athabasca River waters entering the lake.

Sampling

During late September 1977, samples of bottom material were taken from the 30 locations shown in Fig. 1.

In Lake Athabasca, 21 samples of bottom sediments were taken along various transects between Bustard Island and the mainland using a Ponar grab sampler. A deep water coring device was tried; however, it proved to be unsatisfactory.

In the Athabasca delta, nine sampling locations were established (Fig. 1; no. 22-30). Bedload samples were obtained using a modified Bogardi bedload sampler, whereas bottom sediments were taken using a Ponar

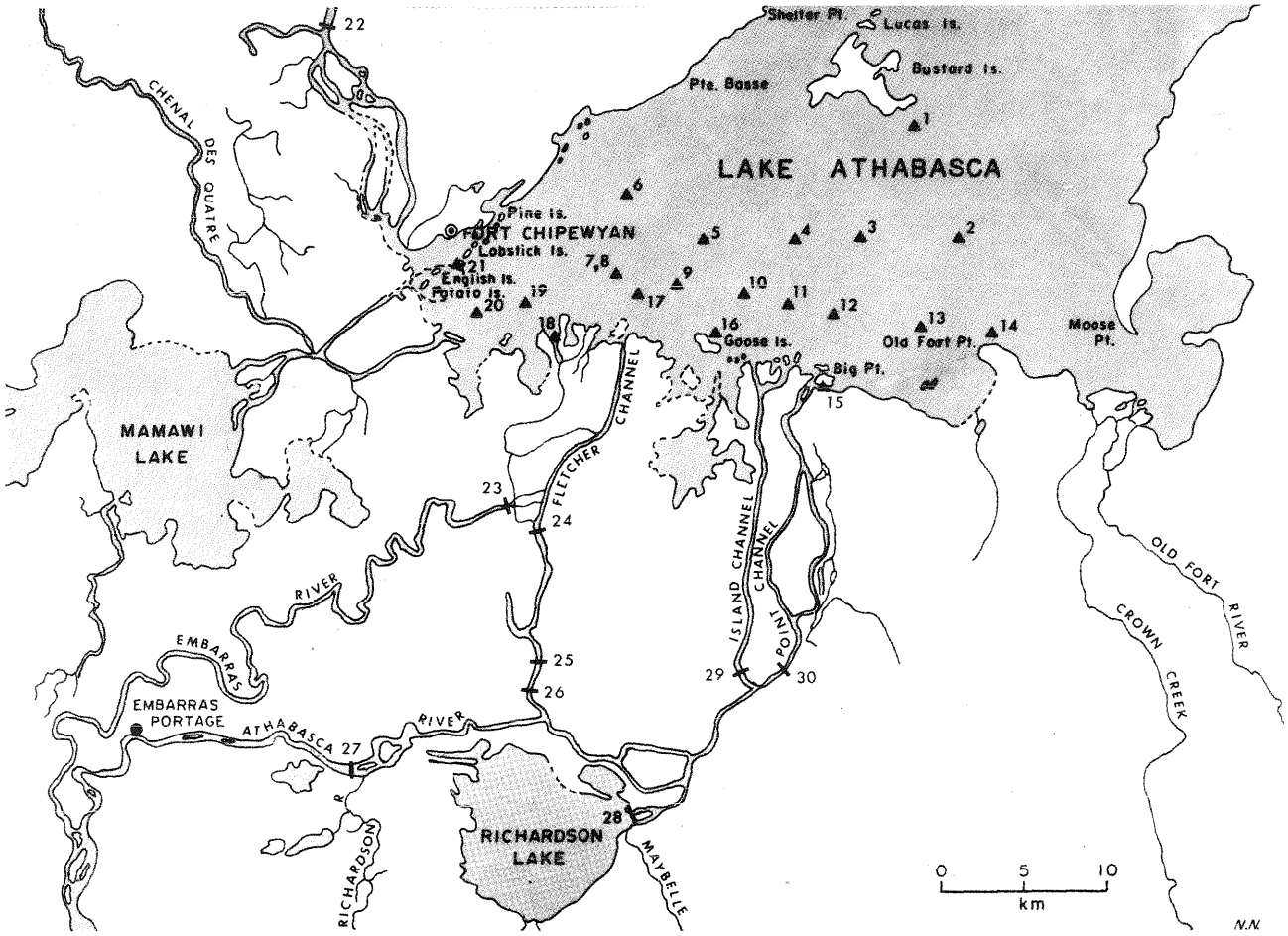

Fig. 1. Location of sample sites in Lake Athabasca and the delta of the Athabasca River in northern Alberta.

grab sampler and a simple 7.5-cm core sampler. The core sampler was used extensively to obtain samples along shorelines or in areas of high sedimentation (sandbars, etc.) in either shallow water or in areas where sedimentation had occurred during periods of high water levels.

Analytical Procedures

Small field-collected samples were placed in plastic bags directly, whereas large samples were well mixed and a 2-kg subsample taken and placed in a plastic bag. All samples were kept cool (maximum of 2 days) and then frozen and held at -30°C until residue analyses could be carried out.

Samples were thawed and mixed to obtain a homogeneous subsample of about 500 g from which water was removed using a Buchner funnel with a vacuum receiver. The sample with the free-water removed was again mixed and four 100-g samples were weighed out: one sample for moisture analysis, one sample for spiking with methoxychlor, and two samples for analysis of the insecticide levels.

Samples were extracted using a mechanical shaker under the following regime. To each 100-g sample, 100 ml of acetone were added, the mixture shaken for 2 hr, then centifuged and the supernatent decanted. To the solid portion, 100 ml of acetone plus n-hexane (1:1) was added, the mixture shaken overnight, then allowed to settle and the supernatant decanted. The solid portion was again suspended in 100 ml of acetone plus n-hexane (1:1) and shaken for 2 hr. After the liquid had cleared, the supernatant was decanted and 25 ml of n-hexane were added to the solid portion. The mixture was again shaken, for 15 min, and the supernatant decanted and the solid discarded. All the supernatant solutions were combined into one separatory funnel together with 400 ml of 2% NaCl solution and shaken vigorously. This liquid extraction procedure resulted in the hexane phase separating from the aqueous-acetone phase. The aqueous phase was collected in one flask and the hexane phase collected in another. The aqueous phase was transferred back to the separatory funnel and extracted twice more with 85-ml portions of n-hexane. The combined hexane phases were dried with 10 g of Na_2SO_4 (anhydrous), and finally evaporated to about 5 ml.

Table 1. Chemicals recovered from 50 g activity IIab Florisil column; 28 x 650 mm chromatographic tube; 300 ml fractions, all fractions eluted (in order)

Fraction A: 7% CH_2Cl_2 - Petroleum Ether	
aldrin	heptachlor
aroclor 1254	hexachlorobenzene
aroclor 1260	lindane
BHC, alpha	mirex
BHC, beta†	PCNB
chlordane, tech.	pentachlorobenzene
chlordane	perthane
p,p'-DDD	strobane
p,p'-DDE	TCNB†
o,p'-DDT	toxaphene
p,p'-DDT	
Fraction B: 25% CH_2Cl_2 - Petroleum Ether	
BHC, beta†	leptophos
dieldrin	leptophos, ph analog
dursban*	methoxychlor*
endrin	ronnel
heptachlor epoxide	TCNB†
kelthane	thiodan I
Fraction C: 40% EtOAc - Petroleum Ether	
ciodrin	MCPA, Me ester
2,4-D Me ester	methoxychlor*
diazinon	parathion
dursban*	parathion, methyl
EPN	phorate
ethion	picloram, Me ester
guthion	2,4,5-T, Me ester
imidan	thiodan II
malathion	
Not Recovered by the Above Eluants	
bromacil	dimethoate
coumaphos	fenthion
dasanit	methomyl
dibrom	ruelene
dichlorvos	

† Elutes in both fractions A and B.
* Elutes in both fractions B and C.

Sample extract concentrates were 'cleaned-up' on a Florisil column prepared according to Currie (1977). Three fractions were collected from the column (Table 1). The first two fractions were analyzed by electron capture detector (Ni-63, pulse-modulated); carrier gas 10% methane:argon (50 ml/min); 1 m x 6 mm OD borosilicate glass column, 12% OV-101/QF-1 (2:3) on Gaschrom Q (80-100 mesh); injector 210°C, oven 190°C, detector 350°C. The third fraction was analyzed for common organo-phosphorous pesticides using an alkali flame ionization detector; carrier gas, helium at 50 ml/min; column as above except 0.6 m x 6 mm OD; injector 200°C; oven 185°C, detector 200°C.

RESULTS AND DISCUSSION

The results of the analysis for methoxychlor, organochlorine, and organophosphorus insecticides together with unidentified hydrocarbon residues for Lake Athabasca bed material are given in Table 2 and for Athabasca delta bed material in Table 3. No residues of methoxychlor or other known organochlorine or organophosphorus insecticides were identified in any of the sample materials analyzed. However, a substantial amount of unidentified hydrocarbon material (quantitated relative to the response of α-benzene hexachloride) was found.

Table 2. Methoxychlor, organochlorine (OC), organophosphorus (OP) insecticides and unidentified hydrocarbon (HC) residues in Lake Athabasca bed material (Ponar grab samples), 1977

	Residues (ppb, dry weight)			
Site	MeOCl	OC	OP	HC[a]
1	-	-	-	9
2	-	-	-	30
3	-	-	-	6
4	-	-	-	45
5	-	-	-	3
6	-	-	-	38
7	-	-	-	-
8	-	-	-	4
9	-	-	-	-
10	-	-	-	-
11	-	-	-	5
12	-	-	-	-
13	-	-	-	5
14	-	-	-	10
15	-	-	-	-
16	-	-	-	10
17	-	-	-	-
18	-	-	-	-
19	-	-	-	-
20	-	-	-	1
21	-	-	-	4

[a] Quantitated relative to the response of α-benzene hexachloride.

The levels of unidentified hydrocarbon residues in the Lake Athabasca material varied from 0 to 45 ppb calculated on the basis of dry weight of bed material. In the Athabasca delta bed material, the unidentified hydrocarbon residue level varied from 0 to 184 ppb (on the same basis). The nature of this unidentified hydrocarbon was not established because of the extremely variable nature and the large number of apparently different compounds making up what is reported here as a single compound. Time did not permit a comparison of these unidentified hydrocarbons with those reported in the paper describing the background levels in fish (see Charnetski and Currie, pp. 75-87). It is conceivable that the high levels of unidentified hydrocarbons found in walleye and northern pike could be attributable to the levels of these compounds found in the beds of the Athabasca River Delta and Lake Athabasca.

Table 3. Methoxychlor, organochorine (OC), organophosphorus (OP) insecticides, and unidentified hydrocarbon (HC) residues in Athabasca Delta bed material, 1977

Site	Sample[a]	Residues (ppb, dry weight) MeOCl	OC	OP	HC[b]
22	Bd	-	-	-	<1(1)
	S	-	-	-	2(3)
23	Bd	-	-	-	11(2)
	P	-	-	-	13(2)
24	S	-	-	-	5(2)
	P	-	-	-	4(2)
25	S	-	-	-	57(3)
26	S	-	-	-	4(2)
	P	-	-	-	-(3)
27	Bd	-	-	-	8(2)
	S	-	-	-	33(4)
	P	-	-	-	38(3)
28	P	-	-	-	6(1)
29	Bd	-	-	-	8(2)
	S	-	-	-	4(1)
	P	-	-	-	13(3)
30	Bd	-	-	-	8(2)
	S	-	-	-	3(2)
	P	-	-	-	184(2)

[a] Bd = bedload sample, S = 7.5-cm sediment core; and P = ponar grab sample.

[b] Quantitated relative to the response of α-benzene hexachloride. Values in parentheses are numbers of samples.

CONCLUSIONS

Analysis of samples of static or moving bed from 21 sites in Lake Athabasca and nine sites in the delta of the Athabasca River indicated that methoxychlor is not accumulating and therefore does not pose any threat to the biota in the Athabasca delta or Lake Athabasca. The treatment of the Athabasca River some 600 km upstream from the delta could be carried out on a controlled basis with no effect in the area investigated in this study.

The area sampled is free of contamination by organochlorine and organophosphorus insecticides commonly used in agricultural practices, but does contain levels of unidentified hydrocarbons that may bear a relation to levels found in walleye and northern pike fish further upstream.

ACKNOWLEDGEMENT

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REFERENCE

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METHOXYCHLOR RESIDUE CHECK SAMPLE STUDY FOR WATER, FISH MUSCLE, AND FISH OIL

W. A. CHARNETSKI

INTRODUCTION

The environmental sensitivity of the Athabasca black fly program required as complete an account of methoxychlor residues as possible. However, the wide scope of the types of substrates and the number of samples required to describe the dynamics of methoxychlor in a river ecosystem made it impossible for any one laboratory to conduct all the analyses. The residue analyses for the Athabasca program were actually carried out by four different labs.

It is well understood that the proficiency of analysis of different labs using the same technique can vary. Although all residue labs must evaluate established analytical procedures and modify them or institute new procedures to obtain the optimum procedure for their specific conditions, it is still necessary to compare analytical results from similar substrates. It was therefore decided early in the Athabasca program that just such a check sample study would be carried out for methoxychlor residues in water, fish muscle, and fish oil. All labs would be supplied with subsamples of a common substrate treated and homogenized with various specific levels of methoxychlor.

MATERIALS AND METHODS

Residue Analysis

This study was not designed to dictate to any cooperating lab what procedures they should use for the analysis of these materials. All the labs that finally cooperated and provided their results already had methods for analysis of insecticide residues in water, fish muscle, and fish oil. Therefore, the results discussed here are from several different analytical techniques. However, we are interested only in the final residue levels that were provided to the research team.

Water Check Samples

Water was collected from the Athabasca River and immediately shipped to the residue lab at the Lethbridge Research Station, where 15-liter lots were treated with the formulated methoxychlor (25% emulsifiable concentrate) - to achieve final concentrations of 0, 3, 30, 300, and 3,000 µg/liter.

The 15-liter samples were well mixed to obtain a homogeneous level of methoxychlor and then subsampled into 1-liter glass containers that had previously been acid-washed, baked, and rinsed with pesticide-grade, glass-distilled, acetone and n-hexane. The final rinses of these containers had been checked by gas-liquid chromatography to determine if there were any materials in the containers that would be extracted in a normal residue analytical procedure and that subsequently would interfere with the determination of methoxychlor. Only those containers that were absolutely clean were used.

Each lab was sent three 1-liter bottles by air express in an insulated container for analysis.

Fish Muscle

Fish were collected from the Athabasca River before the first treatment of methoxychlor. The dorsal muscle tissue, excluding any skeletal or skin material, was homogenized and five initial large subsamples were spiked with formulated methoxychlor (25% EC) to achieve final concentrations of 0, 1, 10, 200, and 4,000 ng/g of homogeneous tissue. Subsamples of each level were frozen and sent, by air express in an insulated container packed in dry ice, to each cooperating lab.

Fish Oil

A commercial fish oil was purchased and analyzed by several labs to determine if there were any interferring peaks that would hinder the analysis of methoxychlor. In the fish oil used in this portion of the study, no hindering peaks, as judged by gas-liquid chromatography using electron-capture detectors, were found. Large amounts of the fish oil were treated with formulated methoxychlor (25% EC) to achieve final concentrations of methoxychlor of 0, 2, 20, 100, and 4,000 ng/g. The spiked oil was well mixed and subsampled. The subsamples were frozen, packed in dry ice in insulated containers, and shipped by air express to the cooperating labs.

RESULTS AND DISCUSSION

Water Check Sample Study

Four laboratories (in alphabetical order; Agriculture Canada, Lethbridge; Alberta Agriculture, Edmonton; Alberta Environment, Edmonton; and Environment Canada, Winnipeg) participated in the methoxychlor water-check sample program. Each returned their results of duplicate blank and methoxychlor spiked river water samples. The summary of their final results are given in Table 1.

Preliminary reports from labs 2, 3, and 4 indicated that recoveries were substantially low and that a reanalysis and investigation of their analytical procedures was necessary. The low residue values were due to poor sample handling and subsampling procedures. These two factors alone are by far the most important steps in obtaining accurate residue analyses from environmental materials.

In each case, these labs assumed that any residue in the water at the time of initial sampling would remain dissolved or suspended. This was not the case, however, as some of the methoxychlor, or the substrate to which it had adsorbed, was attached to the walls of glass container. Thus, when analyzing any insecticide in water, one cannot simply take an aliquot from a container and assume that the levels of residues are representative of the amounts present in that water at the time the sample was removed from its normal environment.

The amount of methoxychlor on the glass is denoted as 'in rinse', and does not seem to be constant between duplicate samples within or between labs. Clearly the phenomenon of binding was not consistent between containers, further emphasizing the need to analyze the total contents of each container together with quantitative rinses of the inside of the container.

Laboratory 1 was the only lab that obtained consistant recoveries for all concentrations. The high levels of methoxychlor identified by lab 2 in the blank sample (0 µg/liter) cannot be explained. Likewise the lower, but still unacceptable, levels reported by lab 3. Laboratories 2, 3, and 4 were consistently high in the analysis of the subsample containing 3 µg/liter (3 ppb); a level that would be easily detected and generally above levels usually considered in environmental research. All labs reported reasonable recoveries for the levels of 300 and 3,000 µg/liter; however, because of the very large amounts of methoxychlor to be detected, these results are not surprising.

Fish Muscle and Fish Oil Check Samples

Duplicate blank and methoxychlor spiked (at four concentrations) fish muscle homogenate and fish oil samples were distributed to three analytical labs in Alberta and Manitoba. Only two labs (in alphabetical order; Alberta Agriculture, Edmonton; and Environment Canada, Winnipeg) provided residue data, which are summarized in Table 2.

The high recoveries of methoxychlor in muscle samples, spiked with methoxychlor at 0, 1, and 10 ng/g, by lab 2 indicate an inherent problem in their handling procedure or analytical technique. This problem was apparently avoided when the fish oil was analyzed, but they failed to detect any methoxychlor in the oil spiked with methoxychlor at 1 ng/g.

Laboratory 1 also tended to have higher recoveries than expected but they were in a more reasonable range of values for the methoxychlor residues in fish muscle homogenate. In the fish oil samples, lab 1 had respectable levels of recovery with the exception of the samples spiked to a concentration of 4,000 ng/g.

CONCLUSIONS

Clearly, when conducting any environmental study where more than one analytical lab is concerned, the investigators must definitely identify where any differences in sampling, handling, or preparation may occur and subsequently identify how well the results can be correlated between labs. It was clear that three major labs in Western Canada would have reported lower residues than in fact would have occurred in the natural situation in the environment, particularly in the case of water.

Table 1. Summary of total methoxychlor (MeOCl) residues in water analyzed by four laboratories cooperating in the Water Check Sample Program

MeOCl spike (µg/liter)	Lab 1		Lab 2			Lab 3			Lab 4		
	Total (µg/liter)	Recovery (%)	In H_2O (µg/liter)	In rinse[a] (µg)	Recovery[b] (%)	In H_2O (µg/liter)	In rinse[a] (µg)	Recovery[b] (%)	In H_2O (µg/liter)	In rinse[a] (µg)	Recovery[b] (%)
0	0		20.6	6.4		0.13	0.17		0	0	
0	0		21.1	0.5		0.11	0.42		0	0	
Avg	0		20.9	3.5		0.12	0.30		0	0	
3	2.2		4.4	5.5		2.40	1.70		3.0	1.08	
3	2.8		4.6	5.3		1.59	3.95		3.0	1.58	
Avg	2.5	83.3	4.5	5.4	330.0	2.00	2.83	160.7	3.0	1.33	144.3
30	27.7		26.7	0.4		19.7	13.8		31.0	0.49	
30	29.0		22.9	0.4		18.0	12.0		28.0	1.70	
Avg	28.4	94.5	24.8	0.4	84.0	18.9	12.9	105.8	29.5	1.09	102.0
300	266		275	9.0		215	64		210	13.5	
300	278		285	0.7		210	66		257	17.3	
Avg	272	90.7	280	4.9	94.9	213	65	92.5	234	15.4	83.0
3000	3013		1739	663		1157	1987		2890	555	
3000	2923		1853	803		614	2114		2900	32	
Avg	2968	98.9	1796	733	84.3	886	2051	97.9	2895	293	106.3

[a] The amount of MeOCl attached to the wall of the container.

[b] Recovery calculated on the total MeOCl in water and rinse.

Table 2. Summary of methoxychlor (MeOCl) residues in fish muscle and oil as analyzed by two laboratories cooperating in the Fish Check Sample Program

MeOCl Spike (ng/g)	MeOCl recovered				MeOCl Spike (ng/g)	MeOCl recovered			
	Lab 1		Lab 2			Lab 1		Lab 2	
	(ng/g)	(%)	(ng/g)	(%)		(ng/g)	(%)	(ng/g)	(%)
	From Muscle					From Oil			
0	0		20		0	0		0	
0	0		20		0	0		0	
Avg	0		20		Avg	0		0	
1	1		20		2	2.0		0	
1	1		30		2	1.0		0	
Avg	1	100	25	2500	Avg	1.5	75	0	0
10	13.0		20		20	21		20	
10	14.0		20		20	21		20	
Avg	13.5	135	20	200	Avg	21	105	20	100
200	257		180		100	97		110	
200	252		160		100	104		100	
Avg	255	128	170	85	Avg	101	101	105	105
4000	4860		2640		4000	5170		4050	
4000	4450		2990		4000	5050		4280	
Avg	4660	117	2820	71	Avg	5110	128	4170	104

ACKNOWLEDGEMENTS

The unquestioned support of the four residue laboratories and their analysts is greatly appreciated.

MIXING AND EFFECTS OF INSECTICIDES: A WORKING HYPOTHESIS FOR AN ANALYTICAL MODEL

S. BELTAOS

(Alberta Research Council Contribution Series 956)

INTRODUCTION

This report is the first of two parts dealing with the mixing of methoxychlor in the Athabasca River. It describes the activities of the Transportation and Surface Water Engineering Division of the Alberta Research Council pertaining to the abatement program and presents the results of such activities. However, a detailed analysis of time-concentration variations observed at various locations downstream from each methoxychlor injection site is covered by Beltaos and Charnetski (pp. 123-130).

The main thrust of this report is the formulation of an analytical model that, in addition to mixing processes imposed by the river flow itself, accounts for processes associated with physical and chemical properties of methoxychlor that can influence mixing patterns. The quantitative expression of these processes is based mainly on a study of observed downstream variations of insecticide recovery. It is shown that the analytical expressions derived here can describe these variations adequately. However, this finding alone is not deemed sufficient to confirm the assumptions involved in the present analysis. Thus, the value of the latter lies mainly in illustrating the possibility of describing the movement of the insecticide analytically and pointing out specific research needed to either confirm or modify the present hypotheses.

To illustrate the utility of the analysis, a method for correlating larval control with local amounts of methoxychlor is developed by postulating the nature of the control mechanism. The results of this operation are encouraging; however, it is shown that further work is needed to elucidate the mechanism(s) by which larvae detach when subjected to insecticides.

The practical application of the present analysis is illustrated by means of a numerical example in which it is required to determine the amount of insecticide and location of the injection site for optimizing larval control in an infested reach of a hypothetical stream.

Objectives

By tacit understanding, the Division has been responsible for river engineering aspects of the abatement program, such as hydrometric surveys and investigation of mixing characteristics of selected river reaches. Such studies are essential in evaluating the movement of insecticides and insecticide residues in a river ecosystem. At the same time, this work contributes to the Division's continuing research program on the mixing characteristics of Alberta streams.

The specific objectives of the work have been shaped as the Program progressed and are summarized below.

(a) Establish necessary hydraulic parameters of the Athabasca River in the study area (Athabasca to Fort McMurray) and

provide background information necessary for designing injection and sampling procedures, as well as for intepretation of data by other members of the research team.

(b) Analyze insecticide concentration data obtained in the field to identify substance-specific processes that may influence insecticide movement and mixing, and assess the possibilities of developing analytical models to describe the movement and mixing of the insecticide and its effect on larval populations.

Brief Review of Mixing in Natural Streams

General considerations

The behavior of a substance after its injection into a stream is governed by processes that can be characterized either as river-specific or substance-specific. River specific processes are diffusion and advection.

Diffusion is the process by which a substance suspended or dissolved in a fluid is transferred from regions of high concentration to those of low concentration due to random (molecular or turbulent) motions of fluid particles.

Advection is transport by the mean motion of the fluid. This process would present no particular difficulty if the flows considered exhibited uniform velocity distributions. However, natural streams are typical cases of so-called shear flow, characterized by significant velocity gradients in both the vertical and tranverse directions. Non-uniform velocity distributions cause differential advection and it is this process that further complicates mixing in natural streams. The interaction between differential transport in the longitudinal direction and lateral diffusion results in an enhanced longitudinal spread of the diffusing substance. This effect is termed dispersion (see also Beltaos 1978).

The above processes are entirely attributable to the nature of river flow and act regardless of the nature of the diffusing substance (or tracer). Consideration of these processes alone is sufficient when the substance is a 'neutral' tracer - one that has properties identical to those of water. In practice, additional processes, associated with the physical and chemical properties of the tracer, must be generally considered. Buoyant or settling tendencies, chemical reaction and decay, ad- and absorption are but a few of the processes that may be encountered.

Although the following discussion assumes a neutral tracer, it is believed to apply in general on a qualitative level.

When a tracer is injected at a point in a stream, more-or-less instantaneously, the concentration at any given point downstream will vary with time (Fig. 1). The times t_a and t_d (see Appendix I for symbols, p. 115) are two important parameters of this

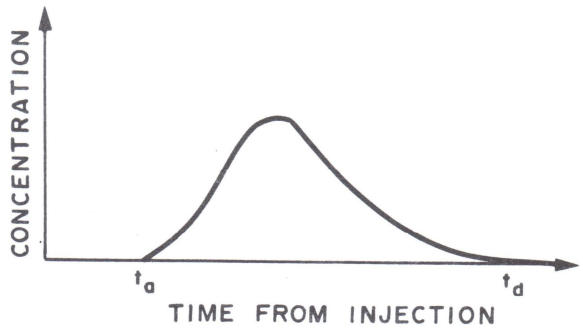

Fig. 1. Typical concentration curve for instantaneous injection.

function and denote the arrival and departure of the tracer respectively. These times increase with distance downstream, as does the difference $(t_d - t_a)$, which represents the 'residence' time of the tracer at a given point. Such a situation is termed unsteady.

If injection takes place at a constant rate over a finite period of time, $t = 0$ to $t = t_{inj}$, a steady condition will be established for some time for locations within a certain distance downstream of the injection point (Fig. 2). In the time interval t_1 to t_2, the concentration is independent of time and is called steady.

It can be shown that $t_1 = t_d$ and $t_2 = t_{inj} + t_a$, where t_a, t_d are the arrival and departure times of a slug injected at the same point at time $t = 0$ (Fig. 3). At any distance from the source, the time during which a steady concentration persists will be t_s and this quantity will decrease with distance downstream. Beyond a point x_o (where $t_{inj} + t_a = t_d$), t_s will be zero and the shape of the time-concentration curve will revert to the type depicted in Fig 1.

If the injection time, t_{inj}, is made sufficiently large, a given reach of interest can be subjected to a steady concentration for a prescribed sampling period, provided sampling is done after the elapse of time t_d from start of injection. The concentration during this period will then vary only with distance downstream and with the location in the cross-section of the channel.

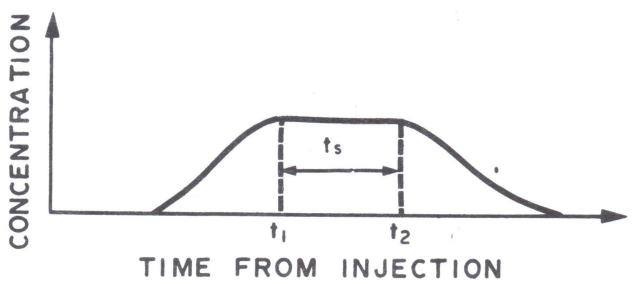

Fig. 2. Typical concentration curve for finite-time injection.

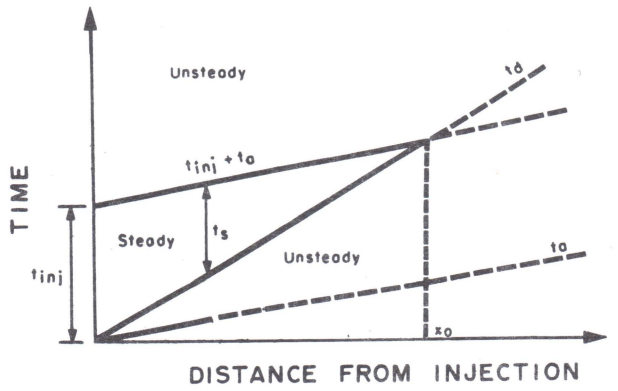

Fig. 3. Graphical determination of steady and unsteady periods.

Degree of mixing

For steady-state concentration distributions, a parameter called the degree of mixing can be defined (Yotsukura and Cobb 1972). This is a measure of the variation in the cross-sectional distribution of concentration. It increases with increasing distance downstream of the source and approaches 100% asymptotically.

In the unsteady case (concentration varies in space and time), one could, in principle, use the same definition for the degree of mixing by taking instantaneous cross-sectional distributions of the concentration. However, this degree of mixing would depend not only upon the distance from the source, but could change erratically in time. However, it has been shown (Beltaos 1975) that, in steady flow, the quantity D, referred to here as the dosage and defined at any point in the stream by:

$$D = \int_0^\infty C\,dt \qquad (1)$$

where C = concentration and t = time, behaves exactly as the steady concentration arising from continuous injection at the same point(s). It follows that D is not only independent of time, but is also a much more stable quantity than the concentration C for the unsteady case. Thus, it is expedient to redefine the degree of mixing in terms of D rather than C. For this case, full mixing would imply that each point across the channel is exposed to the same dosage, even though the concentration may vary across the channel at any instant.

Recovery of tracer

Assume that a certain amount of tracer, M_o, has been injected in a stream at a longitudinal position x = 0 over a finite time interval, t_{inj}, beginning at a time t = 0, and that water sampling has been carried out at several points within a cross-section located x km downstream of the injection site during the anticipated time of passage of the tracer cloud. Analysis of the samples will result in a set of time-concentration curves (C vs t). These curves will generally be different for different points in the stream.

With reference to Fig. 4, if C(t) is the time-concentration function observed at a point with coordinates y and z, and u is the longitudinal flow velocity at this point, then the amount of tracer passing through the small area dA centered at the point (y,z) during a small time increment, dt, is:

$$dM = CudAdt \qquad (2)$$

The total amount of tracer, M, passing through a cross-section of area A, is then:

$$M = \int_t \iint_A CudAdt \qquad (3)$$

where C depends upon y, z, and t, i.e. [C = C(y,z,t)]. To ensure that the entire tracer cloud is taken into account, the lower and upper time limits in Equation 3 are set equal to 0 and ∞. For steady river flow, as is usually the case to a good degree of approximation, the velocity u does not change with time and Equation 3 can be simplified to:

$$M = \int_A DdA \qquad (4)$$

where the dosage, D, has been defined in Equation 1 and is equal to the area under the C-t curve. Equation 4 provides a means for estimating the recovered amount of the tracer at a site, x, if a sufficient number of time-concentration curves have been observed across the stream.

The recovery ratio, R, defined by:

$$R = M/M_o \qquad (5)$$

then provides a means for establishing whether the tracer in question is neutral or subject to losses. If R is nearly equal to one throughout a study reach, it can be concluded that no significant losses occur. If, on the other hand, R changes with x, it must be concluded that certain substance-specific processes occur that cannot be ignored. Study of the variation of R with x can provide some clues regarding the nature of these processes, as will be illustrated later.

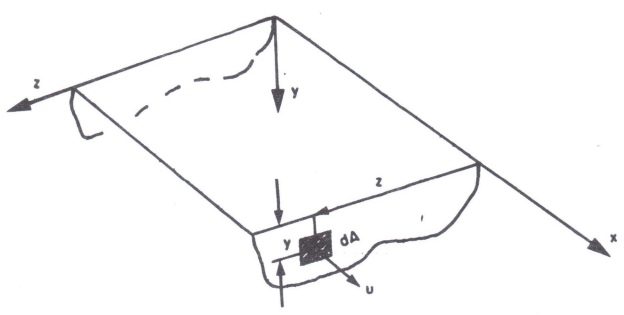

Fig. 4. Definition sketch.

Analytical considerations

Prediction of tracer concentration as a function of time and location is a complex problem at present and can hardly be considered solved. The basic tool that is available for quantitative descriptions of the mixing process is a differential equation that expresses the principle of conservation of tracer mass within the fluid. For neutral tracers, analytical integration of this equation for natural streams is possible under certain circumstances. In general, however, such integration is not possible and it is necessary to resort to numerical computation schemes.

Analysis of the mixing of non-neutral tracers requires identification and quantification of substance-specific processes. Invariably, additional terms must be added to the differential equations, and these increase the complexity of the problem.

The state of the art regarding mixing calculations in laboratory and natural streams has been discussed recently (Beltaos 1978). It was shown that river processes can be effectively accounted for by means of a 'transverse mixing coefficient', E_z; this coefficient has dimensions of diffusivity (L^2/T) and expresses the combined effect of diffusion in the transverse direction (z) and tranverse dispersion that arises due to differential transport in the z direction. This type of dispersion, although weak in straight, prismatic channels, can be very significant in natural streams with curvilinear planform. Satisfactory prediction of this coefficient for a natural stream of given geometry and hydraulics is not possible at present and, generally, one must resort to field tests.

ACTIVITIES AND METHODS

The Division's activities pertaining to the objectives outlined in the Introduction are summarized here with brief descriptions of the methods used.

Hydrometric Surveys

Numerous river cross sections have been surveyed within a reach beginning about 60 km upstream of Athabasca and ending at Fort McMurray, and a longitudinal depth profile of the river near the thalweg has been obtained from 60 km above Athabasca to Grand Rapids. Echo-sounders and Raytheon recorders were used to measure depths while transverse locations in the stream were estimated using optical range finders. Cross-sectional velocity distributions were measured using Price current meters at selected cross sections. Occasional discharge measurements of significant tributaries between Athabasca and Grand Rapids were included to permit an assessment of downstream changes in the discharge of the Athabasca River.

On the days before each of the four methoxychlor injections, the cross sectional velocity distributions at the injection sites were measured in detail to enable calculation of respective flow distributions. The latter is essential for designing injection procedures (see also Depner et al. pp. 21-37).

Shape and size of bed material were documented at several locations within the study reach either by sieve-analysis of grab samples or by photographing the bed material where exposed near banks or bars.

Insecticide Sampling

The Division cooperated in an extensive field program carried out by Charnetski to sample river water at different times and locations after each methoxychlor injection. The contribution to this program has been two-fold:

(a) To provide information of river engineering nature necessary to design each sampling program, such as determination of sampling times at the various sampling sites; and

(b) To provide sampling crews when and where necessary.

Analysis of Insecticide Concentration Data

Sample concentrations have been determined by Charnetski and the processed results have been made available for interpretation. Preliminary work has shown that, as had been expected, the insecticide is subject to considerable losses and cannot be assumed to behave as a neutral tracer. After consultation with Charnetski and other members of the research team, a physical model was formulated that seems capable of explaining the observed variations in recovery ratio with downstream distance. This is discussed in more detail later.

Neutral Tracer Tests

It was mentioned earlier that, at present, prediction of the transverse mixing coefficient in terms of stream hydraulics is not possible and that field tests are the only means for obtaining reliable estimates.

Two mixing tests were performed, on 26 September 1974 and 27 February 1975, to study both open-water and ice-covered conditions respectively. The test reach was about 20 km long, beginning at the bridge below the town of Athabasca. The information gathered is necessary for assessing initial rates of mixing, which are the most critical. The tracer used was 20% Rhodamine W.T. fluorescent dye. Both tests were of the slug-injection type and have been described in some detail elsewhere (Beltaos 1978).

Visual Documentation of Study Reach

A flight over the river between Athabasca and Fort McMurray was undertaken

on 13 November 1975 and various features of interest were photographed.

RESULTS AND ANALYSIS

River Description

Figures 5a and b show the study reach of the Athabasca River. This begins about 60 km upstream of Athabasca and ends at Fort McMurray. The following information has been taken from Kellerhals et al. (1972) and, although it is based on surveys conducted within a 5-km reach near Athabasca, it is thought to apply in general, at least above Grand Rapids.

The terrain surrounding the river valley is a moderately forested plain, partly cultivated and built-up. The mean temperatures for January and July are -14 and +15°C, respectively; the mean annual precipitation is 500 mm; and mean dates of river freezeup and breakup are 4 November and 23 April.

The valley is streamcut with moderately forested walls and is about 75 m deep. The top and bottom widths are about 2.5 and 0.3 km, respectively.

The channel is entrenched in the valley and exhibits an irregular pattern of considerable sinuosity (ratio of channel length to corresponding distance along the valley axis = 1.2) with occasional islands. The channel is stable laterally though the banks are subject to occasional slumping. The channel bed consists of a shallow layer of gravel with local sand over soft, cohesive clay.

Figure 6 is a longitudinal profile of the Athabasca River containing the study reach; this is reproduced from Kellerhals et al. (1972) with some modification. Beginning at Athabasca, the river steepens progressively until Fort McMurray and flattens drastically thereafter. Using the profile shown in Fig. 6, five sections with more or less constant slopes can be distinguished (Table 1).

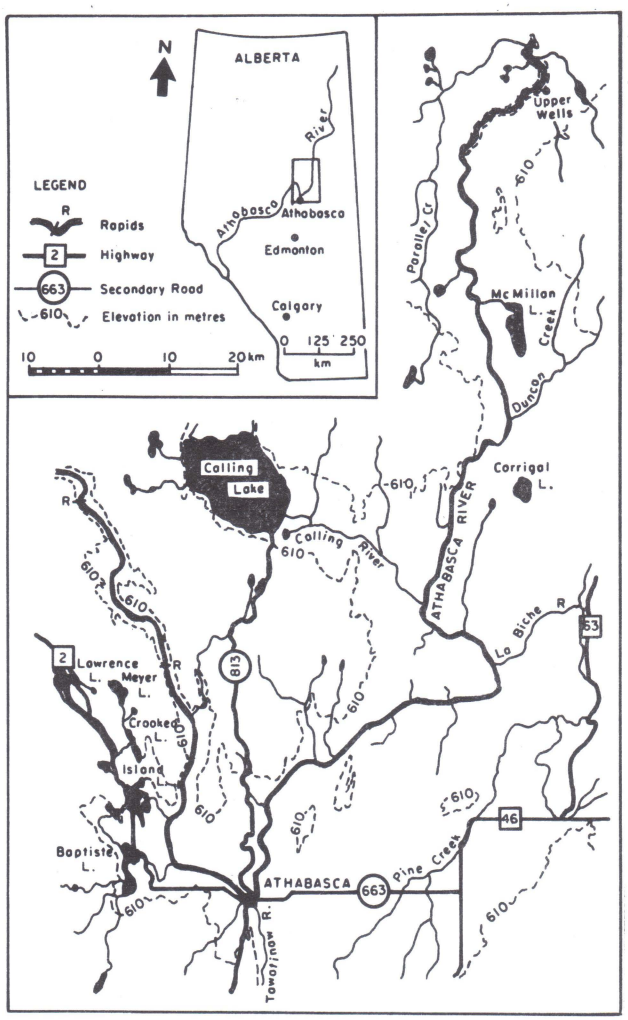

Fig. 5a. Study reach, Athabasca to Upper Wells.

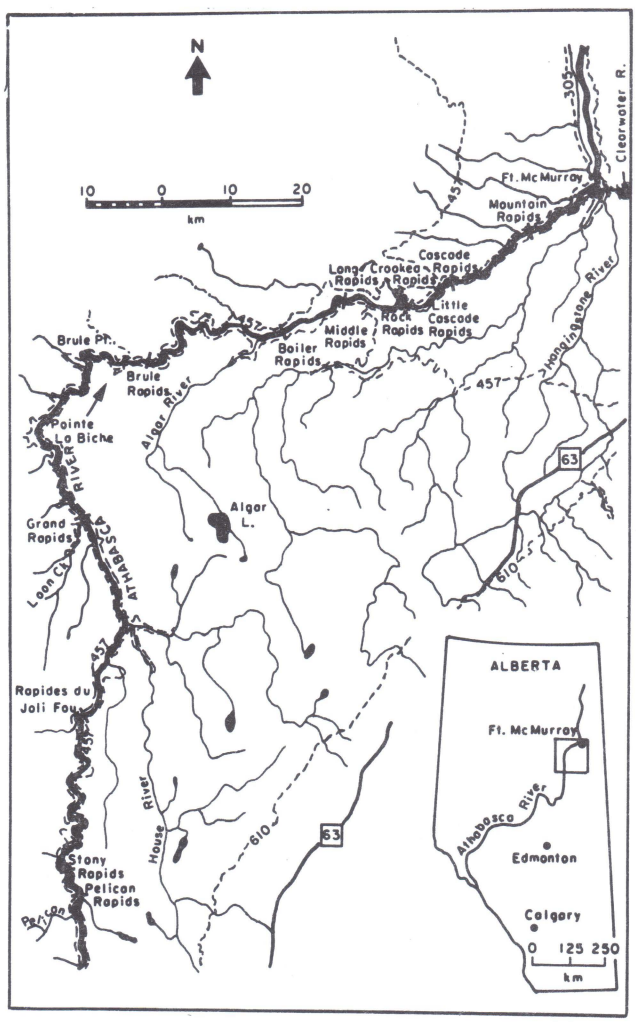

Fig. 5b. Study reach, Pelican River to Fort McMurray.

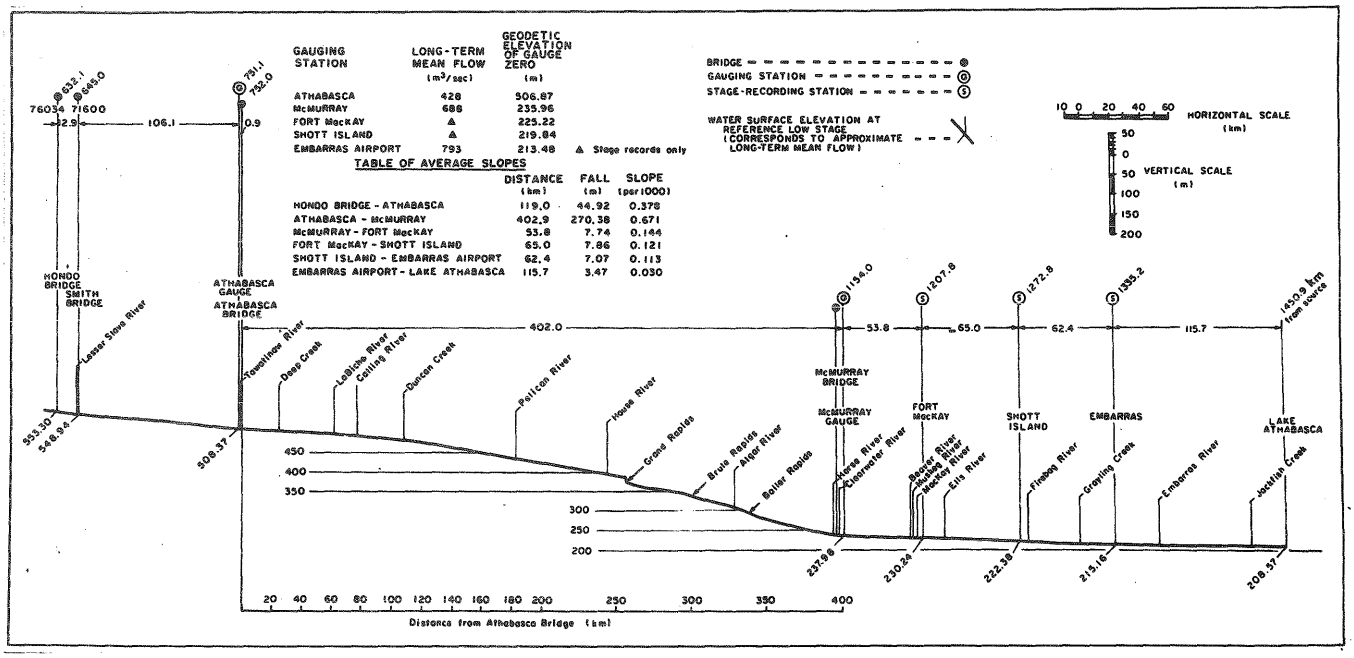

Fig. 6. Longitudinal profile of the Athabasca River from Hondo Bridge to Lake Athabasca.

Table 1. River slope for various reaches of the Athabasca River

Distance (km) from Athabasca Bridge	Description	Slope to next location (m/km)
0	Athabasca Bridge	
		0.26
95	Between Calling River and Duncan Creek	
		0.44
140	Between Duncan Creek and Pelican River	
		0.71
208	Between Pelican River and House River	
		0.61
258	Grand Rapids	
		0.98
396	Fort McMurray	

Grand Rapids is the third set of rapids encountered when traveling downstream from Athabasca, the previous two being Pelican Rapids and Stony Rapids, located a few kilometres below the mouth of Pelican River. The latter are relatively minor and generally passable by boat except at low water. However, Grand Rapids presents extreme hazards to boat passage and access to sites downstream has been achieved by air. Through this set of rapids, a fall of some 10 m is accomplished within a distance of about 1 km. (In Table 1, the final slope shown is between the toe of Grand Rapids and Fort McMurray.) Between Grand Rapids and Fort McMurray, the river steepens further and is ridden with more rapids, such as Brule, Boiler, Middle, Long, Rock, Crooked, Little Cascade, Cascade, and Mountain Rapids.

Hydrologic data for the study reach can be obtained by examining the Water Survey of Canada records for the gauge located at Athabasca (No. 07BE001). Kellerhals et al. (1972) indicate the long-term mean discharge to be 430 m^3/sec. The minimum flow was recorded on 14 December 1956 at 46 m^3/sec and the maximum on 10 June 1954 at 5,650 m^3/sec. Statistical analysis of the records indicates the 2-, 5-, 10-, and 50-yr floods to be 1,870, 2,775, 3,400, and 4,870 m^3/sec, respectively. Flows equalled or exceeded 0.5, 2, 10, and 50% of the time amount to 2,269, 1,650, 990, 254 m^3/sec. The bankfull discharge is estimated at 8,500 m^3/sec. Using data provided by the Water Survey of Canada, a rating curve can be determined for the gauge station. Kellerhals et al. (1972) indicate that the gauge height corresponding to zero discharge is -0.61 m. A plot of height above this datum versus discharge on log-log paper is shown in Fig. 7. The straight line defined by the data points has the equation:

$$Q = 96(gh + 0.61)^2 \qquad (6)$$

where Q is the discharge (m^3/sec) and gh is the gauge height (m). It should be noted that the above relation applies for open-water flow, and is not likely to hold during ice-covered conditions.

Daily flows for the years 1974, 1975, and 1976, as reported by the Water Survey of Canada are presented in Appendix 3 (1 ft^3/sec = 0.028 m^3 /sec).

River Hydraulics

General considerations

Because of the substantial volume of hydraulic data obtained by the Division during the 3 yr of field operations, it was

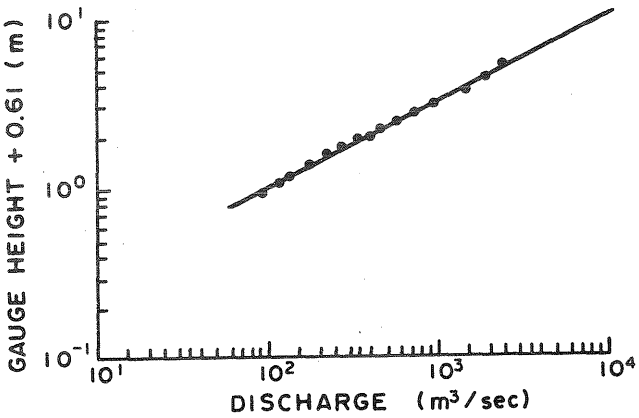

Fig. 7. Stage-discharge relationship for Athabasca River at Athabasca (Water Survey of Canada Gauging Station 07BE001).

felt that this material would be best presented separately, as an addendum to this report. The addendum is in the format usually adopted by the Division for filing data on various rivers of the province.

The information contained in the addendum includes 1:50,000 map coverage of the study reach, cross-sections and short longitudinal profiles, velocity distributions, bed material photographs, and miscellaneous photographs from both ground and air intended to provide visual descriptions of selected river sites. Brief explanatory notes are included at the beginning of the addendum. River thalweg profiles are in the files of the Alberta Research Council and may be inspected on request.

Table 2 is a summary of surveyed cross-sections in the study reach giving dates of survey and estimated discharge both at Athabasca and at the cross-section. The latter ignores tributary inflows below Athabasca.

For applying water level corrections due to different discharges at a section, it can be assumed that the water surface rises and falls as the discharge changes but remains parallel to itself. If the water level is available for a given discharge at a section and it is desired to determine the water level at a different discharge, the necessary correction can be found by subtracting the water stages corresponding to these discharges at the gauging station using Fig. 7 or Equation 6. This procedure will become increasingly unreliable with increasing distance from the gauge.

Assuming that a cross section has been sounded and the desired water level has been determined, the transverse distribution of depth-averaged velocity, u_d, can be derived using the following, approximate, procedure:

(i) Determine the cross-sectional area, A, and cross-sectional average velocity, V(=Q/A);

Table 2. Summary of surveyed cross sections

Distance from Athabasca Bridge (km)	Date surveyed	Estimated discharge (m^3/sec) At Athabasca	Estimated discharge (m^3/sec) At cross section
-61.80	22.05.74	1294	1256
-42.90	22.05.74	1294	1256
-21.70	22.05.74	1294	1294
- 0.03	10.09.74	515	515
	29.05.74	991	991
	03.06.74	793	793
0.06	28.05.74	1048	1048
0.28	28.05.74	1048	1048
0.69	28.05.74	1048	1048
1.76	12.09.75	430	430
2.74	17.09.74	521	521
3.74	23.05.74	1218	1218
	06.06.74	717	717
	11.09.74	575	575
	17.09.74	521	521
	11.09.75	448	448
5.54	17.09.74	521	521
6.92	17.09.74	521	521
8.53	17.09.74	521	521
8.65	28.05.74	1048	1048
	06.06.74	717	717
	17.09.74	521	521
8.77	12.09.75	430	430
10.08	05.06.74	722	722
	17.09.74	521	521
12.07	17.09.74	521	521
16.67	05.06.74	722	722
	16.09.75	360	360
17.11	16.09.75	360	360
18.46	16.09.75	360	360
19.06	28.05.74	1048	1048
	16.09.75	360	367
21.47	23.05.74	1218	1218
	11.09.75	448	459
	14.05.76	581	581
27.77	11.09.75	448	459
39.01	23.05.74	1218	1256
	11.09.75	448	459
	19.05.76	496	517
62.88	23.05.74	1218	1256
	17.09.75	346	360
77.33	29.05.74	991	1067
	17.09.75	346	360
	11.05.76	484	504
81.47	23.05.74	1218	1294
102.45	23.05.74	1218	1294
118.85	18.09.75	340	360
123.21	23.05.74	1218	1294
141.95	23.05.74	1218	1335
160.10	29.05.75	445	456
	09.09.75	501	572
160.40	19.05.76	496	569
161.82	23.05.74	1218	1335
163.86	11.05.76	484	507
178.00	24.05.74	1147	1256
	10.09.75	470	554
	18.05.76	538	615
199.09	19.06.75	612	574
	12.05.76	484	506
244.29	18.06.75	617	484
	12.05.76	484	507
276.12	06.06.76	478	511
326.00	03.06.76	498	493

(ii) Determine the average depth, H(=A/W), where W is the water surface width;

(iii) At a lateral location where the depth is h, estimate the value of u_d using the relation

$$u_d \simeq V(h/H)^{0.5} \qquad (7)$$

Flow of tributaries

Figures 5a and b show that several tributary streams enter the Athabasca River within the study reach; this results in a continuous downstream increase in the main channel discharge. Unfortunately, these streams are ungauged. To provide a 'feel' for the magnitude of tributary contributions to the flow recorded at Athabasca, the discharges of the major tributaries were measured in 1975 and 1976 (Table 3).

Table 3. Tributary discharges

Stream	Location of mouth (km)	Survey date	Discharge (m^3/sec) Stream	Athabasca[a]
La Biche River	63	16.09.75	40	360
		17.05.76	15	569
Calling River	77	17.09.75	27	346
		18.05.76	4	538
Duncan Creek	109	18.09.75	6	340
		18.05.76	0	538
Pelican River	182	10.09.75	28	470
		18.05.76	2	538
House River	244	18.09.75	40	538
		19.05.76	2	496

[a] Discharge estimated for Athabasca River at indicated location

The La Biche, Calling, Pelican, and House Rivers had similar and substantial flows in September 1975 but, with the exception of La Biche River, contributed negligible amounts to the Athabasca River flow in May 1976 (Table 3). Evidently, the relative contributions of the various tributaries to the main channel flow are subject to fluctuations, depending upon the size, type, and meteorologic conditions associated with the respective drainage basins. Because the tributaries are ungauged, there seems to be no simple or quick method for accurately predicting tributary inflows. Considering, however, that one is mainly interested in predicting the discharge of the Athabasca River between Athabasca and Fort McMurray, rather than tributary flows as such, the following procedure is suggested:

(i) Determine times of travel between Athabasca and Fort McMurray for a range of representative stages at Athabasca;

(ii) Taking into account the time of travel, compare the flow at Athabasca with the flow at Fort McMurray upstream of the Clearwater River mouth. The latter can be determined by examining simultaneous discharge values at three Water Survey of Canada gauges: Athabasca River below Fort McMurray, Clearwater River at Draper, and Hangingstone River at Fort McMurray;

(iii) Assume that the difference in discharge between Fort McMurray and Athabasca is due to the major tributaries, i.e. La Biche, Calling, Pelican, House, and Horse Rivers. Assign appropriate weighting factors for each of these streams by examining geographical and meteorological conditions as well as catchment areas. Divide the discharge differential according to the weighting factors.

Table 4 summarizes comparisons between flow data at the methoxychlor injection sites and corresponding flow data at Fort McMurray; times of travel have been considered. It is seen that, with the exception of the 20 May 1976 treatment, the cumulative tributary contribution is significant, ranging between 24 and 52% of the discharge at Athabasca.

Table 4. Estimates of total tributary inflows during treatments

Injection date[a]	Discharge (m^3/sec) At injection site	At Fort McMurray[b]	Total tributary contribution (m^3/sec)
04.06.74	748	929	181
04.06.75	484	734	250
20.05.76	538	553	15
25.05.76	419	530	111

[a] Except for 20.05.76 when injection was at 160 km, injection site was at Athabasca (0 km).

[b] Below Horse River but above Clearwater River.

Assuming, for simplicity, equal weighting factors for the major tributaries, one can use the data of Table 4 to determine the discharge at different sections of the Athabasca River for each injection (Table 5).

Flow distribution at injection sites

On the day before each treatment, designated injection sites were current-metered to determine the velocity and flow distributions. This information was necessary for designing injection procedures (see also Depner et al. pp. 21-37).

The first treatment took place in the early morning of 4 June 1974, and was carried out from seven point sources located

Table 5. Estimated discharge in reaches of Athabasca R. between major tributaries

Location	Site (km)	Discharge (m^3/sec) in reach for injection on-- 4.06 1974	4.06 1975	20.05 1976	25.05 1976
Athabasca[a]	0				
		748	484	538	419
La Biche[b]	63				
		784	534	541	447
Calling[b]	77				
		820	584	545	474
Pelican[b]	182				
		857	634	548	502
House[b]	244				
		893	684	551[c]	529[c]
Horse[b]	394				
		929	734	553	530
Ft McMurray[a]	396				

[a] At Bridge. [b] At River mouth.
[c] Water Survey of Canada data for Horse R. above mouth (gauge after 1976) considered.

on the downstream side of the Athabasca bridge. To avoid pier interference, a cross section located 30 m upstream of the bridge was surveyed and assumed to be representative of the injection site. The results were adjusted to the 4 June 1974 discharge (Fig. 8). The methoxychlor injection sites are also shown in this figure.

Beginning in 1975, the injection site was located a short distance downstream of the bridge and the injection procedure was changed in the hope of improving initial mixing. Figures 9, 10, and 11 summarize hydraulic characteristics for the 1975 and 1976 injection sites.

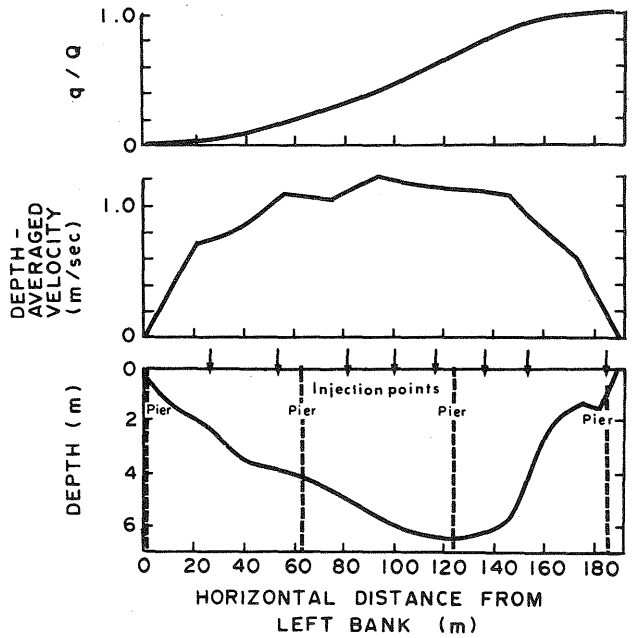

Fig. 8. Hydraulic characteristics of section 30 m upstream of injection site, 4 June 1974.

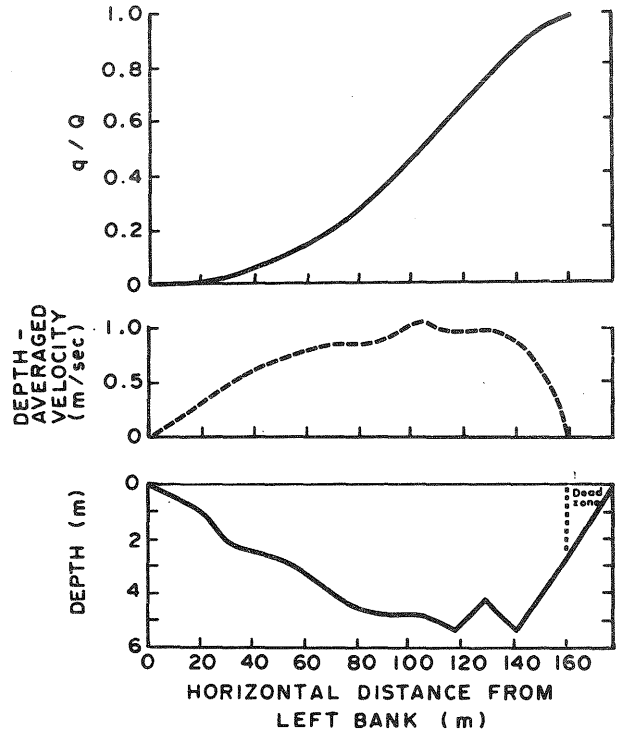

Fig. 9. Hydraulic characteristics of injection site, 4 June 1975.

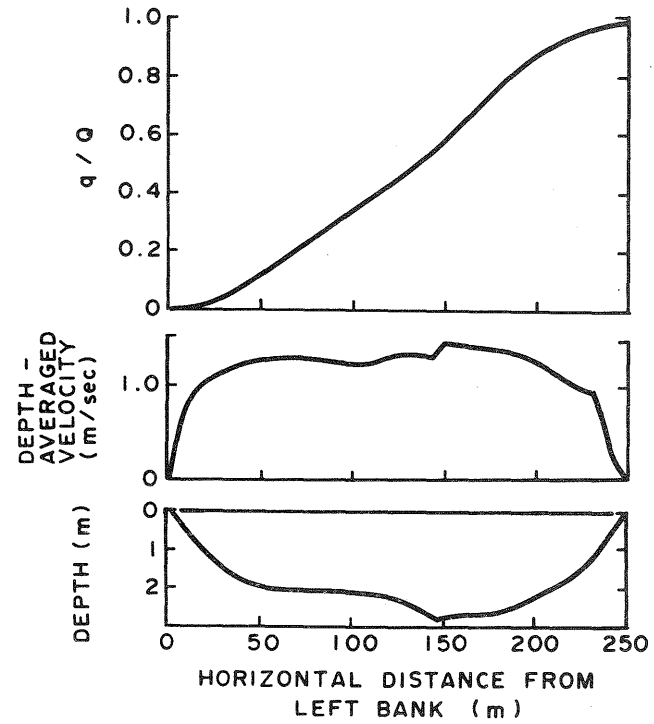

Fig. 10. Hydraulic characteristics of injection site (160 km), 20 May 1976.

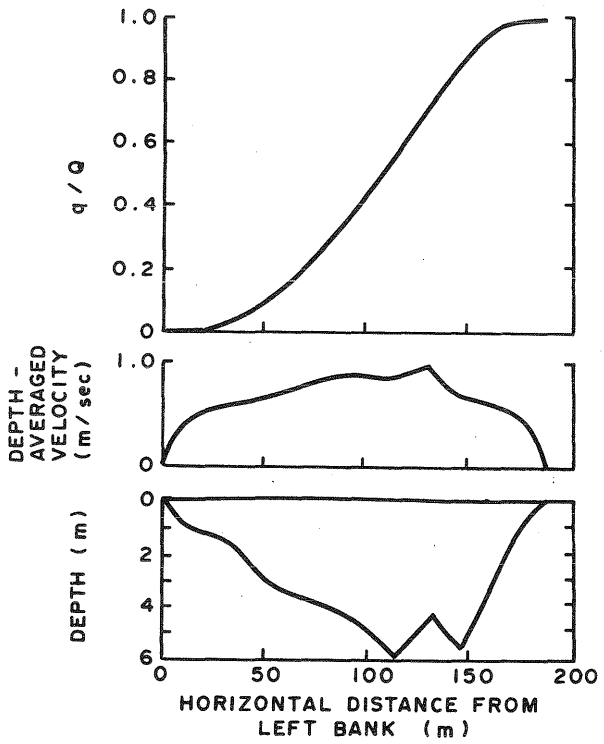

Fig. 11. Hydraulic characteristics of injection site, 25 May 1976.

Mixing Characteristics

Transverse Mixing Coefficient

As mentioned earlier, two neutral tracer tests were carried out in a 20-km reach beginning at the Athabasca bridge. These tests are described by Beltaos (1978). The hydraulic characteristics of the test reach were documented in considerable detail as indicated by the high frequency of surveyed cross sections in the first 20 km below Athabasca (see Table 2).

The main objective of these tests was to determine the transverse mixing coefficient for both summer and winter conditions. The results are summarized in Table 6 where H is the average flow depth (for a river reach, H is computed as the ratio of average flow area to average water surface width); and V_* is the shear velocity defined by:

Table 6. Transverse mixing coefficients from tracer tests

Date of test	Athabasca River discharge (m^3/sec)	Transverse mixing coefficient E_z (m^3/sec)	E_z/V_*H
16.09.74	566	0.067	0.41
27.02.75	105	0.010	0.28

$$V_* = (gR_hS)^{0.5} \quad (8)$$

where g is the acceleration of gravity, S is river slope, and R_h is the hydraulic radius, determined from the relations:

$R_h = H$ in open-water condition (9a)

$R_h = H/2$ in ice-covered condition (9b)

The relationship between flow stage, or discharge, and E_z is not known at present. It is believed, however, that for stages not very different from those prevailing during the tests, the respective dimensionless quantity E_z/V_*H will remain approximately constant. For open-water conditions, this assumption will result in the following approximate relation between E_z and Q:

$$E_z \simeq 3.7 \times 10^{-4}Q^{0.82} \quad (10)$$

where Q is in m^3/sec and E_z in m^2/sec. It is estimated that this relationship will be roughly valid for discharges between 400 and 800 m^3/sec.

Degree of mixing for methoxychlor injections

It was suggested in the Introduction that the degree of mixing for time-dependent processes should be based on the dosage, D (defined by Equation 1), as this is independent of time.

The degree of mixing can be defined in several ways, all of which are intended to provide a quantitative measure of how uniform a lateral distribution of concentration (or dosage) is. Regardless of definition, however, the degree of mixing increases with increasing distance downstream of the source and approaches 100% asymptotically.

Using the definition proposed by Yotsukura and Cobb (1972) and the transverse mixing coefficients outlined in the previous section, one can evaluate the degree of mixing for the first methoxychlor treatment, assuming the seven point sources shown in Fig. 8. For a neutral tracer, the degree of mixing would have been 90, 95, and 98% at 1.5, 19, and 48 km from the bridge, respectively. Though methoxychlor is subject to substantial losses, as will be seen later, it is believed that the above estimates provide a fair indication of the distances required before a desired degree of mixing is achieved.

Subsequent injections (1975 and 1976) were carried out from three boats moving across the stream, each boat covering lateral sections containing one-third of the flow. This procedure approximates a line source across the river and is believed to result in more efficient mixing than the procedure used in 1974.

Transport and Mixing of Insecticide

It was outlined in the Introduction that, in addition to purely hydraulic mixing processes, the spread of contaminants is influenced by substance-specific processes, such as buoyancy, decay, and absorption. Discussion with other members of the Blackfly Abatement team indicated that the main process of this kind for aquatic applications of methoxychlor is adsorption by bottom and suspended sediments. This notion can also be found in pertinent publications (e.g. see Gardner and Bailey 1975).

The first step in examining substance-specific processes on the basis of available information is to study the downstream variation of the recovery ratio. Figure 12 shows the methoxychlor recovery ratio plotted against x, the distance from the injection point, computed according to Equations 4 and 5. At sites where several time-concentration (C-t) curves were available, the numerical average of the dosage was used; when only one such curve was available, it was assumed that the dosage was reasonably well-mixed. Downstream changes in discharge due to tributary inflows have been approximated using the estimates shown in Table 5. The C-t curves used for computing the recovery ratios were provided by Charnetski. It is noted that concentrations are based on the entire amount of methoxychlor found in a water sample; this includes methoxychlor that is adsorbed by fine particles suspended in the water.

Inspection of Fig. 12 shows that the methoxychlor is subject to substantial losses, presumably caused by adsorption on the bed sediments. For the Athabasca injections, the amounts recovered in the water at Fort McMurray were between 10 and 14% of the injected amount. With the exception of two data points for 1975, the three injections at Athabasca seem to have resulted in similar downstream variations of the recovery ratio. Relatively high recoveries were observed below the 1976 injection site located at 160 km.

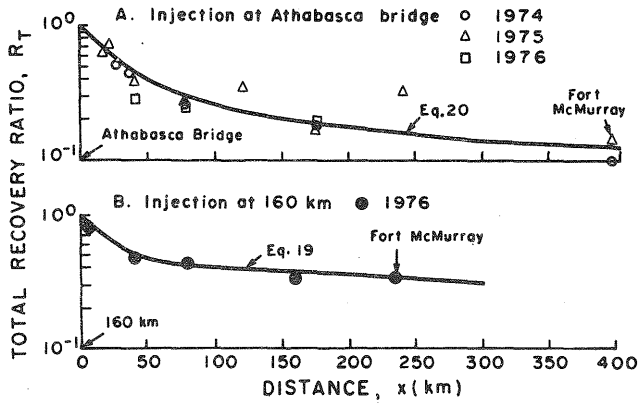

Fig. 12. Observed recovery ratio versus distance from injection; recovery ratios computed from data provided by Charnetski.

Analysis

The trends indicated by the data in Fig. 12 can be used as a starting point for identification of substance-specific processes associated with methoxychlor.

The simplest loss model is perhaps one where the effects of fine particles suspended in the water are ignored and it is assumed that the rate of loss to the channel boundary is proportional to the prevailing concentration. This model results in an exponential decline of R with x, which would be described by a straight line on a semi-logarithmic plot such as that of Fig. 12. However, the data points in Fig. 12 define curved lines, indicating a high initial rate of loss that decreases in the downstream direction.

Obviously, this simple model ignores one or more important processes. The following mechanism could account for the shapes of the curves of Fig. 12. The fine solid particles suspended in the water tend to adsorb dissolved methoxychlor. The loss to the boundary will then reflect both the rate of loss from the water and the rate of deposition of contaminated particles. The latter is expected to be very small for the fine sizes in suspension and, as a first approximation, could be neglected. Thus, a progressive transfer of methoxychlor to the suspended solids would result in less methoxychlor being available for transfer to the bed and thus causing a continuous reduction in the apparent rate of loss. This agrees with the trends shown in Fig. 12.

To translate this concept into quantitative terms, two assumptions were made.

1. The rate of mass adsorbed by suspended particles per unit volume of water is given by a linear sorption-desorption equation, viz.:

$$\Delta m_S / \Delta \Psi \Delta t = K_1 C_W - K_2 C_S \qquad (11)$$

where Δm_S is the net amount sorbed by fines within an elementary water volume $\Delta \Psi$ during a small time increment Δt; C_W and C_S are methoxychlor concentrations in water and in sorption, respectively, in terms of the water volume $\Delta \Psi$; K_1 and K_2 are coefficients with dimensions of $(\text{time})^{-1}$.

Implicit in Equation 11 is the assumption that the rates of sorption and desorption are proportional to the amounts of methoxychlor in the water and on the sediment, respectively. Positive values of $K_1 C_W - K_2 C_S$ imply net sorption and negative values imply net desorption. It is recognized that Equation 11 is a crude formulation. Adsorption phenomena can be very complex, especially when the process is

not confined to a single layer of adsorbed molecules around a particle. Furthermore, even when adsorption is of the monomolecular-layer type, Equation 11 is valid only when the amounts sorbed are very small in comparison to the maximum 'sorbable' amount. This consideration is illustrated in Appendix II where a simple quantitative description of monomolecular adsorption is presented. The derivation of the rate equation indicated further that the coefficient K_1 is proportional to C_o, the concentration of fines that contribute to sorption. On the other hand, the coefficient K_2 seems to depend only upon physical properties of the sediment and the water.

2. The rate of loss to the channel boundaries per unit boundary area was assumed to be proportional to the prevailing amount in the water, viz.:

$$\Delta m_B/\Delta A_B \Delta t = K_L C_W \qquad (12)$$

where Δm_B is the mass transferred to the boundary over a small area of the bed, ΔA_B, during a small time increment, Δt. The 'loss' coefficient K_L has the dimensions of velocity and could vary along and across the river. Generally, K_L is expected to increase with increasing intensity of turbulence near the bed. Note that losses due to deposition of contaminated particles have been neglected. Moreover, it is assumed that re-entrainment from the boundary is insignificant during the relatively short time of passage of the methoxychlor cloud (as is discussed later).

Integration of these equations for the recovered amounts M_W and M_S, in the water and on the suspended fines respectively, is possible under some simplifying assumptions, and results in (see Appendix II for derivations):

$$R_T = Be^{-r_1 x} + (1 - B)e^{-r_2 x} \qquad (13)$$

$$R_W = B_1 e^{-r_1 x} + (1 - B_1)e^{-r_2 x} \qquad (14)$$

$$R_S = B_2(e^{-r_1 x} - e^{-r_2 x}) \qquad (15)$$

Where e is the base of natural logarithms, $B = B_1 + B_2$ and the coefficients B_1, B_2, r_1, and r_2 depend on K_1, K_2, and K_L as well as on bulk hydraulic parameters such as Q, A, and W. Pertinent relationships are presented in Appendix II.

In deriving Equations 13, 14, and 15, it was necessary to make two simplifying assumptions.

1. Adsorbing particles are mostly very small, so that their fall velocities can be neglected. Hence, it is assumed that these particles remain permanently in suspension and are thus uniformly distributed throughout the flow.

2. The dosage, herein defined as the area under a C-t curve ($\int_o^\infty C dt$), is uniformly distributed across the river after a relatively short initial reach. This holds true for neutral tracers, but in the present situation it can be shown that perfect uniformity cannot be established. Despite this fact, this assumption is not a bad approximation, as detailed data from the 1975 sampling program show. For example, data provided by Charnetski have been used to calculate the dosages. At 8.8 km below the injection site, the dosages were 1,125, 1,734, 1,194, 1,461, and 1,994 µg min/liter at sampling points located at 0 (left bank), 0.25W, 0.5W, 0.75W, and W (right bank) from the left bank, respectively (W = river width). This shows poor mixing of dosage. However, at 21 km mixing was already nearly complete. The dosages at 0.25W, 0.5W, and 0.75W were 1,810, 1,625, and 1,509 µg min/liter respectively. For practical purposes, it could be assumed that uniformity of dosage was established at, say, 30 km with the possible exception of the 1974 injection.

The utility of making these assumptions is obvious. By means of Equations 13, 14 and 15, it is possible to obtain estimates of the amounts in the water and in sorption. It is shown later that this type of information may be crucial in quantifying blackfly control levels.

Another quantity of interest, which can also be estimated by the present analysis, is the residual amount of methoxychlor on the river bed. If M_B is the average amount of methoxychlor per unit bed area, it can be shown that (see Appendix II):

$$M_B = K_L \int_o^t [C_W]_{y=h} dt \qquad (16)$$

where $(C_W)_{y=h}$ denotes the concentration of methoxychlor in the water near the bed. The variation of M_B with time at a site where C_W varies as shown in Fig. 13a, is shown in Fig. 13b. The final value of M_B is denoted by M_{BF} and occurs at the time of departure of the water cloud, t_d. According to Equation 16, M_{BF} should remain unchanged after t_d. In actuality, however, one would expect the bed residue to decrease after t_d due to decay. These processes, as well as the downstream movement of the bed surface as bed load, have been ignored in deriving Equation 16. This was felt justified because rates of bed movement relative to water velocities are very low and very little is known about decay rates. Assuming again that good mixing of the dosages has been established, the final bed residue can be shown to be given by the following equation:

$$QM_{BF}/K_L M_o = R_W = B_1 e^{-r_1 x} + (1 - B_1)e^{-r_2 x} \qquad (17)$$

To express the bed residue in terms of an average bed concentration, C_B, the thickness of the contaminated bed layer, y_B,

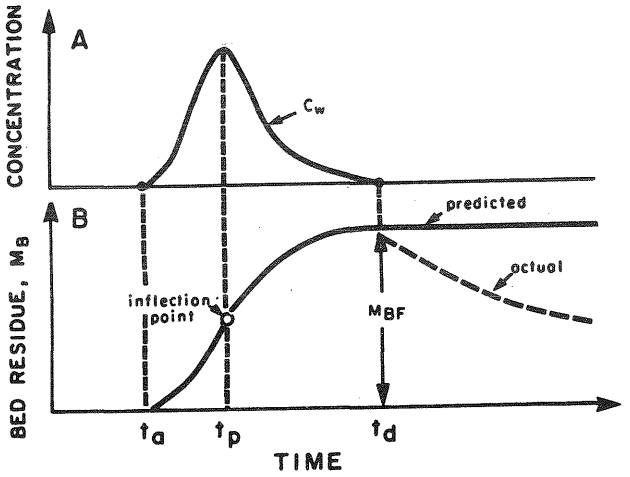

Fig. 13. Sketch of bed residue variation with time.

must be known or estimated. If C_B denotes mass per unit bed volume, then $C_B = M_B/y_B$. If the porosity of the contaminated bed layer is p_B and ρ_B is the density of the bed material, the concentration C'_B expressing mass of methoxychlor per unit mass of bed material will be $C'_B = C_B/\rho_B(1 - p_B)$. It follows that:

$$C'_{BF} = [K_L M_o/\rho_B(1 - p_B)y_B Q]R_W \qquad (18)$$

Determination of Sorption and Loss Coefficients

Figure 12a shows that the observed R_T - x variations for the three injections at Athabasca are nearly identical but differ from the curve observed below 160 km, associated with the first 1976 treatment (Fig. 12b). The difference lies mainly in that recovery ratios for the latter are generally greater than corresponding values for the Athabasca treatments. The river profile (Fig. 6) between Athabasca and Fort McMurray shows a 'flat' section upstream of about 140 km that is succeded by a 'steep' section extending from 140 km to Fort McMurray. Through the steep section, the river is capable of transporting a greater amount of fines in suspension than through the flat section. Since the suspended fines act as 'carriers' of the methoxychlor, this would explain the relatively high recovery below 160 km. Considering Fig. 12b, it was found that the equation

$$R_T = 0.44e^{-0.0012x} + 0.56e^{-0.0518x} \qquad (19)$$

described the data points satisfactorily. Equation 19 implies that B = 0.44, r_1 = 0.0012/km, and r_2 = 0.0518/km. Using Equations A40 - A43 (Appendix II), we find further than B_1 = 0.018, B_2 = 0.422, K_1A/Q = 0.0214/km, K_2A/Q = 0.0021/km, and K_LW/Q = 0.0295/km. Analysis of C-t curves associated with this treatment (see Beltaos and Charnetski, pp. 123-130) indicated that the mean rate of travel of methoxychlor was 1.17 m/sec. This provides a good estimate of the average flow velocity, V, which is equal to Q/A, A being the reach-average cross sectional area. It follows that K_1 = 0.0214 x 1.17 x 10^{-3} = 2.5 x 10^{-5}/sec or 2.16/day. Similarly, K_2 = 0.25 x 10^{-5}/sec or 0.21/day. Using available cross-sectional measurements, the average width below 160 km is estimated as 275 m. This value together with a value of Q = 538 m^3/sec (Table 4) can be used to determine K_L; this gives: K_L = 0.0295 (1.96 x 10^{-3}) = 5.77 x 10^{-5} m/sec or 5.0 m/day.

Inspection of Equations A36 - A38 shows that the calibration coefficients B_1, B_2, r_1, and r_2 are determined uniquely by the quantities K_1A/Q, K_2A/Q, and K_LW/Q. Since the values of A/Q and W/Q are expected to change with stage, the calibration coefficients are likely to vary with discharge within a river reach, even if K_1, K_2 and K_L do not. Therefore, there is no theoretical justification for the apparent coincidence of R_T - x variations observed after the three treatments at Athabasca. However, preliminary calculations have shown that Equation 13 is rather insensitive to changes in K_1A/Q, K_2A/Q, and K_LW/Q and this could account for an approximate coincidence of recovery ratios below Athabasca. The curve drawn in Fig. 12a has the equation,

$$R_T = 0.24e^{-0.0016x} + 0.76e^{-0.0284x} \qquad (20)$$

and seems to describe the data points satisfactorily. Equation 20 implies B = 0.24, r_1 = 0.0016/km and r_2 = 0.0284/km. From Equations A40 - A44, we find further that B_1 = 0.018, B_2 = 0.222, K_1A/Q = 0.00594/km, K_2A/Q = 0.00212/km, and K_LW/Q = 0.02196/km. Using again observed mean rates of travel for the reach Athabasca - Fort McMurray, the average flow velocities for the 1974, 1975, and 1976 treatments at Athabasca were estimated as 1.21 m/sec, 1.08 m/sec, and 0.94 m/sec, respectively. Therefore, K_1 = 0.56 x 10^{-5}/sec - 0.72 x 10^{-5}/sec (0.48/day - 0.62/day); and K_2 = 0.20 x 10^{-5}/sec - 0.26 x 10^{-5}/sec (0.17/day - 0.22/day). The average values of Q/W were estimated as 3.06, 2.23, and 1.85 m^2/sec for the 1974, 1975, and 1976 treatments, respectively. Therefore, K_L = 4.06 x 10^{-5} - 6.72 x 10^{-5} m/sec (3.51 - 5.81 m/day).

The average values of K_1, K_2, and K_L for the three treatments at Athabasca work out to be 0.64 x 10^{-5}/sec (0.55/day), 0.23 x 10^{-5} /sec (0.20/day), and 5.23 x 10^{-5} m/sec (4.52 m/day) respectively. These values are believed to be fair averages for the reach Athabasca - Fort McMurray. Note that, strictly speaking, one should split this reach in two sections, above and below 140 km, and assign different sets of coefficients to each. However, in view of the tentative nature of the analysis (see also later discussion), the additional effort required for this elaboration is felt to be unjustified. Table 7 summarizes the sorption and loss coefficients.

Table 7. Summary of sorption and loss coefficients

Reach	Coefficient K_1 (days^{-1})	K_2 (days^{-1})	K_L (m/day)
Athabasca to Ft. McMurray[a]	0.55	0.20	4.5
160 km to Ft. McMurray[b]	2.2	0.21	5.0

a Averages of three treatments.
b First treatment, 1976.

The simple sorption-desorption model outlined in Appendix II indicated that K_2 depends solely upon physical and chemical properties of the liquid-suspended solids combination. Table 7 seems to confirm this prediction, since the values of K_2 for the two reaches studied practically coincide, despite differing hydraulic characteristics. However, the value of K_1 for the steeper reach is some four times that found for the flatter reach. The present sorption model predicts that K_1 should be proportional to the concentration of adsorbing fines and thus agrees qualitatively with this finding, since the steeper reach can support higher suspended material loads. The values of K_1 shown in Table 7 are comparable, the second one being somewhat greater than the first. This probably reflects increased turbulence in the steep reach. Using the coefficients corresponding to Equations 19 and 20 and applying Equations 14 and 15, one can compute the recovery ratios for the water and sediment, R_W and R_S

for Athabasca - Fort McMurray:

$$R_W = 0.18e^{-0.00164x} + 0.982e^{-0.0284x} \quad (21a)$$

$$\text{and } R_S = 0.222(e^{-0.00164x} - e^{-0.0284x}) \quad (22a)$$

for 160 km - Fort McMurray:

$$R_W = 0.18e^{-0.0012x} + 0.982e^{-0.0518x} \quad (21b)$$

$$\text{and } R_S = 0.422(e^{-0.0012x} - e^{-0.0518x}) \quad (22b)$$

Figure 14 shows these variations graphically. It is of interest to note that the amounts on the sediment peak within 75-100 km from the injection site. Obviously, upstream of the location of this peak there is net sorption but downstream there is net desorption. For the 160 km injection, the peak of R_S occurs earlier than that for the Athabasca injections because of the higher sorption coefficient, K_1.

The amounts in the water are seen in Fig. 14 to decrease continuously and at 400 km become only 1% of the injected amount. At this location, between 12 and 26% of the insecticide is on the suspended sediment.

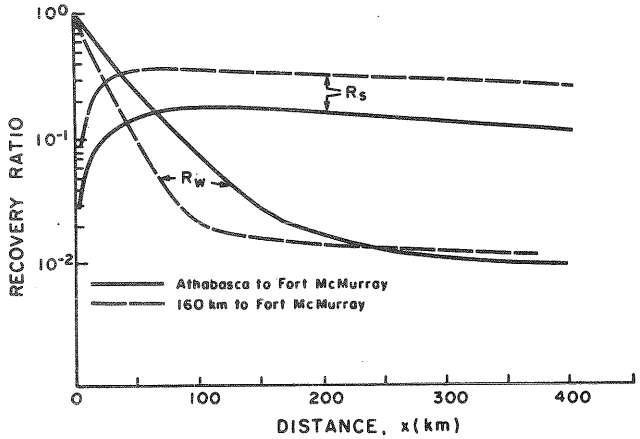

Fig. 14. Calculated recovery ratios for methoxychlor in the water and in sorption.

If the river water contained no adsorbing particles, the total recovered amount would decline very rapidly and be only 0.5% of the injected amount at 200 km.

The final bed residue can be computed using Equation 18 which shows that it decreases as R_W. To determine numerical values of C_{BF}, an estimate of the contaminated bed layer thickness is required. This could perhaps be done by comparing Equation 18 to the bed residues measured by Charnetski. It should be noted that, because of the extreme variability of bed conditions that is typical of natural streams, bed residue calculations cannot be expected to provide any better accuracy than order-of-magnitude estimates.

Numerical Techniques

Work toward the development of a computer program that will successfully simulate the processes involved in the movement of the insecticide was started in 1974. The first stage of this attempt consists of simulating the purely river-induced processes, such as advection and diffusion, on the assumption that the injection material is a neutral tracer possessing physical and chemical properties identical to those of water.

Difficulties experienced with conventional explicit-type numerical schemes led to the development of a more elaborate, but still explicit, computation program. This program, which employs a space grid with elements of variable size, has been tested successfully using suitable data available from the literature. The program is thus deemed satisfactory and a sub-routine, which generates the space grid for natural stream applications, has been developed for convenience.

Incorporation of the sorption/desorption and bed loss processes, expressed quantitatively by Equations 11 and 12, is now possible. However, in view of the as-yet

speculative nature of these hypotheses, and of the additional complexity that will be introduced due to the requirement for simultaneous solutions for C_W and C_S, it is felt that this task should not yet be undertaken. A practical approach would be to use the program as it is and reduce the computed concentrations at any one site by factors equal to corresponding recovery ratios.

Quantification of Control Data

To quantify the larval control observations, it is necessary to establish the precise cause of a larva's detachment. Although a number of possible control mechanisms can be postulated at present, the simplest would probably be to assume that a larva detaches when the amount of methoxychlor accumulated inside it becomes equal to, or greater than, a certain critical mass, say m_{cr}. This critical mass is likely to vary among individuals of a given population and it is thus reasonable to assume that there exists a statistical distribution function, p(m), such that:

$$P(m \leq m_{cr} \leq m + dm) = p(m)dm \qquad (23)$$

where P(E) is the probability of an event E occurring and p(m)dm is the probability that m_{cr} lies between m and m + dm, dm being an elementary increment of m. Figure 15 gives a schematic representation of a plausible function for p(m).

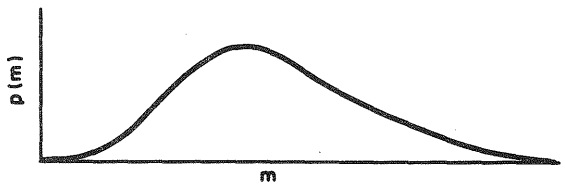

Fig. 15. Probability density function of m_{cr}.

Considering a sufficiently large larval population whose individuals are subjected to, and take up, increasing amounts of insecticide, it can be shown that the total number detached at any one time t (at which the uptaken mass is m) is given by:

$$N_{det} = N_o \int_o^m p(m)dm = N_o F(m) \qquad (24)$$

Where N_o is the initial number of larvae. Hence the control, expressed as a fraction, will be:

$$\text{Control} = N_{det}/N_o = F(m) \qquad (25)$$

where F(m) is the cumulative density function of m. Thus one would expect that the control levels observed in the Athabasca River will correlate with the methoxychlor amounts taken up by the larvae. It is possible that F(m) depends upon the stage of larval development so that correlations between control and m might be subject to seasonal variations.

To calculate values of m, it is assumed that uptake occurs by two mechanisms, ingestion and skin adsorption. Let f be the number of 'feeding' movements per second, $\forall_o$ the volume of water intercepted at each movement, and $\forall_1$ the volume of water discarded before ingestion. Then, the rate of methoxychlor ingestion will be:

$$dm_i/dt = f\forall_o\{[1 - (\forall_i/\forall_o)]C_W + C_S\} \qquad (26)$$

and the total amount ingested after the passage of the methoxychlor:

$$m_i = f\forall_o D_o(\beta_1 R_W + R_S) \qquad (27)$$

where D_o is the injected dosage and β_1 denotes the quantity $1 - (\forall_1/\forall_o)$. Obviously, β_1 varies between zero and one and reflects the degree of larval preference for solid particles. The lower limit, $\beta_1=0$, implies that the intercepted amount of water is discarded entirely, while the upper limit, $\beta_1 = 1$, implies that no water is discarded. To calculate m_a, the amount absorbed by skin contact, it is assumed that the rate of absorption is proportional to the concentration of methoxychlor in the water, viz.:

$$dm_a/dt = qC_W \qquad (28)$$

where the coefficient q reflects larval properties. The total amount absorbed after the passage of the methoxychlor is then:

$$m_a = qD_oR_W \qquad (29)$$

Adding Equations 27 and 29 gives the total uptake, m:

$$m = m_i + m_a = f\forall_o D_o(\beta R_W + R_S) \qquad (30)$$

where $\beta = \beta_1 + (q/f\forall_o)$. Note that q is equal to the volumetric rate of water absorption while $f\forall_o$ is the volumetric rate of interception of water during 'feeding'. Intuitively, one would expect that the latter is considerably larger than the former, so that the ratio, $q/f\forall_o$, should be much less than one.

The quantities f, $\forall_o$, q, and β are not known at present but can be assumed to be larval constants, possibly dependent upon stage of development or age. If this is so, the observed control levels should correlate with the quantity $D_o(\beta R_W + R_S)$. The coefficient β can be chosen so as to optimize the correlation. Preliminary calculations showed that a value of β of about 0.25 results in variations of $\beta R_W + R_S$ with x

that exhibit a long, initial 'plateau' followed by a gradual decline. This variation is similar to the measured control variations shown in Fig. 16.

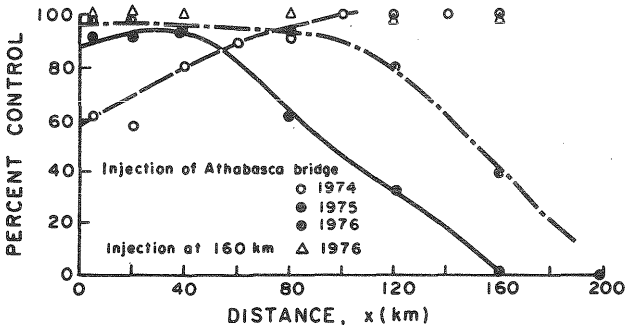

Fig. 16. Variation of control with distance from injection; control data provided by Depner.

Plots of observed control levels for all treatments versus corresponding values of 'uptaken' dosage, $D_0(0.25\ R_W + R_S)$, are shown in Fig. 17. It is seen that a good correlation exists between this dosage and control for all the treatments with the exception of four data points from 1974 showing a decline of control, despite increasing dosage, beyond 870 µg min/liter. These points correspond to the early sites and attempts to improve the correlation by lowering the values of β were not successful. At present, it is not known whether this effect is genuine or caused by factors such as insufficient mixing or statistically inadequate larval populations. If, for the present, the data points beyond 870 µg min/liter are ignored, Fig. 17 would suggest that the minimum uptake necessary for 100% control is about 650-700 µg min/liter, while no control can be expected for uptakes less than 350-375 µg min/liter.

The 1975 and 1976 data in Fig. 17 show two relationships. Depner indicated (pers. commun.) that this cannot be ascribed to

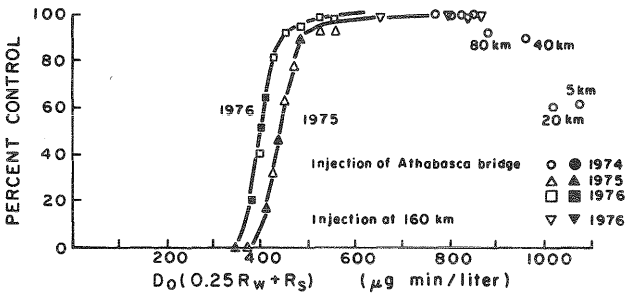

Fig. 17. Observed control versus uptake of methoxychlor; control data provided by Depner. (Open symbols indicate observed control values; closed symbols indicate interpolated control values.)

different larval susceptibilities in the different treatments. Considering also the many assumptions used in computing uptakes and that only a 10% shift in uptake would cause the curves (Fig. 17) to coincide, this difference could be attributed to experimental and analytical uncertainties. It is also noted that use of uncorrected 1975 control data (Charnetski et al., fig. 8, p. 51) would almost result in a single curve for 1975 and 1976 in Fig. 17.

The value 0.25 suggested by the present analysis for coefficient β indicates that ingestion of contaminated particles of sediment controls larval populations four times more efficiently than water ingestion and skin absorption combined.

Applications

Though the model described in the previous sections should not be regarded at present as anything better than a working hypothesis (see also later discussion), it is of interest to illustrate its practical application. This can best be accomplished by working out an example.

Consider a stream in which a 100-km reach is known to be infested with blackfly larvae. It is required to determine the location of treatment and the amount of methoxychlor necessary for full control of the larvae within this reach. It is estimated that, at the time of the treatment, the stream width, velocity, and discharge will be 100 m, 1.0 m/sec, and 300 m^3/sec. The stream is thought to carry a moderate load of suspended fines.

At this time, it is not known how the coefficients K_1, K_2, and K_L relate to stream characteristics and thus it is necessary to use values similar to those deduced for the Athabasca River. With reference to Table 7, let K_L = 5 m/day, K_1 = 1.0/day, and K_2 = 0.2/day. This selection gives K_1A/Q = 0.01157/km, K_2A/Q = 0.00231/km, and K_LW/Q = 0.01929/km. Applying Equations A36 - A39 gives further: r_1 = 0.00141/km, r_2 = 0.03177/km; B_1 = 0.0298, B_2 = 0.381, and B = 0.411. Recalling Equations 14 and 15 indicates that the value of $0.25\ R_W + R_S$, denoted by R' for simplicity, is:

$$R' = 0.3885e^{-0.00141x} - 0.1385e^{-0.03177x} \quad (31)$$

The uptaken dosage is D_0R'; the location of injection and D_0 should be selected so that D_0R' exceeds 700 µg min/liter throughout the infested reach. This should be accomplished with the minimum possible value of the initial dosage, D_0. Table 8 shows the variation of R' with distance, x, downstream of the injection site. Obviously, injection at a site 30 km upstream of the beginning of the infested reach will result in values of R' that are equal to, or greater than, 0.32 in the infested reach. The initial dosage should be such that

$$D_0R' \geq 700 \text{ µg min/liter} \quad (32)$$

This gives $D \geq 700/0.32$ µg min/liter. Therefore, the minimum required dosage is 2,190 µg min/liter. Inspection of Table 8 will indicate that if the injection site is placed anywhere else than 30 km upstream of the infested reach, the dosage required for full control will exceed the above value.

Table 8. Calculated downstream variation of uptake

x (km)	R'
0	0.250
5	0.268
10	0.282
30	0.319
50	0.334
100	0.332
130	0.321
200	0.293

DISCUSSION

A simple analytical model for larval control by means of insecticide applications in rivers has been presented. Three basic hypotheses are necessary for constructing a model of this type:

1. Description of sorption/desorption phenomena by a rate equation;

2. Description of loss mechanism at channel boundaries by a rate equation; and

3. Description of insecticide effects on larvae by postulating the detachment mechanism.

The assumptions employed in formulating the present model are summarized in Equations 11, 12, and 23. Equation 11 gives the net rate of adsorption of methoxychlor by the suspended fines per unit water volume. This rate is assumed to be related linearly to the prevailing methoxychlor concentrations in the water and on the sediment. Detailed calculations presented in Appendix II indicate that this assumption will be valid so long as adsorption occurs on one-molecule thick layers around the adsorbing particles and the amounts sorbed remain much smaller than the maximum sorbable values.

The sorption coefficient K_1 was shown to depend on physical and chemical properties of the liquid-sediment combination; at the same time, it was predicted to vary in direct proportion to the concentration of adsorbing particles. This prediction was supported qualitatively by the numerical values of K_1 deduced from recovery ratio observations for both the Athabasca and 160 km injections.

The desorption coefficient K_2 was shown in Appendix II to depend only upon physical and chemical properties of the liquid-sediment combination. This expectation was also supported by the values determined empirically for the two treatment reaches involved.

Equation 12 gives the rate of methoxychlor transfer to the bed per unit bed area; this is assumed to be proportional to the prevailing concentration in the water. This hypothesis implies that: (a) losses due to deposition of contaminated adsorbing particles are negligible, (b) decay of bed residue is negligible during the passage of the methoxychlor cloud, and (c) no re-entrainment of methoxychlor from the bed to the water occurs during the passage of the cloud. The first of these assumptions is thought to be reasonable because, even though the contaminated particles are expected to strike the bed frequently, they would normally bounce back into the flow almost instantaneously. However, deposition can occur if a particle is 'buried' on impact by the moving bed load. This eventuality cannot be precluded, but it is believed that only a very small fraction of particles impinging on the bed are retained. Little is known at present about decay rates of bed residues of methoxychlor. However, some of Charnetski's data seem to suggest 'half lives' of several days. With the exception of sites located at Fort McMurray, the time of passage of methoxychlor at the various sampling sites did not exceed 3 days; this would seem to suggest that one could, as a first approximation, neglect the decay process. If necessary, re-entrainment of methoxychlor from the bed could be accounted for by generalizing Equation 12 to read:

$$\Delta m_B / \Delta A_B \Delta t = K_L C_W - K_E M_B \qquad (33)$$

K_E being an 'entrainment' coefficient. However, this was felt unjustified at present in view of the additional complexity involved.

To integrate the differential equations describing methoxychlor amounts in the water and in sorption, it was necessary to introduce three additional assumptions: (a) adsorbing particles are very small and thus have negligible fall velocities: this, in turn, suggests that they are uniformly distributed throughout the channel; (b) the dosages D_W and D_S become almost uniformly distributed across the channel beyond a sufficient distance downstream of the injection site; and (c) the downstream movement of the surficial bed layer as bed load is negligible.

Because of the many assumptions involved in the derivation of the present model, the available field data are hardly sufficient to provide satisfactory confirmation. Therefore, this model should be regarded at present as only a working hypothesis. Its value lies mainly in illustrating that analytical formulation and solution of the abatement problem is possible. Based on the preceding discussion, it is felt that future research in this regard should include laboratory

experiments to elucidate sorption-desorption processes. By eliminating the additional complications imposed by advection and diffusion effects that are present in natural streams, it will be possible to isolate the sorptive process and thus obtain direct tests of the hypotheses advanced here. If these are found inadequate, the laboratory results will provide a basis for appropriate modifications. Field tests, preferably in small streams, are also deemed desirable; specific objectives and procedures should only be considered after the results of the laboratory work become available.

A method for correlating control with amounts of insecticide to which the larval populations are subjected was presented earlier in this report. For simplicity, it was postulated that the fundamental control mechanism is the uptake of methoxychlor by both ingestion and skin absorption. This method has resulted in some encouraging findings, but it is possible that the assumed control mechanism is too simple. For example, the accumulation of insecticide within a larva may be partly counteracted by internal degradation or excretion, or both (R. Wallace, personal communication); larvae might possess an 'irritability'-type defense mechanism that causes detachment when ambient concentrations become too great (K. R. Depner, personal communication). Such processes have been ignored for the present, but they may prove to be important. Obviously, laboratory experiments to identify the control mechanisms involved would be desirable. If irritability turns out to be important, it is comforting to note that the statistical approach outlined earlier can be extended to include a 'critical concentration' concept.

Despite the many uncertainties associated with the present analysis, it is felt that two major conclusions can be drawn.

1. The progressive transfer of methoxychlor from the water to fine suspended particles by adsorption greatly enhances the capacity of natural streams to carry the insecticide for long distances below the injection site.

2. The effectiveness of the insecticide in controlling larval populations in the Athabasca River is mostly due to ingestion of contaminated solid particles by the larvae.

These results suggest that there may be merit in using particulate formulations of methoxychlor. Identification of particle sizes preferred for ingestion by target and non-target organisms would seem to be the starting point for efficient design of selective control operations (R. Wallace, personal communication).

SUMMARY AND CONCLUSIONS

The field work, results, and analysis carried out by the Transportation and Surface Water Engineering Division of Alberta Research Council in conjunction with the Athabasca Blackfly Abatement Program have been described in this report. The Division's objectives consisted mainly of providing hydrometric documentation of the river in the study area and studying the movement and mixing of the methoxychlor in the river.

After a brief, introductory review of mixing processes in natural streams and a summary of activities and methods, the results and pertinent analysis have been presented in detail. The hydrometric information included a general description of the river in the study area as well as river hydraulics. The latter addresses specific problems such as river geometry and velocity distributions, tributary inflows, and flow distribution at injection sites. Because of the large volume of field documentation accumulated to date, it was decided to present this information in the form of an addendum and concentrate here on the analysis of the results.

Mixing characteristics of a 20-km reach beginning at Athabasca were documented by tracer tests under both open-water and ice-covered conditions. These tests provided estimates of the respective mixing coefficients. For open water conditions, the results are summarized by Equation 10, which relates the transverse mixing coefficient to river discharge. This relationship was used to compute the efficiency of mixing during the first treatment (1974), which was carried out in a manner that is thought to have been less effective than subsequent injections. It was found that satisfactory mixing would occur only beyond some 50 km from the injection site. It is believed that this distance was greatly reduced for the 1975 and 1976 injections.

Examination of methoxychlor recovery and its variation downstream of each injection site indicated that this substance is not a neutral tracer. To explain the observed variations, two substance-specific processes were postulated, namely adsorption by fine particles in suspension and losses to the river bed. Quantitative formulation of the problem and integration of the resulting differential equations enabled the derivation of analytical relations to describe the observed recovery ratio variations and to distinguish between amounts in the water and in sorption, respectively. Numerical applications require knowledge of three, at present empirical, coefficients. The values deduced from recovery data for the Athabasca River were consistent with a simple sorption-desorption model described in Appendix II.

To quantify the observed control levels, a probabilistic approach was developed which, together with the above results, enabled correlation between control data and uptake of insecticide by the larvae. It was found that full control would require an 'uptaken' dosage of 700 µg

min/liter or more, whereas no control should be expected below 350 µg min/liter. 'Uptaken' dosage depends on injected dosage, river hydraulics, and sorption-loss coefficients as well as distance from the injection site. An example of applying the present findings to optimize treatment procedures was worked out as an illustration.

The importance of adsorbing particles suspended in the water for both long range transport of the insecticide and efficient control of larval populations was well documented.

Discussion of the several assumptions involved in deriving the present model enabled identification of future research needs. These should aim at testing the sorption-desorption mechanisms postulated and identifying the mechanisms that cause detachment of larvae.

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APPENDIX I. LIST OF SYMBOLS

SYMBOL	DESCRIPTION
A	cross sectional area
A_B	channel bed area
a_a	area of an adsorbing site
a_p	surface area of a particle
B, B_1, B_2	dimensionless coefficients
C	concentration
C_B	bed concentration
C'_B	bed concentration in terms of dry bed weight
C_S	concentration of methoxychlor in sorption
C_T	total concentration of methoxychlor
C_W	concentration of methoxychlor in the water
C_o	concentration of suspended adsorbing fines
D	dosage
D_S	dosage of methoxychlor in sorption
D_T	total dosage of methoxychlor
D_W	dosage of methoxychlor in the water
D_o	initial dosage of methoxychlor
E_z	transverse mixing coefficient
e	basis of natural logarithms
F	a function
F_y, F_z	fluxes in y and z directions
f	frequency of larval feeding movements

SYMBOL	DESCRIPTION
H	average flow depth
h	local flow depth
K_E	entrainment coefficient, (T^{-1})
K_L	loss coefficient, (LT^{-1})
K_1	sorption coefficent, (T^{-1})
K_2	desorption coefficient, (T^{-1})
M	mass
M_B	methoxychlor residue per unit bed area
M_S	mass of methoxychlor in sorption
M_W	mass of methoxychlor in the water
M_o	injected mass of methoxychlor
m	mass
m_a	mass of methoxychor entering a larva by skin absorption
m_B	mass of methoxychlor on river bed
m_{cr}	critical mass for larval detachment
m_i	mass of methoxychlor entering a larva by ingestion
m_M	mass of a methoxychlor molecule
m_S	mass of methoxychlor adsorbed by suspended fines
N	number of adsorbing particles in a small water volume
N_{det}	number of detached larvae
N_o	initial number of larvae
N_W	number of water molecules per unit volume
n	number of occupied adsorption sites
n_a	number of adsorbing sites per particle
p	a probability density function
p_a	probability of a methoxychlor molecule being adsorbed on striking an adsorption site
p_B	porosity of river bed
p_d	Probability of a methoxychlor molecule being desorbed when struck by a water molecule
Q	river discharge
q	rate of water absorption by a larva due to skin contact

SYMBOL	DESCRIPTION
R	recovery ratio
R_h	hydraulic radius
R_S	recovery ratio for methoxychlor in sorption
R_T	total recovery ratio
R_W	recovery ratio for methoxychlor in the water
r_1, r_2	coefficients, (L^{-1})
t	time from beginning of injection
t_a	time denoting arrival of a tracer cloud
t_d	time denoting departure of a tracer cloud
u	local flow velocity in longitudinal direction
u_d	depth-averaged value of u
V	cross-sectional average velocity
V_*	shear velocity
$\forall$	water volume
$\forall_o$	volume of water intercepted by a larva during a feeding movement
$\forall_1$	volume of water discarded before ingestion during a larval feeding movement
v_p	volume of an adsorbing particle
W	river width
x	longitudinal distance from injection site
y	vertical coordinate
y_B	depth of contaminated bed layer
z	lateral coordinate
z_m	number of liquid molecules striking adsorbing particles per unit time and per unit area
β, β_1	dimensionless coefficients
Δ	used as a prefix to denote small increments or changes
$\epsilon_x, \epsilon_y, \epsilon_z$	turbulent diffusivities in x, y, and z directions
ρ_B	density of bed material
ρ_p	density of adsorbing particles
$\emptyset$	inclination of lateral bed profile with respect to the horizontal direction

APPENDIX II - DERIVATIONS

SIMPLIFIED DESCRIPTION OF SORPTION-DESORPTION PROCESS

Consider a volume of water, $\Delta\forall$, in which a large number, N, of identical solid particles are suspended. If ρ_p is the density of a particle and v_p its volume, the concentration of the suspended particles, C_o, is

$$C_o = N\rho_p v_p/\Delta\forall \qquad (A1)$$

Assume that there exist n_a 'adsorbing' sites on the surface of each particle. An adsorbing site is such that, when struck by a methoxychlor molecule, it retains this molecule with a certain finite probability, p_a. Let a_a be the area of each adsorbing site. If z_m is the number of liquid molecules striking a unit particle surface per unit time, the total number of liquid molecules striking the solid particles during a small time increment Δt, is $Nz_m a_p \Delta t$, where a_p is the surface area of each particle. Of these, a number equal to $C_W N z_m a_p \Delta t/m_M N_W$ are methoxychlor molecules (C_W = concentration of methoxychlor in the water, m_M = colecular mass of methoxychlor; and N_W = the number of water molecules per unit volume). From these particles, a fraction equal to $(n_a - n)a_a/a_p$ will strike potential adsorption sites (n = number of adsorption sites already occupied). The number of methoxychlor molecules actually adsorbed is then

$$p_a(n_a - n)a_a C_W N z_m \Delta t/m_M N_W$$

The mass rate of adsorption per unit volume is

$$\Delta m/\Delta\forall\Delta t = (p_a a_a z_m C_o/N_W\rho_p v_p)\,(n_a - n)C_W \qquad (A2)$$

At the same time, liquid molecules striking molecules of methoxychlor already in sorption can cause them to be desorbed, with a probability, say, p_d. The total number of methoxychlor molecules struck during Δt will be $(na_a/a_p)Nz_m a_p\Delta t$ and, of these, a fraction p_d will be desorbed. The rate of mass desorption is then:

$$\Delta m/\Delta\forall\Delta t = (p_d a_a z_m C_o m_M/\rho_p v_p)n \qquad (A3)$$

The net rate of adsorption can be found by subtracting Equation A3 from Equation A2:

$$\Delta m_S/\Delta\forall\Delta t = \{a_a z_m C_o/\rho_p v_p\}\{[p_a/N_W]$$

$$[C_W(n_a - n) - p_d m_M n]\} \qquad (A4)$$

The concentration of methoxychlor in sorption, C_S (= mass in sorption/$\Delta\forall$) is given by:

$$C_S = nm_M N/\Delta\forall$$

$$= nm_M(C_o/\rho_p v_p) \qquad (A5)$$

Using this relation, Equation A4 becomes

$$\Delta m_S/\Delta\forall\Delta t = z_m a_a\{(p_a/N_W)C_W[(n_a C_o/\rho_p v_p)$$

$$- (C_S/m_M)] - p_d C_S\} \qquad (A6)$$

Finally, if the quantity $n_a C_o m_M/\rho_p v_p$, which represents the total sorbable mass of methoxychlor per unit volume of water, is denoted by $C_S^{(S)}$, the superscript indicating a 'saturated' condition, we can write:

$$\Delta m_S/\Delta\forall\Delta t = z_m a_a\{(p_a/m_M N_W)(C_S^{(S)} - C_S)C_W$$

$$- p_d C_S\} \qquad (A7)$$

If $C_S << C_S^{(S)}$, Equation A7 reduces to:

$$\Delta m_S/\Delta\forall\Delta t = z_m a_a\{(p_a C_S^{(S)}/m_M N_W)C_W - p_d C_S\} \qquad (A8)$$

and can be further manipulated to give:

$$\Delta m_S/\Delta\forall\Delta t = (z_m a_a p_a C_S^{(S)}/m_M N_W)C_W$$

$$- z_m a_a p_d C_S \qquad (A9)$$

Setting:

$$K_1 = z_m a_a p_a C_S^{(S)}/m_M N_W$$

$$= C_o(z_m p_a n_a a_a/\rho_p v_p N_W) \qquad (A10)$$

$$K_2 = z_m a_a p_d \qquad (A11)$$

gives Equation 11. It is seen that K_1 is proportional to C_o, the concentration of suspended particles and inversely proportional to the third power of particle size. On the other hand, the coefficient K_2 seems to depend on fluid and particle properties alone.

TRANSPORT AND MIXING OF METHOXYCHLOR

Assume, for simplicity, a prismatic channel, as shown in Fig. 4. Using Equation 11, consideration of mass conservation gives the following differential equations for C_W and C_S:

$$(\partial C_W/\partial t) + u\partial C_W/\partial x$$

$$= -(K_1C_W - K_2C_S) + (\partial/\partial x)(\varepsilon_x \partial C_W/\partial x)$$

$$+ (\partial/\partial y)(\varepsilon_y \partial C_W/\partial y) + (\partial/\partial z)(\varepsilon_z \partial C_W/\partial z) \quad (A12)$$

$$\partial C_S/\partial t + u\partial C_S/\partial x$$

$$= +(K_1C_W - K_2C_S) + (\partial/\partial x)(\varepsilon_x \partial C_S/\partial x)$$

$$+ (\partial/\partial y)(\varepsilon_y \partial C_S/\partial y) + (\partial/\partial z)(\varepsilon_z \partial C_S/\partial z) \quad (A13)$$

Implicit in the derivation of these equations is the assumption that adsorbing particles are mostly very small, so that their fall velocities can be neglected. This, in turn, implies that these particles are premanently in suspension and are uniformly distributed throughout the flow The three terms of the form $(\partial/\partial j)(\varepsilon_j \partial C/\partial j)$, $j = x,y,z$ express fluxes due to the turbulent diffusion whereas the term $(K_1C_W - K_2C_S)$ is the local rate of change due to adsorption and has a negative sign in Equation A12 and a positive sign in Equation A13. These signs denote loss and gain respectively.

The boundary conditions to be applied should reflect the fact that there is no transport of methoxychlor across the water surface and the assumption expressed by Equation 12 regarding the rate of loss to the river bed.

$$y = 0: \quad \varepsilon_y C_S/\partial y = \varepsilon_y \partial C_W/\partial y = 0 \quad (A14)$$

$$y = h: \quad F_y{}^S \cos\phi - F_z{}^S \sin\phi = 0 \quad (A15)$$

$$y = h: \quad F_y{}^W \cos\phi - F_z{}^W \sin\phi = \Delta m_B/\Delta A_B \Delta t \quad (A16)$$

where F_y and F_z are the local fluxes in the y and z directions respectively, and the superscripts denote fluxes from the water and sediment. Equation A16 requires that the net flux in a direction normal to the boundary (designated by (n) in Fig. A1) be equal to the rate of mass transfer per unit bed area. Since tan ϕ = dh/dz and $F_y{}^W = -\varepsilon_y \partial C_W/\partial y$, $F_z{}^W = -\varepsilon_z \partial C_W/\partial z$, Equation A16 can be recast in the form:

$$y = h: \quad \cos\phi\{[-\varepsilon_y \partial C_W/\partial y] + [(\varepsilon_z \partial C_W/\partial z)$$

$$(dh/dz)]\} = K_L C_W \quad (A17)$$

Since natural streams are generally much wider than they are deep, the angle ϕ is small and $\cos\phi \simeq 1$.

If M_B is the mass of methoxychlor per unit bed area, then the differential equation for M_B will be:

$$\partial M_B/\partial t = K_L[C_W]_{y=h} \quad (A18)$$

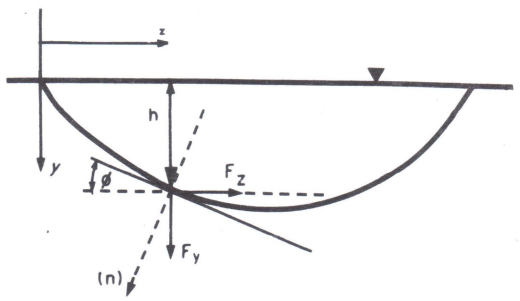

Fig. A1. Sketch illustrating boundary fluxes

Complete solution of the system of Equations A12, A13, A14, A15, A17, and A18 can only be carried out numerically. However, integration to examine the variation of corresponding recovery ratios is possible, as illustrated below.

Let us consider first the equations describing the corresponding dosages, D_W and D_S (recall that $D = \int C dt$). Neglecting longitudinal diffusion as very small in comparison with dispersive effects and integrating Equations A12, A13, and A18 with respect to time from zero in infinity, we find:

$$u\partial D_W/\partial x = -(K_1D_W - K_2D_S) + (\partial/\partial y)(\varepsilon_y \partial D_W/\partial y)$$

$$+ (\partial/\partial z)(\varepsilon_z \partial D_W/\partial z) \quad (A19)$$

$$u\partial D_S/\partial x = +(K_1D_W - K_2D_S) + (\partial/\partial y)(\varepsilon_y \partial D_W/\partial y)$$

$$+ (\partial/\partial z)(\varepsilon_z \partial D_S/\partial z) \quad (A20)$$

$$M_{BF} = K_L[D_W]_{y=h} \quad (A21)$$

(where M_{BF} is the ultimate value of M_B)

with the boundary conditions:

$$y = 0: \quad \varepsilon_y \partial D_W/\partial y - \varepsilon_y \partial D_S/\partial y = 0 \quad (A22)$$

$$y = h: \quad -(\varepsilon_y \partial D_S/\partial y) + (\varepsilon_z \partial D_S/\partial z)(dh/dz)$$

$$= 0 \quad (A23)$$

$$y = h: \quad -(\varepsilon_y \partial D_W/\partial y) + (\varepsilon_z \partial D_W/\partial z)(dh/dz)$$

$$\simeq K_L D_W \quad (A24)$$

To arrive at total, or overall, recoveries, we can integrate throughout the flow cross-section. Equation A19 becomes:

$$\int_A u(\partial D_W/\partial x)dA = -[K_1 \int_A D_W dA - K_2 \int_A D_S dA],$$

$$+ \iint_{yz} [(\partial/\partial y)(\varepsilon_y \partial D_W/\partial y)$$

$$+ (\partial/\partial z)(\varepsilon_z \partial D_W/\partial z)]dydz \quad (A25)$$

The left hand side of this equation can be recast in the form

$$(d/dx)\int_A uD_W dA = dM_W/dx$$

where $M_W(x)$ is the total amount of methoxychlor in solution passing through a cross section located at x. The first term on the right hand side of Equation A25 can be abbreviated as:

$$-A[K_1\bar{D}_W - K_2\bar{D}_S]$$

where the overbar denotes cross sectional average. Though examination of Equations A19 and A20 will show that D_W and D_S cannot become uniformly distributed in any one cross-section, it is not unreasonable to expect nearly uniform distributions far downstream from the source. As a first approximation, one could then write:

$$M_W \approx Q\bar{D}_W \qquad (A26)$$

$$M_S \approx Q\bar{D}_S \qquad (A27)$$

To evaluate the second term on the right hand side of Equation A25, we can apply Greene's theorem (Kreyszig 1965) that relates double integrals to simpler line integrals. This term will become:

$$\int_L - \varepsilon_z(\partial D_W/\partial z)dy + \varepsilon_y(\partial D_W/\partial y)dz$$

where L denotes the perimeter of the cross section and consists of the water surface (y = o) and the boundary (y = h). Due to the boundary condition expressed by Equation A22, the line integral is zero at the water surface, hence:

$$\int_L - \varepsilon_z(\partial D_W/\partial z)dy + \varepsilon_y(\partial D_W/\partial y)dz =$$

$$\int_{y=h} - \varepsilon_z(\partial D_W/\partial z)dy + \varepsilon_y(\partial D_W/\partial y)dz$$

Since at y = h, dy = dh, we can rewrite this term as:

$$\int_{z=0}^{W}[\varepsilon_z(\partial D_W/\partial y) - \varepsilon_z(\partial D_W/\partial z)(dh/dz)]_{y=h}dz$$

which, by Equation A24, is equal to

$$-\int_0^W K_L(D_W)_{y=h}dz$$

Assuming again a nearly uniform distribution of D_W, this is roughly equal to $-K_L W\bar{D}_W$ where now K_L should be viewed as averaged across the channel.

Based on this analysis, Equation A25 can approximately be simplified to:

$$dM_W/dx = -(A/Q)(K_1M_W - K_2M_S) - (K_LW)M_W/Q \qquad (A28)$$

Dividing through with the injected mass, M_o, gives:

$$dR_W/dx = -(A/Q)(K_1R_W - K_2R_S) - (K_LW)R_W/Q \qquad (A29)$$

where R_W and R_S denote corresponding recovery ratios for amounts in the water and in sorption. Similar reasoning can be applied to simplify Equation A20 as follows:

$$dR_S/dx = (A/Q)(K_1R_W - K_2R_S) \qquad (A30)$$

Adding Equations A29 and A30 and recalling that the total concentration and dosage are simply $C_T = C_W + C_S$ and $D_T = D_W + D_S$ gives:

$$dR_T/dx = -(K_LW)R_W/Q \qquad (A31)$$

The differential Equations A29 and A30 are ordinary and linear and can be solved simultaneously for the unknown functions R_W and R_S. After a somewhat laborious but simple algebra, the final solution is as follows:

$$R_W = B_1e^{-r_1x} + (1 - B_1)e^{-r_2x} \qquad (A32)$$

$$R_S = B_2(e^{-r_1x} - e^{-r_2x}) \qquad (A33)$$

$$R_T = (B_1 + B_2)e^{-r_1x} + [1 - (B_1 + B_2)]e^{-r_2x} \qquad (A34)$$

where B_1, B_2, r_1, and r_2 are coefficients depending on the values of K_1, K_2, K_L, and bulk hydraulic parameters such as Q, A, and W. If K_1, K_2, K_L, Q, A, and W are given, B_1, B_2, r_1, and r_2 can be determined from the following relations:

$$r_1 = 0.5\{[(K_1 + K_2)A + K_LW]/Q - [(\{[K_1 + K_2]A + K_LW\}/Q)^2 - 4(K_2A/Q)(K_LW/Q)]^{0.5}\} \qquad (A35)$$

$$r_2 = 0.5\{[(K_1 + K_2)A + K_LW]/Q + [(\{[K_1 + K_2]A + K_LW\}/Q)^2 - 4(K_2A/Q)(K_LW/Q)]^{0.5}\} \qquad (A36)$$

$$B_1 = [(K_2A/Q) - r_1]/[r_2 - r_1] \qquad (A37)$$

$$B_2 = (K_1A/Q)/(r_2 - r_1) \qquad (A38)$$

$$r_2 - r_1 = \{[(\{K_1 + K_2\}A + K_LW)/Q]^2 - 4[K_2A/Q][K_LW/Q]\}^{0.5} \qquad (A39)$$

In the present application, however, the coefficients K_1, K_2, and K_L are unknowns to be deduced from the total recovery curves R_T versus x, shown in Fig. 12. Equation A34 indicates that one can evaluate the coefficients $(B_1 + B_2)$, r_1, and r_2 to fit the observed R_T - x variations. The remaining coefficients can be computed from the following relations:

$$K_L W/Q = r_2 - (r_2 - r_1)(B_1 + B_2) \quad (A40)$$

$$K_2 A/Q = r_1 r_2/(K_L W/Q) \quad (A41)$$

$$K_1 A/Q = (r_2 - r_1)(B_1 + B_2) + r_1 - (K_2 A/Q) \quad (A42)$$

$$B_2 = (K_1 A/Q)/(r_2 - r_1) \quad (A43)$$

$$B_1 = (B_1 + B_2) - B_2 \quad (A44)$$

The final bed residue, M_{BF}, can be determined using Equation A21 and assuming nearly uniform cross sectional distributions of dosage. Then

$(D_W)_{y=h} \approx \bar{D}_W$, hence

$M_{BF} = K_L M_W/Q$, or

$$(QM_{BF})/(K_L M_o) = R_W = B_1 e^{-r_1 x} + (1 - B_1) e^{-r_2 x} \quad (A45)$$

Appendix III. Daily discharge (ft^3/sec) for the Athabasca River at Athabasca (Station 07BE001), 1974-1976.

1974

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1	4300 B	4130 B	3910 B	3840 B	81800	32200	41200	28300	19500	12800	9940	4850 B	1
2	4200 B	4110 B	3860 B	3880 B	77600	30000	36400	29900	18900	12200	9770	5290 B	2
3	4200 B	4070 B	3840 B	3920 B	70900	28000	32800	31100	18400	11700	9600	5730 B	3
4	4100 B	4010 B	3850 B	3960 B	66800	26400	35700	30700	18600	11300	9420	5580 B	4
5	4100 B	3980 B	3830 B	4000 B	62600	25500	37100	29100	18200	11200	9180	5240 B	5
6	4000 B	3890 B	3770 B	4100 B	58600	25300	34600	28000	17400	10900	9010	5250 B	6
7	4000 B	3730 B	3710 B	4200 B	55900	26000	32000	28000	16700	11800	8770	4800 B	7
8	3900 B	3660 B	3660 B	4300 B	55500	26200	30500	28800	16400	12400	8480	4870 B	8
9	3890 B	3720 B	3650 B	4400 B	57100	26000	30900	29800	16700	11900	8390	5040 B	9
10	3910 B	3780 B	3670 B	4500 B	58100	25800	30200	28400	18200	11600	8220	4780 B	10
11	3950 B	3860 B	3640 B	4600 B	57900	25200	29100	25600	20300	10900	7770	4740 B	11
12	3920 B	4010 B	3650 B	5400 B	62400	25200	31200	22700	20500	10900	7660	4510 B	12
13	3870 B	4050 B	3680 B	7300 B	69200	25000	38100	21100	21000	11300	7720	4440 B	13
14	3820 B	3990 B	3650 B	10000 B	70900	23500	57400	20300	22600	11600	7280	4400 B	14
15	3840 B	3910 B	3590 B	13000 B	67300	23200	71900	20300	21800	11500	6820	4360 B	15
16	3840 B	3870 B	3540 B	16100	63000	28600	67000	20000	20000	11300	6840	4310 B	16
17	3730 B	3920 B	3530 B	21600	59800	33800	59000	19400	18400	11200	6920	4280 B	17
18	3620 B	3990 B	3530 B	25500	56800	36900	54600	18500	17300	11200	6850	4210 B	18
19	3560 B	4050 B	3550 B	32900	54400	42900	55200	17700	16600	10900	6050	3870 B	19
20	3550 B	4100 B	3570 B	60600	51700	48500	53900	17200	16100	10500	6150	3830 B	20
21	3530 B	4090 B	3570 B	65600	48600	49100	48300	17600	15700	10600	6760	3680 B	21
22	3530 B	4130 B	3560 B	64800	45700	47400	46400	19600	15300	11800	6440	3640 B	22
23	3590 B	4170 B	3580 B	70700	43000	46300	47800	21900	14900	12700	4760	3770 B	23
24	3710 B	4140 B	3600 B	76400	40500	47100	45300	23000	14300	12600	4000	4060 B	24
25	3800 B	4120 B	3630 B	82500	38600	49300	40700	21700	13800	12400	3270	4070 B	25
26	3870 B	4070 B	3650 B	85100	38300	51900	37400	20800	13400	11800	5310 B	3930 B	26
27	3960 B	4000 B	3680 B	88500	38200	52800	35900	21100	13100	11100	4710 B	3570 B	27
28	4020 B	3950 B	3710 B	89000	37000	50600	34200	22900	13000	10700	4470 B	3690 B	28
29	4050 B		3740 B	86300	35800	47000	32200	22900	12700	10500	5660 B	3780 B	29
30	4070 B		3770 B	83400	35600	44400	30200	21800	12700	10200	4620 B	3710 B	30
31	4100 B		3800 B		34400		28800	20400		10100		3650 B	31

1975

1	3970 B	3990 B	3670 B	3900 B	21400	13900	63200	27500	27100	10200	7070	5200 B	1
2	4040 B	3940 B	3680 B	3790 B	21400	14000	58000	27000	30700	9870	7310	5150 B	2
3	4120 B	3910 B	3760 B	3790 B	20700	15300	52000	24200	29700	9650	7220	5100 B	3
4	4260 B	3780 B	3740 B	3760 B	20100	17100	48600	21700	26800	9640	7470	5000 B	4
5	4290 B	3670 B	3730 B	3850 B	18900	19300	46900	20100	23700	9490	7950	4900 B	5
6	4160 B	3630 B	3690 B	4010 B	17700	22700	45600	20400	21700	9360	7800	4850 B	6
7	4050 B	3560 B	3740 B	3960 B	18700	24600	44700	20700	20200	9250	8250	4800 B	7
8	4070 B	3490 B	3730 B	3920 B	19900	23300	44400	19400	18900	9340	8110	4700 B	8
9	3870 B	3470 B	3670 B	3950 B	21800	21800	44100	18900	17700	10200	8290	4650 B	9
10	3680 B	3450 B	3640 B	4000 B	23300	20900	43500	19500	16600	10100	10800	4600 B	10
11	3560 B	3410 B	3670 B	4030 B	24100	19800	42000	18400	15800	9550	10900	4550 B	11
12	3620 B	3390 B	3670 B	4070 B	23200	18000	40100	17100	15200	9450	9870	4500 B	12
13	3610 B	3470 B	3650 B	4230 B	22300	16200	38500	16100	14600	9220	8900	4450 B	13
14	3600 B	3510 B	3630 B	4510 B	21800	15600	37300	15200	13900	9030	8230	4400 B	14
15	3640 B	3500 B	3610 B	4710 B	21300	17100	37400	14900	13200	8890	7380	4400 B	15
16	3620 B	3490 B	3600 B	4830 B	21000	19900	39200	14900	12700	8820	6820	4400 B	16
17	3500 B	3470 B	3620 B	5260 B	20000	20600	41400	14400	12200	8740	6600 B	4370 B	17
18	3430 B	3450 B	3670 B	5890 B	18500	21800	45000	14100	12000	8750	6450 B	4370 B	18
19	3430 B	3440 B	3700 B	6830 B	17600	21600	46000	14100	12000	8670	6300 B	4370 B	19
20	3500 B	3460 B	3720 B	7390 B	17400	21400	45200	14100	12200	8670	6200 B	4370 B	20
21	3550 B	3510 B	3760 B	7950 B	16800	22300	42100	14500	12800	8680	6050 B	4370 B	21
22	3690 B	3560 B	3790 B	8900 B	15600	23100	37300	15600	12700	8570	5900 B	4360 B	22
23	3850 B	3600 B	3820 B	10800 B	14700	22900	33200	17100	11900	8890	5800 B	4360 B	23
24	3900 B	3650 B	3830 B	15300 B	14300	24200	30200	17800	11300	8960	5700 B	4360 B	24
25	3950 B	3700 B	3810 B	16700 B	14500	25800	27500	19300	10900	8730	5600 B	4360 B	25
26	4030 B	3750 B	3690 B	17000 B	15400	26700	25500	22600	10700	8410	5550 B	4360 B	26
27	4090 B	3700 B	3750 B	20200 B	16100	30400	23700	23800	10600	8060	5500 B	4360 B	27
28	4080 B	3680 B	3840 B	19400	15800	39300	22800	21400	10500	7930	5400 B	4360 B	28
29	4080 B		3850 B	20100	15700	50100	23600	20000	10500	7720	5300 B	4360 B	29
30	4040 B		3900 B	21900	15200	63300	24200	20100	10400	7430	5250 B	4360 B	30
31	4020 B		3930 B		14400		25100	22500		7140		4360 B	31

1976

1	4360 B	4600 B	3690 B	4140 B	14100	18400	30600	25000	34300	14800	9410	3700 B	1
2	4360 B	4620 B	3640 B	4520 B	14100	18500	29000	25400	31700	14700	9370	3600 B	2
3	4360 B	4630 B	3600 B	4840 B	14500	17600	32400	26900	30200	14700	9470	3550 B	3
4	4350 B	4630 B	3570 B	5280 B	15000	17900	42100	27500	29000	14900	9280	3500 B	4
5	4350 B	4620 B	3530 B	5870 B	15600	17000	42600	28400	28200	15200	8900	3500 B	5
6	4350 B	4610 B	3500 B	6560 B	16300	15800	37500	32100	27200	14700	8750	3450 B	6
7	4350 B	4600 B	3460 B	7290 B	16900	14900	32300	38400	25800	14300	8540	3400 B	7
8	4350 B	4550 B	3430 B	8620 B	17400	14300	30600	40200	24700	13800	8350	3400 B	8
9	4360 B	4500 B	3400 B	11800 B	17900	14100	31200	38400	29700	13200	8350	3400 B	9
10	4370 B	4450 B	3370 B	13300 B	17800	14200	31600	36400	29900	12700	7960	3400 B	10

Appendix III continued.

1976 (continued)

Day	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
11	4380 B	4400 B	3330 B	13000 B	17100	14400	33500	37200	28000	12300	7750	3350 B	11
12	4380 B	4330 B	3300 B	16900 B	17100	15700	35000	38200	25400	11900	7070	3350 B	12
13	4390 B	4260 B	3260 B	21400 B	18500	17700	34900	37100	23300	11800	6280	3350 B	13
14	4400 B	4200 B	3230 B	23400 B	20500	19400	32900	34600	22900	11800	5520	3310 B	14
15	4400 B	4180 B	3200 B	22700 B	22600	20000	31500	31800	23100	12000	5300 B	3300 B	15
16	4410 B	4140 B	3170 B	30100	21700	19600	30700	30300	22800	12000	5100 B	3300 B	16
17	4420 B	4100 B	3130 B	26400	20100	18600	30700	30800	22000	11800	4900 B	3300 B	17
18	4430 B	4060 B	3100 B	24000	19000	18100	31000	33500	20900	11700	4800 B	3300 B	18
19	4440 B	4030 B	3160 B	21800	17500	18400	29900	48500	19900	11700	4600 B	3300 B	19
20	4450 B	4000 B	3220 B	20200	16400	20600	29900	57500	19000	11300	4500 B	3300 B	20
21	4460 B	3980 B	3240 B	18700	16100	23000	31500	50700	18200	10900	4400 B	3350 B	21
22	4470 B	3960 B	3260 B	17000	15500	25200	31900	43000	17900	10700	4300 B	3350 B	22
23	4480 B	3940 B	3320 B	16300	15100	29900	31100	38300	17300	10400	4250 B	3400 B	23
24	4490 B	3920 B	3400 B	15500	14800	30500	30200	34300	16800	10200	4200 B	3400 B	24
25	4500 B	3890 B	3480 B	14900	14800	27900	29600	31000	16300	10100	4100 B	3400 B	25
26	4520 B	3860 B	3560 B	14400	14800	27100	26900	29800	16000	9920	4050 B	3450 B	26
27	4540 B	3820 B	3640 B	14300	15700	28900	24700	32800	15800	9760	4000 B	3450 B	27
28	4560 B	3780 B	3720 B	14300	17500	31200	25700	40000	15500	9700	3900 B	3450 B	28
29	4570 B	3730 B	3800 B	14400	18800	32900	27200	45000	15300	9720	3800 B	3500 B	29
30	4580 B		3900 B	14200	18100	33200	27600	43500	15000	9880	3750 B	3550 B	30
31	4590 B		4000 B		17400		27000	38700		9710		3600 B	31

Note: "B" denotes ice conditions

MIXING OF INSECTICIDE: ONE DIMENSIONAL ANALYSIS OF METHOXYCHLOR CONCENTRATION DATA

S. BELTAOS AND W. A. CHARNETSKI

(Alberta Research Council Contribution Series 957)

INTRODUCTION

This report is the second of two parts, both dealing with the mixing of methoxychlor in the Athabasca River below Athabasca. The first part (Beltaos, p. 97) concentrated on describing the hydrometric measurements to date as well as formulating a physical mixing model that would account for substance-specific processes. It was shown that using two hypotheses-sorption by suspended solid particles and losses to the channel boundaries - resulted in fair predictions of the downstream decline of the recovery ratio. However, quantitative prediction depends on three empirical coefficients that were determined to fit the observed variations of the recovery ratio. Therefore, only partial verification of this model has been achieved to date and some further research was thus recommended. In view of this, it is felt that use of the sorption-loss model in conjunction with numerical simulation techniques for predicting detailed mixing characteristics (such as time-concentration curves across the stream) is not justified at this time.

Measured time-concentration curves below the injection site for the four methoxychlor treatments have been reported elsewhere (Charnetski, et al p 39). The main objective of this report is to analyze these data within the framework of one-dimensional theories, normally applicable to neutral substances (tracers). Although the assumptions of one-dimensionality and neutral tracer behavior may be gross simplifications, the semi-empirical approach described here is thought to have some practical value, especially when quick estimates are required.

THEORETICAL CONSIDERATIONS

A sufficient distance below the site of an injection of a slug of a neutral tracer, the time-concentration curves observed across the channel at any one site, become nearly identical. If C is the cross-sectional average concentration at any one instant, the C-t (t = time) curve can be used as a satisfactory approximation to all other curves. Since C depends on only one space coordinate, namely the longitudinal distance, x, from the injection site, this final stage of the mixing process is approximately one-dimensional and commonly referred to as 'longitudinal dispersion'.

A typical time-concentration curve is shown in Fig. 1 together with some important characteristics that are defined in Appendix I.

Obviously, ΔT is a measure of the temporal spread of the tracer. With increasing distance from injection, all time characteristics - t_a, t_d, t_1, t_2, t_p, and ΔT - increase whereas the peak concentration, C_p, decreases. These changes occur in such manner that the area under a C-t curve, called here the dosage, D, remains constant, i.e.

$$D \equiv \int_0^\infty C\,dt = \text{const} = M_0/Q \equiv D_0 \qquad (1)$$

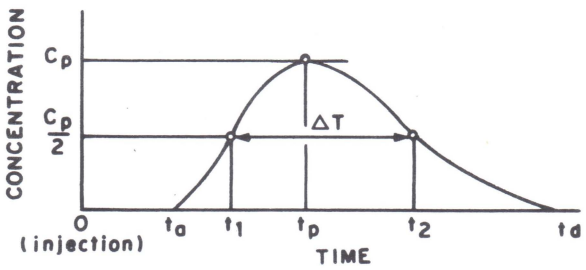

Fig. 1. Definition sketch.

where M_o is the injected mass of the tracer, Q is the river discharge, and D_o is the initial value of D, defined as M_o/Q. Equation 1 is valid for neutral tracers and reflects the conservation of tracer mass in the channel.

Based on an extensive reanalysis of published field data involving 51 dispersion tests, Beltaos (1978) proposed the following model for the longitudinal dispersion of neutral tracers.

Time of travel - The growth of the time to peak concentration, t_p, with x can be used to provide a good approximation for the average flow velocity, V, via the relation:

$$V = (dt_p/dx)^{-1} \qquad (2)$$

Spread of tracer cloud - The 'half' temporal spread of tracer, ΔT, increases with x according to the relation:

$$\Delta T^2 = 11.1\beta[L/V]^2[(x/L) + e^{-(x/L)} - 1] \qquad (3)$$

where β is a dimensionless coefficient and L is a characteristic river length. The coefficient β reflects the degree of non-uniformity of cross-sectional velocity distributions of the channel and, broadly speaking, is a function of the ratio V_*/V, where V_* is the shear velocity, given by:

$$V_* = (gR_hS)^{0.5} \qquad (4)$$

in which, g is the acceleration of gravity, R_h is the hydraulic radius (for open-water flow R_h is almost equal to the average flow depth), and S is the water surface slope. The characteristic length, L, is given by a relation of the form:

$$L \propto (W^2/R_h)(V/V_*) \qquad (5)$$

where W is the water surface width.

The above relations were derived assuming uniform flow in a prismatic channel, that is, a straight channel for which the cross-sectional geometry and velocity do not change in the downstream direction. However, natural streams are characterized by ever changing cross-sectional shape and velocity, even though such changes are usually fluctuations about well defined average values. Since Equation 2 indicates that $dt_p = dx/V$, application of Equation 3 to natural streams will give less scatter if x/L is replaced by t_p/t_{pL}, with $t_{pL} \simeq L/V$. Hence, for natural stream applications, Equation 3 is re-cast in the form:

$$\Delta T^2 = 11.1\beta t_{pL}^2[(t_p/t_{pL}) + e^{-(t_p/t_{pL})} - 1] \qquad (6)$$

For small values of t_p/t_{pL} (or x/L), Equation 6 simplifies to:

$$\Delta T = (5.55\beta)^{0.5}t_p \qquad (7)$$

which implies that ΔT increases linearly with t_p (or x).

On the other hand, when t_p/t_{pL} is large, Equation 6 reduces to:

$$\Delta T = (11.1\beta t_{pL}t_p)^{0.5} \qquad (8)$$

The latter equation implies that, in the final stage of the mixing process, ΔT grows as the square-root of t_p (or x).

For a neutral tracer, conservation of the tracer mass is expressed by Equation 1. Beltaos (1978) showed that Equation 1 can be reduced further to the approximate form:

$$C_p\Delta T/D_o = 0.94 \qquad (9)$$

Using Equation 9 in conjunction with Equation 3, one can calculate the peak concentration, C_p.

OBJECTIVES AND LIMITATIONS

As was stated earlier, the objective here is to analyze the methoxychlor concentration data in the framework of a simple, one-dimensional model. For the model outlined above, an attempt is made to use the field data as a guide for evaluating the parameters β and L applicable to the two study reaches associated with the field operations of the Black Fly Program. When this is done, quick engineering calculations can be performed, based on the above equations and the appropriate values of β and L.

Time-concentration data for the methoxychlor have been reported by Charnetski et al (p 39). Inspection of these data showed that C-t curves measured at different points of the same cross-section are sometimes perceptibly different. This violates the condition of one-dimension-

ality, as defined above, which is necessary for Equations 2, 3, and 9 to hold. (The present analysis is therefore intended to provide a means for rough predictions of mixing patterns in an 'average' sense.) The fact that methoxychlor is not a neutral tracer is believed to be largely responsible for this discrepancy. The mixing process and hence the appearance of C-t curves are influenced by the capacity of the channel boundaries to retain methoxychlor. This capacity is very likely to be unevenly distributed along and across the stream, given the characteristic variability of bed conditions of natural streams. The observed departures from one-dimensionality are thus thought to have been, at least partially, caused by non-uniformities in the capacity of the boundaries to retain methoxychlor.

The analysis presented in the next section has been based on cross-sectional average values of the various mixing characteristics. When two or more C-t curves are available in a cross-section, the simple arithmetic averages of respective characteristics are used. When only one curve is available, it is assumed to be representative of the corresponding cross-sectional average.

ANALYSIS OF RESULTS

Available field data on methoxychlor concentrations are analyzed in this section, according to the procedures outlined earlier.

Time of Travel

Average values of t_p are plotted versus x for each treatment in Figs. 2-5.

The results for the three Athabasca injections (Figs. 2-4) show a definite break in the t_p-x relationship about 100 km below the injection site. The data indicate that average velocities in the reach 0-100 km are smaller than those in the reach 100-400 km. This finding is consistent with the variation of the slope along the channel. Indeed, table 1 of Beltaos (see p. 102) shows that the river slope between 0 and 95 km is 0.26 m/km whereas it changes to 0.44-0.98 m/km in the reach 95-400 km.

Figure 5 shows that the movement of the methoxychlor in the reach 160-400 km occurred at a fairly constant rate after the first 1976 treatment.

Table 1 summarizes average hydraulic data for the two study reaches and the four treatments. Using the average velocities determined according to Equation 2, the average cross-sectional areas, A, can be computed from the relation:

$$A = Q/V \qquad (10)$$

The average water surface width, W, has been determined from cross-sectional data

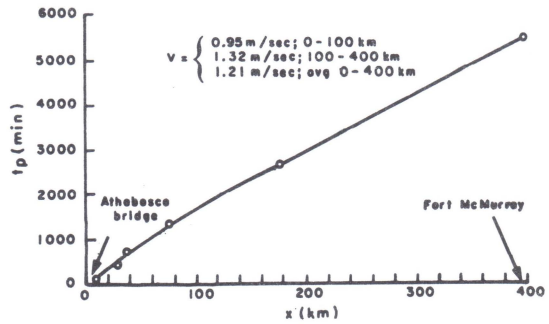

Fig. 2. Time of travel; 1974 treatment.

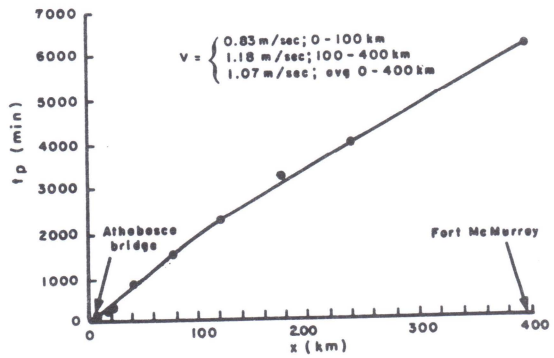

Fig. 3. Time of travel; 1975 treatment.

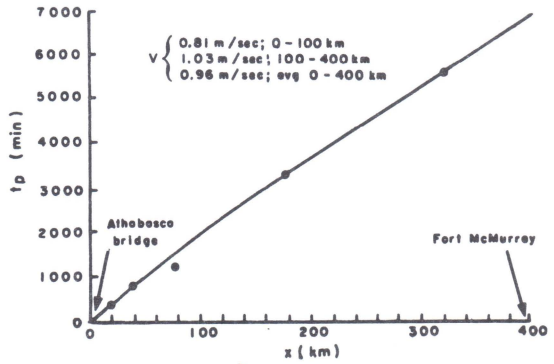

Fig. 4. Time of travel; second 1976 treatment.

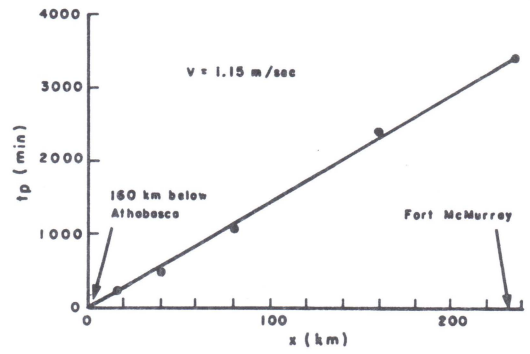

Fig. 5. Time of travel; first 1976 treatment.

Table 1. Reach-average hydraulic parameters

Treatment	Reach (km)	Discharge (m^3/sec)	Velocity (m/sec)	Cross-sectional area (m^2)	Water surface width (m)	Depth (m)
1974	0-100	770	0.95	811	286	2.84
	100-400	854	1.32	647	277	2.34
	0-400	833	1.21	688	281	2.45
1975	0-100	514	0.83	619	279	2.22
	100-400	638	1.18	541	271	2.00
	0-400	607	1.07	567	275	2.06
1976-2nd	0-100	436	0.81	538	276	1.95
	100-400	501	1.03	486	265	1.83
	0-400	485	0.96	505	270	1.87
1976-1st	160-400	550	1.15	478	275	1.74

presented in appendix II of Beltaos (p.117). The average value of the channel depth, H, can then be computed from:

$$H = A/W \qquad (11)$$

Using reach-averaged slopes (see Beltaos, table 1, p. 102), one can compute the shear velocity V_*, according to Equation 4. For the four treatments shown in Table 1, the ratio V_*/V was calculated as 0.103, 0.107, 0.095, and 0.104 respectively. Obviously, assuming a common value of 0.10 is a fair simplification.

Evaluation of β and L

The coefficient β and the length L can be evaluated by plotting ΔT against t_p and selecting a pair of the parameters β and L that optimize agreement between observations and predictions using Equation 6.

It was mentioned earlier that, when t_p/t_{pL} (or x/L) is small, ΔT increases linearly with t_p. Using Equation 6, it can be shown that an experimental plot of ΔT versus t_p may appear to be linear even if t_p/t_{pL} is as large as 1. Considering that, in this range, Equation 6 reduces to Equation 7 which does not contain t_{pL} (or L), a linear plot of ΔT versus t_p can only provide the appropriate value of β. All that may be said about L (or t_{pL}) is that it exceeds the value associated with the farthest downstream data point.

Data on the length L from 52 field tests have shown that, for the average hydraulic characteristics of the Athabasca River during the four treatments, the ratio L/W should be between 640 and 2,500 with a likely value of 1,350. Using W ≃ 0.275 km, this implies that L should be between 180 and 700 km, with a probable value of about 400 km. Therefore, it is expected that graphs of ΔT against t_p will be linear, at least for the first 180 km below the injection sites.

Figure 6 shows ΔT plotted against t_p for the second 1976 treatment. The data are seen to define a straight line which corresponds to $\beta \simeq 0.0045$. Figure 7 shows that the data for both 1974 and 1975 treatments are described fairly well with the same straight line for the first 176 km. However, the data points for Fort McMurray fall well below the value that would be indicated by extrapolating this line to 396

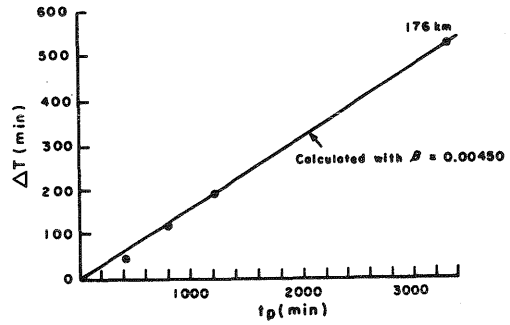

Fig. 6. Rate of spread of methoxychlor; second 1976 treatment.

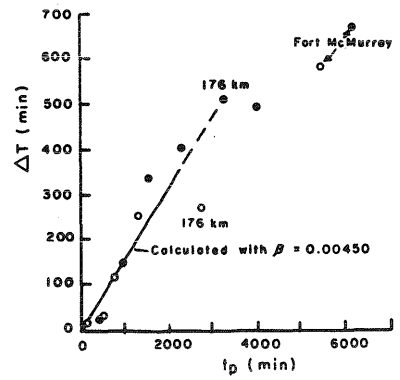

Fig. 7. Rate of spread of methoxychlor; 1974 (o) and 1975 (●) treatments.

km. This may be the result of (a) the length L being less than 400 km or (b) the large methoxychlor losses (which occur by the time the cloud arrives at and departs from Fort McMurray) distorting the time-concentration curve in a way that reduces the apparent spread.

Based on the preceding discussion, it is concluded that for the reach 0-176 km the value of β is 0.0045. The characteristic length, L, seems to exceed 176 km but is probably less than 400 km.

Figure 8 shows the results of the first 1976 treatment plotted in the same form as those of the treatments at Athabasca. For the first 160 km from the injection site, the data points define a straight line with a slope indicating that β = 0.00276. This value is considerably less than the value determined for the reach 0-176 km. It was mentioned earlier that β is a function of the ratio V_*/V. Figure 9 shows the range of scatter associated with this relationship, as determined by Beltaos (1978) based on published field data. The data points determined for the Athabasca river are also plotted in Fig. 9 and fall within the limits of the scatter band. In addition, the difference between the values of β determined for the reaches 0-176 km and 160-320 km cannot be attributed to effects of V_*/V, since this parameter has the same value for both reaches. Beltaos (1978) suggested that other factors in addition to V_*/V influence β and could, for the present, be summarized into differing stream types. If this is true, the lower value of β obtained for the reach 160-320 km would imply that, in this reach, the channel is more regular than in the reach 0-176 km.

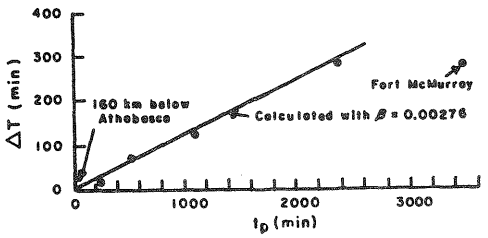

Fig. 8. Rate of spread of methoxychlor; first 1976 treatment.

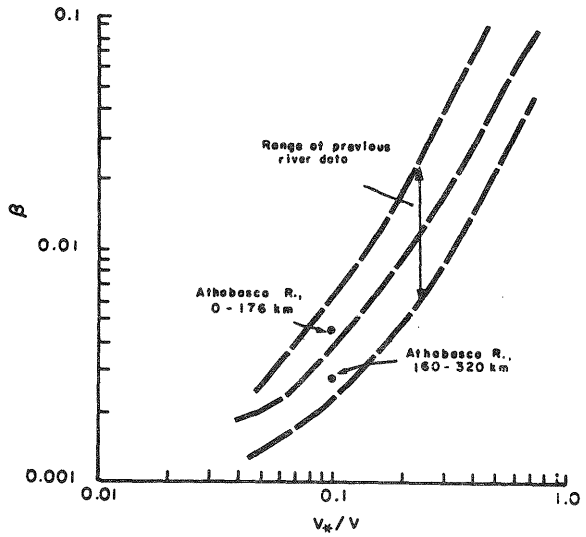

Fig. 9. Comparison of rates of spread of methoxychlor with other river data (from Beltaos 1978, with changes).

Time Characteristics

Considering the time characteristic t_1, which locates a C-t curve with respect to time, Fig. 10 shows t_1 plotted versus t_p for all treatments; a well defined linear relation is suggested which has the equation:

$$t_1 = 0.945\ t_p \qquad (12)$$

Other characteristics of interest are the times of arrival and departure of the methoxychlor. Figure 11 shows t_a and t_d (defined as the time when the concentration drops to the arbitrarily selected value of 2% of the peak concentration) plotted against t_p. The following average relationships are suggested:

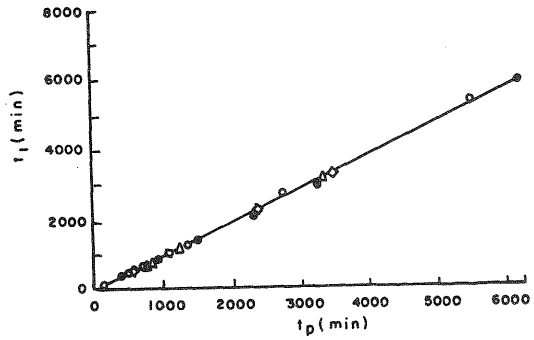

Fig. 10. Growth of time characteritic, t_1; 1974 (o), 1975 (●), 1976 - 1st (◇), and 1976 - 2nd (△).

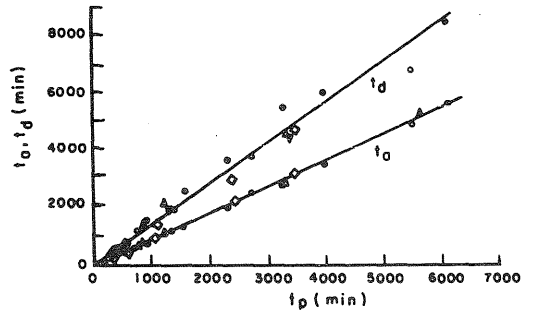

Fig. 11. Growth of arrival and departure times; 1974 (o), 1975 (●), 1976 - 1st (◇); and 1976 - 2nd (△).

$$t_a = 0.904\ t_p \qquad (13)$$

$$t_d = 1.41\ t_p \qquad (14)$$

It is noted that the scatter associated with t_d is considerable. This is not surprising, in view of the long tails of the C-t curves that render accurate determinations of t_d difficult; at the same time, measurements are rather inaccurate in this range because of the very small concentrations involved.

Decay of Peak Concentration

Adapting Equation 9 to a non-neutral tracer, so as to account for tracer losses, we have:

$$(C_p \Delta T)/D = 0.94 \qquad (15)$$

in which $D\ (\equiv \int_0^\infty Cdt)$ now decreases with x. Using the available data, the quantity $C_p \Delta T/D$ was computed for all measured C-t curves. This resulted in an average value of 0.78 which is some 20% less than the theoretical value of 0.94. Since $D = R_T D_0$, R_T being the total recovery ratio and D_0 the injected dosage (see also Beltaos, equation 5, p. 99), we have (using also Equation 7):

$$C_p(5.55\beta t_p)^{0.5}/D_0 R_T = 0.78 \qquad (16)$$

which can be recast in the form:

$$C_p t_p/D_0 = 0.78\ R_T/(5.55\beta)^{0.5} \qquad (17)$$

For the injections at Athabasca, $\beta = 0.0045$, while R_T was found to decrease with x in the same manner for all three treatments at Athabasca. Therefore, plots of $C_p t_p/D_0$ versus x for the treatments at Athabasca should define a relationship described by the equation:

$$C_p t_p/D_0 = 4.94\ R_T \qquad (18)$$

in which (see Beltaos, equation 20 p. 109):

$$R_T = 0.24e^{-0.0016x} + 0.76e^{-0.0284x} \qquad (19)$$

Figure 12 shows $C_p t_p/D_0$ plotted against x for the treatments at Athabasca together with Equation 18. The present analysis seems capable of predicting C_p to within a factor of about 1.5.

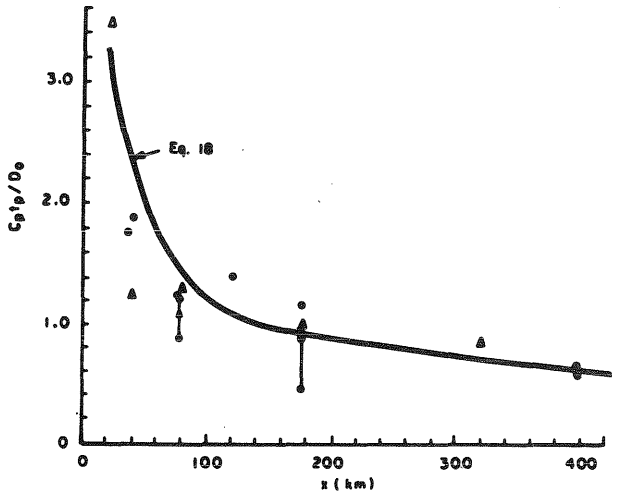

Fig. 12. Decay of peak concentration of methoxychlor in 1974 (o); 1975 (●), and 1976 (Δ) second treatment.

DISCUSSION

It appears that when the observed temporal concentration variations are adjusted by the recovery ratio, the mixing of methoxychlor resembles that of a conservative tracer. Of course, this is to be taken in an average sense, i.e. it applies to site-averaged time and concentration parameters.

Using the analytical equations and the coefficients suggested in the previous sections, one can roughly predict the C-t curve that will occur somewhere below the point of injection, provided the flow discharge and location of the injection site are given.

It is emphasized that these predictions are crude and should be used with this qualification in mind. Better predictions might be possible by means of a numerical solution of the governing differential equations in two dimensions with proper consideration of the adsorption-loss processes discussed by Beltaos (pp. 117). Although a method for accomplishing the latter task has been postulated and partially tested using the field observations, it is felt unjustified to try numerical solutions at this time. It should also be kept in mind that much of the discrepancy found occasionally among C-t curves observed at the same cross-section may be due to non-uniformities in the spatial distribution of the capacity of the channel boundaries to retain the methoxychlor. Such non-uniformities can conceivably be severe, but rather impossible or at least impractical to be accounted for, even in a numerical solution of the problem. If this is true, then numerical solutions will result in little improvement over the predictive method described herein.

Finally, the above apply to the Athabasca River below Athabasca and above Fort McMurray. Extrapolations to other reaches of this river or to other rivers are not justified.

EXAMPLE OF APPLICATION

It is given that an injection of methoxychlor is to be carried out on a specified day in the Athabasca River at the bridge located about 1 km below the town of Athabasca. The flow discharge downstream of the injection point is estimated as 600 m^3/sec. Injection is to be carried out across the stream and the amount to be injected will be adjusted so as to provide the equivalent of 0.3 mg/liter for 7.5 min. It is desired to determine the peak concentration and the time characteristics of the C-t curves of methoxychlor at sites located 100, 200, and 300 km downstream of the bridge.

Site 100 km

Using the results summarized in Table 1 for the reach 0-100 km, we find by interpolation the average velocity as: V = 0.89 m/sec = 3.2 km/hr. The time to peak, t_p, is then 100/3.2 = 31 hr and, from Equations 13 and 14, t_a = 0.904 t_p ≃ 28 hr and t_d = 1.41 t_p = 44 hr. The time characteristic t_1 is 0.945 t_p = 29.5 hr and the half spread $\Delta T = [5.55(0.0045)]^{0.5} t_p \simeq 5$ hr. The peak concentration can be found using Equation 18 or the graph of Fig. 12. For x = 100 km, the latter gives $C_p t_p / D_0$ = 1.23, therefore C_p = 0.3(7.5)1000(1.23)/31(60) = 1.5 µg/liter.

Site 200 km

For the reach 100 - 400 km, we again interpolate the data in Table 1 to find V = 1.1 m/sec = 4.0 km/hr. The time to peak, t_p, is then 31 hr + (200 - 100)/4.0 = 56 hr. Therefore, t_a = 0.904(56) ≃ 51 hr and t_d = 1.41(56) ≃ 79 hr. Further, t_1 ≃ 0.945(56) = 53 hr. To compute ΔT, we should take into account the fact that the coefficient β changes at about 160 km from 0.0045 to 0.00276. Therefore,

$$\Delta T \simeq [5.55(0.0045)]^{0.5} [(t_p)_{160\ km}] + [5.55(0.00276)]^{0.5} [(t_p)_{200\ km} - (t_p)_{160\ km}]$$

$$= 0.1580[(t_p)_{160\ km}] + 0.1238[(t_p)_{200\ km} - (t_p)_{160\ km}]$$

$$= 8.5 \text{ hr}$$

(Since

$$(t_p)_{160\ km} = 31 + (60/4) = 46 \text{ hr}$$

$$(t_p)_{200\ km} = 31 + (100/4) = 56 \text{ hr})$$

Then

$$\Delta T \simeq 7.27 + 1.23 = 8.5 \text{ hr}$$

Finally, Fig. 12 gives, for x = 200 km, $C_p t_p / D_0$ = 0.87, hence C_p = 0.87 (2250)/56(60) ≃ 0.6 µg/liter.

Site 300 km

For this site, we proceed as above to find:

$$t_p = 31 + (200/4) = 81 \text{ hr}$$

$$t_1 = 76.5 \text{ hr} \quad t_a = 73 \text{ hr} \quad t_d = 114 \text{ hr}$$

$$\Delta T = 7.27 + [5.55(0.00276)]^{0.5}(81-46) = 11.5 \text{ hr}$$

$$C_p t_p / D_0 = 0.73 \text{ and } C_p = 0.73(2250)/81(60)$$

$$= 0.34 \text{ µg/liter}$$

REFERENCES

BELTAOS, S. 1978. An interpretation of longitudinal dispersion data in rivers. Alta. Res. Counc., Transp. Surface Water Eng. Div., Rep. SWE/78/3 .

APPENDIX I: LIST OF SYMBOLS

A	cross sectional area
C	cross-sectional average concentration of methoxychlor
C_p	peak value of C
D	dosage of methoxychlor
D_0	injected dosage of methoxychlor
e	basis of natural logarithms
g	acceleration of gravity
L	a characteristic river length
M_o	injected mass of methoxychlor
Q	river discharge
R_h	hydraulic radius
R_T	total recovery ratio of methoxychlor
S	river slope
t	time after injection of methoxychlor
t_a	arrival time of methoxychlor
t_d	departure time of methoxychlor
t_1, t_2	times when C= $C_p/2$

t_p time from injection to peak concentration

V average flow velocity

$V*$ shear velocity

W river width

x river distance from injection site

β dimensionless coefficient describing rate of tracer spread

ΔT time during which concentration exceeds 50% of peak value

EFFECTS OF AN EXPERIMENTAL INJECTION OF METHOXYCHLOR IN 1974 ON AQUATIC INVERTEBRATES: ACCUMULATION, STANDING CROP, AND DRIFT

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INTRODUCTION

Injection of methoxychlor directly into streams is an experimental technique for controlling black fly larvae, particularly *Simulium arcticum*, at their growing sites (Fredeen 1974, 1975). *S. arcticum* is not a direct threat to man but has been blamed for the death of about 1,100 livestock between 1944 and 1947 in Saskatchewan (Fredeen 1974). After this period, DDT was used for about 20 yr in the Saskatchewan River to control the larvae (Fredeen et al. 1971) and, with the restrictions in the use of DDT, it has been replaced by methoxychlor.

Various authors (Burdick et al. 1969; Fredeen 1972; Merna and Eisele 1973) have shown that methoxychlor is at least as acutely toxic to non-target aquatic invertebrates as DDT. However, the use of methoxychlor has continued because it is supposedly not persistent in the environment (but see Merna and Eisele 1973); does not readily accumulate in fish (Kapoor et al. 1970; Fredeen et al. 1975); and is thought to be selective to black flies because it is adsorbed onto suspended particles in rivers and thus selected by the filter-feeding simuliid larvae (Fredeen et al. 1975). Wallace and Hynes (1975) and Wallace et al. (1976) have shown catastrophic drift (as defined by Waters 1965) of non-target aquatic invertebrates associated with methoxychlor treatments in clear streams in Quebec, and Fredeen (1974, 1975) indicated major, but apparently short-lived, effects on the fauna of the Saskatchewan River, Sask.

The study reported here was carried out to assess the impact of a black fly larviciding program on non-target aquatic invertebrates of the Athabasca River and to develop methods to provide impact assessment of the effects of chemical treatment of large, fast-flowing rivers.

METHODS

The Athabasca River is a large, fast glacial river draining north-east from the Rocky Mountains into Lake Athabasca. The mean flow at the town of Athabasca in 1974 was 572 m^3/sec, the maximum flow was 2,520 m^3/sec recorded on 28 April. The flow in early June was about 750 m^3/sec (Anon. 1975).

On the morning of 4 June 1974, 796 liters of 24% emulsifiable concentrate methoxychlor were poured into the Athabasca River from the bridge at the town of Athabasca. The liquid was dispensed simultaneously from a number of points across the bridge at a rate calculated to give a 15-min pulse of 300 µg methoxychlor/liter.

Four stations were established on the Athabasca River: I - the control station, upstream of the treatment point and about seven-eighths of the way across the river from the town of Athabasca; II - about 200 m downstream from the treatment point; III - 67 km downstream; and IV - about 400 km downstream. Stations III and IV were just upstream of the confluence of the Athabasca

River and the Calling and Clearwater Rivers, respectively. All three downstream stations were near the left bank of the river.

Methoxychlor Residue Sampling

Benthos samples were collected at each of the stations, downstream from the drift nets, using a dip net. These samples were sorted live to Order, wrapped in aluminum foil, frozen, and returned to the Freshwater Institute for methoxychlor analysis (Solomon and Lockhart 1977). Two groups of animals, the clam, *Lampsilis radiata* (Barnes), which occurs naturally in the river, and the crayfish, *Orconectes virilis* (Hagen), which does not, were suspended in cages in the river at each station (four clams/cage and three to six crayfish/cage). (To avoid accidental introduction of an exotic animal into the river, only male crayfish were used in the experiment.) Animals were monitored regularly for mortality and general health (activity, posture, etc.) and were sampled at various times before and after treatment at each station. Crayfish blood was analyzed for calcium and the remaining body together with the clam samples were wrapped, frozen, and shipped to Winnipeg for methoxychlor analyses as previously described. The clam gill-marsupium tissue was analyzed separately from the remaining soft body tissues and whole-body (less blood) analyses were carried out on the crayfish.

Sampling of Methoxychlor Effects

Drift sampling was carried out every 4 hr starting 24 hr before the treatment time (i.e. on 3 June) at Stations I, II, and III, and 48 hr after treatment time at Station IV (to allow time for the methoxychlor to reach this station) and continued for 4 days. At each station, two drift nets were used, a 400-µm mesh 'bomb' (Burton and Flannagan 1976) and a standard 400 µm drift net. Both were suspended from an anchored buoy to sample at about 0.5 m above the river bed. At Station IV, the 'bomb' sampler was lost in the evening of the 1st day of sampling and could not be replaced until 1500 hr on the 3rd day of sampling. During this time, it was replaced by another standard drift net.

Artificial substrate samplers, consisting of barbecue baskets filled with 5-7 cm diameter stones as described by Anderson and Mason (1968) but with a pan of fine sediment attached below the basket to simulate the rock over sand situation common in the Athabasca River, were set at each station shortly after ice break-up (ca. 1-5 May). The samplers were all recovered from Station III; some were lost at Station I and II; and all were lost at Station IV. The remaining 60 samplers were removed from the three stations in groups of three at various times before and after the treatment.

Triplicate bottom samples, using a modified Ekman grab (Burton and Flannagan 1973) at Stations I and II and a Ponar grab (Powers and Robertson 1967) at Stations III and IV, were taken before, during, and three to five times after the calculated arrival time of the treatment at each station.

The grab and artificial substrate samples were sieved to remove the silt or sugar floated (Flannagan 1973) and then sieved. Drift, grab, and artificial substrate samples were all preserved in 10% formalin solution and sorted in the laboratory under the low power of a dissecting microscope.

After sorting, individual artificial substrate samples from each station were grouped into a pretreatment group, before any one station was influenced by the pesticide; a treatment group, including the 1st day the station was influenced by the pesticide, plus at least 2 other sampling days within 5 days of treatment; and a post-treatment group, samples taken 5-20 days after treatment. These three temporal groups allowed a relatively large number of samples to be used to estimate population densities.

Similarly, the grab samples were sorted into one of five temporal groups 24 May - 3 June (T1); 4-5 June (T2); 7-8 June (T3); 11 and 18 June (T4); and 24-27 June (T5). Each temporal group contained a minimum of six Ekman or Ponar samples. All data were converted to number per square meter to facilitate comparisons. Preliminary analyses of the material indicated that means and variances were nearly always equal because of wide variability in the data. The raw data was therefore transformed as $[\log_n (\text{no./m}^2 + 1)]$ which, according to Bartlett (1947), makes the variances homogeneous and thus gives 'truer' values of statistical significance. The transformed data were then compared using t-tests.

RESULTS

Methoxychlor Residues

No mortalities attributable to the methoxychlor treatment were observed in the caged crayfish or clams. Methoxychlor residue data (Fig. 1) indicate that this chemical was concentrated above the treatment level (300 µg/liter) by all the animals sampled. The maximum concentration factor is about 33 times for the naturally occurring animals, about three times for caged clams and 1.6 times for caged crayfish. The caged animals accumulated proportionately less methoxychlor than the wild ones at Station II but proportionately more at Station III. At Station II, the Trichoptera and Plecoptera, mainly predaceous species, show methoxychlor levels at about the same maxima as the herbivorous Ephemeroptera. However, the Ephemeroptera seem to have taken up the insecticide faster than the other two groups since the first posttreatment samples of Emphemeroptera were an order of magnitude higher than those for the Trichoptera and Plecoptera.

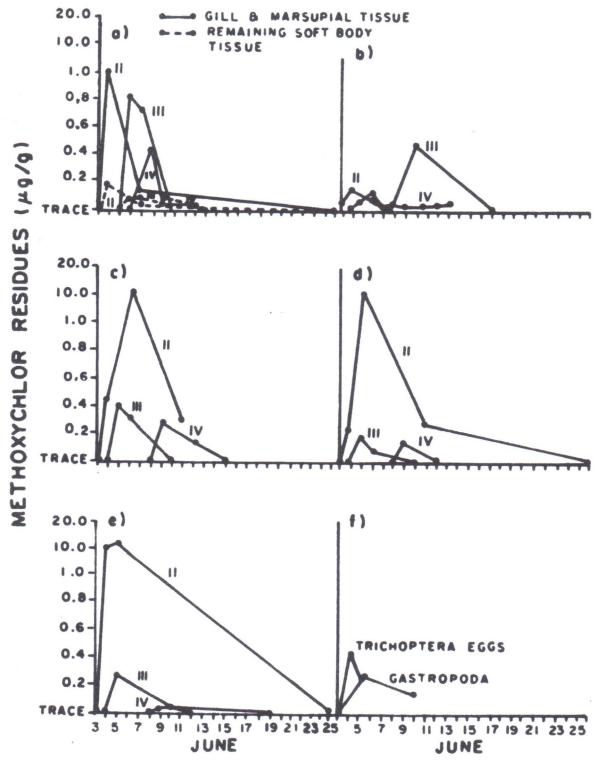

Fig. 1. Concentrations of methoxychlor in surviving non-target invertebrates after treatment a) clams, b) crayfish, c) Plecoptera larvae, d) Trichoptera larvae, and e) Ephemeroptera larvae at Stations II, III, and IV, and f) miscellaneous samples at Station II.

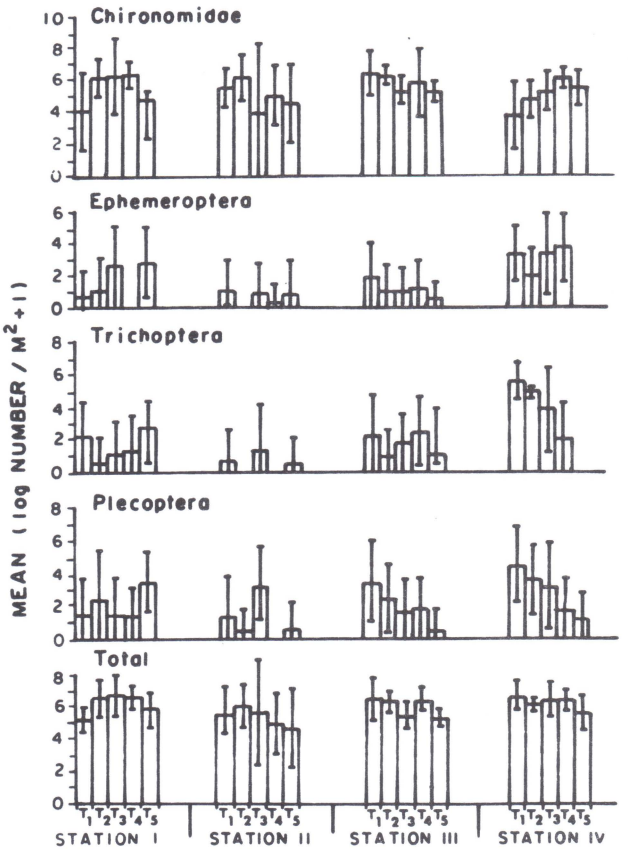

Fig. 2. Mean numbers [$\log_n$(number/m^2 + 1)] and standard deviation of benthic animals collected in grab samples (Ponar, and Birge-Ekman) at various stations over the five time intervals.

In all cases, the methoxychlor residues, which were at trace levels or undetectable in all the control situations (Station I + pretreatment samples at the other three stations), returned to these levels within 23 days after treatment.

Grab Samples

The results from the Ponar and modified Ekman samples are presented in Fig. 2. Only the Chironomidae, Ephemeroptera, Plecoptera, and Trichoptera and totals for these four taxa are presented since the remaining animals were not consistently caught at all four stations.

The population densities at Station I either remained stable or had a tendency to increase over the sampling period. This is substantiated by the results of *t*-tests comparing the pretreatment (T1) with the various posttreatment densities (Table 1; T1 vs. T2, T3, T4, and T5) where the only significant changes ($P<0.05$) in the densities were increases in chironomids and total benthos.

Station II results show very large standard deviations in all the sets of samples, with only the Plecoptera and Ephemeroptera showing significant changes from the T1 samples. The Ephemeroptera were totally eliminated for one sampling period (T2) and then apparently recolonized. The Plecoptera showed a temporary increase at T3 followed by total elimination at T4 with some evidence of recovery at T5.

All taxa at Station III, and the Ephemeroptera and total benthos at Station IV, show a similar pattern - an initial decline in population after treatment, an increase at T4, then a decline at T5. This phenomenon is probably the result of disturbed and drifting animals from upstream temporarily colonizing the downstream stations and then, because of population pressures or because of a delayed toxic effect, a partial or total collapse of the population occurs. Trichoptera and Plecoptera populations at Station IV appear to react differently since they do not show the temporary post-treatment population increases.

Except for the chironomids at Station IV, the mean densities of all the taxa at the three treated stations were always lower at T5 than at T1 (Fig. 2) while the reverse was true for the control (Station I).

Artificial Substrate Samples

Invertebrate populations at Station I essentially doubled over the sampling period while the populations at Stations II and III decrease markedly over the same period with perhaps some posttreatment recovery at Station II (Fig. 3). As indicated by the grab sample data, Plecoptera and Ephemeroptera are the most seriously affected taxa, reductions in numbers at Station III being more extreme than at Station II (Fig. 4). Some signs of recovery in Ephemeroptera, Plecoptera, and hydropsychid Trichoptera are evident. Chironomids were apparently unaffected at Station II but showed drastic decline with time at Station III. Simuliids, Crustacea, and Oligochaeta were recorded only at Station III thus no control results are available. However, it is evident that numbers of these animals were very drasticly reduced over the sampling period at Station III.

Drift

Catastrophic drift, especially of Plecoptera (Fig. 5), were recorded at Stations III and IV simultaneously with the expected arrival of methoxychlor at these stations. In most cases, the non-target insect drift continued at above normal densities for 4-12 hr then dropped to below

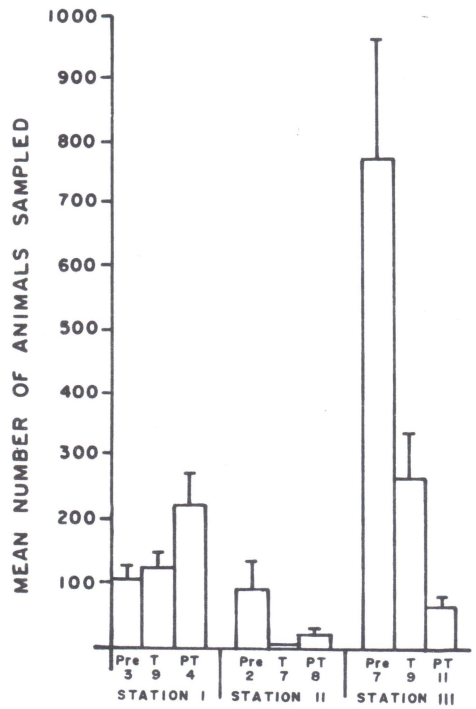

Fig. 3. Mean numbers and standard deviations of total animals sampled from artificial substrates at the upper three stations. (Pre, T, and PT = Pretreatment, treatment, and posttreatment samples respectively.)

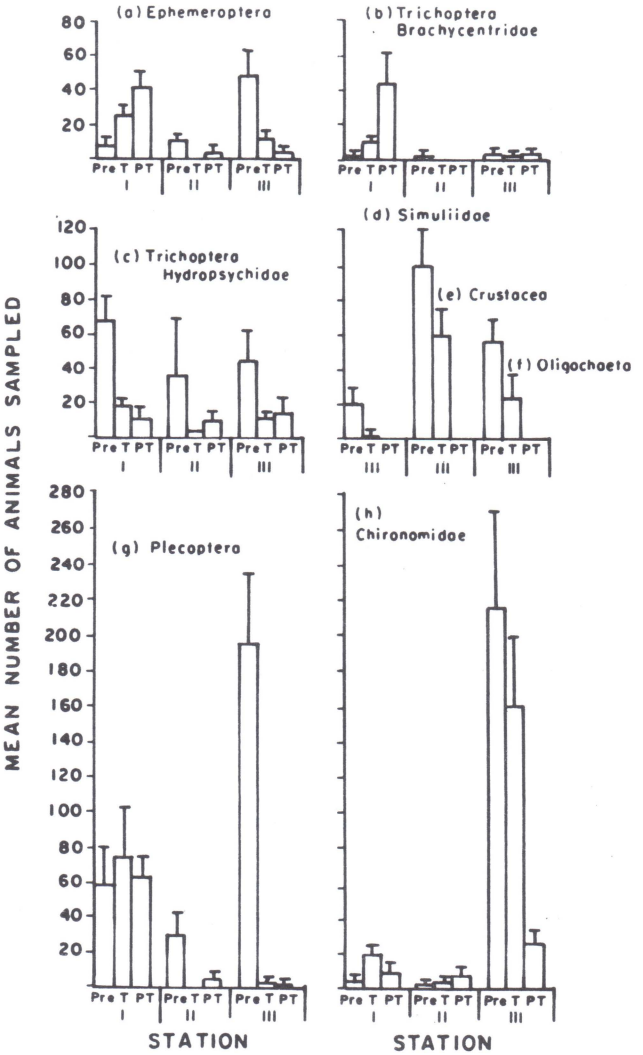

Fig. 4. Mean numbers and standard deviations of the various animal groups sampled at the upper three stations in artificial substrates. (Pre, T, and PT = Pretreatment, treatment, and posttreatment samples respectively.)

pretreatment levels. An exception to this was the Trichoptera drift, which exhibited large increases in densities coincident with the insecticide arrival at Stations III and IV but did not show a posttreatment decrease. This continued drift suggests that the effect of the treatment on Trichoptera is much longer lasting or that some Trichoptera are slower to react than other groups of invertebrates.

Comparison of the individual species making up the drift indicate only small differences in the sensitivities of the various species to the methoxychlor: at Station III, the plecopterans *Isogenus expansus* (Banks) and *Peltoperla* sp. reached peak numbers about 4 hr before *Isogenus frontalis* (Newman) and *Hastaperla* sp. (Fig. 5) and, at Station IV, *I. expansus* peaked 8 hr before *Hastaperla* sp. Similar differences

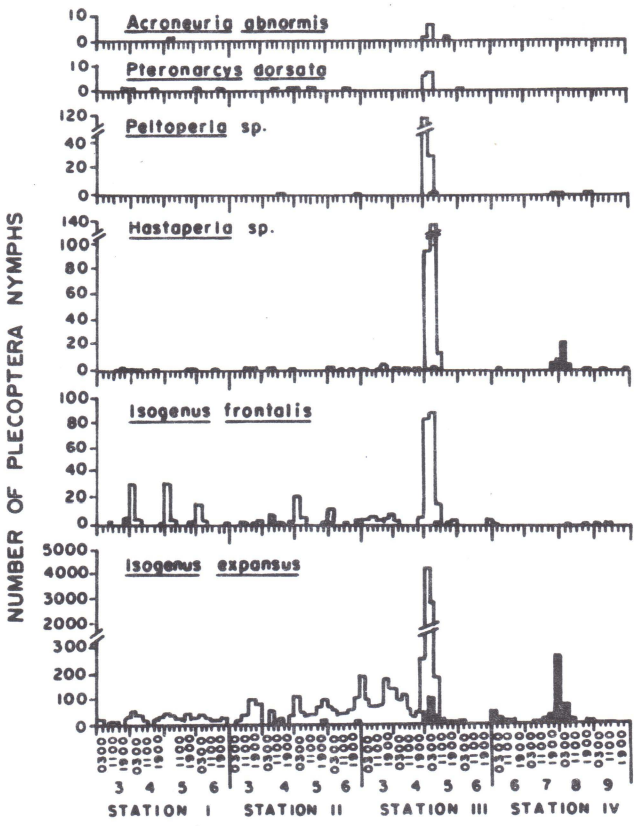

Fig. 5. Numbers of each species of Plecoptera caught every 4 hr by drift samplers (bomb, open columns; net, closed) during the 4 sampling days at Stations I - IV.

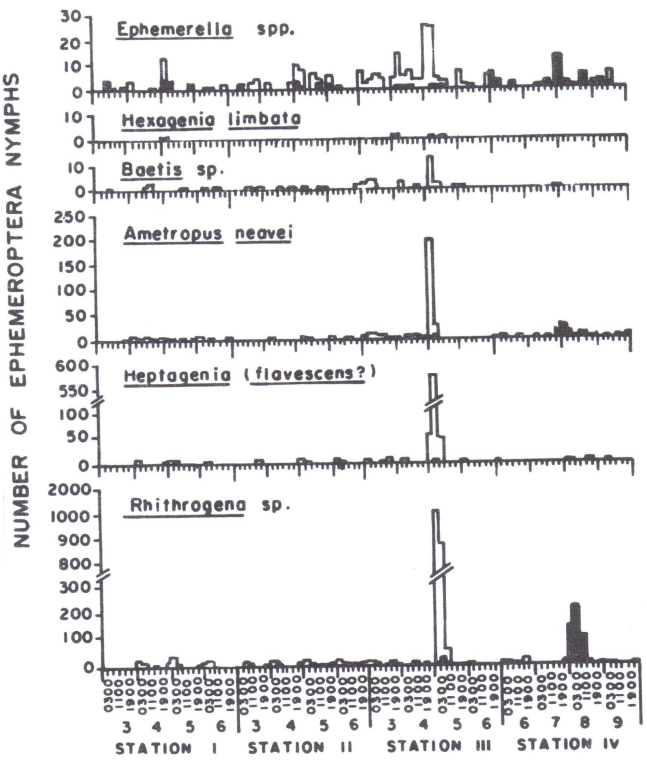

Fig. 6. Numbers of each species of Ephemeroptera caught every 4 hr by drift samplers (bomb, open column; net, closed) during the 4 sampling days at Stations I - IV.

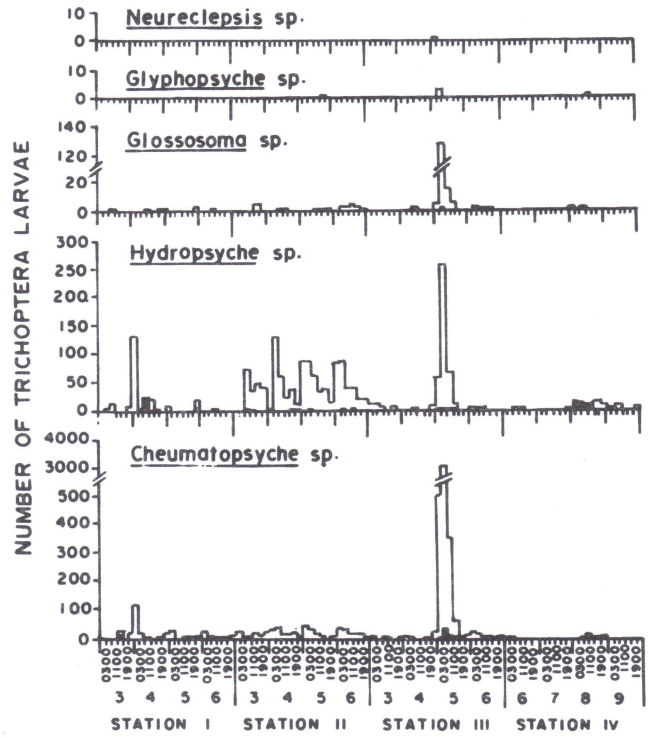

Fig. 7. Numbers of each species of Trichoptera caught every 4 hr by drift samplers (bomb, open column; net, closed) during the 4 sampling days at Stations I - IV.

are evident among the ephemeropteran species (Fig. 6) with *Rhithrogena* sp., *Ametropus neavei* McD., and *Ephemerella invaria* Walker peaking 4 hr before *Heptagenia flavescens* Walsh and *Baetis* sp. at Station III. The latter two species showed little or no increase in drift at Station IV whereas the first three species showed a decided disturbance.

Among the species of Trichoptera (Fig. 7), the catastrophic drift appears to be synchronous at Station III but as much as 8 hr apart even within one family, the Hydropsychidae (*Cheumatopsyche* sp. and *Hydropsyche* sp.) at Station IV.

Small fish, mainly alevins and fry of the white sucker, *Catostomus commersoni* (Lacepede), appeared sporadically in the drift at the first three stations and, bearing in mind the inefficiency of the standard drift net (see Burton and Flannagan 1976), exhibited a very large increase in numbers, coincidently with the increase in invertebrate drift, at Station IV followed by a steady increase in numbers until the end of the sampling period (Fig. 8). Possibly this first peak is due to a disturbance or kill of these animals by the methoxychlor followed by a disturbance or kill due to the lack of food items. Since

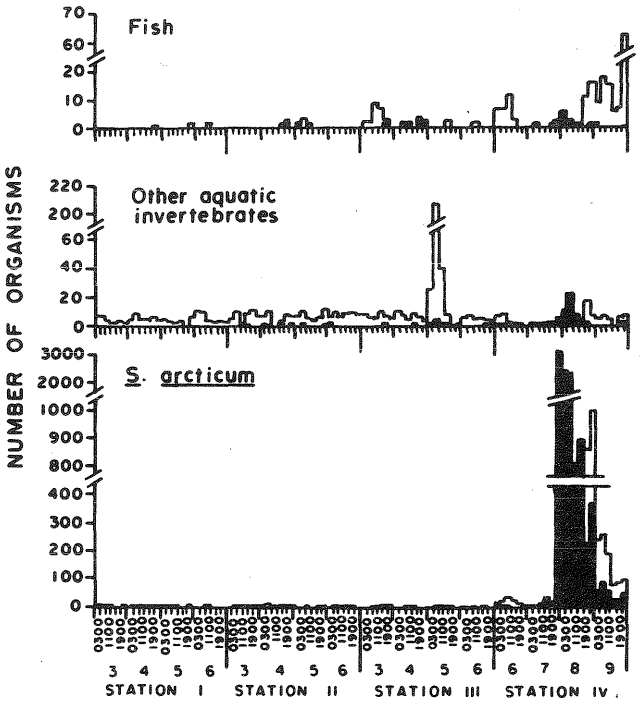

Fig. 8. Numbers of fish alevins, *S. arcticum*, and other aquatic insects caught by the drift samplers (bomb, open column; net, closed) during the 4 sampling days at Stations I - IV.

little is known of the migratory habits of the young of this species, however, the steady increase, but not the initial increase recorded, may be a natural distributional phenomenon.

Simulium arcticum appeared in the drift at Stations I, II, and III relatively consistently but in very low numbers (Fig. 8). At Station IV, they showed a decided and long-lasting catastrophic drift that, although still above the pretreatment levels (Table 1), declined towards the pretreatment levels by the last day of sampling. The distribution of *S. arcticum* in the pretreatment drift suggests that although this species is present along most of the river, the largest concentrations occur between Station III, 67 km downstream from the treatment injection point, and Station IV, 450 km downstream. This area contains several rapids, which are probably the main growing areas for *S. arcticum*.

A comparison of mean pretreatment numbers of the various taxa of aquatic invertebrates caught in the artificial substrate and grab samples and mean pretreatment number per 24 hr in the drift samples with the last set of posttreatment samples is presented in Table 2. Increases in population density, many of them very large, occurred in all the taxa at Station I. Reductions, in some taxa almost total, occurred in most taxa from the treated areas. Further, the general rise in standing

Table 1. *t* values comparing mean densities of the various taxa of invertebrates estimated from Ponar and modified Birge-Ekman samples at time T1 with those at T2, T3, T4, and T5 at the various stations

	T1 vs. --			
Station	T2	T3	T4	T5
		Ephemeroptera		
I	0.321	1.576	1.392	1.699
II	1.885a	0.171	1.059	0.204
III	1.139	1.210	0.753	1.454
IV	1.279	0.036	0.322	4.173a
		Plecoptera		
I	0.676	0.088	0.231	1.682
II	1.037	1.804b	1.976a	0.675
III	1.080	1.883a	1.682	2.821a
IV	0.596	1.010	2.250a	2.651a
		Trichoptera		
I	1.574	0.981	0.764	0.374
II	1.215	0.778	1.282	0.104
III	1.352	1.163	0.221	0.080
IV	1.095	1.603	3.515a	9.889a
		Chironomidae		
I	2.191b	1.707	2.674b	0.497
II	0.948	1.059	0.773	1.349
III	0.210	2.007a	0.639	1.809a
IV	0.969	1.978b	2.553b	1.866b
		Totals		
I	2.127b	2.337b	3.433b	0.458
II	0.814	0.072	0.784	0.817
III	0.350	2.022a	0.308	1.823a
IV	1.197	0.366	0.343	1.813a
		Number of Samples		
I	13	15	15	11
II	17	13	18	13
III	19	19	19	14
IV	11	18	12	11

a-b Significant ($P < 0.05$) decrease (a) or increase (b) from T1.

crop that occurred at the control station makes the percentage decreases even larger at the treated stations. It therefore seems clear that post-catastrophic reductions in both drift and standing crop of benthic invertebrates occurred downstream from the injection site.

DISCUSSION

In this study, Station II drift does not show any clear signs of increased posttreatment drift resulting from the methoxychlor addition. However, there seems to be no doubt that the invertebrates in the area of this station were severely depleted since collections of 1 g of animals required for the methoxychlor analyses took one person only a few minutes before treatment but took four people several hours after treatment. Also, the artificial substrate samples show decided decreases in population

Table 2. Percent change between pre- and late posttreatment numbers in the drift, grab, and artificial substrate (A.S.) samples at the various stations

Taxon	Drift	Grabs	A. S.
	Station I		
Plecoptera	2.7	445.0	20.7
Ephemeroptera	31.5	364.9	362.5
Trichoptera	16.1	265.0	1200.0
S. arcticum	32.5	- -	-
Chironomidae	-	660.3	275.0
Other invert.	9.1	503.9	-
	Station II		
Plecoptera	19.9	-73.0	-83.3
Ephemeroptera	35.5	-27.6	-66.0
Trichoptera	-3.8	-8.8	-100.0
S. arcticum	-12.3	-94.5	-
Chironomidae	-	38.9	-
Other invert.	7.4	-	-
	Station III		
Plecoptera	-95.5	-89.0	-99.0
Ephemeroptera	-83.8	-63.6	-90.0
Trichoptera	5.2	-51.6	0.0
S. arcticum	-8.5	100.5	-100.0
Chironomidae	-	-41.1	-88.2
Other invert.	-20.1	-14.1	-100.0
	Station IV		
Plecoptera	-85.6	-95.4	-
Ephemeroptera	-49.0	-100.0	-
Trichoptera	180.0	-100.0	-
S. arcticum	664.7	-100.0	-
Chironomidae	-	98.0	-
Other invert.	-32.3	-9.2	-

after treatment at this station. It therefore seems likely that, in a large fast river such as the Athabasca, drift populations are recruited from areas at least several hundred meters upstream. Invertebrates normally drift only a few meters or tens of meters (Waters 1964, 1965). The failure to demonstrate catastrophic drift at this station is thus probably related to the origin of the drifting animals caught being upstream of the injection site. Also the distance between the injection point and Station II was probably insufficient to allow the dead animals to be lifted 0.5 m from the bottom to be caught in the drift samplers. The results at the remaining two stations clearly show that the methoxychlor treatment varied in time of maximum effect, in duration of effect, and in effective distance, depending on the species involved. Serious, and in some cases almost total, reduction occurred in many species.

Fredeen (1974) suggested that methoxychlor was adsorbed onto suspended particles carried in the water and was thus selective to filter-feeding animals, while Wallace and Hynes (1975) have shown this insecticide to be totally non-selective in small clear streams. The present data support the latter suggestion since the predaceous Plecoptera, the detritus-feeding Ephemeroptera, and the filter-feeding animals all appeared to be affected by methoxychlor at about the same time. These data also suggest that methoxychlor is not necessarily an internal poison (as suggested by Fredeen et al. 1975) but may kill or disable on contact.

Fredeen (1974, 1975) suggested that river treatment with methoxychlor was acceptable because no species of non-target invertebrates was eliminated and all Orders had repopulated the treated area in a few weeks. Wallace and his coworkers (Wallace et al. 1973; Wallace and Hynes 1975) have suggested that these two criteria are not necessarily the criteria with which the acceptability of this or any other method of control should be measured. Our grab and artificial substrate samples showed short-term reductions similar to those indicated by the drift method (Table 2) and no significant recovery in 4 wk especially of the furthest downstream station. The apparent anomalies between the studies mentioned above and this one are probably related to the different methodologies used to measure the treatment effect on the system. For instance, the artificial substrates of Fredeen (1974), Fredeen (1975), and ours all differ from each other, and the drift 'bomb' used in this study (Burton and Flannagan 1976) has been shown to be considerably more efficient, especially in sampling the non-target taxa involved here, than the standard drift net utilized by both Fredeen (1974, 1975) and Wallace and Hynes (1975). The distances over which the effect was measured also varied considerably in the various studies and it is obvious from this study that disturbances extend much further downstream than was previously realized.

Residues of methoxychlor in the animals analyzed (Fig. 1) appear to have been relatively short lived, very similar among all the free-living taxa sampled, and decreased with distance downstream. However, one should remember that we were sampling surviving animals and the affected ones may have had much higher residues. The caged animals show concentrations of methoxychlor lower than in the natural populations at Station II, but much higher at Station III. The concentration of methoxychlor in the clam tissues follows the natural populations in that maximum concentrations decrease with distance downstream while the crayfish show peak concentrations at Station III, 67 km downstream. Similar differences between caged and wild fish have been recorded by Lockhart et al. (1977). None of the caged animals died and the series of measurements, taken as indices of sublethal effects (see Leonhard 1978), showed no conclusive evidence that the methoxychlor had any effect on these animals. Although the reasons for the difference in concentration between the caged and wild animals are unknown, they are probably related to factors such as stress produced by captivity and the resultant interference with normal feeding and other behavioural patterns.

However, the results do indicate that caged animals are unreliable as indicators of ecosystem effects, at least in this system. Fredeen et al. (1975) in a study of methoxychlor residues of various components of the ecosystem in the Saskatchewan River after a treatment of the same concentration as in this study found detectable residues in invertebrates only during the treatment time. In studies of five species of fish, they found detectable residues only in goldeye and attributed this to the high lipid levels in this species. Of the five species, however, only goldeye and suckers are mainly insectivorous and, of these two, only goldeye consistently feeds in mid or surface waters and would therefore be the species most likely to take advantage of the catastrophic drift of invertebrates caused by the treatment.

The remaining three sampling methods (drift, grab, and artificial substrate) appear to demonstrate similar decreases as a result of treatment. However, the drift sampling should have been extended by at least 2 days to investigate the possibility of an eventual reduction of densities of Trichoptera and *Simulium* shown by the other two methods.

The grab sample results are more variable than the artificial substrates partly because the grabs sample a variety of substrates and not just the 5-7 cm stones. Thus variation in numbers and kinds of animals should be expected. Further, in a large river like the Athabasca, the only areas effectively sampled with grabs of this kind are those with finer sediments, e.g. the wide calm areas of the river proper, in backwaters, and behind islands. Slow-flowing areas of the river may get a higher concentration of methoxychlor than ambient whereas the backwaters get lower than ambient concentrations because of differential deposition of substrates and the fauna may be showing the difference.

CONCLUSIONS

Methoxychlor treatment for black fly larvae control was effective in removing black fly larvae for long distances downstream. Catastrophic drift of non-target invertebrates followed by large decreases in both drift and standing crop occurred to a distance of 400 km downstream from the injection point. All non-target invertebrates, regardless of trophic level, appeared to be affected at about the same time. The results suggest that methoxychlor is not selective for black fly larvae. Little recolonization of non-target invertebrates was recorded within 4 wk after treatment. Methoxychlor levels well above ambient water levels were recorded in natural populations of invertebrates and, generally, different levels were recorded in caged clams and crayfish. The caged animal method is therefore not recommended for studies of this nature. Measurements of drift and estimates of changes in standing crop using artificial substrate samplers appeared to give the most consistent indications of environmental perturbation.

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EFFECT OF METHOXYCHLOR ON RESIDENT POPULATIONS OF THE INVERTEBRATES OF THE ATHABASCA RIVER

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AND W. O. HAUFE

INTRODUCTION

This report deals with the effects of chemical treatment of the Athabasca River in Alberta on resident populations of non-target organisms. This was a part of a multidisciplinary control program set up in 1974 to chemically reduce populations of the larvae of the black fly *Simulium arcticum* with methoxychlor. The purpose of the study was to determine the immediate and longer term effects on resident populations of invertebrates in the river. No attempt was made to study drifting organisms in this particular study since the relationship between drifting invertebrates and resident populations is unknown. We felt that only one aspect could be dealt with in this study and, since resident populations are the source of organisms involved in drifting behavior, the logical approach seemed to be a study of these invertebrates in their habitats.

The reaches of the river in the study area extended 60 km upstream from the town of Athabasca and 240 km downstream.

MATERIALS AND METHODS

Sampling for non-target invertebrates began in 1973. At that time, no reliable sampling methods existed that were applicable to large river systems. Various bottom-sampling techniques were tried before settling on the one described here. A dredging technique was also developed for use with boats. This was useful for deep-water sampling but was found to have limitations in the numbers of individuals and species taken.

Sampling Stations

In every year of the study, samples were taken on a weekly basis as much as possible, and the same stations set up for black fly sampling were used as locations for non-target invertebrate sampling (Depner et al., table 1, p. 21).

In 1973, the year in which bottom sampling was first attempted, 12 sampling stations were set up on the Athabasca River. These ranged from 65 km upstream from the town of Athabasca to 126 km downstream. In 1974, 12 sampling stations were used and these were located from 60 km upstream to 160 km downstream. In 1975, the upstream portion was reduced to two stations at 20 and 40 km and the downstream portion was extended to 240 km. The same arrangement was also used in 1976 and 1977. In all years, the upstream sampling stations were used as untreated or check stations, and those downstream from the town were in the treatment zone. Sampling began in the 1st wk of May each year and continued on a weekly basis into September.

In those weeks in which there had been a sudden rise in river levels, weekly samples were not taken in areas newly covered to accessible depths but not yet colonized by organisms from deeper areas.

Sites at which samples were taken were kept as uniform as possible. Samples were taken in 1 min from bottom areas 0.6 m wide and 3 m long. Bottom texture depended on the sampling area and ranged from sand through gravel to 20 cm diam. rocks. Sampling required two people, one to disturb the bottom with a long-handled garden cultivator, and the other to hold a net. The net was constructed of plastic screen (490 - 630 μ) as half of a closed cylinder sectioned longitudinally, with dimensions of 91 cm high x 76 cm wide with a maximum depth of 35 cm. This net was attached to two 120-cm poles (2.5 cm diam.) that served as handles.

Sampling required both persons to wade into the river to a depth of 76 cm and align themselves in the current - the person with the cultivator 3 m upstream from the one with the net. The net oparator faced upstream with the net opening spread wide into the current. At a given signal, the upstream sampler began vigorously working toward the net, making sure that alignment with the current was such that all material being disturbed was caught in the net. Total sampling time was 60 sec. After this, the net (which was closed at top and bottom) was carefully lifted from the water in such a way as not to lose any sample material. This material was then washed from the net into a plastic tub (91 x 76 x 35 cm deep) containing water to a depth of 10 cm. After carefully washing all organisms and debris into the tub, its contents were poured through a cloth screen cone (40 strands/cm) to remove water. This concentrated sample material was then placed into a 0.57-liter jar, filled with alcohol, and sealed for transport to the laboratory. At the laboratory, the sample, which had been clearly marked, was poured into a 31 x 42-cm white enamelled-metal tray and very carefully picked over under a bright light to remove all organisms contained in it. These organisms were transferred to 40-ml screw-capped vials and later were counted and identified to generic level. Identifications were made under a microscope using magnifications of 20-100 times.

The first treatment of the Athabasca river with methoxychlor was on 4 June 1974, when a concentration of 0.3 ppm was applied to the river from the bridge at Athabasca for a period of 15 min. On 4 June 1975, the same material was applied at the same concentration for 7.5 min by boat at a point 50 m below the Athabasca bridge. In 1976, the river was treated at two points, the first 160 km downstream from the town of Athabasca on 20 May and the second near the Athabasca bridge on 25 May. Each of these treatments was at a concentration of 0.3 ppm of methoxychlor and for an injection period of 7.5 min.

RESULTS

In the period 1973 to 1977, sampling of resident non-target invertebrates yielded a total of 108 genera in 53 families, and 17 orders (Appendix I). Not all of these were found in every year, and not all were found at every sampling station. Some were plentiful at all stations in every year and 12 of these were selected as key genera (Appendix II). Several genera were more abundant at all stations than other groups. Three of these, *Isogenus*, *Ephemerella*, and *Hydropsyche*, were designated as specified key genera in the three most plentiful orders, and can be used as indicators of the effect of treatment (Appendix III).

In 1973, 17 different genera were found at the upstream control stations. In the same year, 24 different genera were found in the downstream area. The numbers of organisms and number of genera found in 1973 are probably not completely indicative of the potential, since techniques had not been perfected and crews were inexperienced. With more experienced personnel, 1974 sampling yielded a substantial increase both in numbers of genera in the control and treated areas (Table 1) and in the total numbers of organisms.

Table 1. Diversity of non-target invertebrates

	Year					
Site[a]	1973	1974	1975	1976	1977	Total
U2	16	37	26	37	46	65
U1	16	41	34	38	43	71
Total	17	50	35	46	58	81
D1	19	30	30	40	42	65
D2	14	34	24	35	38	55
D3	16	28	30	40	43	63
D4	16	31	31	39	41	61
D5	22	30	31	35	37	57
D6	14	26	29	34	43	54
D7			28	34	39	51
D8			27	31	39	49
Total	24	50	47	66	80	100

[a] Upstream (U) = controls; Downstream (D) = treated.

Effect of Treatment

In every year, May averages of non-target organisms are pretreatment averages. Table 2 shows the average number taken at all stations through the summer.

1974 - Untreated stations

Numbers of organisms increased slightly through the summer and then droppped below summer highs in September.

1974 - Treated stations

The overall effect of treatment in 1974 was a drop in total numbers of organisms in June at distances of 20-80 km below the treatment point but with a recovery in numbers by July, and no further effect for the remainder of the summer.

Table 2. Monthly average frequency for all non-target invertebrates

Year	Month	Site (km from Athabasca)										
		40	20	Control[a]	4.7	20	40	80	120	160	200	240
1974	May	206	202	204	361	304	58	287	67	106		
	June	449	140	295	365	27	59	84	57	162		
	July	422	121	271	563	160	69	136	305	147		
	Aug.	561	122	342	462	174	106	44	408	146		
	Sep.	304	316	310	100	77	112	61	751			
1975	May	342	244	293	305	370	340	330	217	179	296	158
	June	100	141	121	195	125	177	736	208	246	306	90
	July	58	847	453	260	274	197	356	287	320	305	231
	Aug.	592	649	620	679	1290	1289	711	901	445	593	849
	Sep.	233	246	240	252	225	255	215	413	130	259	157
1976	May	148	433	291	565	222	215	164	280	214	398	221
	June	86	449	267	303	67	82	292	253	217	215	187
	July	125	311	218	834	323	191	145	282	361	229	349
	Aug.	122	311	212	151	142	111	178	241	446	456	1099
	Sep.	222	614	418	240	718	524	623	710	650	311	795
1977	May	316	248	282	810	432	295	390	494	386	419	770
	June	672	691	681	985	760	414	227	492	827	238	626
	July	353	689	521	540	232	209	123	248	329	326	859
	Aug.	389	535	462	638	348	372	364	436	270	400	941
	Sep.	136	249	192	713	139	1233	149	428	398	343	530

[a] Average of values for 40 and 20 km upstream.

D1 - 4.7 km - Average of organisms increased after treatment to a high in August and then dropped in September.

D2 - 20 km - Posttreatment numbers dropped sharply in June but recovered in August.

D3 - 40 km - There was no posttreatment decrease in numbers and a gradual increase to September.

D4 - 80 km - Numbers dropped sharply in June increased in July and remained low for the rest of the summer.

D5 - 120 km - Numbers were low in May, remained about the same in June and then increased greatly in July, August, and September.

D6 - 160 km - Numbers increased in June over May and held at uniform levels through the summer.

1975 - Untreated stations

Total numbers of non-target organisms dropped sharply in June, recovered in July, increased further in August, and dropped somewhat in September.

1975 - Treated stations

The effects of treatment in 1975 were minor. Some unknown factor caused a drop in numbers of organisms in June in both control and at some treated stations, but recovery was complete by July.

D1 - 4.7 km - Numbers dropped somewhat in the period after treatment as in the non-treated controls but recovered by July.

D2 - 20 km - The situation was similar to D1 with recovery in July and a very high peak of numbers in August.

D3 - 40 km - Again there was a drop in June, some recovery in July, and a dramatic increase in August.

D4 - 80 km - Numbers increased suddenly after treatment in June, dropped in July, and again increased in August.

D5 - 120 km - Numbers did not change significantly until August when there was a large increase. High numbers were maintained into September.

D6 - 160 km - There was a gradual increase through the summer.

D7 - 200 km - Numbers did not change until August when a significant increase occurred.

D8 - 240 km - Numbers dropped in June, but in July were higher than May and were still higher in August.

1976 - Untreated stations

There was no great variation in numbers in May, June, July, and August, but there was an increase in September.

1976 - Treated stations

This was the year of double treatment of the Athabasca river with the first treatment at 160 km on 20 May and the second at Athabasca on 25 May.

The effects of treatment in 1976 were again negligible and numbers of non-target organisms were not affected greatly in any portion of the treated section of river.

D1 - 4.7 km - Numbers decreased in June, recovered fully in July, dropped again in August, and increased in September.

D2 - 20 km - There was a decrease in numbers of organisms in June and a recovery in July, a decrease in August, and a great increase in September.

D3 - 40 km - Numbers dropped in June but recovered in July and were maintained through the summer with an increase in September.

D4 - 80 km - There was an increase in June, a slight decrease in July with further increases in August and September.

D5 - 120 km - Numbers fluctuated very little throughout the summer and increased in September.

D6 - 160 km - Numbers, which were about the same in May and June, increased in each month thereafter to September.

D7 - 200 km - There was a moderate decrease in June and July but a recovery in August.

D8 - 240 km - There was a moderate decrease in June, an increase above May in July, a great increase in August, and high numbers throughout September.

1977

The Athabasca river was not treated in this year, but sampling of resident populations of non-target invertebrates continued as in previous years.

In general, the year 1977 was one of good numbers of non-target organisms at all stations with levels often higher than in previous years at both untreated check stations and treated downstream stations. Monthly averages from which the following comments were taken are shown in Table 2. Monthly averages for 1974-1977 for 12 key organisms are shown in Appendix II and the equivalent values for the specified key organisms, *Isogenus*, *Ephemerella*, and *Hydropsyche*, are in Appendix III.

1977 - Untreated stations

Numbers increased in June to levels higher than in previous years, continued high in July and August, but deceased in September.

1977 - Treated stations

D1 - 4.7 km - Numbers were high in May and June, and remained at only slightly lower levels for the remainder of the season.

D2 - 20 km - Numbers were high in June and decreased again in July to remain at lower but adequate levels for August and September.

D3 - 40 km - Numbers of organisms remained fairly constant except for a slight increase in June and a great increase in September.

D4 - 80 km - Numbers decreased gradually from May until July, and then increased in August to be followed by another decline in September.

D5 - 120 km - Throughout the summer, numbers were uniform at levels higher than in the 3 previous yr.

D6 - 160 km - Numbers were high with a peak in June.

D7 - 200 km - Numbers displayed very little change through the season and differed little from previous years.

D8 - 240 km - Numbers were very high throughout the season at a level considerably above previous years.

INTERPRETATION AND DISCUSSION

The diversity of organisms, i.e. the numbers of kinds of organisms, remained relatively stable at the untreated upstream sampling stations. At the downstream (treated) stations, a different picture emerged. The numbers of kinds of organisms at all stations from 5-240 km increased within each year of the test. This applies to individual stations, and to all stations collectively, and indicated that, as populations of some of the predominating organisms were lowered, an opportunity was presented for some of the less numerous kinds to increase their numbers. This was also shown by the fact that, while the total number of kinds of organisms found in the check stations in all years was 81, the downstream treated stations yielded 100 in the same period. In the 1st yr of treatment, 1974, the number of kinds of organisms in each of the two areas was 50, but in 1977 this figure was 58 for the upstream stations and 80 for the downstream. This is, we believe, the first time that it has been demonstrated that an insecticidal treatment can result in an increased diversity of organisms in an aquatic environment.

Numbers of individuals taken in a bottom sample normally fluctuate greatly, depending on phenology, river discharge levels, and bottom conditions. In spite of this, there is a clear effect of treatment

shown in some of the downstream sites and a rapid recovery of populations in the month after treatment. The toxic effect of materials other than those introduced into the system by the experiments reported here are also indicated in 1975 when an unknown cause lowered populations of the target organism *Simulium arcticum* and the non-target invertebrates in the untreated upstream areas and in the treated areas to about 40 km.

CONCLUSIONS

1. The use of methoxychlor as a larvicide to reduce populations of black flies in a large silt-laden river had no lasting effect in reducing resident numbers of non-target invertebrates. Recovery of populations was nearly always within 1 mo when a concentration of larvicide of 0.3 ppm for 7.5 or 15 min was used.

2. Treatment of the Athabasca River with methoxychlor as a larvicde increased the diversity of invertebrates in the system.

3. Any effect of treatment on non-target organisms was intensified at low river discharge when current velocities were insufficient to keep bedloads and silt moving.

QUESTIONS REQUIRING FURTHER STUDY

The interrelationships of the invertebrates of large river systems is very poorly understood. A great deal of work remains to be done to identify species and to list organisms present. There are probably many species that have not yet been named.

The ways in which large-river organisms fit into their respective ecological niches is almost completely unknown, as are the complex predator-prey relationships, and the density-dependent and -independent aspects of populations.

An area of investigation in which worthwhile results would almost certainly be achieved is that of the relationships between the drifting and resident populations of invertebrates. In this, the factors that result in drifting behavior, and the duration and reasons for drift should be investigated.

Another area of investigation is the importance of some of the invertebrate groups as members of the food chain in the river. In other words, which invertebrates are important as food for fish and other vertebrates, and what is their relationship to other members of the food chain?

ACKNOWLEDGEMENTS

We specifically wish to acknowledge the help of M. C. Qually and J. H. Carson in the active field work. Without their help, it would not have been possible to complete the sampling. Many other people were involved in the program as well, both as co-operators and as willing hands, and these people, although unnamed, are recognized as being vital to the completion of the program.

Appendix I. Non-target Invertebrates--Presence, Location and Year[a]

Order	Family	Genus	Upstream (km)		Downstream (km)							
			40	20	5	20	40	80	120	160	200[b]	240[b]
Amphipoda	Gammaridae	Gammarus	4567	45	47	46	46	4	67	4567	7	
	Talitridae	Hyalella		47		4	7	7				
Copepoda	-	Copepod							7			
Mysidaecea	-	Mysis		4			5					
Basommatophora	Lymnaeidae	Lymnaea	67	7	67	367	367	67	7	67	7	7
	Planorbidae	Helisoma			6							
		Gyraulus	7	7		7	67	7	7			
		Promenetus		67	67	6	67					6
Mesogastropoda	Valvalidae	Valvata			6							
Rhynchobdellida	Glossiphoniidae	Theromyzon			7		7					7
Coleoptera	Amphizoidae	Amphizoa		4					3			
	Dytiscidae	Agabus				7						
		Deronectes							7			
		Hydrovatus	4	5	4	4	5	57				
		Rhantus		7								
	Elmidae	Optioservus		6	6			7		6	6	7
	Gyrinidae	Gyrinus	47	4			7		36	6		
	Haliplidae	Haliplus	7			4						
	Hydrophilidae	Paracymus								5		
	Ptilodactylidae	-		7				7				
Diptera	Ceratopogonidae	Culicoides	67	7	7		67	6	57	5	7	5
	Chironomidae	Calopsectra	46	56	6	6	6	56	456	6	6	6
		Chironomus	46			6	4		4	7	7	
		Metriocnemus		7								
		Pentaneura	34567	34567	34567	4567	34567	34567	34567	34567	567	567
	Culicidae	Chaoborus	4	4	4	4		4				6
	Dolichopodidae	Dolichopus			67	67	67	6	67	67		7
	Empididae	Hemerodromia	67	67	67	67	67	67	67	67	67	67
	Rhagionidae	Atherix		6	56			567	45		67	67
	Sciomyzidae	-			6							
	Simuliidae	Cnephia		4								
		Simulium	34567	34567	3567	4567	467	34567	34567	34567	567	567
	Tanyderidae	Protoplasa	4		3							7
	Tipulidae	Erioptera	7								6	
		Hexatoma			4			7	46	7		
		Pedicia	47		5			5	6		6	
		Tipula	6		56	67	46	6		6	5	56
Ephemeroptera	Baetidae	Ametropus	67	457	46	345	34567	4567	357	457	567	57
		Baetis	34567	34567	34567	34567	34567	34567	34567	34567	567	567

Appendix I continued

Order	Family	Genus	Upstream (km)		Downstream (km)							
			40	20	5	20	40	80	120	160	200[b]	240[b]
Ephemeroptera	Baetidae	Baetodes					6	5	6			
		Centroptilum	46	46	46	6	46	467	456	46	56	
		Metretopus	46	46	47	46	4567	3467	347	47	67	
		Neocloeon	457	45	4	4	46	46	456	45		5
		Pseudocloeon	4	46	45	46	5	56	6	6	5	
		Siphloplecton	67	467	57	467	67	67	6	67	7	7
	Baetiscidae	Baetisca		4			7					
	Caenidae	Caenis	7	45				457	7			
	Ephemerellidae	Ephemerella	34567	34567	34567	34567	34567	34567	34567	34567	567	567
	Ephemeridae	Ephemera					6					
		Hexagenia	4	4			5	4				
	Heptageniidae	Cinygma	35	3457	357	356	345	35	35	457	5	5
		Cinygmula	5	7			7					
		Epeorus	457	57	347	7	457		347	4567	57	57
		Heptagenia	34567	34567	34567	34567	34567	34567	34567	34567	567	567
		Rhithrogena	34567	34567	34567	34567	34567	34567	34567	34567	567	567
		Stenonema	4567	4567	4567	4567	4567	4567	4567	4567	567	567
	Leptophlebiidae	Habrophlebiodes	6	6								
		Leptophlebia	4567	567	5	4567	6	67	67	57	57	6
		Paraleptophlebia	6	567	7			4				
	Siphlonuridae	Ameletus	456	457	457	4567	5	457	45	45	567	5
		Isonychia	3457	3457	34567	3457	3457	4567	345	4567	567	567
		Parameletus	67	46			67	67	7	67	7	67
		Siphlonisca						6				7
		Siphlonurus		5			5					
	Tricorythidae	Tricorythides	7	5		67			7	7	7	7
Heteroptera	Corixidae	Callicorixa	46	67	467	467	467	46	57	67		
		Cymantia	7	6		67	67	7		7		
		Sigara	467	3467	34567	3467	34567	34567	34567	4567	567	567
	Gerridae	Rheumatobates					7					
	Notonectidae	Notonecta	7		6		7					
Lepidoptera	-	Arzama										7
		Nepticula		7								
Neuroptera	Sialidae	Sialis				7						
Odonata	Gomphidae	Ophiogomphus	34567	34567	34567	457	34567	34567	34567	34567	567	567
Plecoptera	Chloroperlidae	Chloroperla						4	6			
		Hastaperla	4567	4567	4567	4567	567	4567	4567	567	567	567
	Nemouridae	Brachyptera			6		6				67	
		Nemoura	567	567	567	4567	67	567	4567	57	67	567
	Perlidae	Acroneuria	4567	4567	4567	457	45	56	456	567	57	567
		Claassenia	7	57	57	7		57	567	47	56	67
		Neoperla	34	345	3	34		34	34	34		
	Perlodidae	Diura					6					
		Isogenus	34567	34567	34567	34567	34567	34567	34567	34567	567	567

Appendix I continued

Order	Family	Genus	Upstream (km)		Downstream (km)							
			40	20	5	20	40	80	120	160	200[b]	240[b]
Plectopera	Perlodidae	Isoperla	4567	4567	34567	4567	4567	4567	34567	34567	567	567
	Pteronarcidae	Pteronarcella	4		4						7	
		Pteronarcys	34567	34567	34567	34567	34567	34567	34567	34567	567	567
Trichoptera	Brachycentridae	Brachycentrus	34567	34567	34567	4567	34567	34567	34567	34567	567	567
	Glossosomatidae	Agapetus				7			6	7	6	
		Glossosoma	7	47	67			46		7	6	7
	Hydropsychidae	Arctopsyche		46	67	4		6	47	67	6	6
		Cheumatopsyche	34567	34567	34567	34567	34567	34567	34567	34567	567	567
		Diplectrona			7	7					7	7
		Hydropsyche	34567	34567	34567	34567	34567	34567	34567	34567	567	567
		Parapsyche	7	4	7							
	Hydroptilidae	Neotrichia		7								
		Not keyed	7		7						7	
	Leptoceridae	Mystacides	7	7	7		7	7		7	7	7
		Trianodes					7			7		
	Limnophilidae	Drusinus							7			
		Platycentropus			5	5	57	7	5	7		
		Psychoronia	3	6		7	5					
	Psychomyiidae	Neureclipsis		6								
		Polycentropus			7							
		Psychomyia	67				7					
	Rhyacophilidae	Rhyacophila	7	6								
Gordiida	Gordiidae	Gordius			6							67
	Naididae	Stylaria	567	567	567	567	4567	567	567	567	567	567
Heterodonta	Sphaeriidae	Sphaerium						7				

a Individual digits in vertical columns indicate presence and year, e.g. 4567 - 1974, 1975, 1976, 1977.

b Not sampled in 1973-1974.

Appendix II. Monthly average frequency for key genera[a] of non-target organisms

Year	Month	Site (km from Athabasca)										
		40	20	Control[b]	4.7	20	40	80	120	160	200	240
1974	May	181	182	181	350	278	53	270	66	101		
	June	443	137	290	359	26	52	82	49	162		
	July	403	114	258	541	148	63	129	288	214		
	Aug.	548	116	332	229	171	94	44	393	141		
	Sep.	247	309	278	91	32	94	52	740			
1975	May	300	229	265	280	336	297	311	189	157	244	141
	June	90	133	112	170	116	160	682	198	234	264	84
	July	49	754	401	245	245	171	316	260	250	266	199
	Aug.	550	626	588	656	1221	1219	666	864	412	587	786
	Sep.	222	229	225	244	223	254	210	486	129	257	153
1976	May	129	550	340	536	204	202	150	269	205	363	212
	June	57	427	242	282	52	76	244	235	191	199	141
	July	125	287	206	767	236	164	136	268	328	214	327
	Aug.	101	297	199	140	131	97	164	252	432	436	1061
	Sep.	203	137	170	199	667	514	451	697	618	302	694
1977	May	304	235	270	802	424	384	382	592	363	407	712
	June	558	652	605	960	701	375	202	468	796	219	542
	July	347	625	486	524	227	198	119	221	282	303	798
	Aug.	369	522	445	605	317	334	342	404	243	378	877
	Sep.	132	234	183	652	129	1162	143	373	366	334	517

[a] Plecoptera-Isogenus, Isoperla, Pteronarcys; Trichoptera-Cheumatopsyche, Hydropsyche; Ephemeroptera-Baetis, Ephemerella, Heptagenia, Rhithrogena; Heteroptera-Sigara; Odonata-Ophiogomphus; Amphipoda-Gammarus.

[b] Average of values for 40 and 20 km upstream.

Appendix III. Monthly averages for specified key genera

Year	Genus	Site (km from Athabasca)										
		40	20	Control[a]	4.7	20	40	80	120	160	200	240
							May					
1974	Isogenus	43	34	38	176	94	41	66	25	46		
	Ephemerella	36	26	31	32	30	1	70	10	10		
	Hydropsyche	23	16	19	8	30	0	24	5	10		
1975	Isogenus	204	133	168	150	74	124	90	114	83	107	90
	Ephemerella	8	7	7	5	4	9	47	7	4	18	5
	Hydropsyche	3	9	12	17	45	12	12	14	20	26	8
1976	Isogenus	41	316	179	275	102	99	45	114	138	186	96
	Ephemerella	11	50	31	109	18	28	31	49	14	36	16
	Hydropsyche	0	8	4	20	5	1	0	11	8	41	28
1977	Isogenus	91	121	106	264	98	117	45	177	159	141	331
	Ephemerella	105	65	85	239	233	120	160	272	82	150	128
	Hydropsyche	2	2	2	5	4	0	7	7	12	15	12
							June					
1974	Isogenus	100	40	70	221	3	1	2	0	8		
	Ephemerella	81	17	49	63	9	37	55	9	24		
	Hydropsyche	52	5	28	19	2	3	15	0	110		
1975	Isogenus	14	14	14	34	23	33	63	57	74	76	26
	Ephemerella	16	9	12	13	4	13	58	11	11	33	9
	Hydropsyche	1	2	2	14	8	37	190	48	54	62	8

Appendix III continued

Year	Genus	Site (km from Athabasca) 40	20	Control[a]	4.7	20	40	80	120	160	200	240
1976	Isogenus	21	218	120	228	8	44	49	49	94	59	28
	Ephemerella	6	35	21	26	8	11	72	35	15	45	13
	Hydropsyche	0	4	2	6	2	0	6	20	7	13	29
1977	Isogenus	51	51	51	45	35	14	20	31	121	43	66
	Ephemerella	173	170	172	264	247	123	71	80	263	71	99
	Hydropsyche	78	236	157	87	143	63	16	115	42	5	49
							July					
1974	Isogenus	28	16	22	74	16	0	13	27	4		
	Ephemerella	19	6	12	23	10	15	4	7	3		
	Hydropsyche	242	32	137	214	76	11	60	161	64		
1975	Isogenus	7	62	34	28	67	38	45	5	10	9	6
	Ephemerella	2	9	5	17	16	3	8	12	3	17	3
	Hydropsyche	22	314	168	94	61	44	127	147	158	158	136
1976	Isogenus	26	33	29	300	51	19	14	26	5	28	23
	Ephemerella	3	6	5	20	2	1	3	3	3	2	1
	Hydropsyche	7	92	49	146	27	13	11	120	108	75	190
1977	Isogenus	47	42	44	93	25	38	19	42	73	69	125
	Ephemerella	81	291	186	67	25	32	13	13	27	29	23
	Hydropsyche	79	42	60	102	41	13	4	33	16	14	218
							August					
1974	Isogenus	34	17	26	41	21	6	5	48	27		
	Ephemerella	1	2	2	17	0	0	0	0	0		
	Hydropsyche	436	61	249	330	127	15	23	154	75		
1975	Isogenus	77	38	58	65	108	109	59	77	28	20	54
	Ephemerella	1	0	1	0	8	0	0	1	1	1	1
	Hydropsyche	290	375	333	273	489	668	266	546	228	227	266
1976	Isogenus	26	54	40	40	19	28	33	58	63	89	107
	Ephemerella	0	1	1	0	0	0	0	0	0	3	0
	Hydropsyche	6	77	42	30	19	5	21	96	140	116	347
1977	Isogenus	53	92	72	201	76	55	88	68	74	144	177
	Ephemerella	3	124	63	7	3	3	2	1	0	3	2
	Hydropsyche	96	5	51	160	55	19	20	62	32	27	151
							September					
1974	Isogenus	41	83	62	19	12	18	3	156			
	Emphemerella	1	0	1	0	0	0	1	1			
	Hydropsyche	116	153	135	31	4	3	3	299			
1975	Isogenus	21	60	41	41	92	29	80	118	69	83	40
	Ephemerella	0	0	0	0	0	0	0	0	0	0	0
	Hydropsyche	108	20	64	114	19	0	37	159	6	85	15
1976	Isogenus	44	73	59	48	96	36	97	50	112	63	92
	Emphemerella	0	0	0	2	29	1	14	1	2	1	5
	Hydropsyche	86	82	84	43	40	7	97	214	259	67	161
1977	Isogenus	65	76	70	138	62	131	84	178	223	225	397
	Ephemerella	3	2	2	2	0	1	1	1	1	2	4
	Hydropsyche	7	6	6	24	2	0	2	3	4	4	5

[a] Average of values for 40 and 20 km upstream.

ACUTE AND LONG TERM EFFECTS OF METHOXYCHLOR LARVICIDING ON THE AQUATIC INVERTEBRATES OF THE ATHABASCA RIVER, ALBERTA

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INTRODUCTION

In 1974, we used several methods to measure lethal and sublethal short-term effects of the Athabasca River black fly control treatment on the aquatic invertebrates of the system, with specific reference to the non-target aquatic invertebrates (Flannagan et al. 1978).

Three main methods of measuring possible effects were utilized: monitoring the effects on caged crayfish and clams; use of artificial substrate samplers; and attempts to measure natural populations using drift and grab samplers. Each of these methods, although considered to be the best available for measuring changes in the various components of such a large river, has limitations. Caged animals are living in an unnatural situation, in some cases are exotic to the system, and in general are subject to different stresses than wild ones. Artificial substrate samplers often do not give population figures comparable to natural ones but have the advantage of being comparable, after a given colonization period, with each other. The third method, measuring actual populations of benthos in the drift and on the bottom is the most direct one but, in the case of the grabs, suffers severe limitations in a large river like this one, in that most of the river substrate is too large in size or too firmly embedded to be removed by a grab. Thus grab sampling sites are limited to backwaters and other areas where the river slows enough to deposit finer sediments. These areas are rarely typical of the main stream, both in the fauna and in the loading of methoxychlor. In addition to the above, benthos samples were periodically collected at a control and three downstream stations for methoxychlor residue analyses.

The conclusions drawn from this first portion of the program (Flannagan et al. 1978) in terms of methodology were that artificial substrates and drift and grab sampling gave similar indications of the effects on the fauna of the system but that grab samples were, as expected, much more variable than the others. In terms of effect on the non-target fauna, it was clear that catastrophic drift (change in the time of day of maximum drift or an increase of an order of magnitude or greater in drift densities at any particular time of day) and related reductions in density of bottom fauna occurred, at least as far downstream as 400 km from the injection site, and that little recolonization occurred in the affected part of the river in the 3 wk after treatment. The data also suggested that methoxychlor was not selective to *Simulium* or even to filter-feeding animals as was previously suggested. Methoxychlor residue in the surviving animals was shown to be short lived and not biologically magnified.

In the 1975 treatment, we attempted to improve our program by eliminating the caged animal experiments and the residue analyses, and concentrated on extending the period of drift sampling to cover any post-catastrophic reductions. The period of grab and artificial substrate sampling was

extended throughout the summer to study possible recolonization of the benthos over the summer.

METHODS

Four stations, one upstream control (Station I) and three downstream from the injection site were chosen for study in 1975. Stations I, III, and IV were at the same sites as in the previous year (see Flannagan et al. 1978), i.e. Station I, upstream control; Station III, Calling River 67 km downstream; and Station IV, Fort McMurray, ca 400 km downstream from injection site. Station II was changed from the 200 m downstream site to a site about 1 km further downstream.

On the morning of 4 June, methoxychlor was injected into the river by boat at the bridge at the town of Athabasca to give a 0.3 ppm slug 7.5 min in duration (i.e. half the exposure time of the 1974 treatment) in the river.

Drift Sampling

Two bomb drift samplers (Burton and Flannagan 1976) were suspended from an anchored buoy at each of the four stations as previously described and sampled every 4 hr for 5-7 days. Sampling started on 3 June at Stations I, II and III and continued for 5-7 days. At Station IV, sampling started on 7 June and continued for 6 days. This allowed at least 1 day of pretreatment drift to be sampled before the arrival of the methoxychlor at each of the downstream stations based on the flow speed of the river and the previous year's results.

Artificial Substrate Sampling

Barbecue baskets filled with 5-7 cm diam. limestone pebbles (Anderson and Mason 1968) and fitted with a fine mesh nylon net that enveloped them on retrieval, were set into the river at various times at the four stations previously described. These samplers were left in for a minimum of 3 wk and retrieved in groups of three: two or three times before the treatment effects were expected at each station; five or six times in June but after the methoxychlor slug had passed as indicated by the drift sampling; and once each in mid July, late July, and mid August.

Ponar Samples

Sets of six Ponar grab samples (Powers and Robertson 1967) were taken 12 times over the sampling period at each station. Two sets were taken before treatment effects could be expected at any station. One set was taken on the day of expected arrival of the treatment and one set on 3 of the 4 following days. Two further sets were taken in June, three in July (early, middle, and late), and a final set was taken in August.

All of the above samples were preserved in the field in 10% formalin and were sorted in the laboratory to higher taxa, using the low power of a dissecting microscope. Since the variances tended to be as large or larger than the means, the data from the Ponar grab samples were transformed as $\log_n$ (number + $1/m^2$) in the artificial substrates and $\log_n$ (number + 1) which, according to Bartlett (1947), makes the variances homogeneous and thus gives 'truer' values of statistical significance.

A comparison between the pretreatment populations in 1974 and 1975, as measured by artificial substrate samples, was also carried out using t-tests, to ascertain whether any measurable effect remained in 1975 attributable to the 1974 treatment. t-tests on the data indicated that the variances were not significantly different (Elliott 1973); therefore, any differences indicated by the t-tests can be attributed to difference in mean numbers.

Changes in mean numbers of animals in the drift, over the sampling period at the control, were compared with changes in drift of the first and last day of sampling at the treated stations using the formula $[(N_A/N_B) - 1]100$ where N_A = mean number after treatment and N_B = mean number before treatment. In the case of the artificial substrate samples, both this formula and an amended version of Abbott's (1925) formula, to account for change at the upstream control, were used. The amended formula was

$$\% \text{ change} = [N_A/(N_B \times rf) - 1]100$$

where N_A = mean number after treatment, N_B = mean number before treatment at the treated stations, and rf = number after treatment divided by number before treatment at the control. This amended formula assumes that changes in mean numbers at the control station, over the period sampled, also occur at the downstream stations and that they occur before the treatment effects. Thus if a major change occurs at the control station after treatment, the formula will underestimate the treatment effects.

RESULTS

Catastrophic drift related to the methoxychlor treatment was clearly demonstrated at all three downstream stations by Trichoptera and Plecoptera (Fig. 1), and at Station II and III by *Simulium* (Fig. 2), Ephemeroptera (Fig. 3) and the Other Aquatic Invertebrates (Fig. 2). At Station IV, *Simulium*, the Small Fish (mainly white sucker alevins) (Fig. 2), also collected in 1974, and to a lesser extent Ephemeroptera did not show large increases in drift coincident with the methoxychlor arrival at this station but did exhibit a gradual decrease of numbers drifting with time. Comparison of the percentage change in the mean numbers drifting before treatment with those drifting on the last day of sampling (Table 1) indicates substantial reductions,

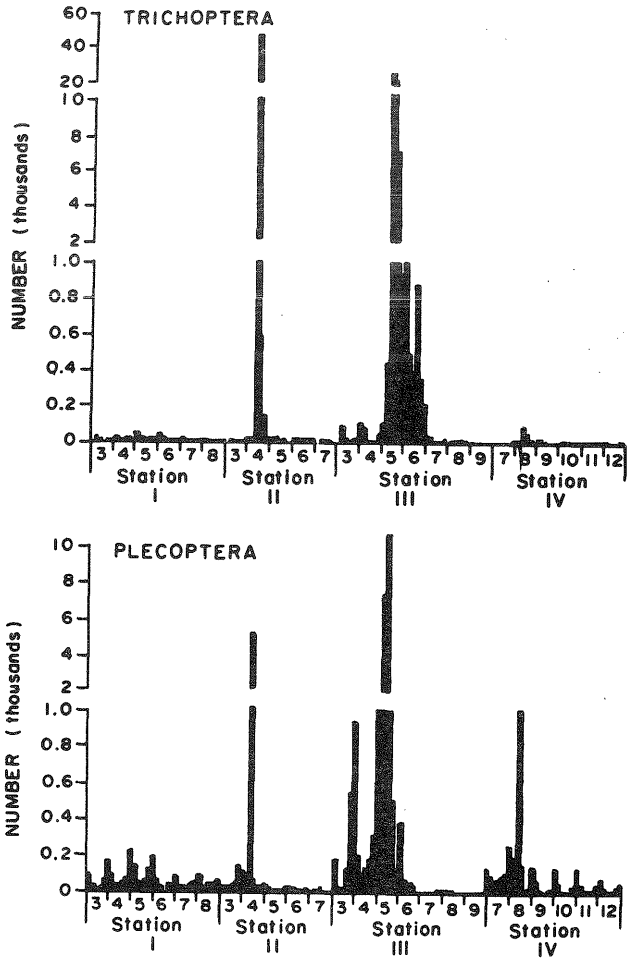

Fig. 1. Mean numbers of Trichoptera larvae and Plecoptera nymphs caught every 4 hr by the drift samplers during 3-12 June at Stations I-IV.

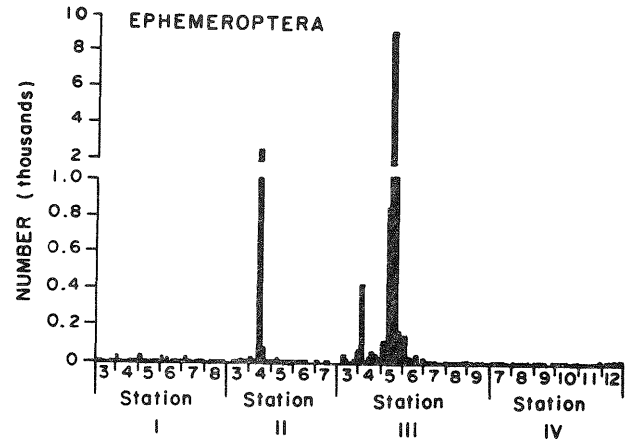

Fig. 3. Mean numbers of Ephemeroptera nymphs caught every 4 hr by the drift samplers during 3-12 June at Stations I-IV.

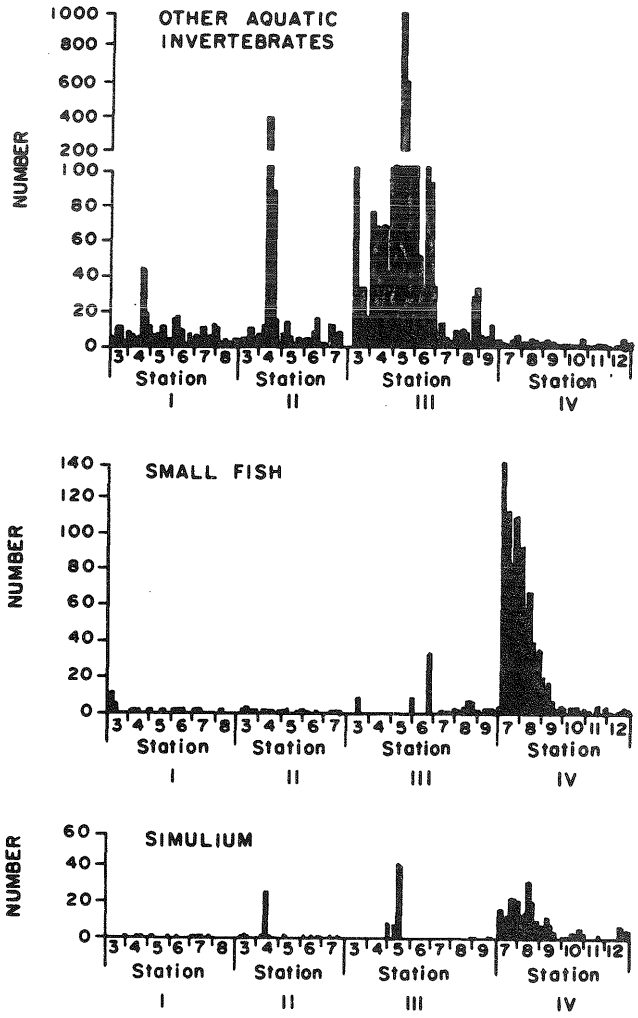

Fig. 2. Mean numbers of *Simulium* larvae, Small Fish, and Other Aquatic Invertebrates caught every 4 hr by the drift samplers during 3-12 June at Stations I-IV.

Table 1. Percent change in numbers of drifting invertebrates 1st day vs mean of remaining days at control (St. I) and day 1 vs. last day at treated stations (II-IV).

	Station			
	I	II	III	IV
Plecoptera	+13.10	-78.75	-98.0	-59.27
Trichoptera	+1.10	-67.18	-91.93	-29.07
Ephemeroptera	+14.10	-87.81	-97.76	-21.79
Other aquatics	+3.75	-40.88	-87.43	-23.32
Totals	+7.30	-63.81	-96.18	-76.21

in some cases almost total, in the drifting populations of animals at the downstream stations and little change over the sample period at the control station. It is of interest to note that the largest reductions in drift occurred at Station III, not Station II as one would expect.

The artificial substrate samples demonstrated that, over the summer at the control (Station I), total fauna, Trichoptera, Other Aquatic Invertebrates, and chironomids gradually increased, while *Simulium*, Ephemeroptera, and Plecoptera densities either remained at about the same levels or decreased (Fig. 4). At the downstream stations, the patterns of change were generally different from these. Station II and III patterns showed, in general, a decrease coincident with the arrival of the methoxychlor slug followed by recovery, in some case, by the August sampling date. Station IV patterns are almost identical to those recorded for this station in the 1974 grab sampling, i.e., an initial increase followed by a drop in density in July, usually continuing to decrease in August. Trichoptera and Ephemeroptera appeared to make a partial recovery at this station in August. The percent change in density from first to last sampling day (Table 2) indicates that the greatest long term effect is at the farthest downstream site (Station IV) where adjusted percent changes range from +52.5% for Plecoptera to -100% (i.e. total elimination) for Other Aquatic Invertebrates and in the unadjusted percent changes from -47.7% in Trichoptera to -100% in Other Aquatic Invertebrates. The very large increases in Trichoptera at Station III is indicative of a secondary disturbance effect.

In contrast to the 1974 results (Flannagan et al. 1978), only Chironomidae

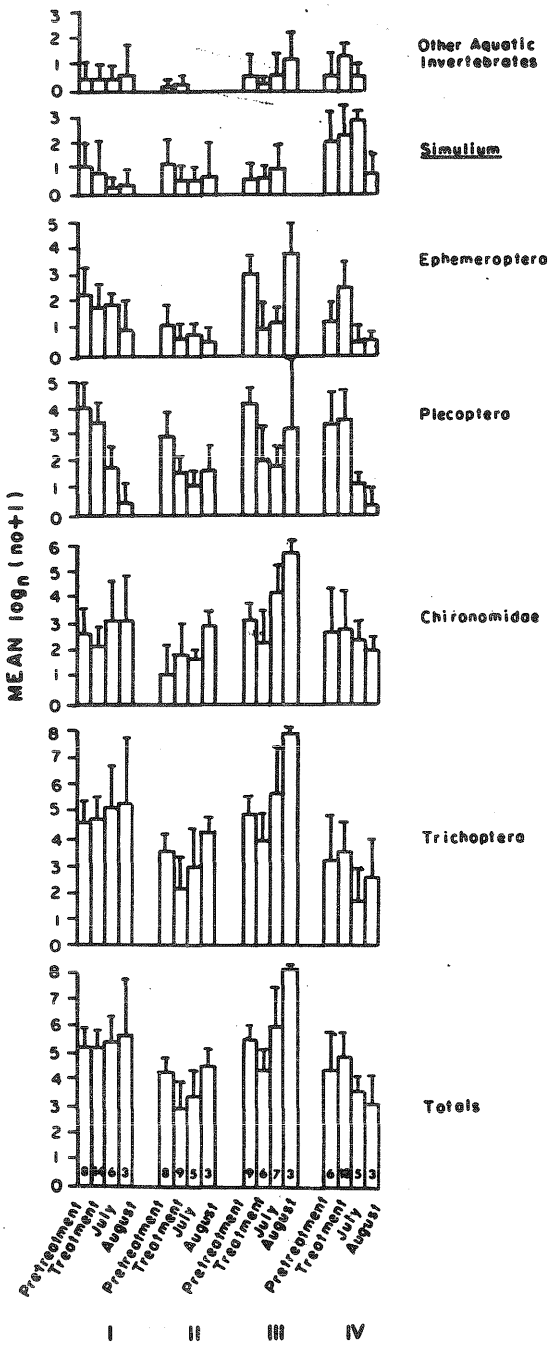

Fig. 4. Mean numbers [$\log_n$(number + 1)] and standard deviations of benthic invertebrates from artificial substrates at Stations I-IV (sample numbers indicated within bars).

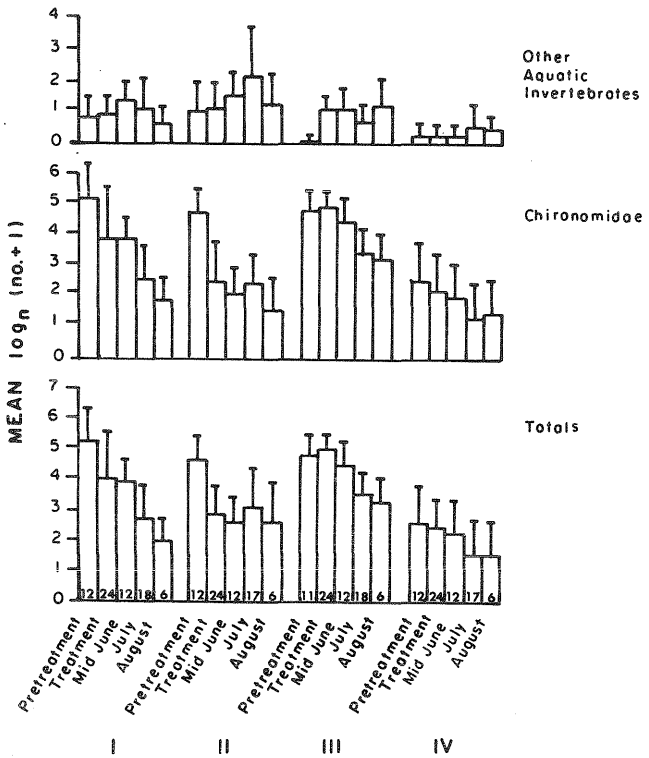

Fig. 5. Mean number [$\log_n$(number/m^2 + 1)] and standard deviations of the benthic invertebrates caught in the Ponar samples at Stations I-IV (sample numbers indicated within bars).

and the Other Aquatic Invertebrates were collected consistently in the Station I, II, and III pretreatment and control Ponar samples and these plus Totals are presented in Fig. 5. Again, it appears that the invertebrate populations at the control station either remained relatively constant or decreased over the summer. However, in 1975, no clear patterns appeared at the treated stations. Some indication of a treatment or post-treatment decrease is evident at Station II in the Chironomidae and total fauna, but otherwise the data are inconclusive.

Statistical comparison of the 1975 pretreatment with the 1974 pretreatment data indicates that, in general, a significant increase ($P<0.01$) in Chironomidae densities occurred at most stations. The remaining three groups, Trichoptera, Ephemeroptera, and Plecoptera, do not show significant population density differences at the control or first downstream (Station II) stations. However, at the further downstream, treated sites (Stations III and IV), an entirely different picture is evident. The grab sample data show

Table 2. Percent change between 1st day and last day of sampling artificial substrates including modified Abbott's formula to adjust for changes at control

	Station I	Station II		Station III		Station IV	
		Not adjusted	Adjusted	Not adjusted	Adjusted	Not adjusted	Adjusted
Plectopera	-98.97	-74.81	+2345.32	-63.03	+3489.98	-98.40	+52.50
Trichoptera	+128.47	+95.36	-14.49	+1874.24	+764.10	-47.70	-77.11
Ephemeroptera	-81.65	-68.59	+71.16	+141.65	+1216.91	-77.24	+24.00
Simulium	-70.53	-52.13	+62.44	-100.00	-100.00	-79.85	-31.61
Chironomidae	+63.71	+547.60	+295.58	+1026.87	+588.33	-48.32	-68.43
Other aquatics	+36.32	-100.00	-100.00	+280.19	+178.89	-100.00	-100.00
Totals	+32.61	-35.10	-1.88	+1053.34	+769.72	-70.55	-77.79

Table 3. t-values for changes in mean numbers of the various taxa at Stations I-IV in pretreatment 1975 samples vs pretreatment 1974 samples

	Station			
	I	II	III	IV
		Ponar and Ekman samples		
Chironomidae	4.904*	4.929*	3.464*	2.078
Trichoptera	2.293	0.764	3.095*	10.734*
Plecoptera	0.763	1.534	4.952*	4.660*
Ephemeroptera	0.623	1.989	3.107*	4.074*
df	16	18	18	17
		Artificial substrates		
Chironomidae	4.640	1.148	3.323*	-*a*
Trichoptera	0.682	1.716	3.335*	-
Plecoptera	0.407	0.565	3.215*	-
Ephemeroptera	0.338	0.952	1.310	-
df	10	10	10	

* 1975 densities significantly different from 1974 ($P<0.01$).

a Not sampled in 1974.

significant decreases in these three taxa at both stations. The artificial substrate data, although not available for Station IV (since the station was not sampled in 1974), show significant increases in Trichoptera and decreases in Plecoptera at Station III.

DISCUSSION

Our 1974 results (Flannagan et al. 1978) indicated that grab sampling methods were much more variable and thus less reliable than the other two methods used here. This deficiency is further enforced by the present data where it is obvious from the drift and artificial substrate results, but not from the grab sample data, that the methoxychlor treatment, even at the reduced dose, had major effects on the invertebrate fauna of the river. It would therefore appear that grab sampling is not efficient in this kind of river.

The populations of Plecoptera, and to a lesser extent Ephemeroptera, on artificial substrates at the upstream control station showed a gradual decline over the sampling period (Fig. 4). Since the young of the year of most species belonging to these two Orders hatched in June and July (Flannagan 1977), one would expect these populations to increase, at least in mid-summer. The fact that they did not do so at the control station tends to bias both the interpretation of what happened downstream and the percent change in calculations using the modified Abbott's formula. The populations of Plecoptera at Stations II and III and Ephemeroptera at Station III show a partial recovery over the summer compared to their pretreatment numbers. Thus it seems likely that the reductions in populations of these two taxa at Station I (and perhaps the Ephemeroptera populations at Station II) are local ones caused by some unknown factor(s). If this is the case, the unadjusted percent reductions for plecopterans and ephemeropterans at the treated stations (Table 2) are probably the more accurate set. Also, since the changes at the control station largely occurred after the methoxychlor affected the downstream stations, the modified formula will underestimate the methoxychlor effects as previously discussed. In general, the artificial substrate samples show that an initial reduction in population took place at Stations II and III coincident with the treatment, usually followed by at least partial recolonization in July and August. Trichoptera and Chironomidae particularly appear to have recolonized, not only to density well above those at their pretreatment times but also to densities well above what might be expected from the upstream control results. These taxa contain species that, in this river, have more than one generation per year (Flannagan 1977). They are thus better able to take advantage of the posttreatment reduction in total fauna than taxa like Plecoptera, which in this river is composed mainly of species with 2-4 yr life cycles. Thus the short life cycle animals are able to assume and occupy a vacant niche.

Recolonization by benthic insects can be expected to come from four main sources - upstream migration of adults (Muller 1954), downstream drift of excess larvae from upstream (Waters 1964; Otto and Svenson 1976), upstream migration of larvae (Bishop and Hynes 1969), and, in certain situations, verticial migration from the hyporheic (Williams and Hynes 1974). Of these, vertical migration is the least likely to contribute significantly to repopulation in this case since the river bed at test sites appears to be mostly too well packed to allow invertebrates to penetrate very deeply into it. Upstream migration of insect larvae is also unlikely to be significant since it has been recorded as occurring only over very short distances and not contributing significantly to recolonization (Williams and Hynes 1976). Downstream drift of larvae and upstream migration of egg-laying females are therefore the most likely mechanism for repopulation in this river, as they were in the small stream studied by Williams and Hynes (1976). The Athabasca River below Fort McMurray changes its character as it approaches its delta and the rheophilic species are likely to be replaced by species adapted to slow water. Also the river upstream of Fort McMurray becomes progressively more acutely affected by the methoxychlor treatment. Thus recolonization, from downstream drift or upstream migration of adults, is least likely at the sites nearest to Fort McMurray while the sites nearest the injection site could easily be recolonized from the unaffected upstream areas. The comparison of the 1974 with 1975 pretreatment populations at the four stations (Table 3) supports this hypothesis since Stations I and II show no significant decreases in density of the taxa sampled, while Stations III and IV show quite drastic changes in populations of Plecoptera, Ephemeroptera, and Trichoptera 1 yr after the first treatment.

During the 4-hr period of maximum methoxychlor-related drift, about 50,000 Trichoptera, Plecoptera, Ephemeroptera, and Other Aquatic Invertebrates (Figs. 1-3) were caught in the 15-cm diam. bomb drift sampler. If we assume that the drift was the same throughout the water column and that the river was 200 m wide and a mean 4 m deep, then more than 2.5 billion animals drifted by this station in 4 hr. Although no direct measure of treatment-related lethality was made on these drifting animals, huge numbers were observed dead on gravel banks, reefs, etc. after treatment. The river downstream is unlikely to be able to support even a fraction of these displaced animals and we must therefore assume that most, if not all, of the animals in the catastrophic drift are ecologically dead (see Flannagan 1973; and others).

Station IV artificial substrate results showed a population increase at treatment time followed by a decrease in July and, with the exception of the Trichoptera, generally a further decrease in August. It therefore appears, both in these results and in our 1974 results, that some of the

drifting animals were able to temporarily colonize this area and then because they were weakened by exposure to methoxychlor or because the area could not support the excess population, as suggested above, a collapse to below the pretreatment population densities occurred. These data further support the hypothesis that actual mortality counts within catastrophic drift need not be made since secondary lethal effects appear to be at least as important as initial mortality.

Ephemeroptera, Other Aquatics Invertebrates, and Small Fish, and to a lesser extent *Simulium*, did not exhibit any clear peak at Station IV associated with the treatment although they did show post-treatment declines (Table 1). Since the drift of Ephemeroptera, *Simulium*, and Other Aquatics Invertebrates at the control station increased over this period, the decreases at Station IV are probably related to the treatment. However, the effects on these three groups cannot be defined as catastrophic. A high initial drift followed by a drastic decline of Small Fish was recorded at Station IV. While the reasons for this drift of fish are unknown, there remains a possibility that it is related to lack of food organisms as suggested by Flannagan et al. (1978).

CONCLUSIONS

The methoxychlor treatment, even at half the 1974 exposure time, caused catastrophic invertebrate drift that, at least in some taxa, extended as far downstream as samples were taken (ca 400 km). Ephemeroptera, Other Aquatic Invertebrates, and Small Fish did not show a drift peak related to the treatment but did exhibit posttreatment declines perhaps related to a secondary effect of the treatment. Since *Simulium* reacted to the methoxychlor treatment at the same time as the non-target invertebrates at Stations II and III but did not show catastrophic effects as far downstream as some of the non-targets, it must be concluded that methoxychlor is more specific for some of the non-targets than it is for *Simulium*.

Long term changes in the Ephemeroptera, Trichoptera, and Plecoptera attributable to the 1974 treatment were recorded as a reduction in density of fauna at Station IV. A disproportionate increase in density of short life cycle species at treated stations followed the 1975 treatment.

The 1975 treatment, in spite of being half the exposure time of the previous year, still had a considerable deleterious effect on the non-target fauna of the river.

ACKNOWLEDGEMENTS

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IMPACT OF METHOXYCHLOR ON DRIFTING AQUATIC INVERTEBRATES

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AND W. A. CHARNETSKI

INTRODUCTION

The impact of a pesticidal treatment on the invertebrate fauna of a river system can have two principle dimensions. One is immediate change in the activity and numbers of displaced elements of populations represented in the downstream drift of organisms. This change may be measured in terms of density of drifting organisms and the percentage affected by toxicity during exposure to the treatment. The other is long-term change in relative abundance of organisms and in natural diversity of the ecosystem. The latter type of change indicates long-term effects on trophic relations following possible redistribution of species, interruption of life cycles, and modification of the ecological balance in the biomass.

This study was an evaluation of changes in the invertebrate fauna. Density of drifting organisms was measured in relation to time of exposure to known toxic concentrations of the pesticide. Changes in diversity of organisms were also studied in relation to the spring-summer phenology of the river system and periods of treatment.

METHODS

Density of drifting organisms was monitored continuously during a 5-day period bracketing the expected time of arrival of a pulse of methoxychlor from upstream. Two treatments applied to different reaches of the river with an interval of 6 days in May 1976 for control of black flies were monitored in succession. The first treatment, downstream, was evaluated about 18 km (Pelican Rapids) and the second, upstream, 77 km (Calling River) below the points of injection.

Sampling Design

The sampling period was scheduled from hydrological estimates of expected time of arrival of the treated pulse and the extension of its length as it passed downstream. The 5-day schedule was designed to intercept the pulse during the third day so that samples would represent 2 days pretreatment and 2 days posttreatment, including possible variations in the diel periodicity of drifting organisms.

Two sets of samplers were anchored in line with a cross-section of the river, one in the thalweg and one midway between the thalweg and ebb-current bank (Figs. 1 and 2). Continuous samples were obtained at two levels, about 50 cm below the surface and at mid-depth, in each set throughout the 5-day monitoring period. Hauls represented density of drifting organisms for 4-hr intervals and were collected in a uniform daily sequence at 0400, 0800, 1200, 1600, 2000, and 2400 hr.

Equipment

The river drift sampler (Burton and Flannigan 1976) was used with modifications for swift current in the set design

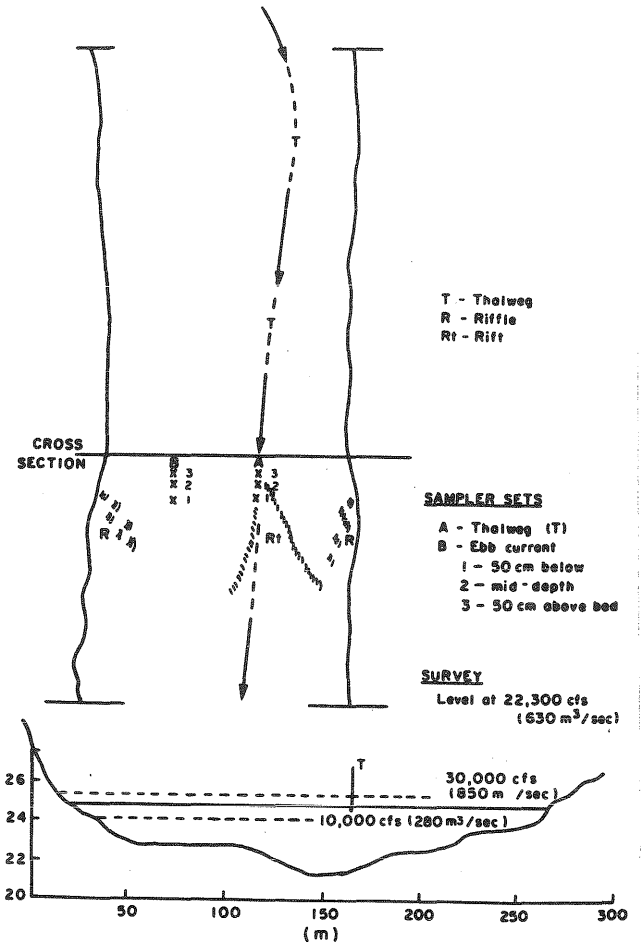


Fig. 1. Surface and cross-sectional diagram of the Athabasca River at the Pelican Rapids monitoring site.

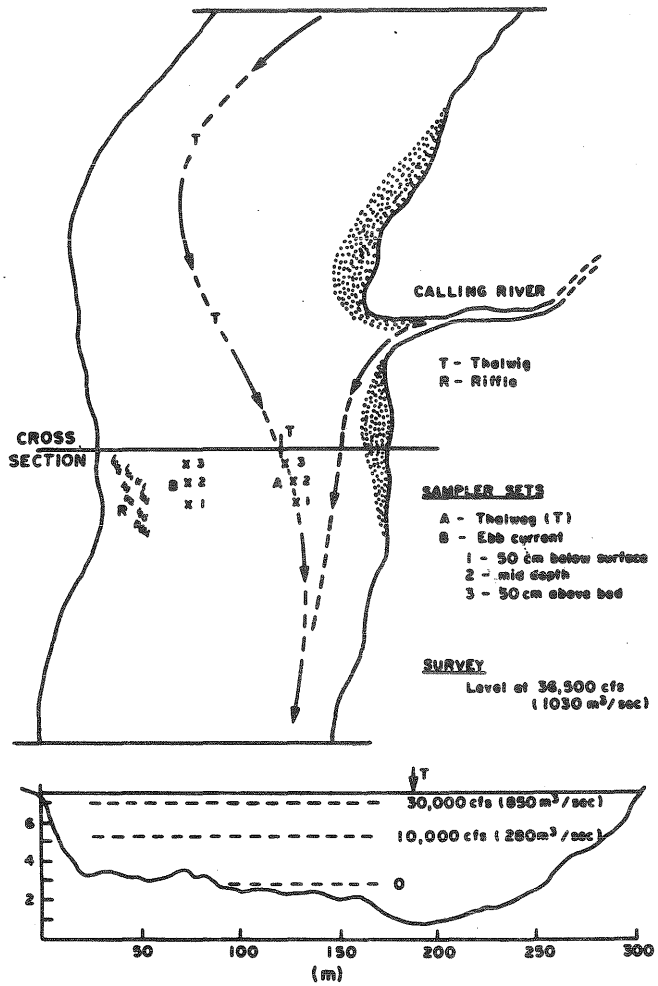


Fig. 2. Surface and cross-sectional diagrams of the Athabasca River at the Calling River monitoring site.

described for monitoring procedures (Haufe et al. p.170). Two samplers were alternated at each sampler link in the set so that collections could be transferred to shore for immediate processing of live material.

Sample Processing

Each sampler and its collecting cup was flushed with river water over a standard-sized white enamel pan to remove all organisms and associated organic and inorganic drift material. All organisms visible to the naked eye were easily detected against the white background of the pan when the drift material was systematically separated in the water. All visible organisms were removed and separated in two glass jars of water according to their state of activity. One jar received active healthy organisms; the other received organisms that displayed sluggish behavior and morbidity or were dead. At 3 hr after collection, organisms that recovered to display activity were transferred to the 'healthy' jar. The separated samples were removed from the water and preserved with ethyl alchohol in sealed containers for later analyses. The healthy active organisms were labelled as the living proportion of the collection, the others as casualties for the sampling period.

Compaction and compression of organisms with drifting debris in the samplers for periods up to 4 hr was a severe stress on organisms, especially on the more fragile taxa. This condition complicated the classification of casualties attributed to toxic effects of the methoxychlor treatment. Bias in classification was measured as a rough approximation by leaving sorted organisms from one set of samples after the peak toxic concentration of the pulse in the jars with river water for an additional 4 hr before preservation in alcohol. Further recoveries among the casualties in the 4-hr period were counted and compared with the total number classified during the standard preceding 3 hr sorting period.

After removal of all visible organisms from a sample in the pan, the remaining organic material was separated from an inorganic residue by a placer technique. The

organic material was preserved in alcohol as a separate part of the drift collection for later microscopic analysis in the laboratory, particularly to detect and examine minute taxa. Distinct differences in color between organisms that were alive or dead at time of preservation could be used to derive rough estimates of casualty rates among taxa recovered from the preserved placer samples of mixed organic material.

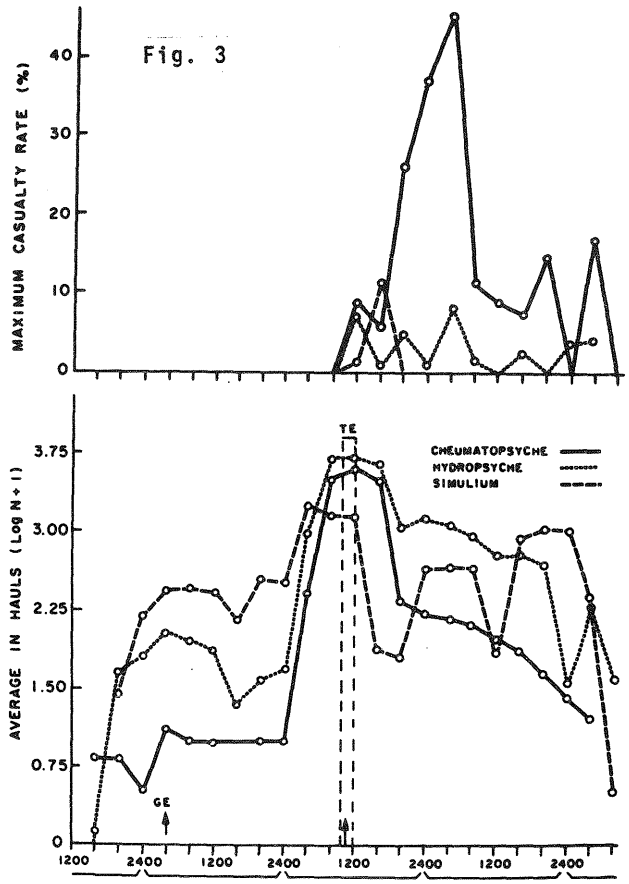
RESULTS

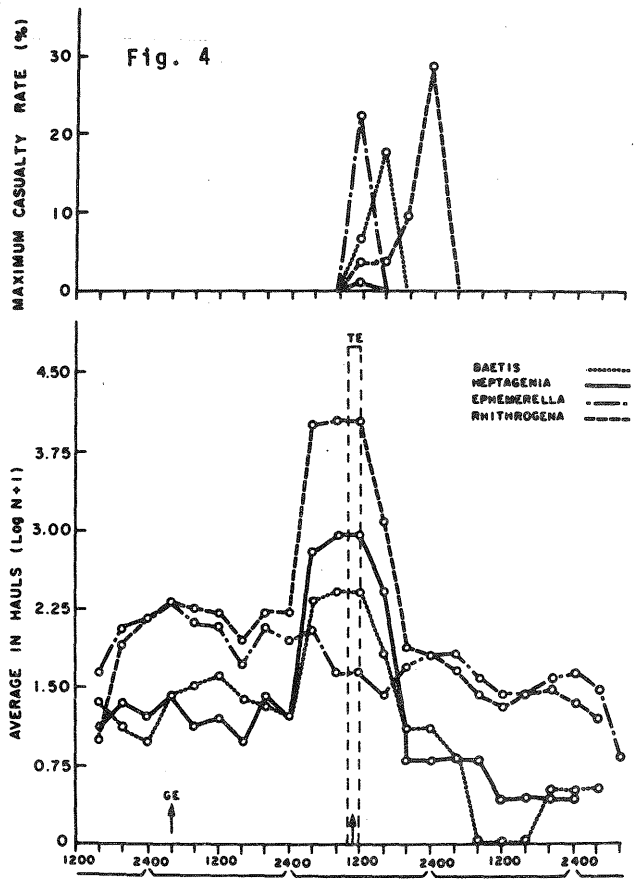
Phenology

The optimum time of treatment to reduce an annual infestation of *Simulium arcticum* corresponds with predominance of sixth-instar larvae in the age distribution of immature populations in the river. This time is associated phenologically with the time of major emergence of some of the most abundant non-target taxa, particularly the Trichoptera, Ephemeroptera, and Plecoptera. In monitoring the first treatment, 18-22 May, emergent Plecoptera were observed under debris on the bank at the Pelican Rapids landing at 0400 hr on 19 May. Newly emerged adults appeared to be concentrated along part of the bank adjacent to the riffle (Fig. 1). Numbers of teneral adults increased through 19-20 May. In monitoring the second treatment, 24-28 May, newly emerged adults of Plecoptera were found at the Calling River site on 24 May. Emergent adults were observed again on one bank adjacent to the riffle (Fig. 2). They were conspicuous during the period 24-27 May.

The periods during which abundant newly emerged adults of Plecoptera were observed on the banks at both sites corresponded with a high proportion of late stage immature forms in drift collections during the early part of the sampling schedule. An increasing proportion of collections in favor of early stage immature forms was observed for most taxa by the last day of each monitoring period. This change in age distribution for many of the taxa during the sampling period was further evidence of a major emergence of some forms preceding and during exposure to the pulse of methoxychlor in both treatments. The common increase in density of drifting organisms for selected taxa (Figs. 3-8) on or about the 3rd day in schedules represented, in part at least, the activity of maturing pre-adults moving to suitable sites of emergence along the banks.

The phenological time scale in 1976 at the Pelican Rapids site downstream was 6 days in advance of that 100 km upstream, at





Figs. 3 and 4. Average haul of *S. arcticum* and taxa in the Trichoptera (Fig. 3) and of Ephemeroptera (Fig. 4) with time, 18-22 May 1976, from the downstream drift in the thalweg shown as running three-interval means (lower curves) and maximum casualty rate among all hauls with time (upper curves) at Pelican Rapids. Toxic exposure to the pulse indicated by TE, observed beginning of emergence of Plecoptera by GE.

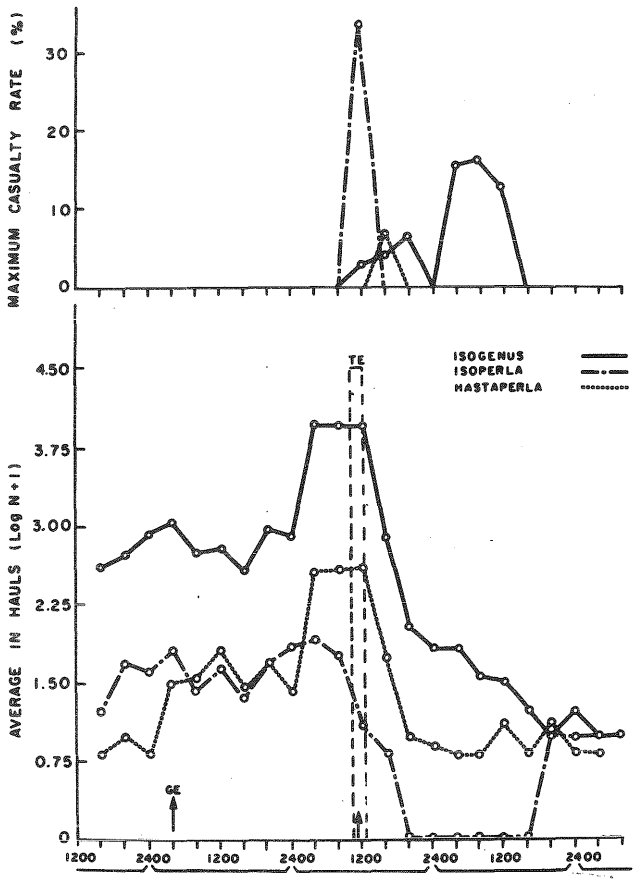


Fig. 5. Average haul of taxa in the Plecoptera with time (see caption for Figs. 3 and 4 for details).

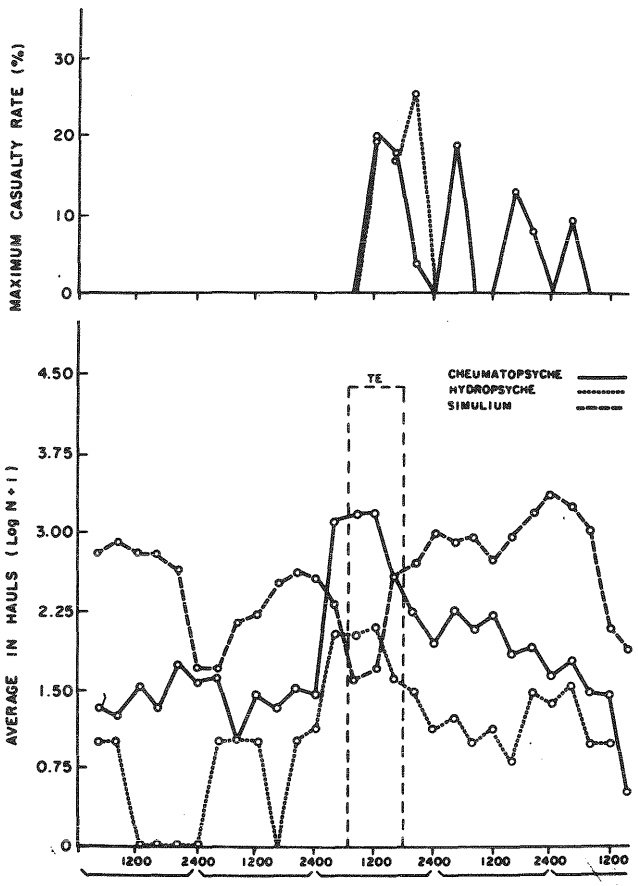
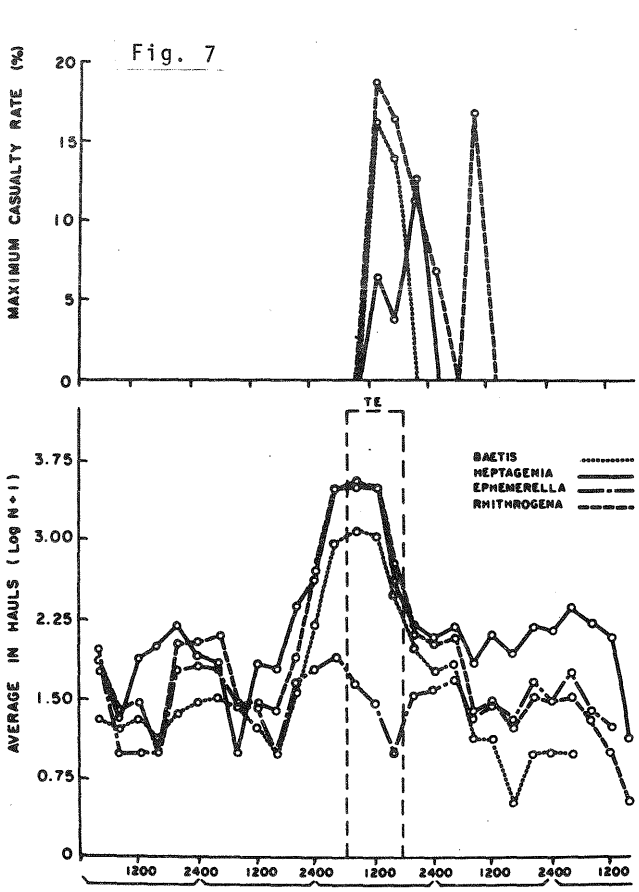


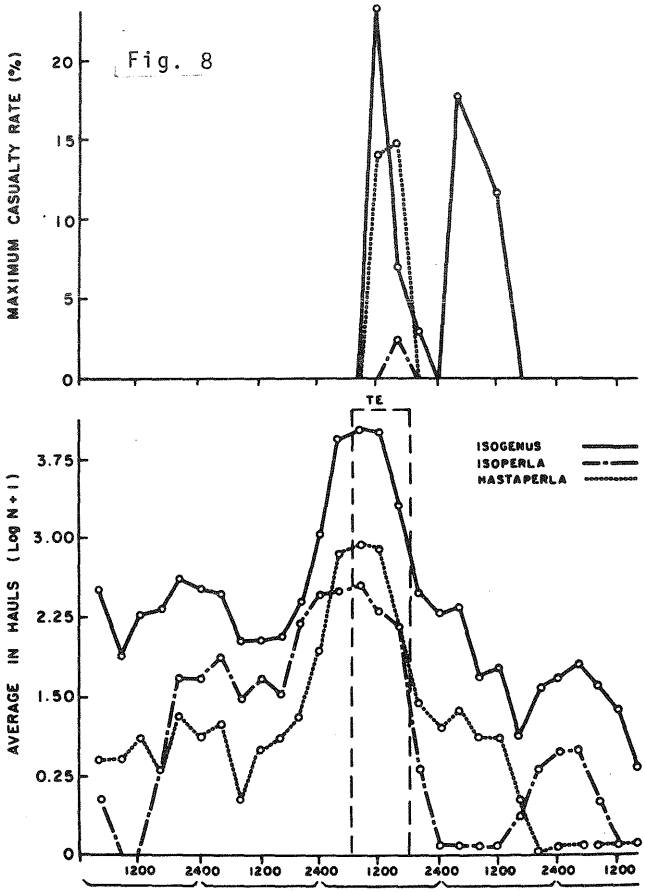
Fig. 6. Average haul of taxa in the Trichoptera and *S. arcticum* with time, 24-28 May 1976, from the downstream drift in the thalweg as running three-interval means (lower curves) and maximum casualty rate among all hauls with time (upper curves) at Calling River. Toxic exposure to the pulse indicated by TE.

the Calling River site. This difference was defined by the time sixth-instar larvae appeared in the age distribution for development of *S. arcticum*. Patterns of density in the drift of some non-target taxa (Figs. 3-8) show clearly that they are synchronized closely within 1 day of the black fly and each other in the phenological time scale for the river ecosystem. A similar calculation based on the development of *S. arcticum* in 1977 indicated that the phenological time scale at the Pelican Rapids site was 7 days in advance of that near the Athabasca townsite about 165 km upstream. This indicates that differences in the phenological time scale between sites are relative to the reach of the river downstream. Phenological timing of river treatment is a major consideration in reducing the impact on non-target organisms as well as in achieving control of *S. arcticum*.

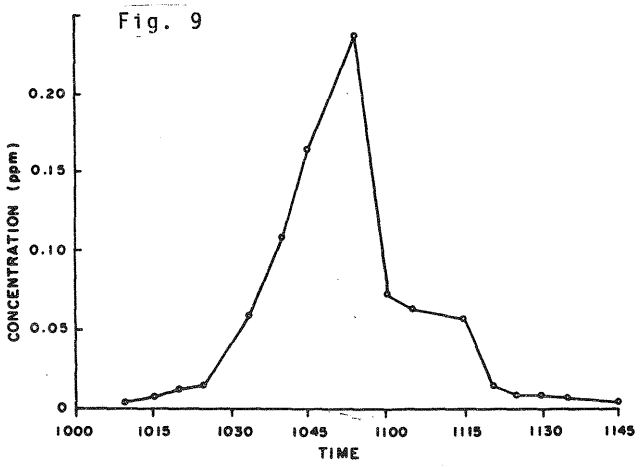
Methoxychlor Treatment

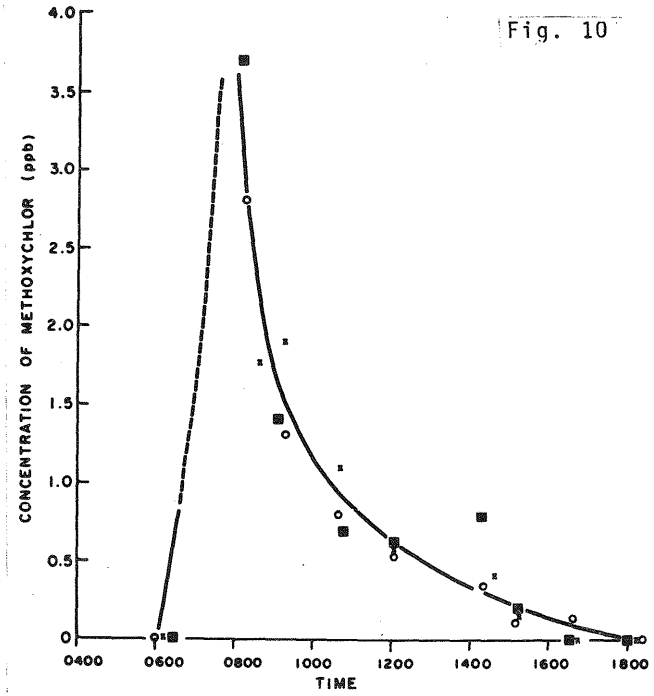
The concentration of methoxychlor overdispersed in time as the treated pulse moved downstream with the current. The overdispersion or 'tailing-out' of concentration was barely discernable at 18 km from the point of injection in the first treatment (Fig. 9), but was highly pronounced at 77 km in the second treatment (Fig. 10). With an accurate hydrological estimate of time of arrival of the pulse in the first treatment, the curve for methoxychlor concentration was defined well within the short-interval sampling schedules for water (Fig. 9). With the rate of movement slightly underestimated in the second treatment, the peak concentration either coincided with or was slightly in advance of the beginning of the short-interval sampling schedule (Fig. 10). The extended-interval sampling schedule showed that the front of the pulse arrived after 0600 hr. Therefore, duration of the pulse was defined as 10-12 hr at 77 km from points of injection in the second treatment as compared with 1.5 hr at 18 km in the first treatment. Since the current proceeds through variable and broad expanses of the river within the reach of the second treatment as compared with the first, there was no rectilinear relation between duration of the pulse and distance from injection. Reduced accuracy in a hydrological estimate of time of arrival of the pulse in the second treatment is also attributable to the variable dimensions of the river in the upstream reaches of the study.





Figs. 7 and 8. Average haul of taxa in the Ephemeroptera (Fig. 7) and Plecoptera (Fig. 8) with time (see caption for Fig. 6 for details).





Figs. 9 and 10. Concentration of methoxychlor in the water of the Athabasca River during passage of the pulse at: Pelican Rapids (Fig. 9), 20 May 1976, and Calling River (Fig. 10), 26 May 1976 (samples from x ¼ cross section-right bank; o center cross section; and ■ ¼ cross section-ieft bank).

Immediate Impact of Methoxychlor on Non-target Organisms

Recovery of organisms from the effects of compression and compaction with organic debris in the drift samplers was incomplete in the standard 3-hr period allowed for sorting the samples of material after successive collections. In the test conducted with the full set of samples collected at 1200 hr at Pelican Rapids on 20 May 1976, organisms that were classified as casualties within the standard 3-hr sorting period but that recovered full activity in river water during an additional 4-hr period ranged from 6-18% of the sample classified as casualties. Therefore, any error in estimates of casualties constitutes an overestimate of a true casualty rate.

Of 46 genera keyed in collections during the monitoring period for methoxychlor treatments, 37 contained no casualty rates exceeding 5%, the limit that was considered insignificant (Table 1). Nine genera exhibited maximum casualty rates of the order of 15-40% and were studied in more detail in the sampling time series (Figs. 3-8). These taxa were confined to three orders - Plecoptera, Ephemeroptera, and Trichoptera. Four genera, *Cheumatopsyche* spp. and *Hydropsyche* spp. in Trichoptera, *Rhithrogena* spp. in Ephemeroptera, and *Isogenus* spp. in Plecoptera, were consistent in exhibiting casualty rates at all locations and with the highest percentages.

Immediate casualty rates associated with the passage of the methoxychlor pulse were exhibited by *Ephemerella* spp. only in the thalweg at Pelican Rapids, by *Heptagenia* spp. at both current locations only at Calling River, by *Baetis* spp. at both monitoring sites with the exception of the ebb-current location at Calling River, and by *Isoperla* spp. only at opposite current locations within the monitoring sites. Generic variation with location indicated that the casualty rates for these taxa were largely attributable to localized effects of treatments on certain habitats before complete mixing and uniform dispersal of the methoxychlor was achieved near the injection point. *Hastaperla* spp. exhibited marginally significant casualty rates in comparison with the other eight sensitive genera.

Maximum casualty rates shown for *Gammarus* spp., *Pteronarcys* spp., and *Glossosoma* spp. (Table 1) were recorded in each case from only one haul (collection from one sampler during a 4-hr period) that exceeded 5% during the complete monitoring schedule. These three isolated casualty rates were insignificant as impacts of the treatment in relation to spurious casualty rates observed in the monitoring operations.

Close scrutiny of casualty rates within the sampling time series in relation to exposure to the methoxychlor pulse revealed different patterns of sensitivity among the nine indicator genera. Toxicity was unimodal in time within about 18 hr of the arrival of the pulse for five genera - *Isoperla, Hastaperla, Ephemerella, Baetis, and Heptagenia*. It was delayed or extended up to 48 hr for four genera - *Isogenus, Rhithrogena, Cheumatopsyche* and *Hydropsyche* (only at Pelican Rapids). Among the extended impacts on four genera, two (*Isogenus* and *Rhithrogena*) displayed a biomodal distribution in time. Genera dis-

Table 1. Maxima in the range of casualties and hauls for non-target organisms of keyed Taxa

	Maximum of range in casualties as % of sample			
	Pelican Rapids		Calling River	
Genus	Thalweg	Ebb	Thalweg	Ebb
Acroneuria	NS[a]	NS	NS	NS
Agapetus	NS	NS	NS	NS
Ameletus	NS	NS	NS	NS
Ametropus	NS	NS	NS	NS
Arctopsyche	-	-	NS	NS
Atherix	NS	NS	-	-
Baetis	17	NS	16	11
Brachycentrus	NS	NS	NS	NS
Brachyptera	-	-	NS	NS
Caemis	-	-	NS	NS
Cataclysta	-	-	NS	NS
Cheumatopsyche	45[b]	32	20	40[b]
Classenia	NS	NS	NS	NS
Copepods	-	-	NS	NS
Culicoides	-	-	NS	NS
Daphnia	-	-	NS	NS
Dolichopus	NS	NS	-	-
Epeorus	-	-	NS	NS
Ephemerella	22	NS	NS	NS
Gammarus	NS	NS	NS	NS
Glossosoma	NS	NS	28	NS
Gordius	NS	NS	NS	NS
Haliplus	-	-	NS	NS
Hastaperla	7	NS	15	8
Heloporus	-	-	NS	NS
Hemerodromia	NS	NS	NS	NS
Heptagenia	NS	NS	12	8
Hexatoma	NS	NS	-	-
Hirudinea	NS	NS	-	-
Hydropsyche	8	8	25	40[b]
Isogenus	15	39	23	16
Isoperla	33	NS	NS	16
Leptophlebia	-	-	NS	NS
Lymnaea	NS	NS	NS	NS
Metretopus	-	-	NS	NS
Mysis	-	-	NS	NS
Ophiogomphus	-	-	NS	NS
Parameletus	NS	NS	NS	NS
Pedicida	-	-	NS	NS
Pentaneura	NS	NS	14	8
Promenetus	NS	NS	NS	NS
Psychomyia	NS	NS	NS	NS
Pteronarcys	NS	NS	14	NS
Rhithrogena	29	39	19	19
Sigara	-	-	NS	NS
Siphlonuris	-	-	NS	NS
Stenonema	NS	NS	NS	NS
Stylaria	-	-	NS	NS
Tipula	-	-	NS	NS
Hydroptilidae[c]	-	-	NS	NS

[a] NS = Insignificant (<5%)
[b] 1 day after treatment
[c] Unidentified

playing extended or bimodal distributions in casualty rates were affected possibly by two kinds of exposure, first to the pulse in the water to account for a mode within 18 hr, and secondly to a pulse adsorbed to the trailing bed load, or to delayed effects of residues accumulated through predation, to account for a mode within 48 hr.

Spurious casualty rates occurred in occasional hauls during pretreatment monitoring at Pelican Rapids but not at Calling River. These spurious casualty rates ranged up to 6% for *Ephemerella*, 16% for *Isoperla*, 17% for *Isogenus*, 33% for *Heptagenia*, 36% for *Cheumatopsyche*, and 48% for *Hydropsyche*. Although they occurred only in the high-velocity currents at Pelican Rapids, the generic impact was random in relation to time, depth, and location in the current. Compaction and compression in the samplers do not account for the random distribution and these casualty rates were attributed to natural or undertermined causes in the ecosystem.

Delayed Effects of Methoxychlor on Non-target Organisms

The diversity of the river ecosystem, as monitored continuously at Calling River for 5 days in 1976, was represented by 46 keyed genera appearing in the drift (Table 2). The monitoring period in this case corresponded with or closely followed the point in the phenological time scale marking the exodus from the river of maturing forms. These forms constituted a major proportion of the aquatic biomass produced in the life cycle of univoltine invertebrate taxa. The phenological time scale for the aquatic system, with *S. arcticum* as the indicator, was advanced in 1977 by about 3 days. An intermittent but regular monitoring of the system without treatment in 1977 was initiated at Calling River on 24 May, the same date on which the 5-day monitoring period for treatment was initiated in 1976. With the 3-day advance in phenological time scale, the monitoring in 1977 followed the brief acceleration of drift activity associated with the exodus of pre-adult immature stages to emerge along the banks of the river as observed on 24-27 May in 1976. The phenology was verified by the fact that, beginning with the 1st wk of sampling during 24-28 May in 1977, hauls were almost entirely composed of early stage immature forms for most taxa. Maturity of forms increased in hauls in successive monitoring periods at 2-wk intervals until early August. All 46 keyed genera were present in the drift during the last week of May but a gradual decrease in the diversity of taxa was evident during successive sampling periods through June and July. Treatments in 1976 had no observable effect on diversity of taxa in 1977 in relation to the phenological time scale for composition of the drift.

Drift Behavior of *S. arcticum*

Substantial numbers of *S. arcticum* were present in all hauls of organisms throughout the 5-day monitoring periods associated with

Table 2. Diversity of organisms sampled in the downstream drift at Pelican Rapids (PR) and Calling River (CR) grouped by orders

Family	Genus	Site CR	Site PR
Amphipoda			
Gammaridae	Gammarus	x	x
Basommatophora			
Hirudidae	Hirudinea		x
Lymnaeidae	Lymnaea	x	x
Planorbidae	Promenetus	x	x
Cladocera			
Daphnidae	Daphnia	x	
Coleoptera			
Haliplideae	Haliplus	x	
Hydrophilidae	Helophorus	x	
Copepoda			
-	Copepod	x	
Diptera			
Ceratopogonidae	Culicoides	x	
Dolichopodidae	Dolichopus		x
Empididae	Hemerodromia	x	x
Rhagionidae	Atherix		x
Simuliidae	Simulium	x	x
Tendipedidae	Peneteneura	x	x
Tipulidae	Hexatoma		x
	Pedicia	x	x
	Tipula	x	
Ephemeroptera			
Baetidae	Ametropus	x	x
	Baetis	x	x
	Metretopus	x	
Caenidae	Caenis	x	
Ephemerellidae	Ephemerella	x	x
Heptageniidae	Epeorus	x	
	Heptagenia	x	x
	Stenonema	x	x
	Rhithrogena	x	x
Leptophlebiidae	Leptophlebia	x	
Siphlonuridae	Ameletus	x	x
	Parameletus	x	x
	Siphlonurus	x	
Gordiida			
Gordiidae	Gordius	x	x
Heteroptera			
Corixidae	Sigara	x	
Lepidoptera			
-	Cataclysta	x	
Mysidacea			
-	Mysis	x	
Odonata			
Gomphidae	Ophiogomphus	x	
Oligochaeta			
Naididae	Stylaria	x	
Plecoptera			
Chloroperlidae	Hastaperla	x	x
Perlidae	Acroneuria	x	x
	Classenia	x	x
Perlodidae	Isogenus	x	x
	Isoperla	x	x
Pteronarcidae	Pteronarcys	x	x
	Brachyptera	x	
Trichoptera			
Brachycentridae	Brachycentrus	x	x
Glossosomatidae	Agapetus	x	x
	Glossosoma	x	x
Hydropsychidae	Arctipsyche	x	
	Cheumatopsyche	x	x
	Hydropsyche	x	x
Hydroptilidae	(Not keyed)	x	
Psychomyiidae	Psychomyia	x	x
	Total genera keyed	47	32

both treatments of the river. Newly hatched first- and early second-instars consistently predominated in all hauls. These stages were undetectable to the eye in the standard on-site sorting procedure and were enumerated in microscopic analysis of the preserved samples of organic material. Larvae in the third to sixth instars were easily detected in the on-site procedures and could be analyzed in terms of casualty rates related to arrival of the pulse of methoxychlor.

Small numbers of *S. arcticum* in the third to sixth instars were collected from hauls at Pelican Rapids from the beginning of monitoring on 18 May until 1200 hr on 20 May. None of these instars appeared in hauls after passage of the pulse of methoxychlor. A similar drift pattern was observed at Calling River with older instars appearing in hauls from 24 May to 1200 hr on 26 May and none during the remainder of the monitoring period. Termination of drifting third to sixth instars on arrival of the pulse indicated that the treatment was effective in eliminating the resident populations of *S. arcticum* on river substrates.

A continuing drift of first and early second instars after the pulse had passed suggested a continuing heavy hatch of eggs during and after the treatment. The proportions of instars in the hauls also indicate that the drift of *S. arcticum* is largely confined to newly hatched larvae that are displaced by currents until they are successful in reaching suitable attachment sites.

INTERPRETATION OF RESULTS

The drift of organisms in the Athabasca River represents displacement activity of taxa that is highly variable within a phenological time scale. Gross analyses of hauls from sampling in a regular time series during the summer of 1977 with no treatment display large variations within genera related to both periodicity in activity and stage in the life cycle. Variations in the thalweg are of the order of four- to five-fold with time (4-hr sampling period within the day) and three-fold with depth. Nine-fold variations with location along the cross section of the river, i.e., thalweg vs. ebb-current, were observed within 4-hr sampling periods. Fluctuations in displacement activity of aquatic forms are commonly of the same order as those of winged adults on land in relation to both time and location within the habitat.

Methoxychlor amplifies the activity of some species in the Plecoptera, Ephemeroptera, and Trichoptera. In both treatments monitored in 1976 (Figs. 3-8), the stimulating effect on arrival of the front of the pulse was transitory and detectable only within a 12-hr period. Transitory effects of the pulse in all cases were superimposed on increasing activities preceding the pulse. Since drift activity of sensitive genera tended to occur after the passing of the pulse within orders of magnitude equal to those preceding the pulse, the displacement was local. There was no evidence that the pulse of methoxychlor had any serious downstream 'sweeping' effect on the displacement of active invertebrates.

The results from these two experiments are in contrast with interpretations of results cited from other reports (Gardner and Bailey 1974). Some of the claims for 'catastrophic' effects of methoxychlor on drift have been based on interpretations of preliminary data and require more convincing substantiation for several reasons. First, none of them has been analyzed within phenological time scales for the life cycles and behavior patterns of taxa in the ecosystem. Secondly, they have not included statistical controls to evaluate effects of treatment against natural variations in a highly dynamic system. Thirdly, diel patterns of activity and changes in hydrological conditions such as discharge, current velocity, and turbulence have not been considered in accounting for fluctuations in numbers of organisms in the drift with time.

A review of literature (Waters 1972) has characterized the downstream displacement of organisms as a combination of ecological phenomena. A 'constant' component represents a continuous stream of members of all species in low numbers occurring at all times. In the turbulent Athabasca River, this is evident particularly in the thalweg. A 'behavioral' drift is characteristic of certain species and is the result of behavioral patterns exhibiting temporal variations with periodicities ranging from the *ultradien to infradien*. It is exhibited particularly by the Plecoptera, Trichoptera, and *Ephemerella*. A third component with extreme variations is induced by physical disturbance of the bottom fauna by hydrological factors such as flooding, changes in current velocity and discharge, bottom scouring, high temperature, and other changes in habitat conditions including pollution. An extremely variable drift of organisms in the Athabasca River is related to rapidly changing current velocity and discharge rate, flooding, turbulence, and a continuous scouring with frequent changes in the river bottom.

The significance of an impact of the methoxychlor treatments on drift of organisms has to be assessed in relation to the inherent variations characteristic of the Athabasca River. If downstream drift is considered in such terms as background amplitudes of variations during the monitoring periods spanning pre- and post-arrival periods of the pulse in the two experiments, the 'exodus' activity normally associated with a general emergence of adults in May, and the lack of any serious aberration in numbers of drifting organisms that can be directly attributed to the pulse of the pesticide within sampling time series, there is no indication of a serious impact other than a transitory amplification of diel

behavioral drift. The concept of the nature of behavioral drift from various other studies (Waters 1972) and the fact that 'constant' drift tended to occur within the same order in pre- and post-treatment periods indicates that no major downstream displacement or 'sweeping' of the bottom fauna could be exclusively associated with river treatment.

The reproductive potential of invertebrate organisms ranges in the order of 10^2-10^3. This high potential normally accommodates high rates of attrition associated with trophic interdependence among taxa in the food chain (predation and parasitism), losses to density-dependent regulation of standing crop within the carrying capacity of habitats, and casualties induced by changes in the physical environment such as unfavorable temperature, erosion of habitats in the river bed, and isolation or elimination of aquatic environments. Life table studies show that low survival rates are not only common in the natural system but have little or no impact in maintaining a high level of regeneration. For example, the highest densities of mosquitoes in subartic Canada are maintained with density-dependent mortality rates as high as 80% in immature stages in pools polluted by overpopulation. The range of these natural survival rates of invertebrates must be considered as a baseline in a rationale for assessing the toxic impact of methoxychlor on non-target organisms.

Casualty rates for non-target organisms monitored in the downstream drift before, during, and after exposure to the methoxychlor pulse were not statistically significant for most of the taxa, i.e. they did not exceed 5% of hauls. Statistically significant toxic effects were detected in consecutive hauls in a time series for nine genera confined to the Plecoptera, Trichoptera, and Ephemeroptera. These sensitivities among taxa correspond with observations on methoxychlor treatments in the Saskatchewan River (Fredeen 1975), with the exception that Chironomidae observed in the Saskatchewan apparently do not enter the thalweg of the Athabasca. The maximum casualty rates for these genera (Figs. 3-8), which are the maxima within all the hauls from one set (4 hr) for the river cross-section in the time series, is an overestimate of an average number representing the actual casualty rate in the biomass. Since none of these casualty rates exceed 40%, the toxic impact of methoxychlor treatment does not approach the order of natural attrition inherent in the aquatic invertebrate ecosystem. Furthermore, the maximum casualty rates synchronized with the pulse are within the range of spurious casualty rates observed for the same taxa in pretreatment sets at the Pelican Rapids site. The toxicity of a methoxychlor pulse at a concentration of 0.3 ppm for 7.5 min, when considered in terms of casualties in the behavioral drift, can be interpreted to have no serious effect on the standing crop of the most sensitive taxa.

No short-term effects of treatment detectable in the downstream drift have appeared in any analyses to suggest a decrease in taxonomic diversity. If Margalef's Formula for diversity is applied to the pre- and post-treatment data from the sampling time series, it shows a slight increase. An *actual increase* in diversity is doubtful, however, since the exodus of individuals to adult emergence during the treatment period is merely reducing number of individuals in total taxa. Effects of abatement operations on diversity will undoubtedly have to be monitored in the long term with a sampling design precisely related to the phenological time scale for all years.

CONCLUSIONS

1. A pulse of methoxychlor at a concentration of 0.3 ppm for 7.5 min has a detectable stimulatory effect on the 'behavioral' drift of some organisms. The stimulation is transitory and coincident with the arrival of the front of the pulse. In both experiments, the activity attributed to transitory effects of the pesticide was within the order of magnitude of natural variations related to diel periodicity, current-related disturbances, scouring of bottom habitats with flood discharges, and behavioral phases such as exodus for emergence related to life cycles. There was no evidence that the pulse induced a significant downstream displacement of the standing crop of taxa.

2. Casualty rates attributed to the pulse were less than 40% for all taxa identified in the downstream drift. Among 49 genera, 37 exhibited no casualties, i.e. casualty rates were within 5% observed as a 'constant' rate in the drift due to natural causes. Only nine genera consistently showed statistically significant sensitivity to the treatment, i.e. consistent casualty rates exceeding 15% of the haul. They are *Cheumatopsyche* and *Hydropsyche* in the Trichoptera; *Baetis*, *Heptagenia*, *Ephemerella* and *Rhithrogena* in the Ephemeroptera; and *Isogenus*, *Isoperla*, and *Hastaperla* in the Plecoptera. Three genera, *Gammarus*, *Pteronarcys*, and *Glossosoma*, each showed a casualty rate exceeding 15% in only a single haul in a set during the passage of a pulse. These casualty rates were insignificant in relation to spurious casualty rates. All casualty rates in sensitive genera were within the range of spurious rates recorded from pretreatment hauls and are considered to have no serious effect on the standing crop of taxa or on trophic relations in the invertebrate food chain.

3. No immediate effects of treatments were detected on diversity in invertebrate taxa as represented in the downstream drift. It is concluded, however, that a measurement of taxonomic diversity should be included in a monitoring system for abatement operations to detect and evaluate long-term effects within the phenological time scale for the reaches of river exposed to treatment.

4. Effects of methoxychlor toxicity on sensitive taxa are generally confined to a period of 18 hr with extensions in a few genera to a maximum of 48 hr. A minimum monitoring period for a treatment is 5 days with the pulse arriving on the 3rd day of the schedule.

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PARAMETERS FOR MONITORING DISPLACEMENT OF DRIFTING AQUATIC INVERTEBRATES

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INTRODUCTION

The environmental acceptability of a chemical abatement program for the control of black flies in a large river system depends on a creditable assessment of impact on the ecosystem including water, the river bed, and the biotic fauna. Impacts have to be assessed with specific reference to toxic and trophic relations within the food chain. In addition to an evaluation of procedures for pest control, economic and environmental accountability in the operation must provide the means and the assurance that undesirable effects on the maintenance of the original environmental system can be detected and eliminated to preserve biological potential and natural diversity in the ecosystem.

Techniques and equipment were evaluated in this study to detect and measure change in pattern and rate of displacement of invertebrate populations. The mobile population of invertebrates in this case is represented by the downstream drift of organisms. Drift of organisms in flowing water during activity is an essential feature in the displacement of populations to maintain natural distributions of species, ecological balance, life cycles, faunal diversity, and repopulation of habitats. It is one of two statistical parameters for numbers of organisms in the aquatic biomass; the other is density of relatively inactive or cloistered resident populations which requires assessment with other techniques described in another report (Depner et al., p. 141).

METHODS

The Athabasca is a large, turbulent, swiftly flowing river. In theory from hydrological principles, the most consistently reliable measure of drift in active invertebrates is to be obtained along the thalweg of the current. The course of the thalweg meanders between the banks. It contributes to the capture of organisms by the swift currents and to a continuing displacement and redistribution of organisms among habitats downstream. Sampling procedures were designed to verify this hydrological principle in the displacement of organisms.

Sampling at any given point in the course of the river employed two indentical sets of equipment. One set was located in the current of highest velocity in the thalweg of the current. The other was located in the same cross-section of the river midway between the thalweg and the ebb-current bank. Each set included sampling devices at three depths: an upper sample at 50 cm below the surface of the water, a low-level sample at 50 cm above the river bed, and one midway between the surface and the river bed. All samples were collected at intervals of 4 hr round the clock with resetting scheduled at 0400, 0800, 1200, 1600, 2000, and 2400 hr.

Equipment

The basic principle of the 'bomb' drift sampler (Burton and Flannagan 1976) was used

in all sampling procedures. Some modifications in design were necessary for operations in swift turbulent currents. The mouth of the frustrum in the original design is 15.1 cm (6 in.) diameter. The intake volume exceeds the volume of water that can be discharged through the net. In swift currents, this imbalance in flow produces excessive internal turbulence under high fluid pressure. Under these conditions and especially with suspensions of heavy inorganic solids in the water, the internal turbulence reduces the organic materials, including live organisms, to an emulsion. In addition to destruction of the more fragile organisms, it was impossible to sort material from the washed sample since emulsified suspensions required up to 36 hr to settle in pans for examination of material.

Internal turbulence and its emulsifying action were eliminated by extending the frustrum with the same angle of sheer to a reduced opening of 7.5 cm in diameter (Fig. 1). This reduced the intake volume to 25% of the original and, with a more favorable balance between intake volume and discharge throught the net cone, also stabilized the 'bomb' sampler to ride level in the current with minimum drag on the anchor line. With the modified design, samples from the highest current velocities encountered in the study were found to clear immediately for detection and separation of organisms.

Each set was held in place by a single anchor constructed of spring steel (Fig. 2). The set line (LD_3) holds the samplers in

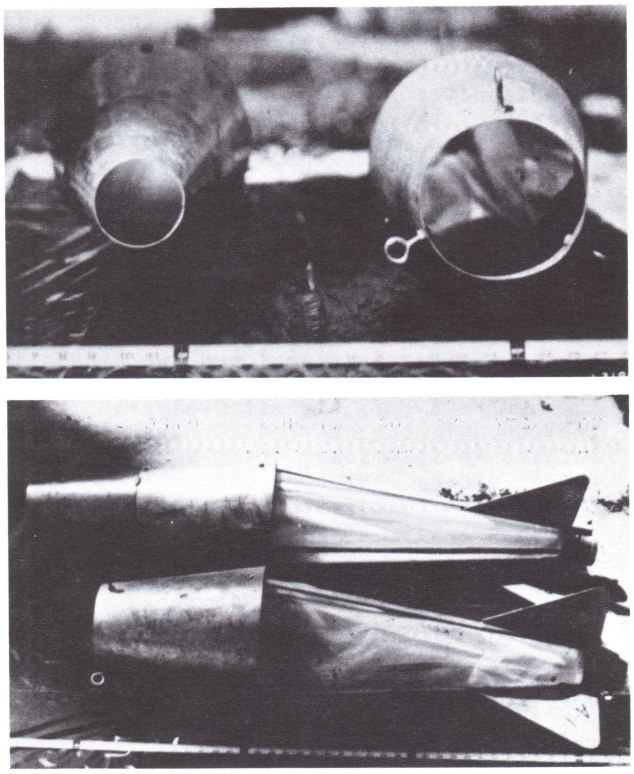

Fig. 1. Drift samplers showing modifications in design.

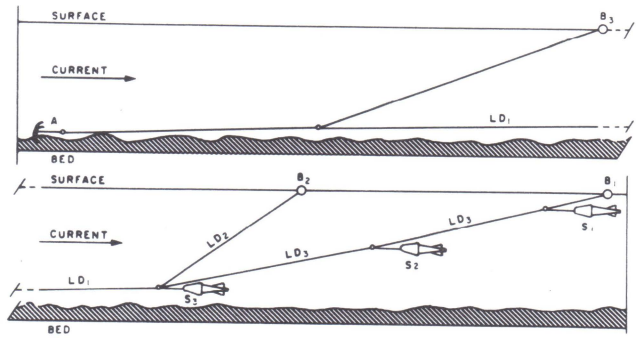

Fig. 2. Sampling set design in longitudinal section of river. A - four-tined anchor; B_1 - tail-set buoy; B_2 - lead-set buoy; B_3 - anchor line buoy; LD_1 - anchor lead line; LD_2 - lead-set line; S_1 - sampler (50 cm below surface); S_2 sampler (mid-depth); and S_3 - sampler (50 cm above bed).

place. It must not exceed half the length of the anchor lead line (LD_1) for operation in swift currents. The length of the set line must be at least four times the depth of the river and carries links for attachment of samplers at 50 cm below the surface, mid-depth, and 50 cm above the river bed. The set is balanced and maintained in place for prescribed sampling depths by adjusting the length of the lead-set buoy line (LD_2) in relation to the length of the anchor lead line (LD_1) for any given current velocity.

Set Operation

Operation of each set required two samplers for each depth to be sampled. One sampler is in place while the other is transported to a suitable shore facility for processing of the sample and refitting for the next sampling period. Rapid removal and replacement of samplers is facilitated from a powered boat by approaching the tail-set buoy (B_1) from downstream and working in order of S_1 to S_3 along the set line (LD_3) (Fig. 2). Under normal river conditions, a three-sampler set can be serviced in about 5 min.

For crew safety in treacherous flood currents carrying large floating debris and particularly while working in the dark, a reverse routine is recommended. The set is approached at the lead-set buoy (B_2) and lifted by the lead-set buoy line (LD_2). Samplers are exchanged in the reverse order S_3 to S_1 by drifting downstream along the set line. This eliminates the hazard of moving along the set line upstream in the face of oncoming debris while attention is concentrated on the sampling system. In the event of sudden confrontation by debris in the dark, the operation can be instantaneously aborted by cutting boat power and drifting out of danger with the current.

Sampling procedures in a turbulent, swiftly flowing, river are normally

complicated by the hazardous conditions of frequent floods with masses of floating debris. The set design as outlined permits uninterrupted sampling during floods according to predetermined schedules. It tends to shed floating debris and, even in the event of entanglement, the anchor releases for downstream displacement with the drift. The set is recoverable with samples intact and can be quickly replaced at the original site. Displacement in the simultaneous operation of two sets rarely exceeds once in 24 hr during the worst conditions of flood and floating debris.

Sample Processing and Analysis

The sample container and the net cone of each sampler was flushed with river water over a standard 30 x 45 cm white enamelled tray. Organisms were removed with small spoon nets from the pan to another receptical containing river water. Spoon nets were fashioned from copper wire to form a handle with a small ring 2 cm in diameter at one end to support a soldered disc of fine-mesh copper screen. Organisms removed from samples were finally separated from the water and preserved with 95% ethyl alchohol in bijou bottles labelled for identification with level, location, and chronological time of sample. The organic matter remaining in the pan was separated from inorganic materials by a placer floatation procedure and also preserved in alcohol in a separate sealed container with a corresponding label. All organic samples were thoroughly examined later under a microscope in the laboratory to recover and identify minute organisms that were missed in the separation of samples at the sampling site.

All organisms in samples were separated taxonimically to genus and numbers recorded by genera for chronological time, location, and depth of sample. Collections of data for individual genera were analyzed for phenological relations in activity, diel periodicity, and variation with depth and rate of flow in the river.

For the purpose of this report, statistical analyses have been confined to *Simulium arcticum* and nine non-target genera sampled in 1977, a year with no river treatment. The non-target genera were identified in a previous monitoring of river treatments in 1976 (Haufe et al., p. 159) as the taxa exhibiting sensitivity to methoxychlor. Background variations in the drift were analyzed to specify minimum procedures and schedules for monitoring and sampling operations in detecting impacts of river treatments. Time series analyses (Box and Jenkins 1969) were used to evaluate variations within the hydrological dimensions of the river with particular consideration of diel rhythms, seasonal periodicity, phenology, and changes in river discharge.

Continuous sampling of the drift for indications of diversity was carried out during 5 days in every 2nd wk from 24 May to 21 July. It is identified for all references in time series analyses as -- Wk 1 - 24-28 May; Wk 3 - 6-10 June; Wk 5 - 20-24 June; Wk 7 - 4-8 July; and Wk 9 - 18-22 July. Genera are designated numerically for brevity in many plots of the data according to the following key for comparisons of the selected taxa -- 1 - Ephemerella; 2 Baetis; 3 - Heptagenia; 4 - Rhithrogena; 5 - Isogenus; 6 - Isoperla; 7 - *Simulium arcticum*; 8 - Hastaperla; 9 Hydropsyche; and 10 - Cheumatopsyche.

RESULTS

The continuous behavioral drift of invertebrates in the Athabasca River is characterized by wide fluctuations in density with variable periodicities. These fluctuations reflect the downstream displacement of organisms as a result of behavioral rhythms, variations in activity in life cycles, shifts in relative abundance among taxa within the phenological time scale for development, and various hydrological influences such as changing water levels, varying rate of river discharge, physical scouring of the bed, and movement of bed loads by currents and turbulence in the river.

The Athabasca River was subject to heavy run-off from one or more of the upstream tributary systems throughout the spring and summer of 1977. Rates of discharge at the sampling site near Calling River remained above normal throughout the period of study in May, June, and July. Density of drift was subject therefore to hydrological conditions that were not representative as a baseline for the average river environment.

Phenological Variations

The phenological time scale was advanced in 1977 as compared with 1976. With the development of *S. arcticum* used as an indicator at a nearby site downstream, this advance was estimated to be at least 3 days. Predominant taxa in hauls beginning with the 1st sampling day on 24 May were in newly hatched and early stages of development. Drift density of taxa predominant in the 1st wk tended to decline in subsequent weeks throughout the season, e.g. Ephemerella spp., Baetis spp., and Isoperla spp. (Fig. 3-5). Other taxa such as Heptagenia spp., Rhithrogena spp., Isogenus spp., and Hydropsyche spp. appeared in the drift in increasing numbers as the early predominant forms declined during the summer. Hauls for all taxa in the drift had extremely high standard deviations about the mean within weekly time series of drift samples (Fig. 3-5).

Except for the sparse presence of some taxa that tended to mature later in the season, the drift was predominantly composed of new generations of the most abundant species after 24 May. Evidently, the major emergence of aquatic forms in terms of

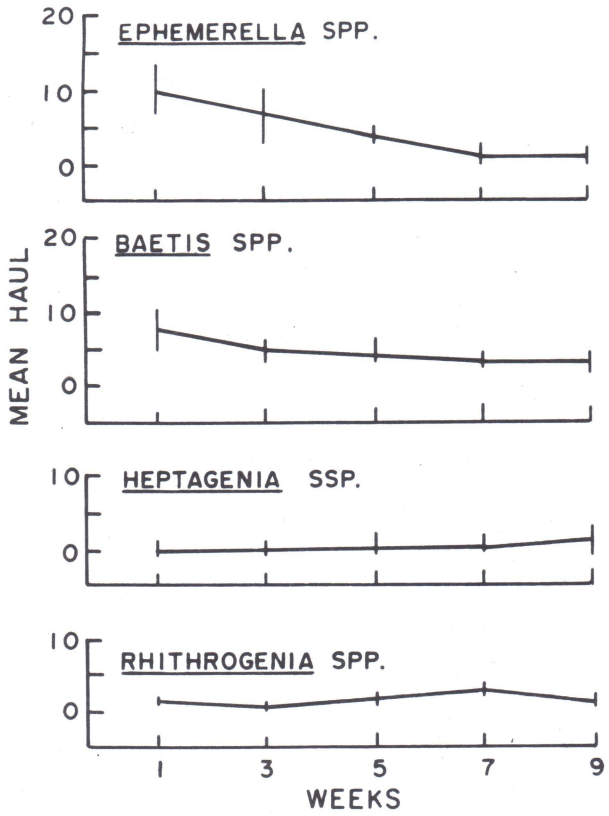

Fig. 3. Mean haul with standard deviation of four ephemeropterus genera, Ephemerella, Baetis, Heptagenia, and Rhithrogenia.

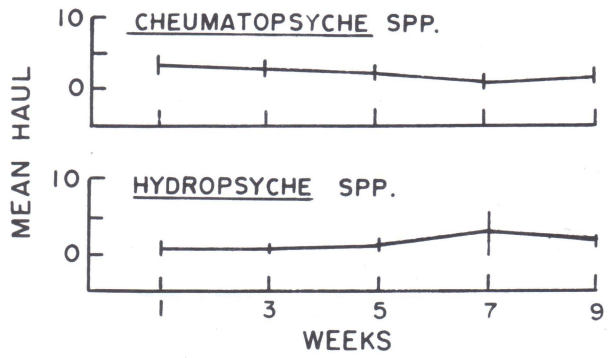

Fig. 4. Mean haul with standard deviation of two trichopterous genera, Cheumatopsyche and Hydropsyche.

biomass occurs during the month of May and precedes the development of *S. arcticum* to the seventh instar.

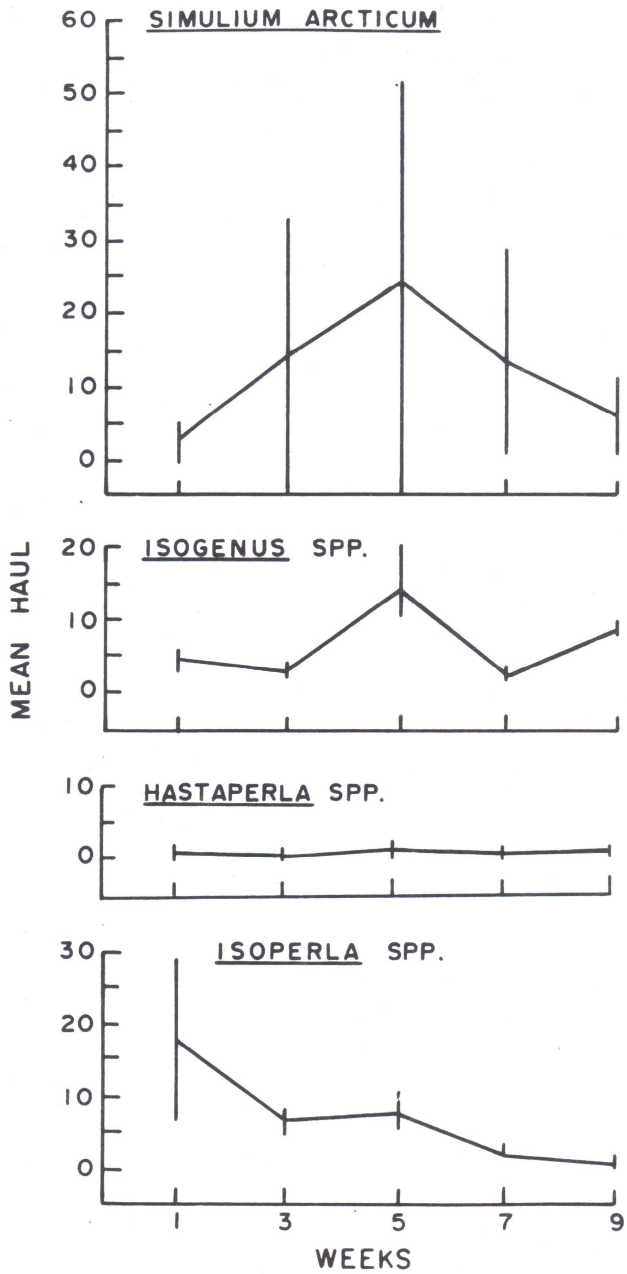

Fig. 5. Mean haul with standard deviation of *Simulium arcticum* and three plecopterous genera, Isogenus, Hastaperla, and Isoperla.

Variations with Current Velocity

Representation of genera within the spectrum of 10 taxa selected for statistical analyses showed about the same profile at the thalweg and ebb-current locations (Figs. 6 and 7). Variance in hauls between locations, however, indicated a trend toward higher abundance and increasing fluctuations within time series for ebb-current conditions. This trend would be accentuated near the ebb-current shoreline with increasing influence of local activity of more abundant populations in the littoral habitats of shallow water.

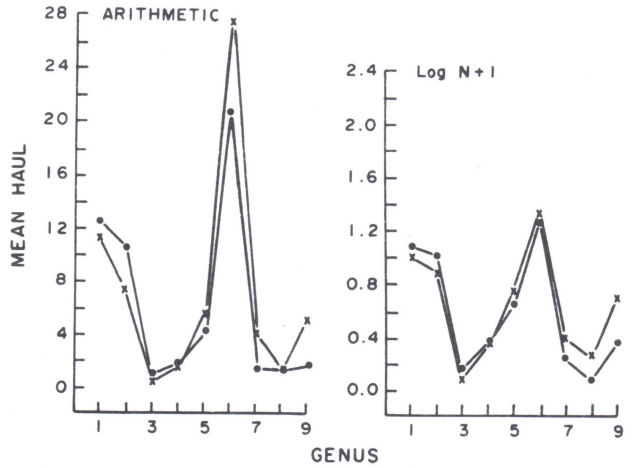

Fig. 6. Generic comparison of mean hauls between thalweg (•) and ebb current (x) during wk 1.

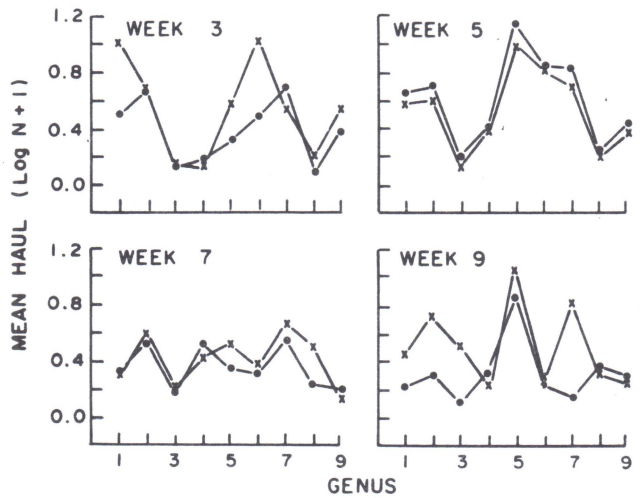

Fig. 7. Generic comparison of mean hauls between thalweg (•) and ebb current (x) in wk 3, 5, 7, and 9.

Variation in the generic profile of hauls between the thalweg and ebb-current locations was related to change in river discharge. Profiles corresponded closely during periods of stable or increasing rates of discharge (wk 1, 5, and 6) and varied for some genera during periods of decreasing rates of discharge (wk 3 and 7). Density of some genera such as Ephemerella, Baetis, Heptagenia, Isogenus, and Isoperla increased in the ebb-current during periods of decreasing discharge. This ebb-current activity represented forced local displacement of taxa to new habitats along the shoreline as water receded. It evidently contributes nominally to the 'constant' downstream drift (defined by Waters 1972) in the thalweg.

S. arcticum inhabits the scoured river bed. Its increased density in the ebb-current in wk 9 followed the second peak in hatching rate (Depner et al., p. 35, Appendix II-C). This displacement in the ebb-current represented movement from hatching sites in sandy or sedimentary parts of the river bed to suitable attachment sites on scoured surfaces.

Variations with Depth

The profiles for generic representation of non-target organisms in hauls corresponded closely for 50 cm below the surface and mid depth in the thalweg and ebb-current locations for all weeks monitored (Fig. 8). While the profiles for depth are similar, they reflect the higher densities of some genera in the ebb-current location during some sampling weeks. The only discrepancy in generic profile for depth is shown by the target organism, *S. arcticum*, in wk 7 in the ebb-current location. The increased displacement of *S. arcticum* near the surface at this time coincided with the lowest rates of river discharge encountered during the sampling schedule. It may reflect release of black fly larvae from shallow scoured channels as the current velocity and water levels were reduced during this period. The fact that this discrepancy occurred in the ebb-current location where shallow channels would be the first to be exposed by rapid reductions in water level supports this observation.

Hauls from 50 cm above the river bed were encumbered with heavy accumulations of organic and inorganic materials moving in the bed load. Consequently, they were more difficult to sort and process. The mean haul in continuous time series was considerably lower than those at the higher levels for the non-target taxa (Table 1). In contrast with the non-target organisms, the major continuous displacement of *S. arcticum* occurs within or just above the bed load at 50 cm above the river bed. Sampling at one level near mid-depth in the thalweg provided a representative estimate of the continuous downstream drift for all non-target taxa entering the current (Table 1).

Diel Variation

Diel rhythms are commonly observed in the activities of aquatic taxa (Waters 1972); but the studies reported have been conducted in smaller streams and rivers with low current velocities and clear water. The Athabasca is a large, swiftly flowing, turbulent river in most of its reaches and the currents maintain a heavy suspension of silt particles. Rates of discharge above normal throughout the spring and summer of 1977 sustained the opaque condition of the water with suspended particles during all periods of the sampling operation. Since the opaqueness of the water would reduce the influence of light in synchronizing or stimulating diel rhythms of activity, the physical and hydrological conditions unique to the Athabasca and similar rivers are important factors in the design of a sampling system for the 'constant' drift of organisms.

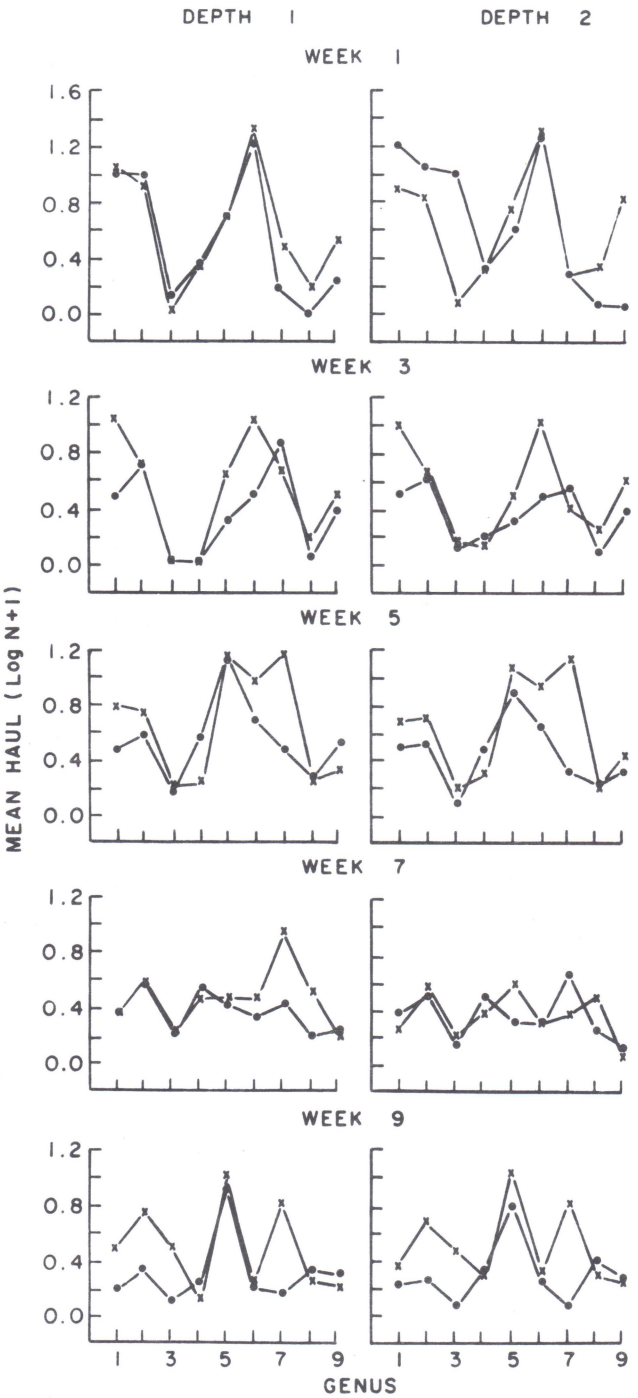

Fig. 8. Generic comparison of mean hauls between thalweg (•) and ebb current (x) in relation to depth for wk 1, 3, 5, 7, and 9.

Table 1. Comparison of the mean density of organisms per haul in the continuous drift at different levels in the thalweg

Genus	Mean number/haul		
	50 cm below surface	Mid-depth	50 cm above bed
Ephemerella	6.25	11.0	5.75
Baetis	16.0	11.0	11.75
Heptagenia	3.75	1.5	1.5
Rhithrogena	13.25	12.0	5.75
Isogenus	9.25	7.75	1.5
Isoperla	9.25	7.75	1.5
Hastaperla	0.25	0.5	0.25
Hydropsyche	6.75	10.0	6.25
Cheumatopsyche	7.25	7.25	5.75
S. arcticum	13.75	14.75	78.25
Mean	8.6	9.4	11.3
Mean (non-targets)	8.0	8.7	3.9

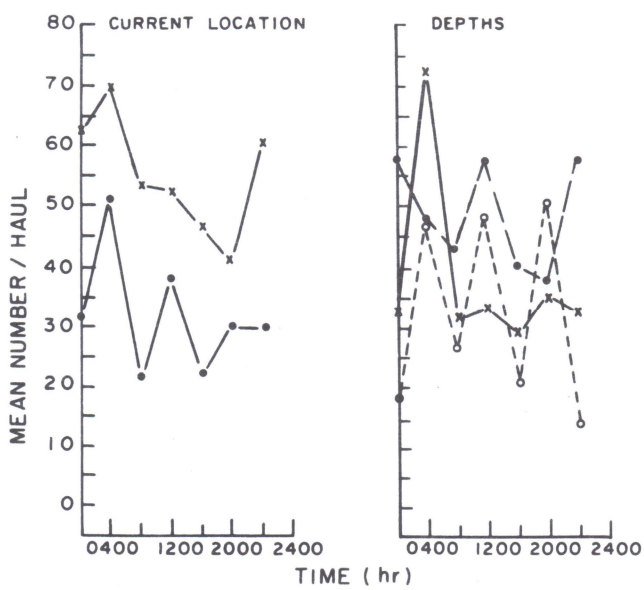

Fig. 9. Variation in mean haul of all indicator genera within 24 hr for sampling periods in all weeks with comparisons between current locations - thalweg (•) and ebb current (x) - and depths - 50 cm below surface (•), mid depth (x), and 50 cm above bed (o).

Analyses of 24-hr sequences for hauls generally showed that the commonly observed diel rhythms in activity are obscured in the Athabasca River system. The expected cycling of behavior in taxa was evident only in the ebb-current location (Fig. 9) and may be expressed more clearly in sampling near the shoreline. The cycle in the general drift from the biomass in the ebb-current with an increase between 2000 and 0800 hr reflects local behavioral activity in shallow habitats along the shores. Cycling in this contribution to the 'constant' drift is obscured by other periodicities in the thalweg. Mean drift along the cross-section of the river displayed different periodicities related to depth. The early morning peak in the ebb-current (Fig. 9) contributes to a similar peak in mean drift at mid-depth. A pronounced 8-hr periodicity characterizes the mean drift at 50 cm above the bed (Fig. 9). Two modes in the mean drift near the surface at 0800 hr and 2400 hr appear to be related to the second and

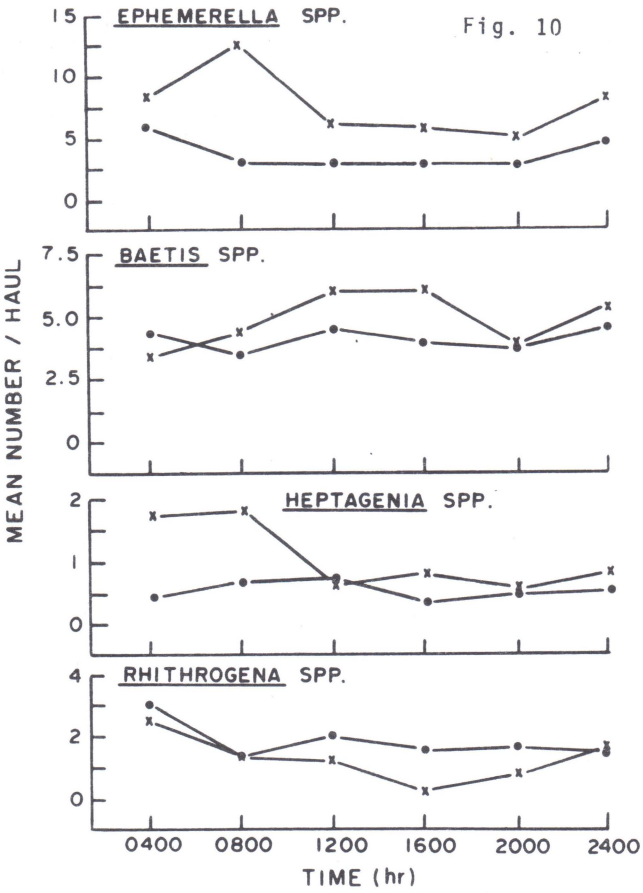

Fig. 10

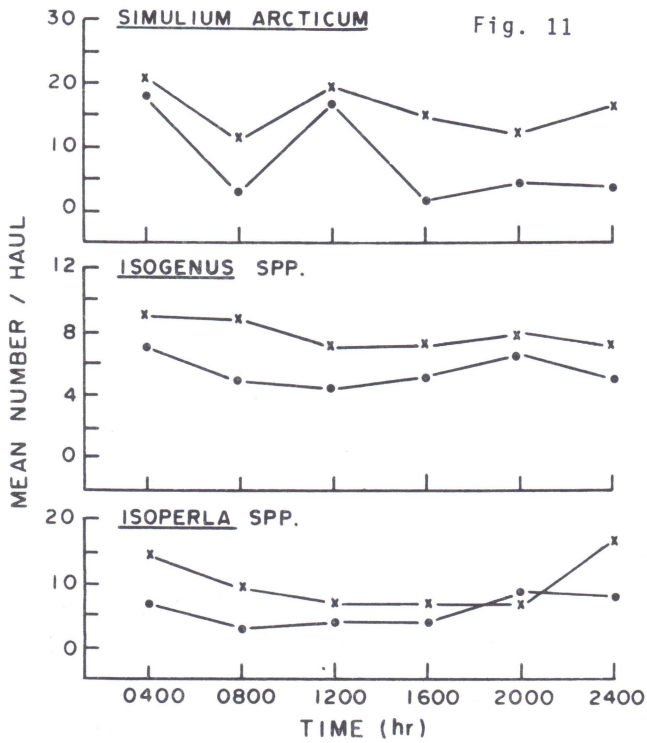

Fig. 11

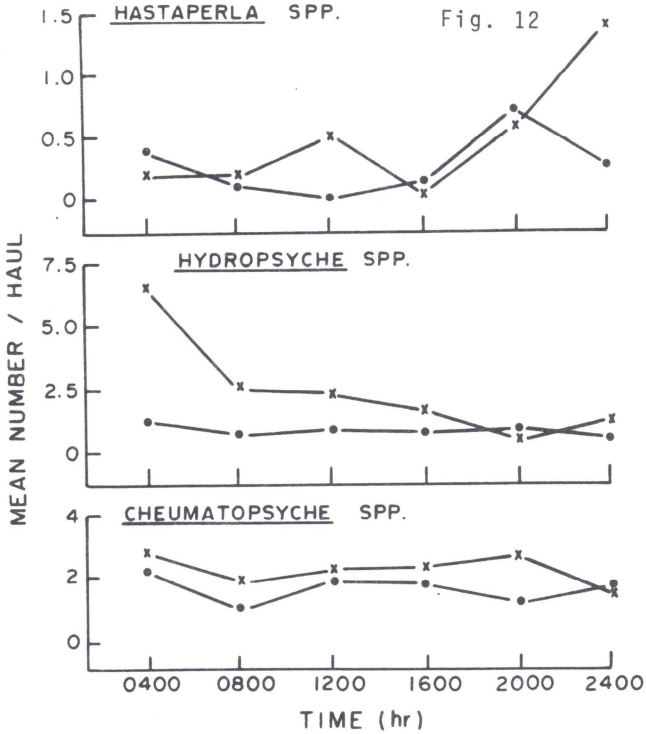

Fig. 12

Fig. 10-12. Variation in mean hauls of each selected indicator genus within 24 hr for all sampling weeks in the thalweg (•) and ebb-current (x) locations: 10 - ephmeropterous genera; 11 - *Simulium arcticum* and two plecopterous genera; 12 - Hastaperla, Hydropsyche, and Cheumatopsyche, the genus most sensitive to methoxychlor toxicity.

third modes of the 8-hr periodicity near the bed load with some lag in the activity about 0000 hr.

Analyses for diel rhythms in selected genera (Fig. 10-12) show some cycling in the ebb-current; but diel rhythms are obscured or indistinguishable in the thalweg. This indicates that the 'constant' drift is represented by mean hauls in the thalweg.

Early morning modes are displayed in the ebb-current by Ephemerella, Heptagenia, and Hydropsyche. Baetis enters the drift in increasing numbers at 1200 hr and Isoperla and Hastaperla at 0000 hr.

Periodicities in the Drift

The pronounced 8-hr periodicity in the 'constant' drift of organisms near the bottom in the thalweg (Fig. 9) has important implications in the design of minimum monitoring schedules for the target *S. arcticum*, non-target organisms, and also for relationships with concentrations of the pesticide moving with the bed load. The influence of this periodicity in the drift at higher levels was studied in time series analyses of the data with the application of the autocorrelation function (ACF) (Box and Jenkins 1969).

The hauls at 4-hr intervals from the sampling run in each week were analyzed for variation in the time series (Z_1, Z_2 .....Z_t) or Z_t in which t corresponds with observations spaced at equal 4 hr intervals. Pairs of hauls (Z_t, $Z_t + k$) were correlated with k as a constant interval or 'lag' k to give autocorrelation values (r_k) at lag k. The ACF was derived for each of the selected genera as a plot of r_k against k. The plots for the genus Isogenus are shown as an example for the five sampling periods (wk 1, 3, 5, 7, and 9) in Fig. 13 in relation to the standard error ($\hat{\sigma}$) in hauls.

Plots for the ACF in the 10 selected genera show only occasional influence of the near-bed 8-hr periodicity on the 'constant' drift of organisms as measured at mid-depth and 50 cm below the surface. Time series analyses generally show a damping of the diel rhythm of activity generated in the ebb-current near shore and also of the 8-hr periodicity in the lower thaleg as influences on the 'constant' drift in the upper thalweg (Fig. 13). For reasons still undetermined, the lower thalweg periodicity is pronounced in the 'constant' drift of the upper thalweg only occasionally for certain taxa such as Iosgenus in wk 9 (Fig. 13). The present analyses indicate that it is not seriously implicated in the design of a limited sampling schedule for 'constant' drift in the upper thalweg.

Diversity in Taxa

Diversity in the drift varies with hydrological conditions of the river and with the phenological time scale. General emergence of maturing taxa in May is followed temporarily by reduced diversity in the drift. Diversity also varies throughout the phenological time scale since contribution to the drift is related to stage of development in some of the taxa. Some forms rarely enter the drift through normal behavior and their displacement, when detected, appears to be the result of hydrological changes affecting habitats on the bottom.

About one-third of the taxa identified in bottom sampling near shore (Depner et al., p. 141) were collected in the 'constant' drift during the five sampling periods in 1977 (Appendix I). About 20 genera contribute continuously to the drift during spring and summer and also tend to appear as the most abundant among the taxa. Less prolific taxa either appear sporadically within the phenological time scale or tend to enter the drift more frequently in the summer.

DISCUSSION AND INTERPRETATION

The 'constant' drift, as defined by Waters (1972), is adequately measured for monitoring purposes in the upper thalweg of the river. It exhibits the lowest variation with time among hauls in the cross-section of the river and represents the principal

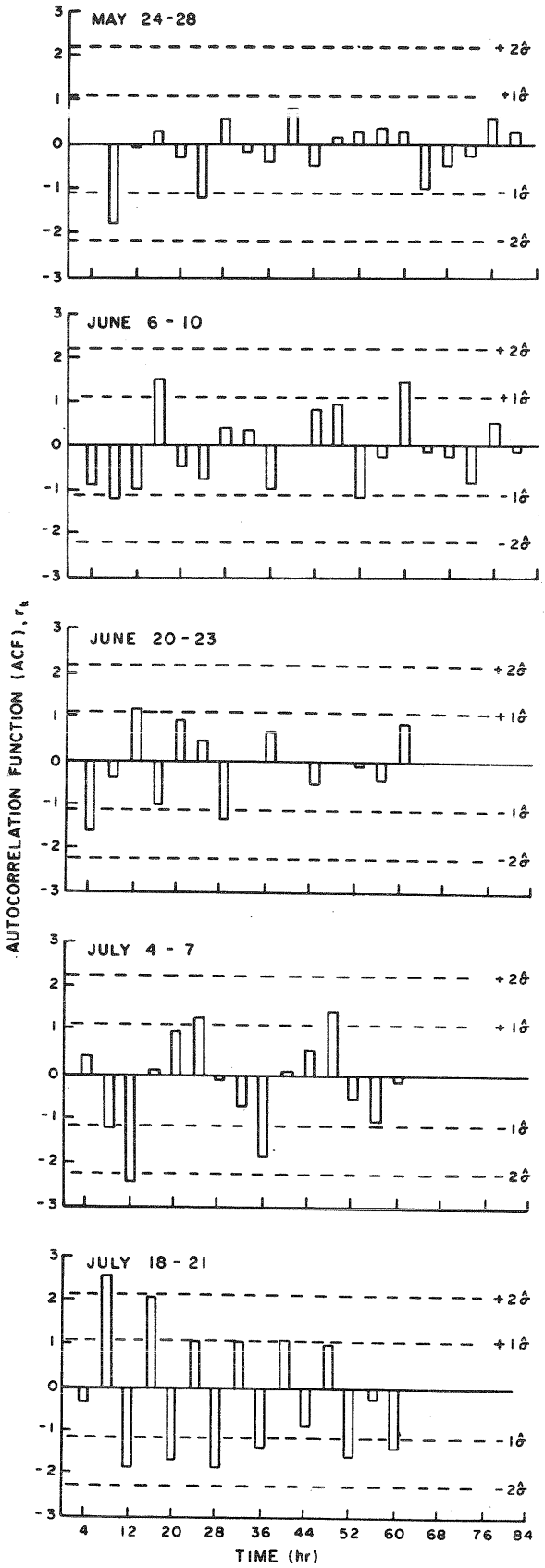

Fig. 13. Autocorrelation functions for periodicity of appearance of Isogenus in hauls within sampling wk 1, 3, 5, 7, and 9.

displacement of organisms downstream. 'Constant' drift in the lower thalweg, especially near the bottom, is characterized by an 8-hr periodicity that so far has no determined origin in the observed hydrological or biological conditions of the river system.

Behavioral drift appears to occur in the ebb-current environments and increases with proximity to the shoreline. High densities of organisms are encountered in the behavioral drift; but they are subject to diel rhythms and wide fluctuations when measured in a continuous time series. Diel rhythms vary among the taxa within the 24-hr day in the ebb-current drift. Continuous sampling is essential therefore to determine effects of time-related events on the behavior of taxa in the ebb-current environments.

Significant downstream displacements are detected in the thalweg since they represent the 'constant' drift that is captured by the main current of the river. They are obviously subject to continuous exchange with the behavioral drift and the hydrological displacement of sedentary taxa on the bottom; but they represent the net downstream displacement influenced by hydrological conditions as well as by behavioral and other phenomena.

Invertebrate drift represents a relatively small part of the taxa in the ecosystem at any given time in the phenological time scale (Appendix 1). Drift collections of taxa are unlikely to have any quantitative contribution to the assessment of diversity in the fauna of a river system unless they are combined with some form of bottom sampling. Taxa appearing in the drift are fairly well distributed throughout the Orders and Families identified from bottom samples taken in shallow water; but representation excludes a large number of genera and also varies with the time of season.

Time series analyses of data have been carried only to the point of identifying periodicities that affect the design of minimum practical monitoring procedures for routine treatment of rivers. Additional, more detailed, analyses of the extensive data collected will be completed to quantify some of the observed periodicities, particularly the important 8-hr frequency that is pronounced in all of the drift including both organic and inorganic materials in the lower thalweg. A better understanding of these phenomena is essential to a hydrological model for long-term application of pesticides to large turbulent rivers.

The quantitative analysis of invertebrate drift has also been confined to selected taxa for the immediate practical requirement in establishing minimum procedures for accountability of treatments within the river system. Detailed quantification of impacts have been limited to 'sensitive' or 'indicator' genera identified in the course of methoxychlor treatments. An extension of these analyses to the full range of drifting taxa may be completed from existing collated data to complete documentation on the Athabasca River invertebrate fauna as a reference point in environmental considerations. These extended documentations from the existing data will be useful in the long term for possible reevaluation of the effect of abatement operations on diversity of aquatic life in the river system.

CONCLUSIONS

1. Monitoring of the drift will provide adequate information for the detection and assessment of general impact of a river treatment on the non-target fauna. However, drift measurements must be combined with other methods designed to sample the resident bottom fauna to make quantitative estimates relating to diversity of taxa in the ecosystem.

2. The most economic design for a drift-sampling system is confined to the 'constant' drift in the upper thalweg of the river. This system may be limited to one drift sampler at mid-depth. If resources are available, additional information on variance for taxa may be obtained by operating traps simultaneously at mid-depth and about 50 cm below the surface.

3. Variation in the behavioral drift is detected in the ebb-current, preferably near the shoreline. It will provide information on diel periodicities if these phenomena are significant in the assessment of the impact of treatments.

4. If monitoring of invertebrate drift includes the immediate processing of hauls (Haufe et al., p. 159) to identify casualties in relation to chemical monitoring of the water for time of arrival of the treated pulse, then sampling of the 'constant' drift within the upper thalweg is adequate for a practical estimate of the impact of treatment on non-target organims.

5. A drift-sampling schedule for 'constant' drift in the upper thalweg may be limited to a 12-hr sampling period embracing the accurately estimated time of arrival of the pulse provided that the pulse arrives within the second of three consecutive 4-hr sampling intervals.

6. The monitoring site should be located about 20 km downstream from the point of injection to accommodate maximum accuracy in estimating the arrival of the pulse in combination with the monitoring of the concentration of pesticide after uniform dispersal in the water at the same site.

7. Two corresponding daily sampling periods are required in 2 days before and 2 days after the day of arrival of the pulse to establish and compare densities and their variance in the pre- and post-treatment 'constant' drift.

8. Schedules for monitoring 'behavioral' drift in the ebb-current will supply additional information on local impacts of treatments near shore but they are not essential for routine monitoring of operations. If implemented for more detailed environmental studies of river treatments, continuous 24-hr sampling during a 5-day schedule is required to provide interpretations of diel rhythms for taxa.

9. Sampling of the 'constant' drift in the lower thalweg, especially near the bottom will include a greater diversity of taxa. However, it is laborious and the hauls are subject to an 8-hr periodicity in the displacement of both inorganic and organic materials in the bed load. More extensive continuous sampling is required in the lower thalweg to resolve the background variation, or 'white noise', within any given time series in a monitoring schedule.

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APPENDIX I. Distribution of invertebrate genera in samples of the taxa in the drift and on the bottom of the Athabasca River

Order	Family	Genus	Bottom sample (Depner)	Collected in the drift					
				1976	1977				
					Wk 1	Wk 3	Wk 5	Wk 7	Wk 9
Amphipoda	Gammaridae	Gammarus	X	X	X	X	X		X
	Talitridae	Hyalella	X			X	X		X
Basommatrophora	Lymnaeidae	Lymnaea	X	X					
	Planorbidae	Helisoma	X						
		Gyraulus	X			X	X		
		Promenetus	X	X		X	X		
Cladocera		Daphnia		X		X	X		
Coleoptera	Amphizoidae	Amphizoa	X						
	Dytiscidae	Agabus	X						
		Deronectes	X						
		Hydaticus	X						
		Hydrovatus	X						
		Hygrotus							X
		Rhantus	X						
	Elmidae	Heterlimnius					X		
		Optioservus	X						
	Gyrinidae	Gyrinus	X						
	Haliplidae	Haliplus	X	X					
	Hydrophilidae	Cercyon							X
		Helophorus		X					
		Paracymus	X						
	Noteridae	Hydrocanthus		X	X				X
	Ptilodactylidae		X						
Copepoda		Copepod	X	X	X	X	X	X	X
Diptera	Ceratopogonidae	Culicoides	X	X	X	X	X	X	X
	Chironomidae (Tendipedidae)	Calopsectra	X						
		Chironomus	X						
		Metriocnemus	X						
		Pentaneura	X	X	X	X	X	X	X
	Culicidae	Chaoborus	X		X	X		X	X
	Dolichopodidae	Aphrocylus				X			
		Dolichopus	X	X	X				
	Empididae	Hemerodromia	X	X	X	X	X	X	X
	Heleidae	Palpomyia						X	
	Rhagionidae	Atherix	X	X	X	X			
	Sciomyzidae		X						
	Simuliidae	Cnephia	X						
		Simulium	X	X	X	X	X	X	X
	Tanyderidae	Protoplasa	X						
	Tipulidae	Erioptera	X						
		Hexatoma	X	X		X			
		Pedicia	X	X					
		Tipula	X	X	X	X			
Ephemeroptera	Baetidae	Ametropus	X	X	X				X
		Baetis	X	X	X	X	X	X	X
		Baetodes	X				X		
		Centroptilum	X						
		Metretopus	X	X	X				
		Neocloeon	X		X				
		Pseudocloeon	X				X		
		Siphloplecton	X				X		
	Baetiscidae	Baetisca	X						
	Caenidae	Caenis	X	X					
	Ephemerellidae	Ephemerella	X	X	X	X	X	X	X
	Ephemeridae	Ephemera	X						
		Hexagenia	X		X	X	X	X	
	Heptageniidae	Cinygma	X				X	X	
		Cinygmula	X						

APPENDIX I continued

Order	Family	Genus	Bottom sample (Depner)	Collected in the drift					
				1976	1977				
					Wk 1	Wk 3	Wk 5	Wk 7	Wk 9
Ephemeroptera	Heptageniidae	Epeorus	X	X	X	X	X	X	X
		Heptagenia	X	X	X	X	X	X	X
		Pseudiron			X	X	X	X	X
		Rhithrogena	X	X	X	X	X	X	X
		Stenonema	X	X	X			X	
	Leptophlebiidae	Habrophlebiodes	X						
		Leptophlebia	X	X	X				
		Paraleptophlebia	X						
	Siphlonuridae	Ameletus	X	X					X
		Isonychia	X					X	X
		Parameletus	X	X	X	X			X
		Siphlonisca	X			X			
		Siphlonurus	X	X					
	Tricorythidae	Trichorythides	X				X		X
Gordiida	Gordiidae	Gordius	X	X	X	X	X	X	X
Heterodonta	Sphaeriidae	Sphaerium	X				X		
Heteroptera	Corixidae	Callicorixa	X				X		
		Cymantia	X			X			
		Sigara	X	X	X	X	X	X	X
	Gerridae	Rheumatobates	X						
	Notonectidae	Notonecta	X						
Lepidoptera		Arzama	X					X	X
		Nepticula	X						
Mysidacea		Mysis	X	X		X	X	X	
Neuroptera	Sialidae	Sialis	X			X	X	X	X
Odonata	Gomphidae	Ophiogomphus	X	X	X	X	X	X	X
Oligochaeta	Naididae	Stylaria	X	X	X	X	X	X	
Plecoptera	Chloroperlidae	Chloroperla	X						
		Hastaperla	X	X	X	X	X	X	X
	Nemouridae	Brachyptera	X	X					
		Nemoura	X						
	Perlidae	Acroneuria	X	X					
		Classenia	X	X				X	X
		Neoperla	X						X
	Perlodidae	Diura	X						
		Isogenus	X	X	X	X	X	X	X
		Isoperla	X	X	X	X	X	X	X
	Pteronarcidae	Pteronarcella	X			X	X	X	
		Pteronarcys	X	X	X	X	X	X	X
Trichoptera	Brachycentridae	Brachycentrus	X	X	X	X	X	X	X
	Glossosomatidae	Agapetus	X	X		X			
		Glossosoma	X	X					X
	Hydropsychidae	Arctopsyche	X	X				X	X
		Cheumatopsyche	X	X	X	X	X	X	X
		Diplectroma	X						
		Hydropsyche	X	X	X	X	X	X	X
		Parapsyche	X						
	Hydroptilidae	Hydroptila		X			X		
		Mayatrichia					X		
		Neotrichia	X						
	Leptoceridae	Mystacides	X			X	X		X
		Trianodes	X			X	X	X	X
	Limnophilidae	Drusinus	X						
		Limnophilus				X			
		Platycentropus	X						
		Psychoromia	X						
	Psychomyiidae	Neureclipsis	X						X

APPENDIX I continued

Order	Family	Genus	Bottom sample (Depner)	Collected in the drift					
				1976	1977				
					Wk 1	Wk 3	Wk 5	Wk 7	Wk 9
Trichoptera	Psychomyiidae	Polycentropus	X						
		Psychomyia	X	X		X		X	X
	Rhyacophilidae	Rhyacophila	X			X			
Total Genera Collected			106	50	35	45	43	37	41

METHOXYCHLOR STUDIES WITH FISH: ATHABASCA RIVER EXPOSURES AND EXPERIMENTAL EXPOSURES

W. L. LOCKHART

INTRODUCTION

The addition of methoxychlor to the Athabasca River in 1974 was monitored by measuring concentrations of the pesticide in fish caged in the river and in fish captured wild there. Fish were also exposed experimentally to methoxychlor to establish which organs were suitable for monitoring purposes and also to associate residue concentrations with gross morbidity. Methoxychlor concentrations in livers of fish experiencing realistic exposures were compared with those in livers of fish poisoned to morbidity. In addition, the time required to poison fish to morbidity was compared with the duration of river treatment at the same concentration. Both of these comparisons were expressed as 'safety factors' in the hope of estimating how closely river larviciding may have approached to poisoning fish.

Experiments were also conducted to identify variables related to rates of methoxychlor uptake by fish. A number of biochemical measurements were made on fish from the Athabasca River and from fish used experimentally to identify sub-lethal responses to methoxychlor; however, none was reliably identified. Biochemical analyses did, however, reveal an abnormality in a group of four fish captured 74.5 km downstream from the treatment point about 7 wk after treatment and that abnormality was consistent with starvation.

That part of the work dealing with development and verification of a procedure to analyze methoxychlor in fish tissues was published separately (Solomon and Lockhart 1977). Residues from fish caged in the Athabasca River and in fish captured wild there were reported (Lockhart et al. 1977).

METHODS

Fish Species

Fish of seven species were used for experimental exposure to methoxychlor: rainbow trout (*Salmo gairdneri* Richardson), white sucker (*Catostomus commersoni* Lacépède), northern pike (*Esox lucius* Linnaeus), channel catfish (*Ictalurus punctatus* Rafinesque), freshwater drum (*Aplodinotus grunniens* Rafinesque), sauger (*Stizostedion canadense* Smith), and walleye (*Stizostedion vitreum* Mitchill). Species captured from the Athabasca River and analysed for residues or biochemicals included some of those listed above and, in addition, longnose suckers (*Catostomus catostomus* Forster), flathead chub (*Platygobio gracilis* Richardson), burbot (*Lota lota* Linnaeus), mountain whitefish (*Prosopium williamsoni* Girard), and goldeye (*Hiodon alosoides* Rafinesque).

Fish Capture Methods

Wild fish were captured at four sites in the Athabasca River by setting hoop nets in water less than 2 m deep. The nets were made of 4.4-cm stretched mesh fixed to hoops 1.52 m in diameter with a trap at one end so

that fish were obtained undamaged. Nets were set with water flow predominately through them from the trap end to the open end, so that any drifting fish would not be collected. Fish were removed from the trap portion of nets as frequently as possible. Fish from the Red River south (upstream) of Winnipeg were captured with the same nets used in Athabasca sampling. Some white and longnose suckers were captured with dipnets from Flat Creek, Alberta (Athabasca drainage) for use in cage exposures.

Athabasca River Fish Cage Exposures

Fish were placed in cages of two types before treatment of the Athabasca River with methoxychlor. Yearling rainbow trout from a provincial hatchery were supplied by the Alberta Department of Lands and Forests and eight of these fish were placed in each of 12 wire cages measuring 10 x 20 x 20 cm, made from 1.27-cm galvanized wire mesh. Three cages of trout were anchored near the river bank about 200 m upstream of the methoxychlor injection and the remaining nine were suspended from a boat and allowed to drift with the mass of treated water. Cages were suspended about 10 cm below the water surface while drifting and three cages were removed during the 1st hr; fish from one cage were sacrificed at each time 0.25, 0.5, and 1.0 hr after treatment. The remaining six drifting cages were then anchored below a riffle area about 5 km downstream from the treatment site and one cage was removed at each time 3, 6, 12, 28, 59, and 101 hr after treatment. The remaining trout cages were examined daily in a check for mortality.

Wild fish species were placed in larger cages made by rolling 123-cm wide wire mesh into cylinders 76 cm in diameter with each end enclosed by a circular section of mesh. Wire was of square mesh construction with wires 2.54 cm apart. Four of these cages were located at each of four sites in the Athabasca River (2.5 km upstream, 4.5, 33.5, and 74.5 km downstream) and 6-11 fish (depending upon availability) were placed in each cage. At the site 4.5 km downstream, varying numbers of white suckers, longnose suckers, and flathead chub were placed together in cages; at other sites, only white suckers were used. Cages were all stocked by 1 June 1974 and they were sampled by removing one cage from each site on the following dates: 5 June, 11-12 June, 18-19 June, and 9-10 July. Fish were not fed during the experiment.

Athabasca Fish Sampling Procedure

Upon removal from either a cage or a hoop net, native Athabasca fish were bled by inserting a hypodermic needle either into the heart (most white and longnose suckers) or caudal vessels (species other than suckers). Fish were weighed, measured for fork length, and examined by opening the abdominal cavity to determine the sex. Organs for methoxychlor residue analysis were dissected and wrapped in foil and frozen until analysed. Blood samples were allowed to clot at 0°C and serum was withdrawn with a Pasteur pipette and stored frozen until analysed for several serum biochemical constituents.

Sampling the small rainbow trout used in the Athabasca River cages was somewhat different. Fish were not bled. Four of the eight fish in a cage were each dissected to obtain samples of liver, kidney, muscle, and digestive tract with associated visceral fat; these four samples of each organ were then pooled together, wrapped in foil, and frozen until analysed. The remaining four fish in each cage were wrapped individually in foil and frozen until analysed.

Experimental Exposures

Yearling rainbow trout from the Freshwater Institute's Rockwood (Manitoba) hatchery were exposed to methoxychlor in an outdoor pool described earlier (Lockhart et al. 1973). Water temperature was 19-20°C and fish were not fed during the exposure. The pool was treated by dissolving 1.34 g methoxychlor in 120 ml ethanol and mixing this solution into the polyethylene-lined pool containing 4,450 liters of water with inflow of untreated water at 15 liters/min. Assuming a balance between pool inflow and outflow, and complete mixing at all times, then nominal concentration at anytime can be calculated and compared with measured concentrations. Comparing these values during the experimental exposure of rainbow trout, it seems that fish may have experienced only about one quarter the anticipated dose (Table 1).

Table 1. Relationship between calculated and measured concentrations of methoxychlor at various times after mixing.

Time after mixing (min)	Concentration (µg/liter)	
	Calculated	Measured
0	300	93.0
15	285	75.0
33	268	116.0
60	245	51.0
120	200	55.0
403	77	7.3
1458	2	0.5

Additional outdoor exposures were carried out at the University of Manitoba's Glenlea Research Station south of Winnipeg. Red river fish species (channel catfish, northern pike, white sucker, sauger, walleye, and drum) were captured with hoop nets and transferred to plastic pools filled with 1,600 liters of river water at ambient temperature. Methoxychlor in ethanol was mixed into pools with stirring to produce the desired nominal concentrations. Since these pools had no flow, an air supply was

used to maintain dissolved oxygen. After the exposure was completed, fish were sampled in a manner similar to Athabasca fish.

Several laboratory exposures were performed using rainbow trout from the Freshwater Institute's wet laboratory and hatchery to determine relationships between methoxychlor uptake and variables such as fish weight, concentration, exposure time, and water quality. Procedures are described below.

The first experiment was performed to determine the relationship between fish body weight and methoxychlor uptake from dechlorinated city water. Rainbow trout were selected visually to give a range of size classes from about 5 to 400 g and 10 fish (two from each of five classes) were placed in 20 liters of water containing methoxychlor (ethanol carrier) at 25 µg/liter at 14.6°C. After 1 hr, fish were removed, weighed, wrapped in foil, and frozen for analysis. The experiment was replicated four times.

A second experiment in dechlorinated city water was carried out to determine whether the product of exposure time and exposure concentration would predict residue accumulation. Sixteen plastic containers each containing 15 liters of water were made to varying concentrations of methoxychlor and rainbow trout (5-12 g in weight) were placed in them for varying periods at 15°C (Table 2).

Table 2. Combinations of methoxychlor concentrations and exposure times

Methoxychlor concentration (µg/liter)	Exposure time (min)
300	15
100	15
50	30
25	60
12.5	120
6.25	240
3.125	480
Control	480

Each of these eight combinations was replicated twice. Six of these combinations of concentration and time yield the same product when multiplied together and the experiment was intended to determine whether fish would also contain the same residues. After the desired exposure period, fish were removed, wrapped in foil, and frozen until analyzed.

The final laboratory exposure reported here was intended to determine the effect of water quality on rates of methoxychlor uptake by rainbow trout. Red River water was collected at Glenlea, Manitoba, and diluted with varying amounts of dechlorinated city water so that five different water types were produced (100% river, 75% river + 25% city, 50% river + 50% city, 25% river + 75% city, 100% city). Water of each type was analyzed for a number of parameters by the Freshwater Institute's water chemistry laboratory using methods described by Stainton et al. (1977). After 1 hr of exposure, fish were removed, wrapped in foil, and frozen for analyses. After analyses, methoxychlor residues and water chemistry values were compared using a multiple stepwise linear regression program to determine whether any of the water chemistry measurements could be related to the methoxychlor in fish.

Methoxychlor in fish tissues and in water samples was measured by gas-liquid chromatography using a Tracor MT-220 gas chromatograph equipped with an electron-capture detector (Solomon and Lockhart 1977). Fish tissue samples were extracted with hexane in a ball-mill (Grussendorf et al. 1970) and 'cleaned-up' either on Florisil columns or by lipid freeze-out followed by Florisil. Cleaned-up extracts in n-hexane were analyzed on a short gas liquid-chromatography column (retention time 2.2 min) described in detail by Solomon and Lockhart (1977). This procedure gave recoveries of 86-101% of methoxychlor added to fish and crab samples at concentrations of 0.01-10.0 µg/g (Solomon and Lockhart 1977).

Several biochemical analyses (Table 3) were made on groups of fish, and these were adaptations of standard procedures in

Table 3. Analyses and methods used

Analyses	Methods
serum glucose	glucose oxidase
serum protein	biuret
serum cholinesterase	hydrolysis of acetyl-thiocholine
serum alkaline phosphatase	hydrolysis of p-nitro-phenylphosphate
serum lactate dehydrogenase	oxidation of NADH
serum glutamate oxalacetic transaminase	oxidation of NADH (using malate dehydrogenase as indicator reaction)
serum calcium	atomic absorption
serum sodium	flame emission
serum chloride	microtitration
serum triglyceride	glycerokinase
total serum lipid	sulfophosphavanillin reaction
serum magnesium	atomic absorption
serum potassium	flame emission
hematocrit	centrifugation
muscle dry weight	gravimetric (wet vs. dry)
muscle ash	dry, 250°C for 0.75 hr then 500°C for 4.5 hr
muscle calories	bomb calorimeter
body lipid	solvent extraction then chromic acid oxidation

analytical biochemistry (Mattenheimer 1970). Chemicals used, for the most part, were prepared reagent kits from Boehringer Mannheim Corp.

Statistical procedures were applied in consultation with Dr. D. P. Scott (Freshwater Institute) and generally consisted of analyses of variance, covariance, and regression.

RESULTS

Methoxychlor Residues in Organs of Rainbow Trout

Uptake of methoxychlor by rainbow trout exposed in an outdoor pool as described in 'Methods' are shown in Table 4. Fish were not fed and they accumulated methoxychlor rapidly into organs such as liver and kidney. A number of grossly morbid fish were collected at 2.17 hr after starting the exposure and these individuals contained the highest liver and kidney residues. Not all fish reached a state of gross morbidity and fish collected at 6 and 24 hr showed no obvious indication of poisoning although some contained even higher residues in muscle and fat than did the morbid fish. Survivors from this exposure were kept for several weeks and no obvious ill effects were noted. Based upon this experiment, liver was selected as the preferred organ to analyze for methoxychlor residues in Athabasca fish. Either liver or kidney would have been suitable since we wished to use residue measurements as indicators of fish poisoning, not as indicators of the quality of fish as food.

Residues in Caged Athabasca River Rainbow Trout

Residues in caged Athabasca River rainbow trout are shown in Table 5. Three cages of trout removed from the water while drifting with the mass of treated water (0.25, 0.5, and 1.0 hr) showed little accumulation of methoxychlor in organs or in whole fish. The remaining six cages were anchored near the river bank below a shallow riffle after the 1-hr sample, and the major accumulation of methoxychlor occurred there between 3 and 6 hr after treatment. Apparently a source of methoxychlor existed some 3-6 hr after treatment only 5 km from the treatment point, presumably due to low water velocity near the edge of the river (Beltaos and Gerard 1975). (Pesticide concentrations in water and sediment have been measured by Charnetski, p. 39 & 63.) It seems possible that these fish may have fed on aquatic insects killed by the treatment; however, examination of gut contents at the time of dissection revealed no undigested material except occasional small stones in a few individuals. Data for pooled organs from four fish and those for whole-body concentrations for the other four fish in each cage agree well up to about 12 hr; after that, particularly at 101 hr, the whole-body residues were sometimes much higher than expected from the tissue residues, raising the possibility of an important tissue reservoir in addition to those analyzed.

Residues in Free-Swimming Athabasca River Fish

Residues in livers of free-swimming Athabasca fish are presented in Table 6. Residues were quite variable but were highest in flathead chub. Methoxychlor was found quite consistently in livers of fish captured after treatment at the upstream site, presumably indicating upstream movement by fish. The highest liver residue found was 9.6 µg/g in a flathead chub captured 4.5 km downstream on 8 June, 4 days after treatment. All samples after 19 June were below 0.02 µg/g; evidently a period of about 2 wk was sufficient for clearance of residues from liver.

Table 4. Methoxychlor concentrations in rainbow trout, Salmo gairdneri, at intervals after exposure to methoxychlor diluting continuously from a nominal concentration of 300 µg/liter. Figures are means of values from four fish with standard deviations

Time after start of treatment (hr)	Methoxychlor concentration (µg/g, wet weight)			
	Liver	Gut + Fat	Muscle	Kidney
Pretreatment	<0.02	<0.02	<0.02	<0.02
0.25	9.10±3.84	2.62±1.33	1.00±0.17	4.60±1.43
0.50	16.9 ±5.99	5.12±3.45	1.29±0.42	10.4 ±5.24
1.0	15.7 ±3.86	9.35±0.78	3.42±0.41	9.83±2.07
2.0	24.9 ±9.21	9.34±3.04	4.30±0.51	19.3 ±7.38
2.17[a]	29.6 ±8.85	17.3 ±3.46	7.64±2.22	20.3 ±5.86
6.0	13.7 ±5.74	34.5±10.75	9.81±2.01	14.9 ±2.16
24.0	2.61±0.65	55.1± 7.58	4.67±3.40	5.89±2.16

[a] Moribund.

Source: Lockhart et al. (1977, p. 628).

Table 5. Methoxychlor concentrations in yearling rainbow trout caged in the Athabasca River, Alberta, at intervals after treating the river with methoxychlor at 300 µg/liter. Organs dissected from four fish were pooled to yield composite samples for tissue analyses. Four whole fish were also analyzed from each cage and the whole-fish column gives the range of concentrations found.

Time after treatment (hr)	Methoxychlor concentration (µg/g, wet weight)				
	Liver	Gut + Fat	Muscle	Kidney	Whole fish
0.25[a]	0.09	<0.02	0.06	0.04	<0.02-0.04
0.50[a]	0.19	0.04	0.05	0.15	0.04-0.10
1.0[a]	0.08	0.05	0.04	0.07	0.04-0.06
3.0	0.16	0.06	0.04	0.18	0.03-0.06
6.0	0.96	0.39	0.30	0.86	0.60-1.56
12.0	1.34	0.58	0.07	0.64	0.69-1.08
28.0	0.34	0.20	0.29	0.28	0.23-1.75
59.0	0.08	0.72	0.08	0.08	<0.02-0.75[b]
101.0	0.03	<0.02	<0.02	<0.02	<0.02-0.71[b]

a Time spent drifting with the pulse of treated water.

b Three fish represented (one lost, one dead).

Source: Lockhart et al. (1977, p. 629).

Residues in Caged Athabasca River Fish

Methoxychlor residues in livers of caged fish native to Athabasca drainage are shown in Table 7. At no time were residues detected in fish from upstream cages, and so errors in sample processing and analyses seem unable to explain residues in free-swimming fish captured upstream. In comparing values from free-swimming fish for those from caged fish (Table 6 vs. 7), it is striking that residues in caged fish were substantially lower. The highest liver residue found in a free fish was 9.64 µg/g in a chub captured 4.5 km downstream on 8 June, as compared with a maximum of 0.79 µg/g for that species caged. Similarly, the highest value for white sucker liver was 0.75 µg/g in a wild fish upstream on 8 June; that for a caged white sucker was 0.11 at the site 35.5 km downstream on the day after treatment. Longnose suckers contained slightly more methoxychlor in liver than did white suckers, peak values for free and caged individuals being 0.94 and 0.07 µg/g, respectively.

Methoxychlor was not found in white suckers caged 4.5 km downstream, even though it must have been available to them since it was found in longnose suckers and chub occupying the same cages. Of the three native species caged, none was completely suitable in these cages; both species of suckers tended to injure themselves in the head region, apparently by striking the wire mesh, and some chub were found caught in the mesh squares, as in a gillnet.

Neither these caged native species nor the caged rainbow trout were killed by methoxychlor treatment, and that alone argues for the safety of larviciding in the Athabasca River. However, relatively low liver residues as compared with free-swimming fish of the same species suggest that some artifact of caging may have reduced pesticide accumulation and hence that survival of caged fish may have systematically underestimated risk to wild ones.

Residues in Ovaries of Prespawning Flathead Chub

Hazards of organochlorine compounds to vertebrates often involve aspects of reproduction, and we have no measure of reproduction in Athabasca River fish populations. Flathead chub had not begun spawning at the time of treatment and ripening ovaries analyzed from 10 females collected 5-16 June all had measurable liver residues (Table 8). Methoxychlor in ovaries varied from 0.03-9.33 µg/g (liver from 0.11-9.64 µg/g) and the correlation coefficient between liver and ovarian residues was +0.90 ($P < 0.01$). Values around 5 µg/g total DDT in eggs have been associated with the onset of reproductive failure in lake trout (Burdick et al. 1964). Some of the ovarian methoxychlor concentrations in flathead chub exceeded 5 µg/g; however, it is not known whether they may have influenced egg or larval development.

Table 6. Methoxychlor residues (µg/g) in native free-swimming fish from the Athabasca River at intervals after water treatment on 4 June 1974 for black fly control

Methoxychlor residue (µg/g, wet weight)	
	Downstream
Upstream	4.5 km
	74.5 km
	5 June
	<0.02 WS[a]
	0.08 WS
	0.15 C
	<0.02 C
	0.33 C
	0.05 P
	<0.02 WS
	6 June
<0.02 WS	
0.10 WS	
	7 June
0.66 WS	
<0.02 WS	
0.03 WS	
0.03 WS	
0.69 LS	
	8 June
0.75 WS	9.64 C
<0.02 WS	
0.72 LS	
0.22 LS	
0.12 LS	
	9 June
<0.02 WS	0.30 WS
0.68 LS	0.43 WS
0.37 LS	0.43 LS
<0.02 P	0.04 LS
	0.13 LS
	0.94 LS
	2.62 C
	2.59 C
	3.01 C
	10 June
<0.02 LS	0.15 LS
0.23 LS	0.70 LS
<0.02 W	
	11 June
	<0.02 WS(7)
	<0.02 P(2)
	12 June
<0.02 WS	<0.02 WS
3.14 C	
	16 June
<0.02 WS(3)	<0.02 C
<0.02 LS(2)	0.04 C
<0.02 W(1)	1.18 C
	19 June - 12 Aug.
26 samples analyzed, various sites and species, all <0.02	

[a] WS - white sucker; LS - longnose sucker; C - flathead chub; P - northern pike; W - walleye. Value in parentheses is number analyzed.

Source: Lockhart et al. (1977, p. 631).

Table 7. Methoxychlor residues in native fish caged in the Athabasca River at intervals after water treatment for blackfly control on 4 June 1974

Liver methoxychlor (µg/g,, wet weight)			
	Downstream		
Upstream	4.5 km	33.5 km	74.5 km
		5 June	
<0.02 WS[a]	<0.02 WS	<0.02 WS	<0.02 WS
<0.02 WS	<0.02 WS	<0.02 WS	0.06 WS
<0.02 WS	<0.02 WS	0.11 WS	0.03 WS
<0.02 WS	<0.02 LS	0.06 WS	<0.02 WS
<0.02 WS	0.07 LS		<0.02 WS
	0.07 LS		<0.02 WS
	<0.02 LS		
	0.47 C		
		11, 12 June	
<0.02 WS	<0.02 WS	<0.02 WS	<0.02 WS
<0.02 WS	<0.02 WS	<0.02 WS	<0.02 WS
<0.02 WS	<0.02 WS	<0.02 WS	<0.02 WS
<0.02 WS	<0.02 WS	<0.02 WS	<0.02 WS
<0.02 WS	<0.02 WS	<0.02 WS	<0.02 WS
<0.02 WS	<0.02 LS		<0.02 WS
<0.02 WS	<0.02 LS		
	0.79 C		
	0.11 C		
	<0.02 C		
	<0.02 C		
		18, 19 June	
<0.02 WS	<0.02 WS	<0.02 WS	<0.02 WS
<0.02 WS	<0.02 WS	0.04 WS	<0.02 WS
<0.02 WS	<0.02 WS	<0.02 WS	<0.02 WS
<0.02 WS	<0.02 C	<0.02 WS	<0.02 WS
<0.02 WS	<0.02 C	<0.02 WS	<0.02 WS
<0.02 WS	<0.02 C	<0.02 WS	<0.02 WS
<0.02 WS	<0.02 C		
	0.03 C		
		9, 10 July	
- [b]		<0.02 WS	- [c]
	<0.02 WS	<0.02 WS	
	<0.02 LS	<0.02 WS	
	<0.02 C	<0.02 WS	
		<0.02 WS	

[a] WS - white sucker; LS - longnose sucker; C - flathead chub.

[b] Fish dead, cage silted.

[c] Fish dead, cage dry.

Residues in Experimentally Exposed Red River Species

Liver residues in Red River species exposed to methoxychlor at a nominal concentration of 300 µg/liter for 20 min and until grossly morbid are shown in Table 9. The 20-min period was chosen in hope that it would represent near the maximum opportunity

Table 8. Methoxychlor concentrations (µg/g wet tissue) in livers and ovaries of prespawning flathead chub from the Athbasca river after black fly larvicing on 4 June 1974

Date captured	Tissue methoxychlor (µg/g wet tissue) Liver	Ovary
5 June	0.15	0.03
	0.33	0.09
8 June	9.64	9.33
9 June	2.62	3.21
	2.59	1.30
	3.01	1.88
12 June	3.14	6.70
	0.79	0.03
	0.11	0.05
16 June	1.18	0.04

for methoxychlor uptake after larviciding. Only white sucker data are comparable between Tables 6 and 9, and it is clear that observed liver residues in the Athabasca fish overlap those from the 20-min experimental exposure. In comparing mean liver residues for 20-min exposures with comparable values for fish at gross morbidity, a ratio tentatively called a 'safety factor' has been calculated. The 'safety factors' calculated for three species listed in Table 9 were 2.8, 4.9, and 6.8.

Fish carcasses (whole fish less liver and a few milliliters of blood) from the 20-min exposure (Table 9) were homogenized by several passes through a meat grinder and subsamples were analyzed for methoxychlor and total lipid (Table 10). The species highest in fat was channel catfish and it did not contain the highest residue concentration. The species lowest in fat was sauger and it did contain the highest residue concentration. Several studies have indicated a role for body lipid in determining accumulation of organochlorine residues, but these data suggest its role may be to determine retention rather than rate of uptake.

Unlike lipid, body weight was related to methoxychlor uptake. Rainbow trout of varying weights (ca. 3-240 g) were exposed to a nominal methoxychlor concentration of 25 µg/liter for 1 hr. Homogenized fish were analyzed for methoxychlor (Fig. 1 and 2). Figure 1 shows whole body methoxychlor concentration as a function of the body size and it indicates that smaller fish are somewhat more efficient at uptake of methoxychlor than larger ones and so identifies a deficiency in our field sampling program since small fish were not taken for residue work. Data of this type are sometimes plotted as body burden of pesticide against weight (Murphy and Murphy 1971) and in this

Table 9. Liver methoxychlor concentrations (µg/g wet tissue) in Red River fish exposed to theoretical methoxychlor concentrations near 300 µg/liter in river water for periods of either 20 min or until morbidity was observed. The 'safety factor' was calculated as the ratio of mean residue concentrations for the different exposures

	Liver methoxychlor Morbidity	20 min	'Safety factor'
	Channel catfish		
mean	10.7	3.76	2.8
SD	3.16	0.70	
range	6.7-15.3	2.9-4.9	
n	5	6	
	Northern pike		
mean	10.3	no	-
SD	5.40	data	
range	5.2-19.4		
n	6		
	White sucker		
mean	5.9	1.2	4.9
SD	1.99	0.76	
range	3.4-8.7	0.48-2.3	
n	5	6	
	Sauger		
mean	69.1	10.1	6.8
SD	39.8	5.53	
range	36.7-132.4	3.1-16.4	
n	5	6	
	Walleye		
mean	46.1	no	-
SD	24.3	data	
range	20.6-68.9		
n	3		
	Drum		
mean	no	3.7	-
SD	data	2.03	
range		1.9-7.3	
n		6	

form (Fig. 2) the data are typical of a familiar biological expression for such measures as oxygen consumption (Beamish 1964) and gill dimensions (Muir 1969). The slope of the regression line in Fig. 2 is 0.84, in good agreement with values obtained in the studies cited.

Another factor that seems to regulate methoxychlor uptake by fish is the nature of the water in which exposure takes place. Rainbow trout were exposed to methoxychlor that had been added to water of differing qualities made by mixing Red River water and city water in differing proportions. Water analyses and mean methoxychlor concentrations in exposed fish are shown in Table 11. Statistical analyses of data in Table 11 by multiple stepwise regression revealed that only two water chemistry parameters could be related to pesticide levels in the fish. These two were suspended solids and ammonia

Table 10. Methoxychlor and lipid concentrations in whole (less liver and blood) bodies of Red River fish (six per species) exposed to methoxychlor at a theoretical concentration near 300 µg/liter for 20 min

	Carcass lipid %	Carcass methoxychlor (µg/g)
	Channel catfish	
mean	13.8	0.72
SD	3.21	0.30
range	9.2-18.1	0.19-1.01
	White sucker	
mean	5.77	0.53
SD	2.39	0.06
range	3.0-9.2	0.46-0.60
	Drum	
mean	7.60	0.94
SD	3.25	0.41
range	4.8-13.2	0.54-1.72
	Sauger	
mean	5.62	1.06
SD	2.84	0.32
range	1.7-9.7	0.73-1.55

which together could account for about 54% of the observed variation in fish methoxychlor. Similar water chemistry analyses applied to a sample of Athabasca river water are also shown in Table 11 and it seems that, at least with regard to suspended solids, exposures in Red River water would be more likely to predict Athabasca River experience than would laboratory water exposures. Fredeen et al. (1975) reported methoxychlor binding to silt particles in the Saskatchewan River. Uptake from silt particles, although possible (Zitko 1974) may be less efficient than uptake of dissolved material (solubility 0.1 mg/liter at 25°C).

The concept of using the product of exposure duration and exposure concentration has been applied to measure pesticide dose (Fredeen 1974) to compare exposures carried out for differing times and concentrations. An experiment was performed by exposing fish to several decreasing concentrations of methoxychlor for increasing periods of time so that the product (concentration times exposure time) was the same for several combinations. Whole fish residues were determined and it is apparent from the result (Fig. 3) that residues at the end of the exposure period were not constant but decreased with decreasing concentration. The longer exposure time did not compensate for lower exposure concentrations in this situation.

Effect Studies

A number of biochemical analyses were made in an effort to find a test for sub-

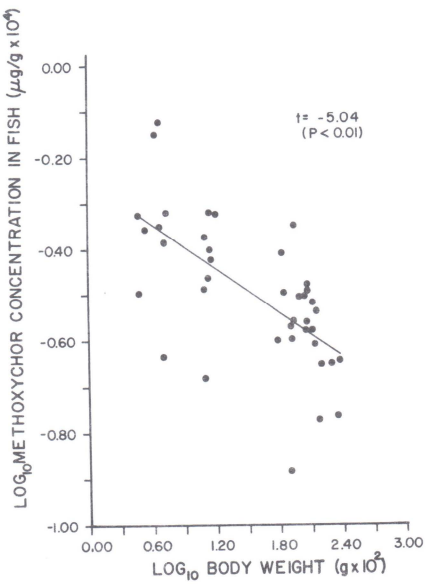

Fig. 1. Methoxychlor concentrations in homogenized fish tissues of rainbow trout of different sizes exposed to methoxychlor at 25 µg/liter for 1 hr. Each point represents a residue measurement for a single fish and data from four independent experiments have been pooled. The regression equation is log Y = -0.1607(log X) - 0.2497 (t = -5.04, df = 38).

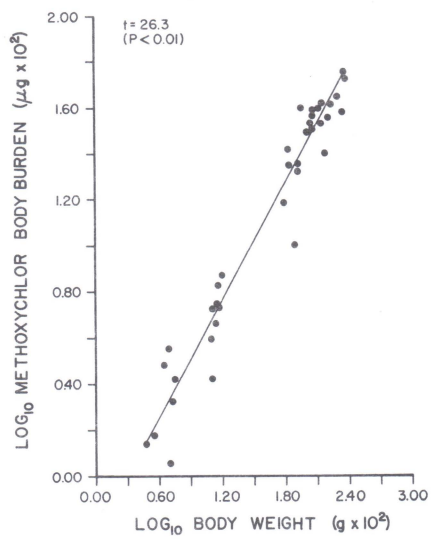

Fig. 2. Methoxychlor content of rainbow trout of differing sizes exposed to methoxychlor at 25 µg/liter for 1 hr. Residue concentrations in Fig. 1 were multiplied by body weights to calculate whole body content. Each point represents the methoxychlor content of a single fish and data from four independent experiments have been pooled. The regression equation is log Y = 0.8393(log X) - 0.2497 (t = 26.3, df = 38).

Table 11. Chemical analyses of waters used to estimate effects of water chemistry on methoxychlor uptake. Athabasca River water from May and August 1975 are also shown. Methoxychlor residue figures are means from six fish per experiment and there were two experiments with each water type

	100% City 0% River	75% City 25% River	50% City 50% River	25% City 75% River	0% City 100% River	Athabasca River (1975) 20 May	Athabasca River (1975) 28 Aug.
				Water Chemistry			
NH_3-N (µg/liter)	40	30	30	30	40	7	<1
TDN (µg/liter)	500	520	530	600	640	478	410
Susp N(µg/liter)	159	216	299	285	403	144	117
SRP (µg/liter)	6	20	30	45	57		
TDP (µg/liter)	19	33	46	64	80	19	14
Susp P (µg/liter)	17	39	58	84	111	41	41
DIC (µmole/liter)	1240	1930	2600	3080	3640		
DOC (µmole/liter)	1470	1540	1690	1780	1950	905	665
Susp C (µg/liter)	1170	1620	2160	2540	3310	2150	2360
Na (mg/liter)	1.86	18.9	34.5	50.7	66.3	7.18	5.47
pH (mg/liter)	7.90	8.14	8.32	8.44	8.54		
Cond. at 25°C (µS/cm)	150	340	500	650	820	245	222
TDS (mg/liter)	90	210	310	400	500	166	165
Chloro a (µg/liter)	3.2	11.2	17.6	20.0	26.3	5.9	3.7
TSS (mg/liter)	2	15	26	31	75	42	74
				Trout methoxychlor (µg/g)			
Exp 1 $\bar{X}$	0.554	0.484	0.568	0.409	0.331		
Exp 2 $\bar{X}$	0.583	0.594	0.570	0.581	0.247		

lethal methoxychlor poisoning. From blood chemistry of rainbow trout exposed to methoxychlor (residues in Table 4), it appeared that the moribund group differed clearly from other groups in serum calcium and in activity of serum cholinesterase. However, these effects have not been reproduced in other species. In spite of considerable effort, we have been unable to identify any biochemical symptom of methoxychlor poisoning that can reliably predict the onset of gross morbidity. The analyses we have tried on serum from Athabasca River fish were glucose, protein, cholinesterase, alkaline phosphatase, lactate dehydrogenase, glutamate oxalacetic transaminase, calcium, sodium, chloride, triglyceride, and total lipid. Techniques of multiple regression have revealed a number of relationships among pairs of measurements; however, no relationships to methoxychlor were evident. On experimentally exposed fish, we used these same measurements plus magnesium, potassium, and hematocrit. Of these, the most promising appeared to be potassium; however, it was exceptionally sensitive to hemolysis during sample collection. An apparent potassium effect was particularly noticeable in northern pike poisoned to morbidity, but confirmatory experiments will be needed to determine whether the measurement can be applied as a diagnostic aid.

Perhaps more interestingly, an abnormality did appear in some Athabasca River fish in 1974. Figure 4 shows serum protein levels in Athabasca River fish in 1974; a group of four fish captured on 24 July was consistently low in serum protein. It may be premature to base any conclusion on a sample of only four fish, but values below 2 g/dl are generally outside the range of previous experience with white suckers (Table 12). Tentatively, it was thought that low protein values suggested a state of starvation in Athabasca River suckers at the Calling River sampling site, and an experimental starvation experiment was carried out using Red River suckers.

Suckers were maintained in the laboratory and were observed to feed readily on 'Silver Cup' trout food until the start of the experiment. Feeding was then stopped for one group and continued for the other. At intervals, five fish were taken from each group and analyzed for serum protein, lipid, and triglyceride, and muscle dry weight, ash, and calorie content (Table 13). Arithmetic means are tabulated; however, for analyses of variance calculations, transformations to natural logarithms (protein, lipid triglycerides, and calories) and arc sines (moisture and ash) were used. Significant treatment effects were present in all measurements except ash and calories.

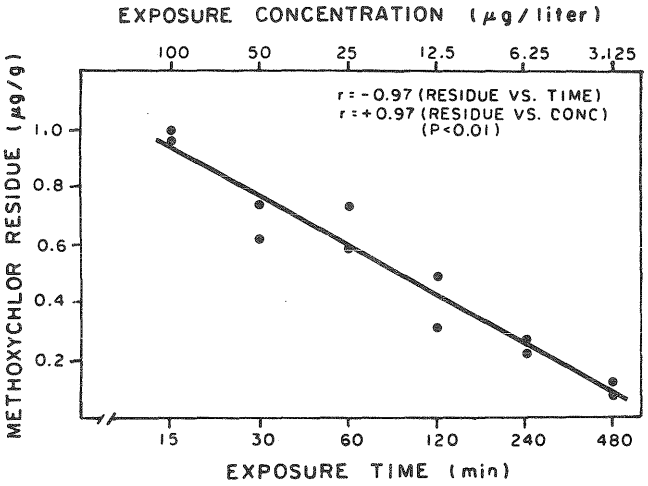

Fig. 3. Whole body methoxychlor residues in rainbow trout exposed for varying concentrations and times such that the product of time and concentration remained constant. Each point represents the mean residue concentration calculated from six fish and there were two independent experiments at each exposure regimen. Fish weighed 5-12 g and exposure temperature was 15°C. Correlation coefficients were -0.97 and +0.97 when residues were plotted against logarithms of exposure times and exposure concentrations respectively.

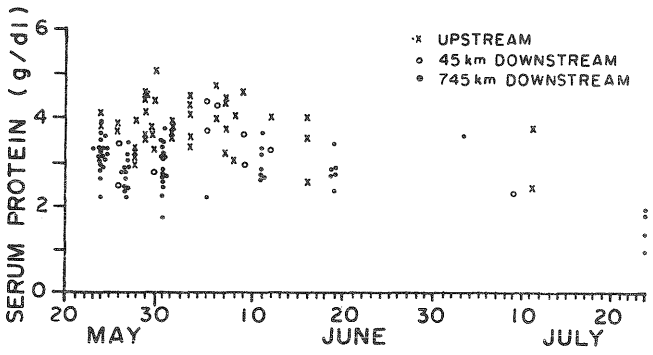

Fig. 4. Blood serum protein concentrations (g/dl) for white suckers from the Athabasca River before and after treatment on 4 June 1974 with methoxychlor at 300 µg/liter. Each point represents the protein content in serum of an individual fish.

The most sensitive measurment was muscle moisture ($F = 18.2$; $df = 1, 32$) and it may offer some promise for future monitoring efforts. Serum protein also responded to starvation ($F = 5.64$) and so at least the interpretation of low field protein values is consistent with the hypothesis that river fish were starving, although the experimental difference did not become apparent until some time between 8 and 16 wk after starting the experiment.

Table 12. Blood serum protein values for white suckers captured at several locations since 1972. Data were transformed to natural logarithms for calculation of means and standard deviations. Means (geometric) are also presented in concentration units (g/dl)

Location	Date captured	Number	Mean ± SD ($\log_e$)	Concentration (g/dl)	
				Mean	Range
George Lake, Ont.	Sep. 1972	22	1.48309±0.15985	4.4	2.9-6.0
Georgian Bay, Ont.	Sep. 1972	11	1.59300±0.16670	4.9	3.8-6.9
Lake Manitoba[a]	Dec. 1972	28	1.46734±0.16574	4.3	3.2-5.7
Prince Albert Park	May 1973	6	1.17867±0.13372	3.3	2.6-3.6
Prince Albert Park	May 1974	12	1.22326±0.13856	3.4	2.7-4.2
Lake 224, Kenora, Ont.	May 1976	12	1.69400±0.09076	5.4	4.9-6.4
Lake 240, Kenora, Ont.	May 1976	12	1.52136±0.09274	4.6	4.0-5.4
Roddy Lake, Kenora, Ont.	May 1976	12	1.36007±0.12918	3.9	3.1-4.7
Roddy Lake, Kenora, Ont.	May 1977	14	1.34365±0.13659	3.8	3.0-4.6
Lake 223, Kenora, Ont.	May 1977	10	1.49788±0.08256	4.5	3.9-5.2

[a] Fish held in the laboratory for several weeks before sacrifice.

Table 13. Mean values for serum and muscle analyses of white suckers maintained in the laboratory and fed laboratory rations (fed group) as compared with an unfed group (starved group)

Time from start of experiment (wk)	Fish group	Serum			Muscle		
		Protein (g/dl)	Lipid (mg/dl)	Triglyceride (mg/dl)	Ash (%)	Moisture (%)	Calories[a] (kcal/g)
0	Fed	4.20	1650	331	6.70	78.7	6.11
	Starved	3.90	1220	214	6.90	80.5	5.82
4	Fed	3.95	1420	344	7.22	80.0	6.02
	Starved	3.82	1110	254	6.76	80.1	5.67
8	Fed	4.10	1390	353	7.60	79.9	6.09
	Starved	4.17	1260	259	7.56	80.1	6.20
16	Fed	4.81	1550	416	6.34	79.6	5.84
	Starved	3.06	662	118	7.40	82.5	5.79

a On a dry ash-free basis.

DISCUSSION

Rapid uptake of methoxychlor into organs such as liver and kidney by non-feeding rainbow trout exposed experimentally implies distribution by blood after uptake at some site, presumably gills (Holden 1962; Fromm and Hunter 1969). The magnitude of methoxychlor concentrations in fish organs (Tables 4 and 9) after short-term experimental exposures suggests that uptake directly from water is sufficient to account for residues in Athabasca River fish. This does not exclude the possibility that fish obtain methoxychlor from feeding on contaminated food organisms but such a mechanism does not seem to be required to account for observed residues.

The observation that liver and kidney residues were highest in a group of rainbow trout (Table 4) showing signs of gross morbidity prompted our use of liver as the organ for monitoring river fish. (Fish go through several easily recognized stages during methoxychlor poisoning; first there are apparently uncoordinated movements of fins and tail; then rapid, erratic swimming frequently resulting in collisions with tank walls; taking air by mouth at the surface; then slowing of movements; and finally morbidity when righting ability is lost but respiratory movements are still perceptible.) Other organs (muscle and gut with fat) contained higher residue concentrations at 6 hr (Table 4) but fish were not visibly injured and use of those tissues may be more suitable for monitoring terminal residues than for monitoring for methoxychlor poisoning. Residues in fish apparently represented no obvious long term hazard since rainbow trout surviving the experimental treatment (Table 4) were held for several weeks with no visible ill effects. This is consistent with previous observations that methoxychlor is readily cleared from fish (Reinbold et al. 1971) and that sub-lethal pathological effects become less severe with clearance of residues (Kennedy et al. 1970).

Methoxychlor uptake into organs of rainbow trout caged in the Athabasca River (Table 5) was reduced much below that expected from the experimental treatment discussed above. Very little accumulation took place during the first 3 hr; the highest uptake rate occurred between 3 and 6 hr after treatment. Some source of methoxychlor obviously existed between 3 and 6 hr after treatment at a site only 5 km from injection.

Residues in livers of caged white suckers, longnose suckers, and flathead chub were generally lower than those in free swimming individuals of the same species captured near cages (Tables 6 and 7). A number of hypotheses may be made in attempting to explain this, but whatever the reasons, reliance upon caged fish for bioassay purposes is questionable. These data suggest, in fact, that caged fish would systematically underestimate risk to wild ones.

Publications on the subject of impact of pesticides on aquatic organisms offer little guidance for use in estimating biological risk to be associated with a specified river treatment. Most toxicological studies report concentrations killing half the exposed organisms over 24-96 hr. As a preliminary approach to assessing biological risk to fish, the liver residues in fish poisoned to gross morbidity have been compared with those given a dose similar to that observed in the river (Table 9).

A major difficulty with this approach is the instability of liver residue concentrations over differing time periods (Table 4); the time course of liver residues in river fish is not well known. Judging from caged trout (Table 5), the peak liver concentrations in wild fish may have occurred within 24 hr of treatment, but high concentrations in wild suckers were noted over the 1st wk after treatment. Use of a measured liver residue at any time to

compare with a residue known to produce morbidity will underestimate risk unless that measured residue is taken at the peak of its time vs. concentration curve. With the exception of rainbow trout, those curves are not known, and so 'safety factors' calculated in Table 9 may be less favourable than indicated. Another approach to 'safety factors' may be use of the time interval required to produce morbidity at a given concentration (Table 14).

Table 14. Time interval to produce morbidity with exposure to 300 µg/liter

Species	Time to first morbidity (min)	Safety factor[a]
rainbow trout	130	8.7
channel catfish	150	10.0
northern pike	40	2.7
white sucker	69	4.6
walleye	80	5.3
sauger	90	6.0

[a] Time to first morbidity ÷ 15

The time to morbidity (min) has been divided by 15 because, during the 1974 river treatment, the chemical was added over 15 min. Both this 'time to morbidity' approach and the 'concentration ratio' approach (Table 9), suggest that river treatment came surprisingly close (within a factor smaller than 10) to poisoning fish. The minimum liver methoxychlor concentration in a white sucker poisoned to morbidity (Table 9) was 3.4 µg/g, and the maximum observed in the Athabasca River was 0.75 µg/g on 8 June, and so it seems that river treatment in 1974 came within a factor of five of poisoning at least some fish. Flathead chub residues were the highest observed in the Athabasca River, but this species has not yet been available for experimental poisoning. In comparison with other river treatments, the Athabasca case seems similar to the Saskatchewan treatments where caged fish have survived and where goldeye accumulated greatest residue concentrations (Fredeen 1974; Fredeen et al. 1975). However, Jamnback (1976) has cited African studies by Philippon (1973) who "observed fish injury 24 hours after aerial application at the rate of 0.3 ppm/10 minutes".

The calculation of 'safety factors' as described above, and most residue measurements, were based upon use of large fish (>100 g). The result of exposing rainbow trout of differing weights to methoxychlor (Figs. 1 and 2) indicate that smaller fish accumulate residues more efficiently than larger ones. These results identify a deficiency in the field monitoring reported here since small fish should have been included. If methoxychlor is as toxic to small fish as to large ones, and if small fish have a higher net accumulation, then they may be at greater risk.

Use of the product of exposure time (t) and concentration (c) has been suggested as a suitable way to compare different experimental exposures (Fredeen 1974). In fact, it was used as the basis for calculating the 1975 river treatment program. Data shown in Fig. 3 suggest that the calculation is not appropriate at least in terms of fish residues, which decreased in spite of exposure to constant (c x t) products. A number of explanations may be suggested for failure of increased exposure time to compensate for decreased exposure concentration but whatever they may be they suggest that the approach is oversimplified and inappropriate.

Methoxychlor does not seem to be a significant long-term hazard to fish. Both laboratory data (Reinbold et al. 1971) and our own field experience (Tables 5-7) suggest that a period of about 2 wk allows clearance of most methoxychlor residues, presumably by metabolism to polar mono- and di-phenolic analogues and excretion. The toxicological risk for fish seems to be one of acute poisoning and Fig. 3 suggests that this can be controlled by manipulation of concentration and exposure time. Obviously one should seek lower concentrations for longer times - if they are successful for black fly control.

Perhaps the risk to fish may be through depletion of food resources. The July sample from Fig. 4 is consistent with fish starvation; however, it may also be consistent with other unknown experience. Even if fish near Calling River were starving in the summer of 1974, it is not possible to conclude that starvation was related to treatment.

The application rate in 1975 was reduced in time of injection from 15 min to 7.5 min at the same concentration of 300 µg/liter. The only data I collected in 1975 were serum biochemical values to determine whether observations consistent with starvation would again occur. Serum protein values were not found to be abnormally low in 1975.

CONCLUSIONS

Methoxychlor rapidly penetrates into deep fish tissues after both laboratory and river exposures. Experimental poisoning of several species suggests that field tissue residues from 1974 approach to within a factor of 10 those causing gross morbidity and death. Similarly, at the 1974 treatment concentration of 300 µg/liter, exposure times leading to gross moribidity were generally less than 10 times the actual treatment duration.

It appears possible that simple experimental exposures can be used to arrive at a close approximation to actual field residue data and to associate residue measurements with risk of acute poisoning. The meaning of residue measurements in terms of sublethal effects other than gross morbidity is, however, still unknown.

Variables such as fish size and water chemistry can influence rates of methoxychlor uptake to extents that are statistically predictable. The slope of the relationships between uptake and weight has a value consistent with such other correlates to weight as oxygen consumption and gill size. Different fish species accumulate methoxychlor at different rates but the basis for these differences remains unknown.

Cage bioassays with rainbow trout, white suckers, longnose suckers, and flathead chub in the Athabasca River all suggest that the treatment was not lethal to fish; however, caged fish contained lower residues than wild ones of the same species captured near cages, and caged fish must therefore have underestimated risk. Most residue information was based upon fish captured within the first few kilometers of the treatment point where the mass of treated water would be expected to have suffered relatively little dilution due to mixing. An experiment varying time and concentration so that the product of the two remained constant showed that short term high concentrations are more likely to yield high fish residues than are long term low concentrations and this suggests that the likelihood of fish poisoning decreases with increasing distance downstream.

Strikingly low blood protein values were observed in a group of four white suckers captured near Calling River (75 km downstream) in July 1974. A number of factors may induce low protein values in fish, but starvation for 8-16 wk has induced a similar observation in white suckers in the laboratory. These observations do not prove that river fish were starving and they do not prove that the abnormality was related to treatment; however, they are consistent with such an interpretation. Similar measurements on the same species in July 1975 after a reduced duration of treatment showed normal protein content.

Questions Requiring Further Substantiation

Further effort is desirable to clarify a number of questions. Those that I think are both feasible and scientifically productive are listed below.

1. The observations that suspended solids relate to methoxychlor uptake suggests that a particulate formulation would protect fish from methoxychlor accumulation (see Sebastien and Lockhart, p. 197). Expansion of research on particulate formulations is desirable.

2. Further refinement of the 'safety factor' argument seems possible using tissue residues to link experimental and river results. It appears quite straightforward to generate residue data associated with morbidity (or death) for fish and non-fish organisms and to then manipulate exposure times and concentrations so that residues do not exceed some agreed upon arbitrary fraction of lethal residues.

3. Some easily quantifiable sub-lethal response to methoxychlor poisoning would be helpful. A number of these exist in the literature (e.g. temperature selection and oxygen consumption) but they are not easily applied to monitoring river treatment. The search for sub-lethal responses to methoxychlor in fish should be continued. Similarly, diagnostic tests of starvation, particularly in young fish, would be helpful.

RECOMMENDATIONS

It is recommended that laboratory experiments be conducted to derive quantitative relationships among exposure regimen, tissue residue, and morbidity or death for different pesticide formulations for several species of river animals including black flies. Once established, these relationships should be applied to select a formulation and treatment regimen that optimizes safety and efficacy.

ACKNOWLEDGEMENTS

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INFLUENCE OF FORMULATION ON TOXICITY AND RATE OF UPTAKE OF METHOXYCHLOR IN RAINBOW TROUT

R. J. SEBASTIEN AND W. L. LOCKHART

INTRODUCTION

In an earlier report, Lockhart (p. 183) presented evidence that suspended solids in exposure water were statistically related to rates of uptake of methoxychlor from water by rainbow trout *(Salmo gairdneri)*. High suspended solid content was associated with reduced pesticide uptake, and it was suggested that particulate pesticide formulations might be less available to fish than emulsifiable formulations. Several preliminary experiments have been completed to test that hypothesis and the results are submitted at this early stage in the hope that they may receive some discussion when future research is planned.

METHODS

Formulations

A particulate formulation of methoxychlor was supplied to us by Dr. A. S. West (Newfoundland-Labrador Hydro). It was originally produced by Johns-Manville Research and Engineering Center, Manville, N. J. as arranged by DuPont of Canada. The formulation consisted of celite particles 8-15 µm in size with a specific gravity of 1.5, and was 63% methoxychlor (Helson 1972; Helson and West 1978).

An emulsifiable concentrate formulation (EC) of methoxychlor was obtained from a drum of commercial material being used by the City of Winnipeg. It was 25% methoxychlor supplied by Sanex Chemicals, Mississauga, Ontario.

Both formulations were analyzed a number of times by gas-liquid chromatography as described by Solomon and Lockhart (1977). The resulting assay values of 60% methoxychlor for the particulate and 21% for the EC were used in calculating desired doses.

Rate of Uptake of Methoxychlor

Four glass aquaria were used for these experiments, each filled with 30 liters of dechlorinated Winnipeg tap water and maintained at 17°C with aeration. The desired quantity of appropriate formulation was added to each aquarium to yield a theoretical concentration of either 0.1 or 0.3 mg of methoxychlor/liter. Ten rainbow trout fingerlings were placed in each aquarium for 1 hr. Fish were then removed from the water, weighed, wrapped in foil, and frozen until analyzed. The entire experiment was performed twice.

Methoxychlor Residue Analysis

Methoxychlor in whole fish was measured by gas-liquid chromatography using a Tracor MT-220 instrument equipped with an electron-capture detector (Solomon and Lockhart 1977). Fish were cut into pieces and extracted with n-hexane in a ball-mill. Samples were 'cleaned-up' on small Florisil columns and column effluents were concentrated with the glass filament concentrator described by Solomon and Muir (1978). Concentrated extracts were analyzed by injection into the gas chromatograph and peak areas were compared with those

resulting from injection of known quantities of methoxychlor.

Toxicity of Each Formulation

Four glass aquaria were used as described above (Rate of Uptake of Methoxychlor). Quantities of methoxychlor used were added to yield 1 or 5 mg/liter. After mixing, 15 rainbow trout fingerlings were added to each aquarium and frequent observations were made to note abnormal behaviour, onset of morbidity, and time of death. Fish were counted as dead when they were in an inverted position with no observable respiratory movement. The experiment was terminated after 48 hr. This experiment also was performed twice.

RESULTS

Fish exposed for 1 hr to emulsifiable methoxychlor accumulated more than five times as much as fish exposed to the particulate material (Table 1). There was very little difference between fish residues at the two application rates for the particulate formulation, but, for the EC, residues at 0.3 mg/liter were two to three times those at 0.1 mg/liter.

Table 1. Methoxychlor residues in whole rainbow trout (10 fish per experiment) after 1 hr exposure to 0.1 and 0.3 mg/liter of particulate and emulsifiable formulations

		Methoxychlor residue (µg/g)	
Exp.	Parameter	Particulate	Emulsifiable
	After exposure at 0.1 mg/liter		
1	mean	0.43	2.80
	SD	0.087	0.534
	range	0.33-0.59	2.01-3.89
2	mean	0.38	2.75
	SD	0.144	0.593
	range	0.22-0.63	2.18-4.15
	After exposure at 0.3 mg/liter		
1	mean	0.71	6.07
	SD	0.176	0.969
	range	0.45-0.98	4.30-7.68
2	mean	0.42	7.11
	SD	0.173	1.317
	range	0.31-0.89	5.75-10.5

Results from the toxicity experiments are shown in Fig. 1 for the higher application rates of 1 and 5 mg/liter. Again, the particulate formulation killed fewer fish than the emulsifiable concentrate. At 1 mg/liter, the difference was most striking since the EC had killed 98% of the fish and the particulate none at the end of the observation period.

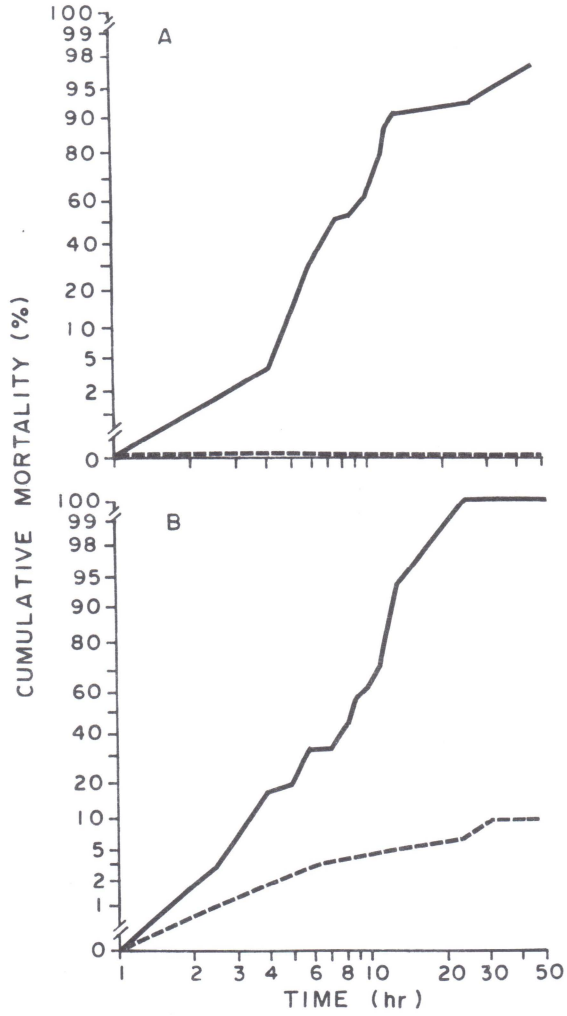

Fig. 1. Cumulative percent mortality of rainbow trout fingerlings exposed to methoxychlor at 1 mg/liter (A) or 5 mg/liter (B) presented as either an emulsifiable concentrate (——) or a particulate (– –).

DISCUSSION

There seems little doubt that the particulate formulation acted to protect fish in these experiments, but we cannot be certain why it did so. Adsorption of pesticide to particles before introduction of fish may impose an unfavorable partition coefficient between pesticide and fish. Although vigorous aeration was maintained in all aquaria during exposures in an attempt to minimize sedimentation of particulates, some proportion of the reduced uptake and toxicity of the particulate formulation may have been due to its physical removal from the water column. However, water analyses for methoxychlor (Table 2) indicate that very little sedimentation took place. These concentrations are very close to theoretical values, much closer in fact than obtained using ethanol solutions of methoxychlor (see Lockhart p. 183). These concentrations are all well above the solubility of methoxychlor, and hence sampling was from a

non-homogeneous mixture and the agreement with the theoretical concentration is all the more striking.

Table 2. Methoxychlor concentrations (mg/liter) in water treated with paticulate and emulsifiable formulations at a theoretical concentration of 5 mg/liter

Aquarium	Mixing period			
	Start	4 hr	8 hr	24 hr
		Particulate		
1	4.5	5.7	4.8	6.0
2	5.4	5.5	4.8	4.1
		Emulsifiable		
1	4.3	2.9	2.2	1.6
2	7.0	2.6	2.2	1.7

Helson (1972) treated several streams in Quebec with this same particulate formulation at a rate of 0.1 mg/liter for 15 min and found it effective against black fly larvae. In comparing this formulation with a liquid preparation, the particulate was less harmful to several kinds of immature stream insects. However, *Philopotamidae* and *Chironomidae* larvae were harmed at least as severely by the particulate as by the liquid.

More recently, Wallace et al. (1976) showed that black fly larvae concentrated particulate formulations more efficiently than methoxychlor applied as an ethanol solution. However, Trichoptera larvae accumulated the ethanolic formulation more effectively than the particulate.

Particulate formulations studied experimentally to date may be far from ideal. For example, Chance (1969) suggested that a praticulate with a size range of 100-250 µm would be more readily ingested by black fly larvae than by other stream insects.

The studies cited above indicate that the use of particulate methoxychlor formulations for control of black fly larvae is sound in principle, and field tests have confirmed this. Our experience reported here suggests that particulates may also reduce uptake and risk of poisoning by fish. In western rivers, adsorption of methoxychlor to suspended materials probably creates a situation very like particulate formulation. Lockhart (p. 183) found that river water (75 mg/liter of suspended solids) decreased fish uptake to about 50% of that in laboratory water containing low suspended solids, and yet the particulate formulation used here decreased uptake to only 20% or less. Apparently, the artificial particulate formulation was more than twice as efficient as natural suspended materials in protecting fish.

We do not suggest that particulate formulations replace emulsifiable concentrates in the Athabasca black fly control program. However, we concur fully with the recent suggestion by Helson and West (1978) that particulates merit further study. Perhaps suitable particulates will be able to control black flies in western rivers and at the same time reduce effects on fish and other organisms.

We hope to provide additional information on toxicology of these formulations at a later date, but these early results were sufficiently encouraging to be submitted at this time.

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DISTRIBUTION, SEASONAL INCIDENCE AND INFESTATION OF CATTLE BY SIMULIUM ARCTICUM AND OTHER BLACK FLY ADULTS

J. A. SHEMANCHUK

INTRODUCTION

This study was initiated to gather data on the seasonal and spatial distribution, abundance, and behavior of *Simulium arcticum* and other black fly species. From these data, the intent was to define the extent and severity of infestation of *S. arcticum* adults emerging from the Athabasca River, determine the pest problem to livestock from *S. arcticum* and other black fly species, and assess the effectiveness of a pesticide treatment of the Athabasca River in reducing adult black fly infestations on farms.

METHODS

Eighty-two farms in 1973 and 1974, 78 in 1975, 61 in 1976, and 60 in 1977 were sampled weekly for black fly adults from about mid-May to mid-October. Distribution of the farms sampled is shown in Fig. 1. The area sampled was 5,595 km^2. At each farm, samples of black fly adults were taken by making 20 sweeps with a standard insect net behind or through a herd of cattle. The insects collected were killed on site and preserved in 70% ethyl alcohol for transportation to the laboratory. At each farm, the number and breed of cattle, the wind velocity and direction, temperature, and cloud cover were recorded.

In the laboratory, the flies collected were counted and identified to species and sex and their feeding status determined. The average number of flies per sweep calculated for each farm each week was used as an index of infestation. These indices were plotted on a map for each week and, from this, the areas and intensities of infestations were determined. An index of more than 1 fly/sweep by this method of sampling was considered to be an infestation serious enough to interfere with cattle activities.

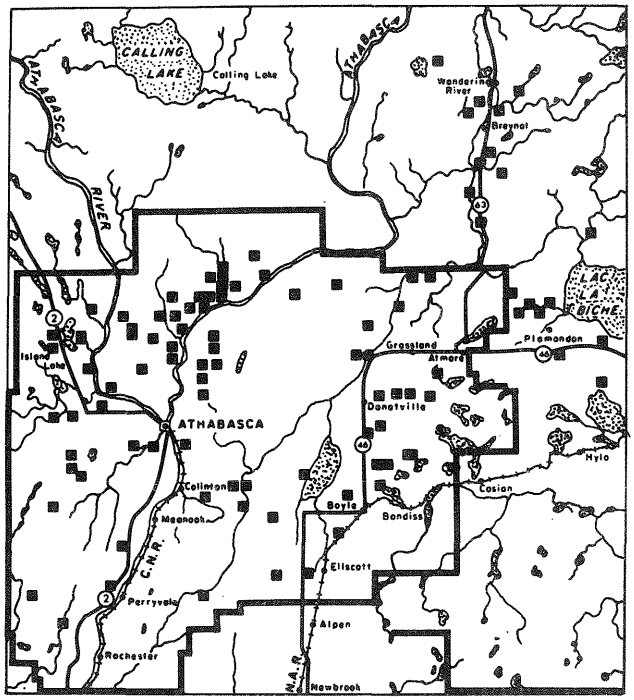

Fig. 1. Distribution of the farms sampled for black fly infestions, 1973-1977.

No larvicide was applied to the Athabasca River during 1973 or 1977, and these 2 yr were used as baseline years to assess the reduction in fly populations around the cattle.

RESULTS

Black flies were collected at all of the farms sampled (Fig. 1) in varying numbers during this study. Of the farms, 75% were positive for *S. arcticum* with some of the locations up to 40 km away from the nearest possible breeding source. The farms encountering consistent *S. arcticum* infestations were in the northeastern portion of the study area (Fig. 2).

The seasonal distribution and relative abundance of females of *S. arcticum*, *S. venustum*, *S. vittatum*, and *S. decorum* collected around cattle in 1973-1977 are shown in Fig. 3. In 1973 and 1977, no pesticide was applied to the Athabasca River and lack of treatment is reflected by higher populations of *S. arcticum* adults during these 2 yr than in 1974, 1975, and 1976. In 1974, 1975, and 1976, numbers of *S. arcticum* around cattle were reduced by 50, 58, and 70% respectively, when compared with the 1973 baseline and by 45, 54, and 67% respectively, when compared with the 1977 baseline (Table 1).

Since *S. venustum*, *S. vittatum*, and *S. decorum* breed mainly in small streams and their numbers were not affected by the pesticide application to the Athabasca River, a considerable variation in numbers between the different years is apparent (Table 2). The variations are directly attributable to the amount of precipitation during the spring and summer.

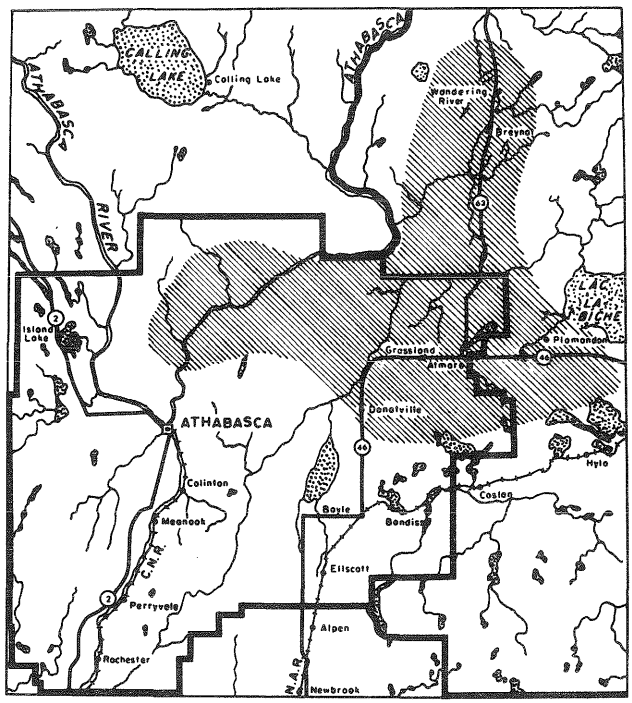

Fig. 2. Area in which consistent severe infestations of *S. arcticum* were encountered.

The portions of the total study area (5,595 km^2) that were infested at the different levels and times during the 5-yr study are shown in Table 3. The infested areas were larger in 1973 and 1977 than in 1974, 1975, and 1976 indicating that river treatment reduced the area of infestation. The area of recurring heavy infestation is about 2,520 km^2 in the northeastern portion of the study area (Fig. 2).

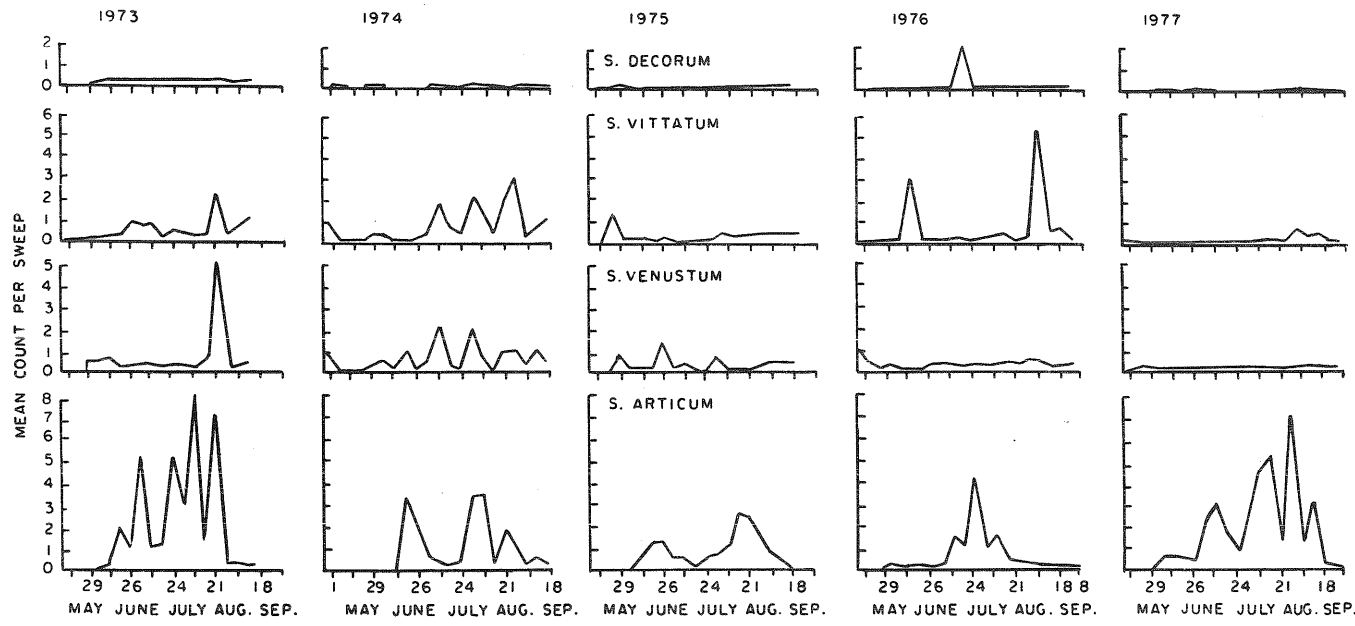

Fig. 3. Seasonal distribution and relative abundance of *S. arcticum*, *S. venustum*, *S. vittatum*, and *S. decorum* in the Athabasca study area, 1973-1977.

Table 1. Percentage change from 1973 and 1977 baseline years in adult populations of four species of black fly around cattle in the Athabasca area during 1974-76

Species	1974	1976	1976
		Base year 1973	
S. arcticum	-50	-58	-70
S. venustum	+9	-46	-58
S. vittatum	+90	-55	+45
S. decorum	-33	-23	+2631
		Base year 1977	
S. arcticum	-45	-54	-67
S. venustum	+1035	+465	+337
S. vittatum	+445	+28	+314
S. decorum	+400	+425	+2625

Table 2. Percentages of the different species of black flies captured around cattle in the Athabasca area during the years 1973-1977

Species	1973	1974	1975	1976	1977
S. arcticum	67	41	63	39	90
S. venustum	18	26	21	15	3
S. vittatum	14	32	14	38	6
S. decorum	1	1	2	8	1

DISCUSSION

The Athabasca River is the main source of *S. arcticum* adults on the farms in the study area. The numerous small creeks and streams in the study area are the source of *S. venustum*, *S. vittatum*, and *S. decorum* adults, which in some years could reach high enough numbers to be a pest to cattle and other livestock. Methoxychlor was applied to the Athabasca River in the spring of 1974, 1975, and 1976, and numbers of *S. arcticum* adults around cattle were reduced during these years. The highest level of reduction (70%) in the numbers of *S. arcticum* around cattle, with a corresponding decrease in the area of infestation (Table 3), was obtained in 1976, when methoxychlor was injected into the river at two sites. In 1976, there was also a reduction in populations of *S. venustum*, *S. vittatum*, and *S. decorum* (Fig. 3) as a result of lower than normal spring run-off and summer rainfall in the study and surrounding areas.

It is clear from the results of this study that none of the river treatments completely eliminated the *S. arcticum*

Table 3. Percentages of study area with black fly infestations at various levels calculated from samples taken around cattle on 82 farms in the Athabasca area, 1973-1977

Week ending	Flies/sweep†					
	1-5	6-10	11-20	21-50	50+	Total
				1973		
11 June	6					6.0
18 June	8					8.0
25 June	15	0.8		1.5		17.3
2 July	26			0.5		26.5
9 July	37	1.3	0.3	2.7	0.7	42.0
16 July	20	0.5				20.5
23 July	37		2.0			39.0
30 July	13		1.5	1.4		15.9
6 Aug.	36	0.5	1.6		0.8	38.9
13 Aug.	24	1.2	1.2	0.5	1.2	28.1
20 Aug.	36	1.0				37.0
27 Aug.	24			1.0		25.0
3 Sep.	19					19.0
10 Sep.	12					12.0
17 Sep.	5					5.0
24 Sep.						0.0
1 Oct.						0.0
8 Oct.	1					1.0
				1974		
4 June	1					1.0
11 June	3					3.0
18 June						0.0
25 June	18		0.7	0.7	0.7	20.1
2 July						0.0
9 July	10	0.7	0.7			11.4
16 July	19					19.0
23 July	28	0.7				29.6
30 July	28	0.7				29.6
6 Aug.	24	0.7	0.7		0.7	26.1
13 Aug.	35	0.7	0.7	0.7	0.7	37.8
20 Aug.	8					8.0
27 Aug.	21	0.7		2.0	0.7	24.4
3 Sep.	18	1.4	0.7			26.4
10 Sep.	7					7.0
17 Sep.	11					11.0
24 Sep.	19					19.0
				1975		
11 June	2					2.0
18 June	14		1.4			15.4
25 June	37		0.7	0.7		38.4
2 July	12	0.7	3.7			16.4
9 July	21	1.0				22.0
16 July	9		0.7			9.7
23 July	16					16.0
30 July	12	0.7				12.7
6 Aug.	29		1.4			30.4
13 Aug.	26		0.7			26.7
20 Aug.	9		2.8	0.7		12.5
27 Aug.	19		0.7	2.4		22.1
3 Sep.						0.0
10 Sep.	6					6.0

Table 3 continued

Week ending	Flies/sweep†					
	1-5	6-10	11-20	21-50	50+	Total
			1976			
4 June	9					7.0
11 June	7					7.0
18 June	11					11.0
25 June	7					7.0
2 July						0.0
9 July						0.0
16 July	5					5.0
23 July	11		0.9			11.9
30 July	24					24.0
6 Aug.	5	1.9	0.9			7.8
13 Aug.	5					0.5
20 Aug.	15					15.0
27 Aug.	20					20.0
3 Sep.	1					1.0
10 Sep.	4					4.0
17 Sep.	4					4.0
24 Sep.	3					3.0
1 Oct.	7					7.0
8 Oct.	3					3.0
			1977			
11 June	16	0.9				16.9
18 June	27	0.9				27.9
25 June	34	0.9				34.9
2 July	33					33.0
9 July	32	0.9		0.9		33.8
16 July	37	0.9	3.0	0.9		41.8
23 July	42	3.0	0.9			45.9
30 July	22					22.0
6 Aug.	37			0.9		37.9
13 Aug.	42	2.8		0.9		45.7
20 Aug.	34	1.4		1.4	1.6	38.4
27 Aug.	12					12.0
3 Sep.	26	3.9	1.9	2.7	1.6	36.1
10 Sep.	25	1.0				26.9
17 Sep.	14			0.9		14.9
24 Sep.	8					8.0
1 Oct.	1					1.0

† Sample levels with six or more flies/sweep are considered as heavy investations.

infestation in the area. About 3.7% of the study area had high enough populations of *S. arcticum* to cause severe illness in four young calves even after the most effective treatment, 1976. The treatment of the Athabasca River with pesticide does not affect the populations of *S. venustum*, *S. vittatum*, and *S. decorum*, thus, even a 100% kill of the larvae in the Athabasca River would not eliminate the problem of these species. The cattle in this area are also attacked by mosquitoes, horse flies, deer flies, and no-see-ums, which are not affected by the treatment of the Athabasca River. Therefore, the treatment of the Athabasca River with pesticides, even though it does reduce *S. arcticum* adults around cattle is not the total answer for protection of cattle from black flies, and even more so, against the other biting flies that are in this area.

Black flies attack cattle during the daylight hours. The response of the cattle was assessed in three categories.

Light - When the population index is not greater than 1 fly/sweep. This level of attack caused irritability among the cattle, which was exhibited by vigorous switching of the tail, frequent licking of the body, and constant ear twitching and walking.

Moderate - When the population index is 2-5 flies/sweep. This level of attack includes all of the characterisitics described for the light attacking behavior but is further characterized by bunching of the herds. These bunches gathering at the highest and windiest spot in the pasture, and much time is spent lying down (Fig. 4). There is usually damage to udders (Fig. 5), scrota, eyelids, and muzzle.

Severe - When the population index is 6 or more flies/sweep. This level of attack includes all the characteristics of the moderate level of attack but is further

Fig. 4. Bunching behavior of cattle during severe attacks by black flies in the Athabasca area.

Fig. 5. Damage to udder caused by black fly bites.

characterized by much tighter bunching and very much more restlessness within the bunches, resulting in trampling of young calves, and much time is spent without grazing. Mothers refuse to feed calves because of severe udder damage. There is swelling around the eyes and muzzles in animals of all ages and death can occur.

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BIONOMICS OF BITING FLIES IN THE AGRICULTURAL AREA OF CENTRAL ALBERTA

J. A. SHEMANCHUK AND J. R. ANDERSON

INTRODUCTION

Species of black flies other than *S. arcticum* breed in the numerous small streams and rivers. Mosquitoes, horse flies, deer flies, and no-see-ums breed in the vast areas of bog that exists in central Alberta. All of these species of biting flies are present in the existing agricultural areas of central Alberta and are pests of cattle and other livestock.

METHODS

In 1973, 14 sampling stations along Flat Creek were selected to obtain data on the species of black flies that breed in small streams that might contribute to the livestock pest problem in the area. Flat Creek, which is about 20 km east of Athabasca (Shemanchuk, fig. 1, p. 201), was selected because of its previous history as a black fly breeding ground and its accessibility by car. The creek is about 10 km long from Flat Lake to Pine Creek. The flow in the creek is regulated by a headgate on the north end of Flat Lake that provides for a fairly constant water level in the creek throughout the spring and summer.

Ceramic drain tiles, 12 cm diameter by 30 cm long, were placed at each sampling site to act as an artificial substrate (Fig. 1). These tiles were left in the stream for 1-wk then removed and replaced with clean ones. When the tiles were removed from the water, they were placed in plastic bags for transportation to the laboratory where the larvae and pupae were scraped off the tiles with a soft-rubber house-hold spatula. The larvae and pupae were stored in 90% ethyl alcohol until they were counted and identified.

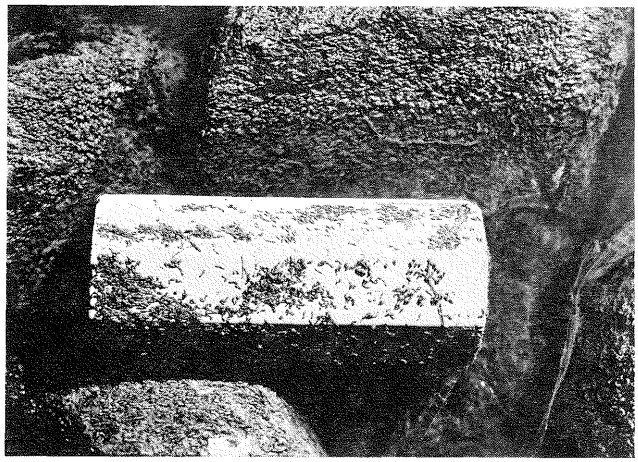


Fig. 1. Ceramic drain tile used as artificial substrate to sample larval and pupal populations in Flat Creek.

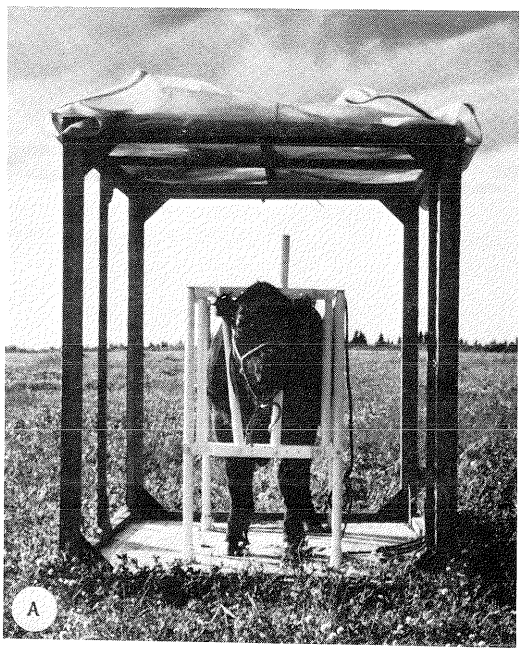
In an attempt to determine the occurrence of black flies in the non-agricultural areas in central Alberta, two Hereford and two Angus steers were transported to one site at House River on Highway No. 63 (67 km north of Wandering River), at Mariana Lake (94 km north of Wandering River), and at Hondo (89 km

northwest of Athabasca). Twenty sweeps with a standard insect net were taken at 30-min intervals and these were compared with similar samples taken around the same number of steers during the same period of the day at the Lantz farm about 32 km northeast of Athabasca (SE 1/4 Sec 29, Twp 68, Rge 19, W4th).

A trap (Fig. 2) was designed to determine the burden of biting black flies and other biting flies on cattle under field conditions. This trap was also used to study the diel activity of black fly adults around cattle and to evaluate repellents for the protection of cattle against naturally occurring populations of biting flies. Six chemicals were tested for repellency.

Two types of self-marking and release cages for marking and releasing black flies in an attempt to determine flight range of black flies were constructed and tested on Flat Creek (Fig. 3) and on the Athabasca River (Fig. 4). Fluorescent dyes were used as marking material as they could be detected on the flies in very small quantities under black light.

The diel activity of adult black flies over the river was studied on three occasions in 1975 and 1976 by taking samples of black flies with two standard insect nets fitted with long handles. These nets were held about 10 cm above the water from the sides of the boat as it travelled at 38 km/hr over a predetermined 8-km stretch of the river. Samples were taken at 1-hr intervals over a 24-hr period. The total number of flies from the two nets was used as the index of abundance.



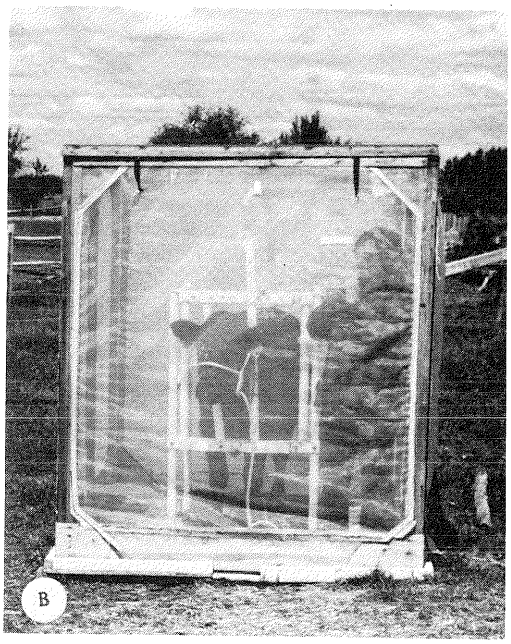


Fig. 2. The type of cage used to determine the number and species of biting flies on a steer. A - open; B - closed.

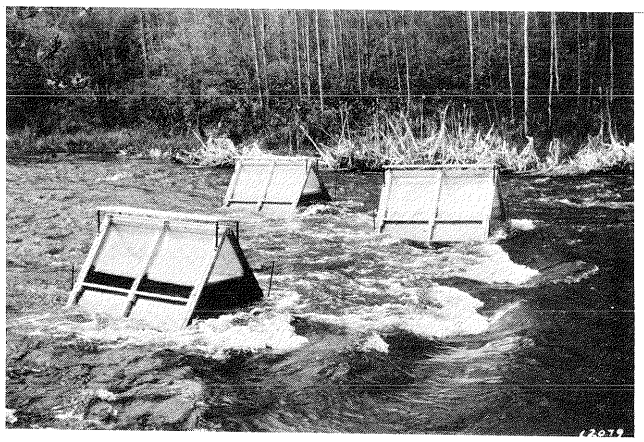


Fig. 3. Self-marking and release cages used on Flat Creek for marking black flies with fluorescent dye.

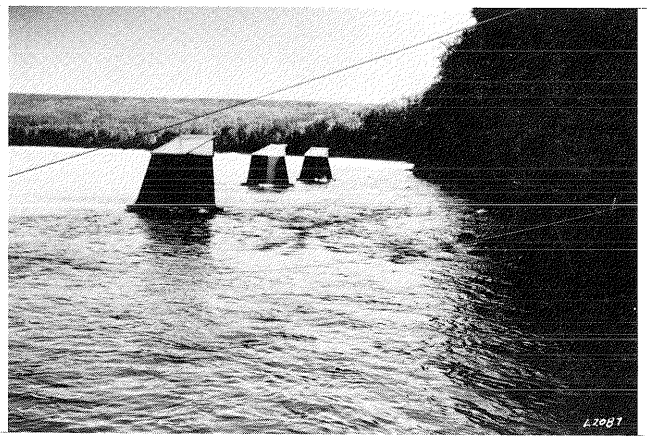


Fig. 4. Self-marking and release cages used on Athabasca River, near Pelican Rapids, for marking black flies with fluorescent dye.

RESULTS

The seasonal distribution and abundance of all species of black fly larvae and pupae at 6 of the 14 sampling sites in Flat Creek during the 1973 study season is illustrated in Fig. 5. These data indicate that black fly breeding in Flat Creek occurs at high levels during the spring and summer. Three species - *S. venustum*, *S. vittatum*, and *S. decorum* - were recorded (Fig. 6). Other small rivers and creeks in the study area were sampled at irregular intervals and were found to contain high populations of black fly larvae and pupae. No larvae or pupae of *S. arcticum* were collected from Flat Creek or any of the other clear-water streams sampled. Adults of these species were found to bite cattle, horses, sheep, and pigs. Results from this study indicate that the small rivers and creeks in central Alberta are sources for the production of high populations of *S. venustum* and *S. vittatum* adults that could affect livestock production in the area.

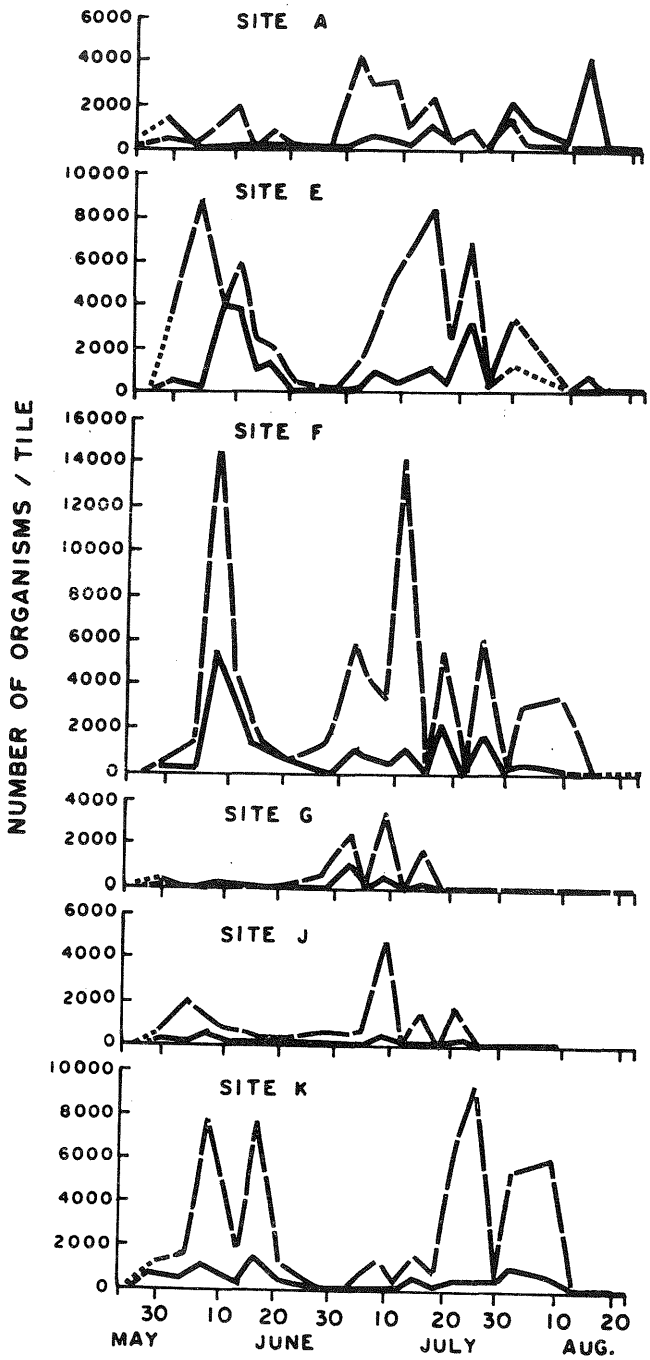


Fig. 5. Seasonal distribution and abundance of black fly larvae (– – –) and pupae (——) in Flat Creek at six sampling sites, 1973.

The number of *S. arcticum*, *S. venustum*, *S. vittatum*, and *S. decorum* collected around steers at House River, Mariana Lake, and Hondo - outside the area of established agriculture - were not as high as those at the Lantz farm (Table 1). However, the data indicated that *S. arcticum* was present throughout the area along the Athabasca River and this should be considered as a potential problem to any further expansion of the cattle industry into these areas.

That *S. arcticum*, *S. venustum*, *S. vittatum*, and *S. decorum* feed readily on cattle is indicated by the number of blood-engorged females collected in the steer-baited trap (Table 2). That large numbers of black flies around the cattle were not feeding is indicated by non-blood-fed specimens in the samples (Table 2). *S. arcticum* was the predominant species present.

Examination of the samples of engorged and non-engorged females taken in the steer-baited trap indicated that females of *S. arcticum* require more than one meal to fully develop a batch of eggs.

Females of at least six species of mosquitoes, *Aedes vexans* (Meigen), *Aedes flavescens* (Müller), *Aedes fitchii* (Felt and Young), *Aedes excrucians* (Walker), *Aedes punctor* (Kirby), and *Culiseta inornata* (Williston), attack cattle in the Athabasca area (Table 3). Even though fewer mosquitoes than black flies were collected, data indicate that this trap could be used for sampling blood-feeding populations of mosquitoes. If the sampling had been conducted earlier, during the period from late April to the end of May, when the mosquito populations are normally high, a larger number of specimens and species might have been collected.

Adults of two species of Ceratopogonidae, *Culicoides yukonensis* (Hoffman) and *Culicoides obsoletus* (Meigen), were trapped (Table 4). Many females of *C. yukonensis* were around cattle during the entire sampling period but fewer *S. obseletus* females were present, and only during the early part of the summer.

Adults of 11 species of Tabanidae were collected (Table 5). Females of at least seven of these species fed on the steers, as indicated by the number of blood-fed flies.

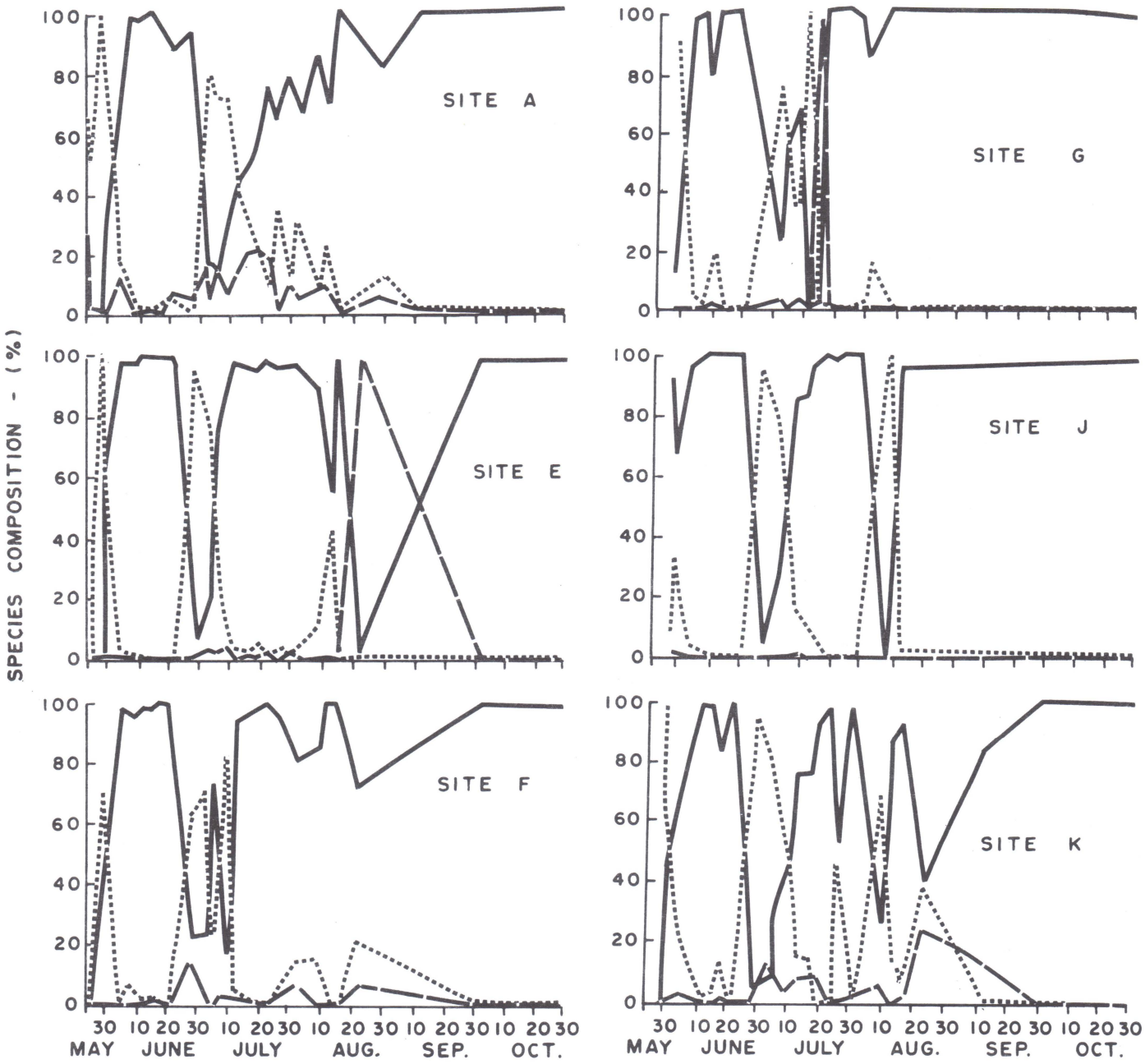


Fig. 6. Species composition (*S. venustum* ----; *S. vittatum* ——; and *S. decorum* — —) of black fly larvae and pupae in Flat Creek at six sampling sites, 1973.

These results indicate that cattle in this area are attacked by mosquitoes, horse flies, deer flies, and no-see-ums, all of which could be a problem in cattle production even if *S. arcticum* can be controlled.

Catches in the steer-baited trap showed that the number of *S. arcticum* females attacking Angus steers were consistently higher than those attacking Hereford steers (Table 6). The higher attack rate on the Angus steers was attributed to color.

Of the two types of self-marking and release cages tested, the one that could be anchored to the bottom of the stream (Fig. 3) worked well on Flat Creek, but the floating type (Fig. 4) for use on the Athabasca River did not stand up to the current and requires further modification and testing. From the estimated 100,000 adults from Flat Creek tagged with fluorescent dye, 22 *S. venustum* (18 females and four males) were recovered. The maximum distance from release site was 6.8 km for the females and 0.8 km for males. All of the marked specimens were captured in the creek valley indicating a dispersal downstream along the creek valley from the release site. Two blood-engorged females were captured in a hog barn near Flat Creek 4.8 km from the release site. These preliminary studies indicate that this technique is practical in studying the dispersal of black fly adults emerging from small streams.

Table 1. Numbers of black flies around two Angus and two Hereford steers taken at the Lanz Farm compared with House River (12 Aug. 1975), Mariana Lake (22 July 1976), and Hondo (26 July 1976)

Time	Lantz farm				Comparison site			
	S. arcticum	S. venustum	S. vittatum	S. decorum	S. arcticum	S. venustum	S. vittatum	S. decorum
Comparison with House River								
1300					7	3	0	4
1330					39(1)[a]	0	3	7
1400					66	6	5	1
1430	80(11)	4	5	0	30	4	0	2
1500	137(19)	9	4	0	20(1)	4	0	6
1530	220(26)	4	1	0	33	5	1	0
1600	127(12)	9	5	0	28	5	0	5
1630	153(28)	12	9	2				
Comparison with Mariana Lake								
1130	7	3	3	0				
1200	2	0	7	0				
1230	5	1	0	0	6	13	5	0
1300	26	1	5	0	4	14	2	0
1330	28	1	3	0	3	6	1	0
1400	74	1	3	2	6	14	2	0
1430	82	5	0	0	6	13	3	0
1500	164	2	7	1	8	16	10	0
1530	294	2	2	2	4	8	3	0
1600	197	1	2	0	5	13	2	0
Comparison with Hondo								
1130	1108	39	29	3				
1200	917	33	3	0	3	83	60	18
1230	1160	21	12	1	13	74	70	9
1300	1844	39	12	2	6	37	46	19
1330	2671	34	11	0	10	30	65	17
1400	1813	17	19	0	19	52	87	53
1430	1193	2	1	0	8	53	32	3
1500	543	2	3	0	10	72	71	22
1530	973	3	13	0	16	90	49	6
1600	1528	8	7	0	17	43	84	1

[a] Values in parentheses are bloodfed insects; other values are for non-bloodfed insects.

Table 2. Average number of blood-fed (BF) and non-blood-fed (NBF) female black flies collected in the bait trap in 75 collections made from 18 June-21 Aug. 1974

Date	Number of collections	S. arcticum		S. venustum		S. vittatum		S. decorum	
		BF	NBF	BF	NBF	BF	NBF	BF	NBF
18 June	7	43.6	54.0	37.7	57.3	0.4	2.3	0.1	0.4
3 July	5	128.4	107.6	42.2	72.4	18.8	56.0	0.2	0.6
4 July	6	39.0	48.8	19.3	26.0	8.3	26.7	0.0	0.0
10 July	9	51.1	82.7	1.1	2.6	5.0	12.6	0.1	0.0
11 July	2	165.0	204.0	38.0	49.0	2.0	7.0	0.0	0.0
14 July	5	86.0	137.8	7.8	16.4	10.4	18.4	0.0	0.0
23 July	7	25.4	31.7	3.6	6.3	6.9	9.6	0.4	0.6
26 July	7	5.0	7.1	1.3	2.0	0.6	0.4	0.0	0.3
30 July	5	135.4	317.0	2.6	15.6	4.8	11.4	0.0	0.2
31 July	6	329.5	497.5	5.0	10.8	8.3	12.2	1.2	4.8
9 Aug.	6	279.5	422.0	3.8	7.3	19.8	47.5	0.3	0.3
12 Aug.	3	804.0	1146.3	16.3	32.0	2.7	7.0	11.7	42.0
13 Aug.	5	106.4	125.0	0.2	0.8	0.0	0.0	1.6	2.4
21 Aug.	2	1116.5	1658.0	2.0	11.0	6.0	12.0	2.5	7.0

Table 3. Number of blood-fed (BF) and non-blood-fed (NBF) female mosquitoes collected in the bait trap in 75 collections made from 18 June-21 Aug. 1974

Date	Number of collections	A. vexans		A. flavescens		A. fitchii		A. excrucians		A. punctor		C. inornata	
		BF	NBF	BF	NBF	BF	NBF	BF	NBF	BF	NBF	BF	NBF
18 June	7	0	0	4	1	65	50	3	1	0	2	0	0
3 July	5	0	1	4	1	87	39	4	4	28	10	0	2
4 July	6	0	0	1	0	46	0	0	0	2	3	0	0
10 July	9	0	0	0	0	14	8	0	0	1	4	0	0
11 July	2	0	0	0	0	49	10	1	0	112	18	10	6
14 July	5	0	0	0	0	4	0	0	0	3	2	1	0
23 July	7	0	0	0	0	0	1	0	0	1	0	2	3
26 July	7	10	13	0	0	3	0	0	0	12	12	3	2
30 July	5	43	32	0	0	0	0	0	0	12	5	0	0
31 July	6	208	172	0	0	0	0	0	0	0	0	48	8
9 Aug.	6	121	66	0	0	0	0	0	0	0	0	18	3
12 Aug.	3	59	42	0	0	0	0	0	0	0	0	4	1
13 Aug.	5	41	67	0	0	0	0	0	0	0	4	8	1
21 Aug.	2	4	2	0	0	0	0	0	0	0	0	0	0

Table 4. Number of blood-fed (BF) and non-blood-fed (NBF) female Ceratopogonidae collected in the bait trap in 44 of 75 collections made from 18 June - 21 Aug. 1974

Date	Collections	C. yukonensis		C. obsoletus	
		BF	NBF	BF	NBF
18 June	7	2	0	0	1
4 July	6	8	3	0	0
10 July	9	47	40	27	0
31 July	6	44	10	0	0
9 Aug.	6	11	3	0	0
12 Aug.	3	367	74	0	0
13 Aug.	5	39	54	0	0
21 Aug.	2	2	3	0	0

Table 5. Number of blood-fed (BF) and non-blood-fed (NBF) female Tabanidae collected in the bait trap in 75 collections made from 18 June - 21 Aug. 1974

Species	Feeding status	
	BF	NBF
Chrysops carbonarius Osten Sacken	0	1
Chrysops frigidus Osten Sacken	0	37
Chrysops furcatus Walker	15	53
Chrysops mitis Osten Sacken	2	3
Haematopota americana Osten Sacken	1	0
Hybomitra affinis (Kirby)	17	108
Hybomitra frontalis (Walker)	2	15
Hybomitra metabola (McDunnough)	0	11
Hybomitra lanifera (McDunnough)	2	30
Hybomitra lasiphthalma (Macquart)	1	0
Hybomitra nuda (McDunnough)	0	7

Table 6. Numbers of S. arcticum (rate of attack) on four Angus and four Hereford steers

Breed	Steer number				Mean
	1	2	3	4	
Angus	908	997	410	1579	974
Hereford	449	381	195	126	288

The flight and biting activity of *S. arcticum* around cattle on a normal summer day occurred during the daylight hours, between 0600 and 2230 hr with two peaks of activity, one at about 1300 hr and one at 1830 hr (Fig. 7). Activity ceased after dark.

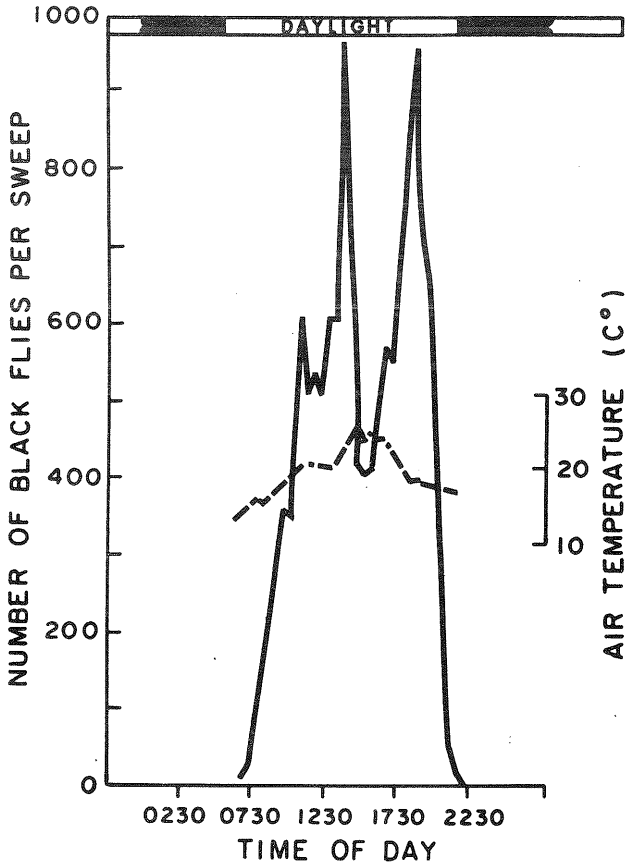


Fig. 7. Diel flight activity of *S. arcticum* around cattle at the Lantz Farm, 1976

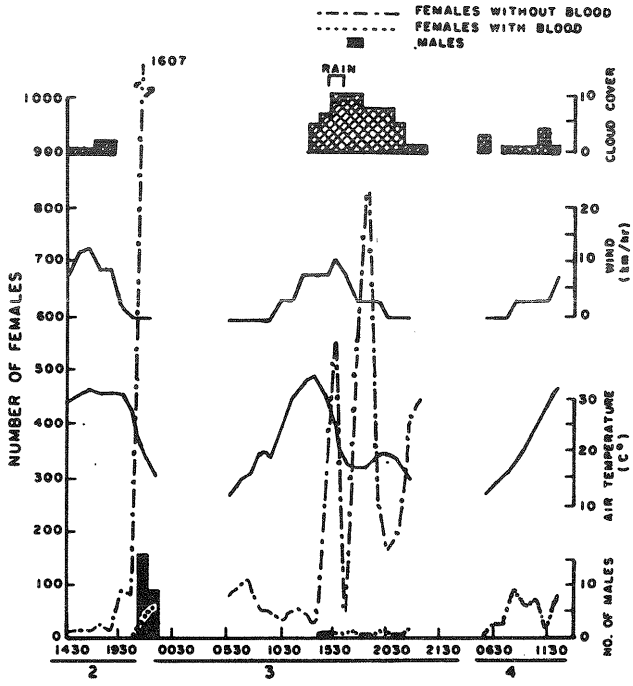


Fig. 8. Diel activity of adults of *S. arcticum* over the Athabasca River, 2-4 July 1975.

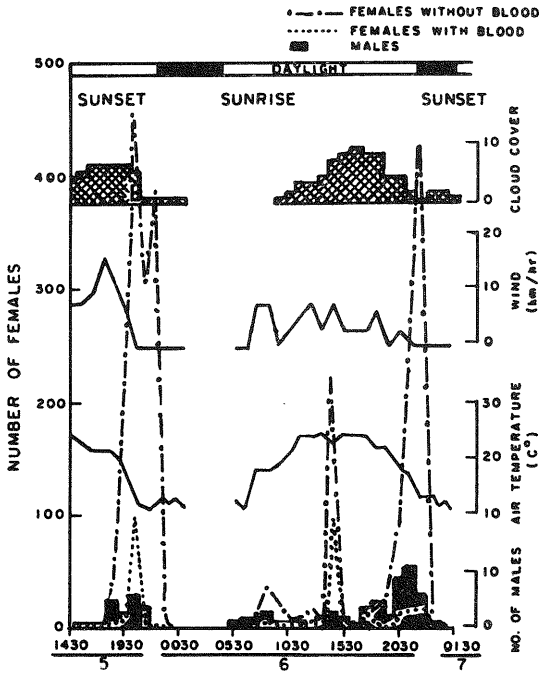


Fig. 9. Diel activity of adults of *S. arcticum* over the Athabasca River, 5-6 July 1976.

The flight activity of *S. arcticum* over the Athabasca River on normal days was characterized by three peaks of activity during a 24-hr period (Figs. 8 and 9) a small peak of activity at about 0930 hr, a larger peak at 1430 hr, and the largest peak at 2230 hr. In all, flight activity over the river occured in the period 0530-0030 hr, a longer period than around cattle. Males and blood-engorged and non-engorged females were collected. It is believed that the flight activity was mainly an oviposition activity. The males and the blood-engorged females are believed to be transient individuals in search of resting sites. From the data, it is evident that flight activity of adult black flies occurs in a wide range of climatic conditions. A more intensive and precise study on the effects of climatic conditions on flight behavior is necessary to identify conditions that affect migration.

The seasonal distribution and the relative abundance of adults of *S. arcticum* over the Athabasca River and around cattle on a farm during 1974 and 1975 is illustrated in Fig. 10. From these data, it is evident that the seasonal distribution of adults around cattle follows very closely the seasonal distribution of adults over the river. River sweep sampling at strategic locations on the river could be used in predicting the time and severity of adult black fly outbreaks around cattle. The seasonal parity structure of *S. arcticum* females captured while flying over the Athabasca River and around cattle in 1974

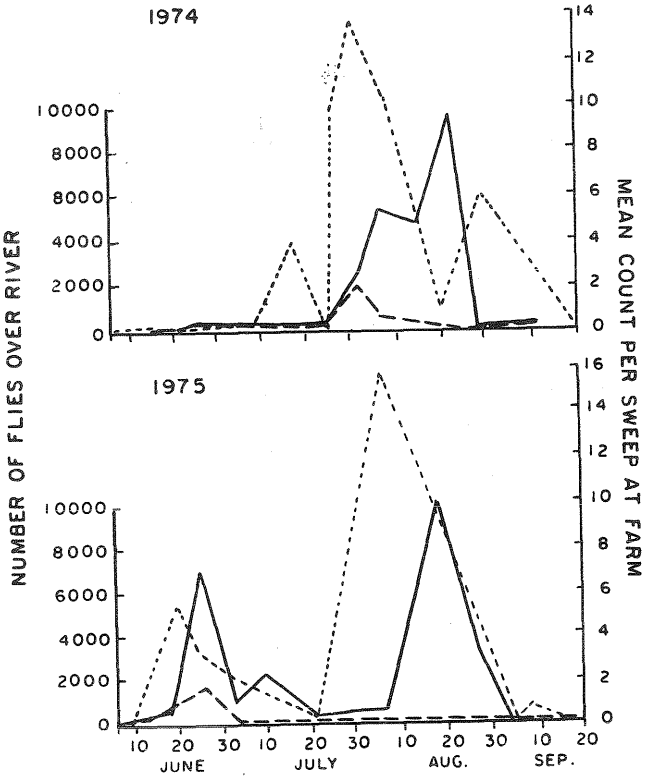


Fig. 10. Seasonal distribution and abundance of *S. arcticum* females (——) and males (——) over the Athabasca River and females around cattle (---) at the Kamelchuk Farm, 1974, and Lantz Farm, 1975.

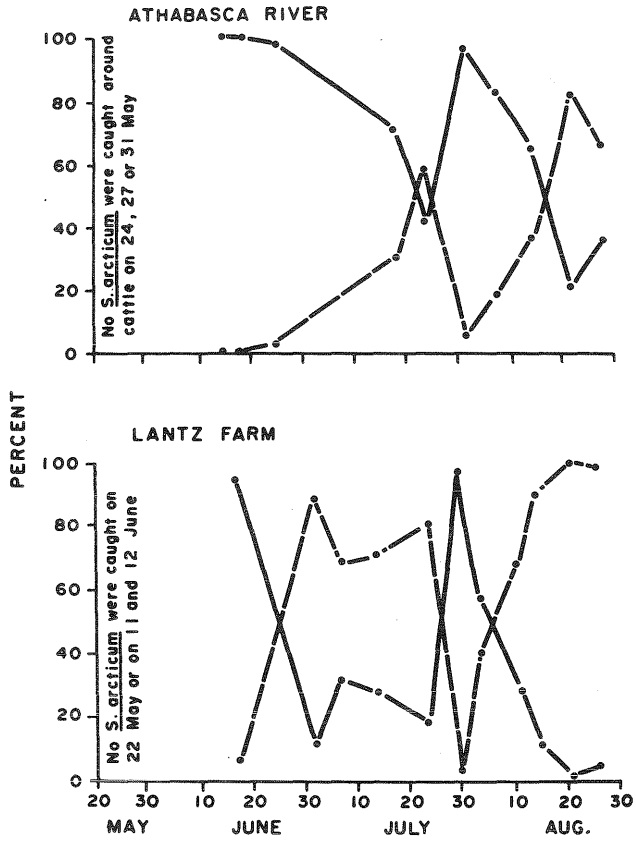


Fig. 11. Seasonal parity structure (parous ——; nulliparous ——) of *S. arcticum* populations, attacking cattle at the Lantz Farm and flying over the Athabasca River, 1974.

is shown in Fig. 11. These data indicate that *S. arcticum* either had two generations per year, or that the eggs deposited by each seasonal 'wave' of flies diapause and hatch synchronously the following year. The former hypothesis is favored at this stage.

PROTECTION OF CATTLE ON FARMS

J. A. SHEMANCHUK

INTRODUCTION

Ideally, the best method of providing relief to cattle from black flies and other biting flies, such as mosquitoes, horse flies, deer flies, and no-see-ums, would be to eradicate them or to reduce their numbers significantly at their breeding grounds. Since *S. arcticum* breeds exclusively in the Athabasca River, it is possible to reduce the numbers of this species by treating the river with a suitable pesticide. However, because of the very many small streams producing other species of black flies and the vast areas of bog and muskeg producing the other biting flies, it is not possible to reduce their numbers at the breeding sources. Therefore, other complimentary or alternative methods of protecting cattle from biting flies are needed. One such method is the use of repellents.

Materials and Methods

The trap illustrated elsewhere (Shemanchuk and Anderson, fig. 2, p. 208) was used to evaluate six chemicals for repellent properties on cattle against biting flies. Yearling steers weighing about 300 kg were used as test animals. The test chemicals were applied by hand to the entire body surface of one steer while another steer was left untreated as a control.

Six compounds - N, N diethyl-M-toluamide (DEET); 2-ethyl-1-3 hexanediol (6-12); 3-acetyl-2-(2,6-dimethyl-5-heptenyl)-oxazaladine (R 69); dimethyl phthalate (DMP) 3-phenoxybenzyl (±)-cis, trans-2, 2-demethyl-3-(2,2-dichlorovinyl) cyclopropane carboxylate (permethrin); and aeroplast (surgical liquid bandage) - were tested for repellency against black flies. An alcohol extract of spruce needles was also tested.

Table 1. Effect of seven repellents against black flies on cattle in central Alberta, 1977

Repellent	Active ingredient per animal	Period of 90% repellency (days)
Permethrin	0.5 g	7
	1.0 g	7
	1.5 g	6
	3.0 g	11
DEET (liquid)	40 ml	1.5
	80 ml	4
DEET (50% W.P.)	20 g	<1
	40 g	<1
6-12	40 ml	1
	80 ml	1
R 69	40 ml	2.5
	80 ml	4
Spruce needle extract	100 g	2.6
Aeroplast	140 g	<0.17

RESULTS AND DISCUSSION

The results from these preliminary tests indicate that permethrin was the most effective repellent (Table 1), providing 90% protection for at least 7 days. The other compounds, even though not as effective as permethrin, provided protection for long enough periods to make them practical in emergency situations.

In these tests, the repellents were applied to the animals by hand, which is not practical under present farming conditions. Simple methods of application must be developed for these repellents before they would be generally accepted by the cattle producers. Limited use of repellents in the near future is envisaged in dairy and small beef herds, and on valuable or pet animals and new born calves.

PROTECTION OF CATTLE FROM BLACK FLIES

M. A. KHAN

INTRODUCTION

Several species of black flies, including *Simulium arcticum*, *S. venustum*, *S. vittatum*, and *S. decorum*, attack cattle and other livestock in parts of the County of Athabasca and neighboring areas. Of these species, *S. arcticum* is potentially the most harmful pest of cattle and by far the most predominant species during an outbreak. *S. arcticum* breeds in the large, fast-flowing Athabasca River, while the other species breed in the smaller streams and creeks in the area.

Swarms of black flies attacking cattle inflict painful bites, draw blood, and inject their toxin(s) through the bite. The toxin(s) causes fatal, or near fatal, anaphylaxis in the newborn calves deprived of colostrum for 6-8 hr after birth and in 'naive' cattle (cattle exposed to black flies for the first time), particularly bulls.

The indigenous cattle harassed and bitten by black flies are severly debilitated. They lose weight and often their breeding cycles are suppressed or interrupted. The lactating cows produce little or no milk and are unable to nurse the young because of reduced milk production and painful black fly bites on the teats and udder. Consequently, the nursing calves remain under-nourished and stunted.

During an outbreak, there is no respite from black flies as they attack cattle both in pastures and in the bush. However, the black flies do not enter or stay in partially darkened buildings and barns. The fly activity ceases after dark.

During the late 1960's and early 1970's, the cattle population increased in the County of Athabasca and the neighboring districts. Cattlemen in the area became increasingly concerned about the black fly damage. Control measures against black flies were nonexistent. The accepted method for controlling black flies had been to kill their larvae developing in the rivers with DDT or methoxychlor. However, these larvicides could no longer be used because of environmental concerns, and other methods for protecting cattle from black flies had to be developed.

In the meantime, phosmet dust had been found to be effective for protecting cattle from horn flies. Although there were marked differences between the horn flies and black flies in their biology, feeding habits, and population densities, it was felt that phosmet dust or other formulations of phosmet might act as contact and systemic insecticides against black flies landing and feeding on cattle.

The biological characteristics of black flies and cattle offered possibilities of protecting the latter from the former. This could be done by means of partially darkened shelters, which the flies would not enter. The cattle could stay in shelters during the periods of black fly activity and graze at night when the flies would not be active.

Additionally, other methods could be investigated to ameliorate black fly losses. These methods included the use of cattle breeds with some resistance to black fly toxins and suitable timing for importing naive cattle into black fly infested areas.

Consequently four experiments, one annually from 1971 to 1974, were carried out to develop economically acceptable methods for protecting cattle from black flies. These methods consisted of pesticides applied to cattle, use of shelters with or without a chemically charged backrubber, and such management practices as introduction of breeds of cattle with some resistance to black fly toxins and importation of new cattle into the area early in the spring before the black fly population reached its peak level.

The effectiveness of these methods could best be determined if the black fly populations prevailed at a high level. During the years of investigation, the population prevailed at or near the required level during all of 1971 and 1972 and during the latter part of the 1974 black fly season.

In 1973, the population declined because of unknown causes. In the early part of 1974 season, it declined because of the use of methoxychlor to kill the black fly larvae breeding in the Athabasca River. This investigation was discontinued in 1975 for lack of resources and increasing emphasis on controlling black flies by treating the Athabasca River with methoxychlor.

METHODS

Experiment 1 (1971)

In this preliminary experiment, coumaphos (Co-Ral; 3-chloro-7-hydroxy-4 methylcoumarin O-ester with O-diethyl phosphorothioate) and phosmet (ProTate; O, O-dimethyl phosphorodithioate S-ester with N-(mercaptomethyl) phthalimide) were used to protect cattle from black flies. Coumaphos was used as a dust containing 1% active ingredient (AI) and phosmet was used as a dust containing 5% AI and as a pour-on formulation, Prolate 4-OS, containing 4% AI. Dust bags containing coumaphos or phosmet dust were hung across lanes at such locations that animals were self-treated at least twice daily. Treatments with coumaphos and phosmet dust were begun on 28 June and were discontinued on 17 July and 1 August, respectively. The treatment with phosmet pour-on was applied on 29 June at the rate of 25 mg phosmet/kg of body weight.

Groups of 36, 39, and 35 mature indigenous cattle were treated with coumaphos and phosmet dust and phosmet pour-on, respectively. A group of 40 mature indigenous cattle was used as the untreated control. The group treated with phosmet pour-on and the control group had free access to a barn and the other two treated groups to their resting areas in the bush.

From 21 June to 9 August, the experimental cattle were observed for their ability to stay in pastures during the periods of the high level of black fly activity. The activity was determined by sight and sound and was considered to be at the high level when the black flies swarmed around cattle in such large numbers that a buzzing sound could be heard at a distance of 10-15 m.

Experiment 2 (1972)

The effectiveness of a pour-on application of phosmet for protecting cattle from black flies was further investigated in this experiment. Preliminary observations were also carried out to investigate the tolerance of Charolais cattle to black fly attacks.

The phosmet treatment was applied to six groups, A-F, of indigenous cattle raised and maintained at a farm located in the black fly infested part of Athabasca. Groups A and B consisted of 17 yearling heifers each, C and D of 14 yearling steers each, and E and F of 36 mature cows each. The groups were formed semi-randomly (Haufe and Thompson 1964) on 29 May, with groups A and B, C and D, and E and F being nearly equal in average weight per animal.

On 28 June, groups A, C, and E were treated with a pour-on application of phosmet at 25 mg/kg. Groups B, D, and F were the untreated controls for groups A, C, and E, respectively.

The experimental animals were maintained in three adjacent pastures, 1, 2, 3 of ca 40, 40, and 20 ha, respectively. These pastures contained a mixture of brome, creeping red fescue, and timothy grasses and white Dutch clover. Groups A and B were maintained in pasture 3 from 29 May to 22 August. Later, from 22 August to 12 October, they had access to all three pastures.

From 29 May to 28 June, groups C-F were kept together in pastures 1 and 2. On 28 June, a partition was placed between the two pastures and, immediately after treatment on that day, the treated groups C and E were placed in pasture 2 and the untreated groups D and F in pasture 1. This arrangement was reversed 1 wk later and, from 5 to 11 July, groups C and E were placed in pasture 1 and groups D and F in pasture 2. On 12 July, the partition between the two pastures was removed and, from 12 July to 27 August, groups C-F had access to both pastures. On 22 August, all six groups, A-F, were mixed together and given access to all the three pastures until 12 October.

From 29 May to 22 August, the black fly activity around the experimental cattle was estimated by sound and sight. Additionally, from 29 June to 11 July, the activity was sampled by sweeping around the cattle with an insect net (38 cm diam.). A maximum of 20 sweeps were made for each sampling and the black flies collected were counted and

identified to species after immobilizing them with a 0.25% pyrethrum aerosol. The mean number of flies caught in 20 sweeps represented the fly activity at each sampling and the highest of the sampling averages in a day represented the peak daily activity (PDA) with the mean of all the samplings within a day representing the average daily activity (ADA). The sampling was generally done only in the morning and afternoon and at any other time when the activity appeared to be at the high level. The activity was ranked as low, medium, and high corresponding to <10, 10-20, and >20 flies/sweep, respectively. The high level was associated with a buzzing sound audible at a distance of 10-15 m.

The experimental cattle were weighed individually 4 wk and immediately before treatment and 1, 2, 4, 6, 8, and 15 wk posttreatment.

The effectiveness of the treatment was determined by comparing, at appropriate intervals, the average daily gains (ADG) of the treated groups with those of their controls. The posttreatment ADG of each animal was adjusted according to its weight at the beginning of the experiment and its ADG during the pretreatment period. The weight gain data were compared by the analysis of variance.

On 3 August, four Charolais-cross yearlings, two bulls and two heifers, that had never been exposed to black flies were brought to the farm and kept protected from black flies in a darkened barn. The following day, one bull and one heifer were treated with a pour-on application of phostmet at 25 mg/kg. The other two yearlings were left untreated. After treatment, all the four yearlings were placed in a pasture adjacent to the one used by the other experimental groups.

The severity of black fly anaphylaxis affecting the yearlings was determined clinically. The black fly activity around the yearlings was determined by the visual and net-sweep methods described earlier.

Experiment 3 (1973)

The experiment was designed to compare the tolerance of the Angus, Hereford, and Charolais breeds to black flies and to determine the effectiveness of a pour-on application of phosmet for protecting cows, bulls, and steers from black flies.

Thirty-four yearling Hereford steers and 36 yearling bulls, 12 each of Hereford, Angus, and Charolais-cross breeds, were obtained from herds in southern Alberta. None of these animals had ever been exposed to black flies. On 10 May, the steers were sorted semi-randomly (Haufe and Thompson 1964) into two groups, A and B, equal in number and average weight per steer. A week later, the steers were trucked to a farm in the County of Athabasca that was known to have been heavily infested with black flies during several previous years. The steers were kept there in a 40-ha pasture (pasture 1) containing a mixture of timothy, brome, and fescue grasses with clover.

On 16 July, group A was treated with a pour-on application of phosmet at 25 mg/kg and group B was left untreated as the control. After treatment, the two groups were kept in separate pens for 3 days and then returned to pasture 1, where they were kept until the end of the experiment.

On 11 July, the 36 bulls were shipped from Lethbridge to a temporary holding facility in the County of Athabasca. The holding facility, located outside the black fly zone in the county was ca 35 km from the experimental farm. On 18 July, the bulls, having recovered from the shipping stress, were transferred to the experimental farm.

Soon after arrival at the farm, six bulls from each breed group were treated with a pour-on application of phosmet at 25 mg/kg and were placed in a 20-ha pasture (pasture 2) adjacent to pasture 1 used by the steers. The remaining six bulls from each breed group were used as the untreated controls and were placed in pasture 3, which was similar and adjacent to pasture 2.

At the experimental farm, each steer was weighed at 2, 4, and 6 wk and immediately before treatment and 1, 2, 3, 5, and 9 wk after treatment. Similarly, each bull was weighed 4 wk and immediately before treatment and 1, 2, 3, 5, and 9 wk after treatment.

The black fly activity around the treated and untreated bulls and steers was sampled at least twice daily by the net-sweep method described in Experiment 2. The effectiveness of the treatment was determined by comparing ADGs of the treated steers and bulls with those of their controls and by comparing clinically the severity of black fly anaphylaxis in the treated and untreated bulls of the three breeds. The differences in ADGs between the treated groups and their controls and the effects on the ADG of the interaction between each breed and the treatment were compared by the analysis of variance.

Experiment 4 (1974)

The effectiveness of free-choice use of partially darkened shelters, equipped or unequipped with a chemically charged backrubber, for protecting cattle from black flies was determined in this experiment. It was conducted at the site of the previous experiment in three adjacent pastures, 1, 2, and 3, of ca 20 ha each. Pasture 2 was located beside and to the south of pasture 1 and pasture 3 was located west of pasture 2, with a 10-m alleyway between the pastures. The pastures contained a mixture of timothy, brome, and fescue grasses with clover.

A shelter ca 12 x 6 m with board walls, ca 2.5 m high, and gable roof was built in both pastures 2 and 3. Each shelter had a gate, ca 2.5 x 2.5 m, on the north side and

three screened windows, 60 x 45 cm, near the ceiling on the west wall. A backrubber charged with 1% ronnel solution (Korlan; O,O-dimethly O-2, 4, 5-trichlorophenyl phosphorothioate) was hung across the gate of shelter I. Ronnel solution was prepared by mixing one part Korlan 24E with 24 parts Shell Oil Pella 911.

On 10 June, 60 commercial grade Hereford yearling steers that had never been exposed to black flies were given free access to the three pastures. Later, on 9 July, the steers were sorted semi-randomly, as in Experiment 2, into three groups, A, B, and C, equal in number and average weight per steer. From 9 July to 18 September, groups A, B, and C were kept in pastures 1, 2, and 3, respectively, with groups B and C having access to shelters I and II from 24 July to 18 September. The backrubber treatment begun on 24 July was discontinued on 18 September. On 19 September, all the three groups were mixed together and placed in pasture 1 for 4 days and thereafter placed in pastures 2 and 3 for 4 days each, until the end of the experiment on 30 September. The steers were weighed individually, after an overnight fast, on 9 July and at 2-wk intervals thereafter until 30 September.

For analysis of the experimental data, the period 9-24 July was described as the pretreatment period and the period 24 July-18 September as the treatment period followed by a posttreatment period up to 30 September.

The black fly activity around the steers was sampled both in the pastures and shelters. The activity in the pastures was sampled and ranked from 10 June to the end of black fly season on 3 September by the method described in Experiment 2. From 10 June to 8 July, the activity was sampled for the entire herd grazing together and, from 9 July to 3 September, it was sampled separately for each group grazing in its allotted pasture. The activity was ranked low, medium, and high as described in Experiment 2.

The activity in the shelters was sampled once each evening from 28 July to 3 September by the following method. The shelters were first cleared of steers and insects. The insects, if present, usually gathered at the shelter windows and were removed from there after a light application of 0.25% pyrethrum aerosol. An hour later, the backrubber in shelter I was raised above the height of the steers and groups B and C were moved into their shelters. They were kept there for 30 min and then turned out. During the 30-min period, the black flies would leave their hosts and gather at the shelter windows where they were sprayed with 0.25% pyrethrum aerosol, collected, and counted. The black flies were identified to species and the percentage of blood-fed black flies was determined.

The collections made for sampling black fly activity in the pastures and the shelters also contained a large number of mosquitoes. These were also counted, and the numbers of blood-fed and unfed mosquitoes were recorded.

The effectiveness of the shelters was determined by observing whether the steers entered the shelters during the periods of black fly activity and whether the black flies and mosquitoes pursued the steers into the shelters. Comparisons were made among the three groups of steers for their ADGs from 9 July to 30 September and for the number of black flies and mosquitoes collected around them in pastures from 9 July to 3 September. Groups B and C were also compared for the number of black flies and mosquites caught in their shelters from 29 July to 3 September.

The data on weight gains of the steers and on the numbers of black flies and mosquitoes collected in the pastures and shelters were compared by analysis of variance. The data on weight gains of steers were also subjected to Tukey's test.

RESULTS AND DISCUSSION

Experiment 1

Black fly activity

The activity was at the high level on 28 and 29 June, 19 July, and 9 August. On these dates, the buzzing sound of the swarming flies was audible at a distance of 10-15 m.

Those cattle treated with a pour-on application of phosmet were able to graze in pastures during the periods of the high levels of black fly activity, whereas the untreated cattle stopped grazing and huddled together or entered any available farm building. This difference in grazing behavior between the treated and untreated cattle was noticeable until 9 August, 41 days after treatment, when the experimental cattle were last observed during a period of the high level of activity.

Self-treatment with coumaphos or phosmet dusts neither protected cattle from black fly bites nor permitted the treated cattle to stay in pastures longer than the untreated ones during the periods of black fly activity. The treatments probably failed because the treated cattle did not receive adequate doses of the pesticidal dusts. No traces of the dusts were visible on the bodies of animals using the dust bags. This was probably because of frequent rains in the area as the moisture from the backs of the cattle moistened the dust, which clogged the pores of the burlap bags.

Experiment 2.

Herd I, black fly activity (Fig. 1)

The black fly activity, seen around the herd from 29 May to 19 September fluctuated

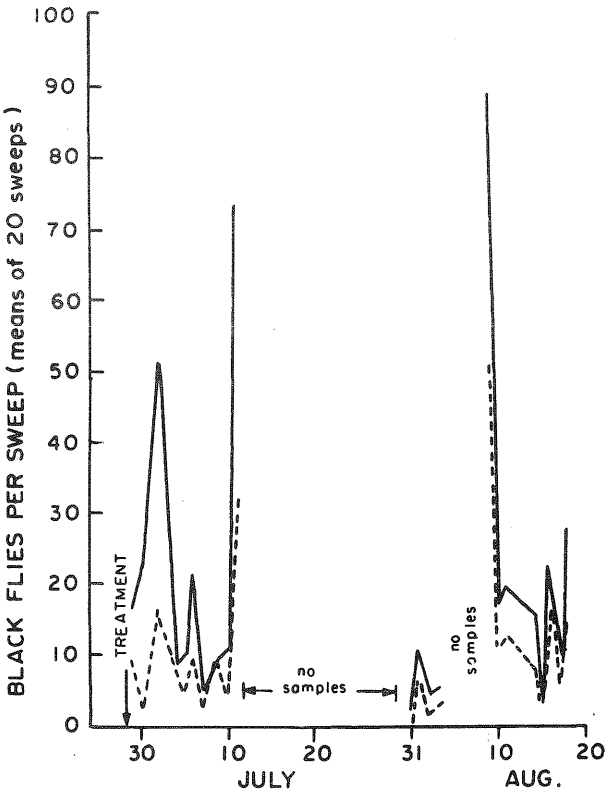


Fig. 1. Peak (——) average (----) daily black fly activity sampled around pastured cattle, 1972.

and was intermittent even on a daily basis. The PDA reached the high level on 15-22 June during the pretreatment period and 30 June-10 July and 26 July-18 August during the posttreatment period. It remained at the low or medium levels during the rest of the season. The ADA remained at the low or medium levels during the entire season, except for 1 day in wk 2 and in wk 8 posttreatment.

S. arcticum was by far the predominant species, representing 95.7% of the black flies collected. Other species of black flies collected were *S. vittatum*, *S. venustum*, and *S. decorum*, representing 4.0, 0.2, and 0.1%, respectively, of the black flies collected. About 97.8% of the black flies collected were without a blood meal.

Weight gains in groups A to F (Table 1)

The ADGs of all the experimental groups fluctuated with fluctuations in black fly activity. However, during the first 2 wk posttreatment, in spite of the PDA reaching the high level, the treated steers and cows gained more weight ($P < 0.01$) than their controls. The trend was also evident in the treated heifers, which, though outgained by their controls ($P < 0.1$) during the pretreatment period, slightly outgained their controls during these 2 wk, 0.80 vs. 0.76 kg/head/day. Furthermore, from 26 July to 8 August, when the PDA was observed at the high levels on 10 of the 14 days, all the groups lost weight, but the weight losses for the treated heifers and cows were lower ($P < 0.05$) than for their respective controls.

From 13 to 25 July, the PDA dropped to the low level resulting in higher ($P < 0.01$) ADGs for the untreated steers and cows than for their treated counterparts. The trend was also evident in the untreated heifers for this period as their ADG exceeded economically, though not statistically, that of the treated heifers, 0.87 vs. 0.75 kg/head/day. Later, from 9 to 22 August, when there was a gradual decline in black fly activity, the untreated heifers outgained ($P < 0.01$) the treated ones.

By 22 August, the ADGs of the treated heifers, steers, and cows did not differ from their respective controls for the 8-wk posttreatment period 28 June-22 August. Nor were there any differences in ADGs between each of the three treated groups and their respective controls during the 7-wk period 23 August-12 October or during the entire experimental period, 29 May-12 October.

Tolerance of Charolais yearlings to black fly attacks

Black fly activity (Fig. 1) - The PDA prevailed at the medium or high levels during the 2 wk after treatment, except for day 12 posttreatment when the PDA was recorded at the low level. During the 2-wk period, the ADA reached the high level on 1 day and fluctuated between the medium and low levels on all other days.

Anaphylaxis - Clinical signs of anaphylaxis were observed in all the four yearlings; the signs being more pronounced in the untreated than in the treated animals. The signs were noticed soon after exposure to black flies.

At first, the four animals were irritable and restless; but 4-6 hr after exposure to black flies, they were off feed, sluggish, recumbent, and reluctant to rise or move around, and had a discharge from the eyes, nose, and the mouth. After exposure for 24 h, there were numerous black fly bites around the eyes and on the underline, particularly on the udder or scrotum. All the four yearlings were showing signs of anaphylaxis including dyspnea with hard, labored breathing. There was generalized cutaneous edematous swelling of the eyelids, jaws, throat, dewlap, brisket, udder or scrotum, and perineum.

The treated animals began recovering earlier than the untreated ones and were seen grazing 2 days after treatment. The treated bull was seen mating with a Hereford heifer 5 days after treatment. One week after treatment, the treated animals appeared to be in normal health, except for the fly bites on their bodies. The untreated animals were in serious distress for 5 days after exposure to black flies and then gradually recovered, gaining normal health in 2 wk after treatment.

Table 1. Weight gains in groups[a] of cattle treated with a pour-on application of phosmet at 25 mg/kg on 28 June 1972

Date or Period	Yearling heifers		Yearling steers		Mature cows		Highest level of black fly activity
	A (17)	B (17)	C (14)	D (14)	E (36)	F (36)	
			Weight/head (kg)				
Pretreatment							
29 May	259.3	259.5	271.9	269.5	409.7	409.0	
28 June	265.6	270.2	281.1	288.1	419.1	420.6	
Posttreatment							
12 Oct.	305.9	309.9	323.0	323.0	433.5	439.9	
			Average daily gain (kg)				
Pretreatment							
29 May-28 June	0.23*b*	0.38	0.31	0.43	0.38	0.46	High[e]
Posttreatment							
29 June-12 July	0.80	0.76	1.32*d*	0.65	1.34*d*	0.68	High
13-25 July	0.75	0.88	0.31*d*	0.71	0.03*d*	1.02	Low
26 July-8 Aug.	-0.17*c*	-0.41	-0.16	-0.01	-0.82*c*	-1.30	High
9-22 Aug.	-0.12	0.34*d*	1.26	1.16	1.50	1.68	
28 June-22 Aug.	0.29	0.38	0.69	0.62	0.53	0.50	
22 Aug.-12 Oct.	0.42	0.41	0.05	0.15	-0.20	-0.26	
29 May-12 Oct.	0.34	0.38	0.37	0.41	0.23	0.22	

a Groups B, D, and F were used as the controls for the treated Groups A, C, and E, respectively. Values in parentheses are numbers of animals within the group.

b-d Differ from their respective controls (*b*, $P < 0.1$; *c*, $P < 0.05$; and *d*, $P < 0.01$).

e High > 20 black flies/sweep; low < 10 black flies/sweep.

The recovery of the yearlings was in sharp contrast to deaths that occurred in other cattle brought earlier in to the area during a period of a high level of black fly activity. On 18 June 1972, when the black fly activity was reported to be at the high level, an Angus bull was brought from outside the black fly infested area to the farm where the herds I and II were maintained. On 19 June, the bull was released in the pasture, while the black fly activity was still at the high level. The following day, the bull was seriously ill with black fly anaphylaxis and died on 21 June.

Similarly, on another farm in this area, a bull and 43 heifers were brought from outside the black fly infested area on 18 June. Eight of these animals died of black fly anaphylaxis: the bull and one heifer on 19 June, three heifers on 20 June, and three heifers on 21 June.

Experiment 3 (Fig. 2)

Black fly activity

The activity began on 30 May and ended 29 September. It fluctuated between the

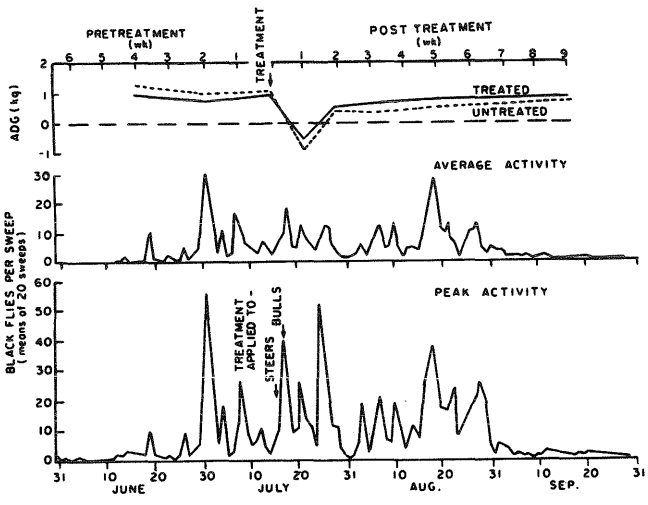


Fig. 2. Peak and average daily black fly activity around two 17-steer groups and their average daily gain (ADG) on pasture in Athabasca County, 1973.

high and the low levels even on days when the PDA was recorded at the high level. For example, on 1, 18, and 26 July, the activity ranged between 1.8-55.9, 2.2-40.1, and 1.8-51.9 black flies/sweep, respectively.

During the black fly season, the PDA was recorded at both the high and medium levels on 14 different days and at the low level on the remaining 94 days. During the season, the ADA was recorded at the high level on 2 days, at the medium level on 15 days, and at the low level on the remaining 105 days.

S. arcticum was by far the predominant species, representing ca 90% of all the black flies collected. Other species of black flies collected were *S. venustum*, *S. vittatum*, and *S. decorum*, representing 5.9, 3.7, and 0.5%, respectively, of the catch.

S. venustum and *S. vittatum* were the first and *S. arcticum* the last to appear on the wing. The first specimens of *S. venustum*, *S. vittatum*, *S. decorum*, and *S. arcticum* were collected on 30 May, 30 May, 2 June, and 11 June, respectively. *S. arcticum* was the first to disappear and was last collected on 19 September. *S. venustum*, *S. vittatum*, and *S. decorum* were last collected on 29, 28, and 29 September, respectively.

Clinical effects of black fly attacks on steers

Clinical signs of acute or subacute systemic anaphylaxis were not seen in the steers. With the first appearance of black flies, they became restless and were seen continuously shaking their heads, flapping their ears, and switching their tails. The first signs of severe annoyance and fright caused by black flies were seen on 19 June, when the ADA reached the medium level with 10.4 black flies/sweep (Fig. 2). There were numerous fly bites and cutaneous edema particularly around the eyes and on the underline. The steers were walking and trotting continuously along the fence as if trying to break out of the pasture.

Later in the season, the steers' reaction to black fly activity changed. Whenever the activity reached the medium or the high level, instead of trotting along the fence, the steers tended to huddle together and sit down at an elevated spot in the pasture, where the wind, if strong enough, would reduce the black fly attacks.

Clinical effect of phosmet treatment

The steers showed no signs of local or general reaction to the dermal application of phosmet.

Effect of the treatment on weight gains in steers (Table 2)

There were no significant differences between the two groups of steers in their ADGs whether recorded at the 2-wk intervals during the pretreatment period or at the end of that period. However, the ADGs for both groups during wk 3 and 4 pretreatment were lower ($P < 0.01$) than their respective ADGs for the 2 preceding or the 2 following wk.

Table 2. Average daily gain in a group of 17 yearling Hereford steers treated with a pour-on application of phosmet at 25 mg/kg on 16 July 1973 and in a comparable control group

Period (wk)	Treated	Control	Black flies/sweep: Avg.	Black flies/sweep: Peak[a]
	Cumulative ADG (kg)			
Pretreatment				
5 and 6	0.93	1.24	2.1	Med. (1)
3 and 4	0.41*b*	0.62*b*	5.7	High (3)
1 and 2	1.29	1.03	6.2	High (3)
Total	0.87	1.00		
Posttreatment				
1	-0.64*c*	-1.02	7.8	High (2)
2	0.51*c*	0.30	6.5	High (2)
3	0.55*c*	0.28	2.9	High (1)
5	0.71*d*	0.43	7.4	High (2)
9	0.83	0.71	4.3	High (3)
Total	0.84	0.83		
	Body weight/steer (kg)			
6 wk pretreat.	265.9	263.3		
Just pretreat.	301.6	304.3		
9 wk posttreat.	354.5	350.3		

a Value in parentheses is number of days when peak level of activity was recorded (medium, 10-15 and high, >20 flies/sweep).

b Lower than other values in column for pretreatment period ($P < 0.01$).

c-d Differs from control group (*c*, $P < 0.05$; *d*, $P < 0.01$).

During the 1st wk posttreatment, both groups lost weight, with the weight loss being less ($P < 0.05$) in the treated than in the untreated group. Thereafter, both groups gained weight, with the cumulative weight gain for wk 1-5 being higher ($P < 0.05$) for the treated than for the untreated group. Later, during wk 6-9, both groups continued to gain weight, but weight gains did not differ between the two groups during the 3 wk. Also, the ADGs did not differ between the two groups for the entire posttreatment period or the pre- and posttreatment periods combined.

The sudden increases in black fly activity probably caused the weight loss in both groups during wk 3 and 4 pretreatment and wk 1 posttreatment (Fig. 2). During the later period, the lower weight loss in the treated than in the untreated group probably resulted from the effects of the treatment,

which appeared to persist for 5 wk post-treatment. With the gradual reduction in black fly activity during wk 6-9 posttreatment, the untreated group appeared to make compensatory gains.

Weight gains were reduced in both groups of steers during wk 3 posttreatment, probably because of poor pastures resulting from lack of rain and weed control. These reduced weight gains in the steers occurred at the same time as the reduced weight losses in the treated bulls, discussed elsewhere.

Although there were no statistically significant differences between the ADGs of the treated and untreated steers for the pre- or posttreatment periods, the treated steers had an economically higher ADG during the posttreatment period. The treated steers, which had lower ADG than that of the untreated steers (0.87 vs. 1.00 kg/head) in the pretreatment period, not only overcame the deficiency but also outgained the untreated steers (0.83 kg vs. 0.71 kg/head) during the posttreatment period at the rate of 6.9 kg/head.

Comparative tolerance of the Angus, Hereford, and Charolais bulls to black fly attacks and anaphylaxis

Acute or fatal anaphylaxis did not occur in any of the treated or untreated bulls. However, all the bulls showed clinical signs of mild or moderate anaphylaxis.

When first exposed to black flies, all the bulls were restless and irritable. Six hours later, the untreated bulls appeared to be lethargic and had ceased all sexual activity exhibited previously by frequently mounting upon each other. They were lying down in small groups and had stopped grazing. They were dyspnic with congested running eyes and a discharge from the nose and mouth. There was generalized edematous swelling and wrinkling of the skin of the eyelids, jaws, throat, neck, brisket, and scrotum.

These signs persisted for 48 hr after treatment and then began to subside gradually. Four days after the treatment date, the untreated bulls appeared to be normal.

The signs of anaphylaxis seen in the untreated bulls were also seen, but less pronounced, in the treated bulls. Except for some swelling of the eyelids and the scrotum, the treated bulls appeared to be normal 2 days after treatment.

Acute or fatal anaphylaxis did not occur in any of the bulls probably because the high level of black fly activity, which they encountered upon their first exposure to black flies, did not last for more than a few hours around the untreated bulls. The treated bulls were largely rid of black flies immediately after treatment. The activity, which was at the high level of 40 black flies/sweep when the bulls were first exposed to it, dropped within a few hours to the low level of 2.5 black flies/sweep. It remained at the low level during the following 7 days, peaking only once briefly to the high level of 25.6 black flies/sweep on the 3rd day posttreatment.

Clinical effects of phosmet on bulls

No acute or subacute clinical effects of the treatment were detected in any of the treated bulls. It was possible, however, that the acute or subacute effects, if any, might have been masked by the signs of anaphylaxis manifested a few hours after treatment.

Effects of phosmet treatment on weight gains of bulls (Table 3)

During the 1st wk posttreatment, all the bulls except the treated Charolais lost weight. The treated Charolais gained a little weight, 0.1 kg/head/day, but this was lower than their weight gain of 0.7 kg/head/day during the pretreatment period.

During the 2nd wk posttreatment, each treated group outgained ($P < 0.05$) its control, but the situation was reversed during the 3rd wk posttreatment when each treated group was outgained ($P < 0.01$) by its control. During the 4th and 5th wk posttreatment, the treated Hereford and Charolais bulls outgained ($P < 0.01$) their controls, but there was no significant difference between the treated Angus bulls and their controls. Thereafter, during the rest of the posttreatment period, there were no significant differences between ADGs of any of the treated groups and their controls.

During the 1st wk posttreatment, the weight loss or reduced weight gain resulted from sudden exposure to black flies. During the 2nd wk posttreatment, the treated groups outgained their controls probably because of the protective effect of the treatment, particularly against the low level of activity prevailing during the later part of the week (Fig. 2). During the 3rd wk post-treatment, when the black fly activity was at a relatively low level (Fig. 2), the treated groups lost weight because of poor pastures mentioned earlier. During the 4th and 5th wk posttreatment, the pastures improved and the treated bulls probably made compensatory gains. During the 6th-9th wk posttreatment, the black fly activity was drastically reduced and had no effect on weight gains of the treated or untreated bulls.

Weight gains for the three breeds of bulls (Table 3)

Since there was no interaction between treatment and the ADGs of the treated bulls of the three breeds, the ADGs of the treated

Table 3. Periodic and cumulative[a] average daily gains in six 6-bull groups, of which three groups were treated with a pour-on application of phosmet at 25 mg/kg on 18 July 1973

Period	Angus		Hereford		Charolais		Black fly activity	
	Treated	Control	Treated	Control	Treated	Control	Avg.	Peak[b]
			ADG (kg)					
Pretreatment								
ca 4 wk	0.35*c*	0.38*c*	0.80	0.56	0.70	0.70	-	-
Posttreatment								
wk 1	-2.73	-2.05	-2.67	-1.68	0.10*c*	-0.75*c*	6.3	High (2)
wk 2	0.25*f*	-0.48	-0.15*f*	-0.50	0.48*f*	-0.48	6.5	High (2)
	(-0.99)	(-1.14)	(-1.20)	(-0.99)	(0.32)*c*	(-0.31)*c*		
wk 3	-1.30*e*	-0.56	-1.79*e*	-0.89	-1.79*e*	-0.65	2.9	High (1)
	(-1.11)	(-0.91)	(-1.44)	(-0.95)	(-0.52)*c*	(-0.45)*c*		
wk 4-5	0.70	0.64	1.42*e*	0.35	0.93*e*	0.29	7.4	High (2)
	(-0.40)	(-0.30)	(-0.31)	(-0.44)	(0.48)*cf*	(-0.16)*c*		
wk 6-9	1.22	1.18	1.13	1.19	1.38*d*	1.57*d*	4.3	High (3)
Total	(0.35)	(0.39)	(0.36)	(0.32)	(0.67)*c*	(0.65)*c*		
Total	0.35	0.39	0.52	0.40	0.68*c*	0.67*c*		
			Body weight/bull (kg)					
Ca 4 wk pretreatment	369.5	364.8	371.1	361.3	327.9*d*	332.1*d*		
Just pretreatment	381.4	377.7	398.6	380.5	351.8	356.0		
9 wk posttreatment	403.6	402.2	421.5	400.6	393.5	396.5		

a Cumulative average daily gain is given in parentheses below average daily gain for the period.

b Value in parentheses is number of days with the high level of black fly activity (>20 flies/sweep).

c-d Pooled value for treated and untreated groups differ from those for treated and untreated groups of other breeds (*c*, $P < 0.01$; *d*, $P < 0.05$).

e-f Different from their respective controls (*e*, $P < 0.01$; *f*, $P < 0.05$).

and untreated bulls of each breed were pooled for comparisons among breeds.

The Charolais bulls, weighing less ($P < 0.05$) than the Angus or Hereford bulls at the beginning of the pretreatment period, outgained ($P < 0.01$) them at the end of the period.

During the posttreatment, as well as the pre- and posttreatment periods combined, the Charolais bulls outgained ($P < 0.01$) the Angus and Hereford bulls. At each posttreatment weighing, the Charolais bulls either gained more weight or lost less weight ($P < 0.05$) than the Angus or Hereford bulls. Consequently, at the end of the experiment, there were no significant differences between the body weights of the Charolais and Angus or Charolais and Hereford bulls.

Experiment 4

Voluntary use of shelters by the steers in groups B and C

The steers entered both shelters freely during periods of black fly activity and the black flies did not pursue them into the shelters. The black flies were seen hovering at the shelters' gates whenever the steers entered the shelters, either voluntarily to seek refuge from black flies or being led for experimental purposes. The steers in both groups often rested outside the shelters, particularly during the later part of the experimental period, when the black fly activity was at or just above the low level.

Black fly activity around the steers in the pastures (Fig. 3 and 4)

The activity had already begun when the steers were placed in the experimental pastures on 10 June (Fig. 3) and it ended abruptly on 3 September with the sudden onset of cold weather. As observed in previous years, the activity was intermittent and showed diurnal fluctuations both during the pretreatment and treatment periods.

During the pretreatment period, as well as during the preceding 4 wk, 10 June-8 July, the PDA remained at the low level, except for 3 days, 20 June and 15 and 16

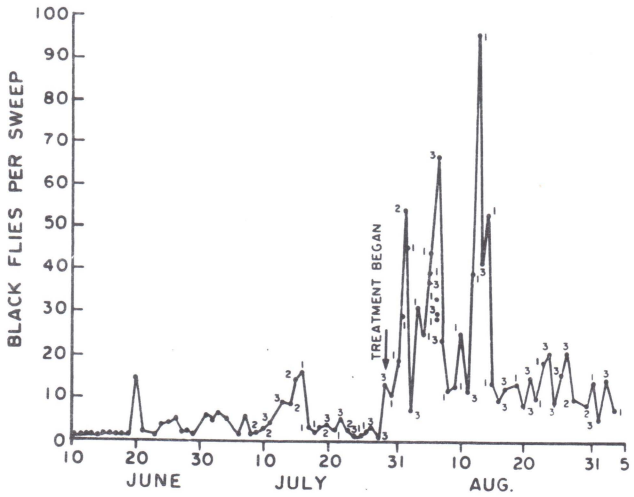


Fig. 3. Peak daily black fly activity around steers kept in three pastures (numerals identify pastures) in Athabasca County, 1974.

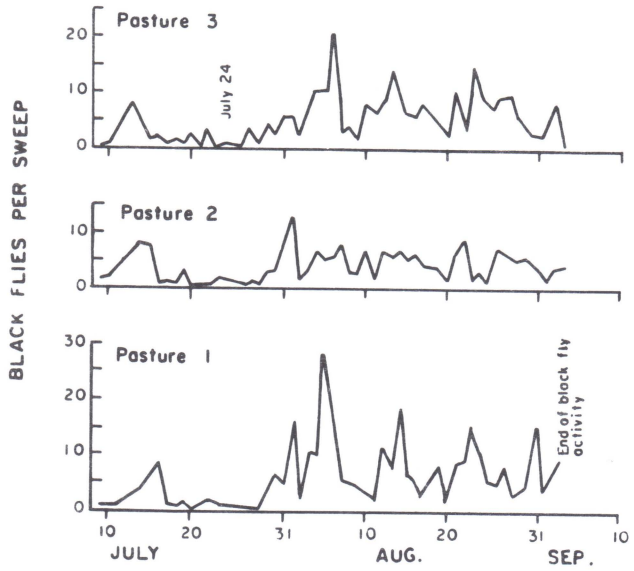


Fig. 4. Average daily black fly activity around steers kept on three separate pastures in Athabasca County, 1974. Steers on pastures 2 and 3 had access to a shelter with and without a backrubber, respectively, from 24 July to 18 September.

July, when it increased to the medium level. The first of these increases occurred before the steer groups were formed and the second and third increases occurred around groups B and A. During the pretreatment period, the ADA around the three groups remained at the low level, with no significant differences among the daily mean numbers of black flies per sweep from the three groups during the entire period. These means, with standard deviation, were 1.5 ± 2.2, 1.6 ± 2.4, and 1.6 ± 2.2 flies/sweep/day for groups A, B, and C, respectively.

During the treatment period, the ADA was higher than that during the pretreatment period (Fig. 4). For the first 2 wk of the period, the ADA was 9.9 ± 8.1, 5.5 ± 3.5, and 7.9 ± 6.8 black flies/sweep around groups A, B, and C, respectively. During the following 2 wk, the ADA declined to 6.3 ± 4.5, 3.9 ± 2.2, and 6.7 ± 3.4 black flies/sweep around groups A, B, and C, respectively. It remained close to this level for the rest of the treatment period with 7.3 ± 4.3, 3.6 ± 2.5, and 6.4 ± 3.9 black flies/sweep around groups A, B, and C, respectively.

During the treatment period, the PDA was recorded 12 times at the high level, all of them during August, occurring six times, once, and five times around groups A, B, and C, respectively. In all, the high level of activity was recorded 20 times during the black fly season, all of them during the treatment period. The high level of activity occurred more frequently around group A and was recorded 12, 1, and 7 times, respectively, around groups A, B, and C, respectively.

During the treatment period, the ADA was highest around group A, followed by that around groups C and B in descending order. The ADA reached the high level only on 1 day around groups A and C, but never around group B. It reached the medium level around groups A and C on 9 and 6 days, but only on 1 day around group B. The ADA for the entire period around groups A, B, and C was 7.7 ± 5.7, 4.2 ± 4.8, and 6.9 ± 4.9 black flies/sweep, respectively.

The single occurrence of the ADA at the medium level and the PDA at the high level around group B occurred on the 4th day of the treatment period. On other days when the activity reached these levels, the steers either went into the shelters or were unattractive to black flies because of the backrubber treatment. Similarly, while the activity prevailed at these levels, group C steers either entered the shelter or, towards the end of the season, stayed close to it.

Numbers of black flies collected in shelters (Fig. 5).

The black flies flying around steers in the pastures did not pursue them into the shelters, but the flies that had already landed or were feeding on the steers were carried into the shelters. The daily mean number of black flies collected from shelter I was ca 72% lower than that from shelter II, 268.9 ± 201.0 vs. 948.7 ± 774.3 black flies.

Incidence of blood-fed black flies in pasture and shelter samples

While most of the black flies caught in the pastures were without a blood meal, nearly 50% of those collected from the two shelters were blood-fed. The percentages of

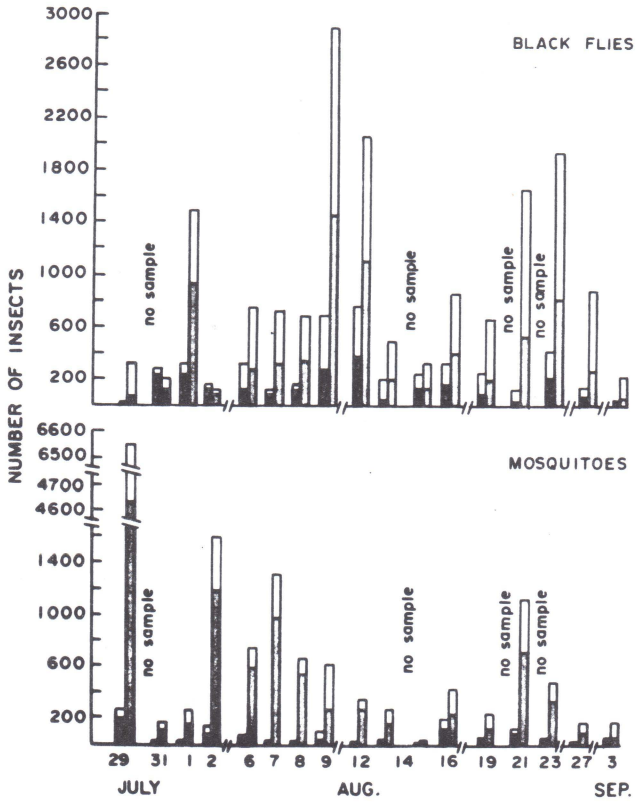


Fig. 5. Number of black flies and mosquitoes collected from two shelters, one with a backrubber charged with ronnel (Shelter I; hatched) and one without (Shelter II; solid). The open part of the column shows the number of blood-fed insects while the shaded part shows the number of unfed insects.

unfed black flies collected from pastures 1, 2, and 3 were 98.3, 97.3, and 98.0 with no significant differences among the three pastures.

Inside the shelters, the black flies did not appear to stay on their hosts long enough to finish a blood meal. The percentages of unfed flies collected from shelters I and II were 49.8 and 53.6, with no significant difference between the two.

The blood-fed black flies collected from the steers using shelter I might have been feeding on parts of steers' bodies not covered by ronnel solution dispensed through the backrubber. The solution probably did not cover the underline of the animals' bodies where the black flies usually feed. It was not known whether the black flies that had fed on treated steers would have died from contact or systemic toxicity of ronnel.

Species distribution on pastures and in shelters

Four species of black flies, *Simulium arcticum*, *S. vittatum*, *S. venustum*, and *S. decorum* were collected from the pastures and the shelters. As in previous years, *S. arcticum* was the predominant species followed by *S. vittatum*, *S. venustum*, and *S. decorum*, in that order (Table 4).

Table 4. Percent distribution of black fly species in samples collected from steers in pastures and shelters in Athabasca County, 1974

Location	*Simulium* species			
	arcticum	*vittatum*	*venustum*	*decorum*
Pretreatment (9-28 July)				
Pasture 1	60.4	37.7	1.9	0.0
2	60.1	37.4	2.4	0.1
3	67.9	29.1	3.0	0.0
Treatment Period (29 July-3 Sep.)				
Pasture 1	82.3	16.0	1.4	0.3
2	85.2	15.9	1.4	0.3
3	82.9	14.2	2.2	0.7
Shelter I[a]	91.6	5.0	2.4	1.0
II	78.2	19.0	2.1	0.7

[a] Flies were collected after keeping the steers from pasture 2 in the shelter with backrubber (I) and those from pasture 3 in the shelter without backrubber (II) for 30 min.

S. vittatum was more abundant in the pastures during the earlier part of the black fly season, the pretreatment period, than during the latter part, the treatment period. It was also more abundant in collections from the shelter II than in those from shelter I. This was possibly because *S. vittatum*, known to feed around the ears and the head of its host, might have been repelled from the steers because of the backrubber treatment.

Mosquito activity around steers in the pastures

Several species of mosquitoes were found regularly in the net sweeps primarily made for black fly collections from the three pastures. The daily collection of mosquitoes during the pretreatment period appeared to be lower than that during the treatment period (Table 5). The collection for each period was highest from pasture 1 followed in descending order by those from pastures 3 and 2.

Mosquito collections from the two shelters

Mosquitoes followed their hosts into the shelters and were not seen hovering at the shelters' gates when the steers entered the shelters voluntarily or were led into

Table 5. Daily means (± standard deviation) of mosquitoes collected from steers in pastures and shelters in Athabasca County, 1974

Location	Pretreatment (9-28 July)	Treatment period (29 July-3 Sep.)	
Pasture 1	0.6±0.6 (12.0)[a]	0.9±1.0	(7.8)
Pasture 2	0.4±0.4 (17.9)	0.6±1.1	(7.7)
Shelter I[b]	-	83.6±78.6	(63.2)
Pasture 3	0.2±0.2 (11.1)	0.4±0.5	(12.2)
Shelter II[b]	-	897.9±1525.5	(69.9)

a Values in parantheses are percentages of blood-fed mosquitoes.

b Mosquitoes were collected after 30 min. confinement of steers from pasture 2 in shelter with backrubber (I) and those from pasture 3 in shelter without backrubber (II).

them. The number of mosquitoes collected daily from shelter I was 90.7% lower than that from shelter II (Fig. 5). The daily mean of mosquitoes collected from shelter I was 4.2/steer compared with 44.9/steer from shelter II.

Incidence of blood-fed mosquitoes in pasture and shelter samples

Most of the mosquitoes collected in the pastures during the pretreatment or the treatment period were without a blood meal (Table 5). The highest percentage of blood-fed mosquitoes was 17.9, among the mosquitoes collected in pasture 2 during the pretreatment period, and the lowest percentage of these mosquitoes was 7.2, among the mosquitoes collected from the same pasture during the treatment period. The percentage of the blood-fed mosquitoes was the lowest in pasture 2 probably because of the backrubber treatment received by the steers grazing in the pasture.

The percentages of blood-fed mosquitoes collected from the two shelters were higher than those collected from the pastures, but did not differ between shelters (Table 5).

Mosquito data from the pastures and shelters were not analyzed in detail as the insect collections were primarily made for sampling black fly and not mosquito populations. The species of mosquitoes collected were *Aedes flavescens*, *A. excruciens*, *A. vexans*, *A. compestris*, *Culiceta inornata*, and *Mansonia perterbans*.

Clinical observation on steers

Anaphylaxis and other health problems - The experimental steers had no history of exposure to black flies but none of them showed signs of black fly anaphylaxis even when subjected to the high level of black fly activity. This, as discussed in experiment 3, probably resulted from continued exposure to low levels of black fly activity.

During the last 2 wk of August and the 1st wk of September, there was an outbreak of infectious keratitis in the herd and one steer in each of groups A and C and six steers in group B had to be treated repeatedly for the disease. Some of the steers in group B showed epidermal desquamation and slight loss of hair on the withers and the rump. This was probably caused by frequent rubbing against the chemically charged backrubber.

Importation of naive cattle - June 7 was suggested as the deadline for importing naive cattle into black fly infested areas of Athabasca County. This was based on observations made in experiments 3 and 4 and also from observations made on private herds in the area. Importation of cattle should be avoided in the face of the high level of black fly activity, which rarely happens before 15 June.

Weight gains of steer groups A, B, and C

There were no significant differences among the three groups in average weight per steer either at the beginning of the pretreatment and treatment periods on 9 and 24 July, respectively, or at the end of the experiment on 30 September (Table 6). However, at the end of the experiment there was an economically, though not statistically, significant difference between the weight gains of groups B and C, as group B outgained group C by 6.9 kg/steer.

Although the ADGs did not differ among the three groups at the end of the experiment on 30 September, they did differ during the treatment period 24 July-18 September. During the first 2 wk of the period, group A had a lower ($P < 0.01$) ADG than those of groups B and C for that period and its own for the pretreatment period. However, during the next 2 wk, the group not only outgained ($P < 0.01$) groups B and C but also gained more ($P < 0.01$) weight than it had during the previous 2 wk. The group continued to gain more weight ($P < 0.01$) than the other two groups during the remaining 4 wk of the treatment period. At the end of the treatment period, the ADG of group A for the period was higher ($P < 0.01$) than those of groups B and C, but not higher than its own during the pretreatment period.

During the first 2 wk of the treatment period, the ADGs of groups B and C were lower ($P < 0.05$) than their ADGs during the pretreatment period, but the ADGs did not differ significantly between these two groups during these 2 wk or the next 2 wk. Thereafter, group B outgained group C not only for the remaining 4 wk of the treatment period ($P < 0.05$) but also for the entire treatment period ($P < 0.01$). During the

Table 6. Weight gains of three groups of 20 yearling Hereford steers kept in pastures during the black fly season, 1974

Period	Group[a] A	B	C
	Average daily gain (kg)		
Pretreatment			
9-24 July	0.82 (1.5)[b]	1.10 (1.6)	1.10 (1.1)
Treatment			
24 July-7 Aug.	0.29 (9.9)	0.74[e] (5.5)	0.72[e] (7.9)
8-12 Aug.	1.04 (6.3)	0.69[d] (0.9)	0.52[e] (6.7)
22 Aug.-18 Sep.[g]	0.86 (7.3)	0.55[e] (3.6)	0.38[ee] (6.4)
18-30 Sep.	-0.59 (0.0)	-0.02 (0.0)	-0.01 (0.0)
24 July-18 Sep.[g]	0.79 (7.7)	0.64[e] (4.2)	0.50[ef] (6.9)
Total			
9 July-30 Sep.[g]	0.58 (5.8)	0.62 (3.5)	0.54 (5.4)
	Body weight/steer (kg)		
9 July	276.6	274.9	275.4
24 July	288.9	291.3	292.3
30 Sep.	324.7	326.8	320.4

[a] Each group stayed in its pasture (A in 1, B in 2, and C in 3) from 9 July to 18 Sep. Afterwards, all the groups were mixed together and rotated among pastures every 3 or 4 days. A shelter with and a shelter without a backrubber was accessible to steers in pastures 2 and 3, respectively, from 24 July-18 Sep.

[b] Value in parentheses is daily mean number of black flies per sweep.

[e-f] Different from Group A ([e], $P < 0.01$; [d], $P < 0.05$); or from Group B ([e], $P < 0.05$; [f], $P < 0.01$).

[g] Blackfly counts were terminated on 3 Sep.

treatment period, both groups gained less weight ($P < 0.01$) than during the pretreatment period.

During the treatment period, group C appeared to be gaining progressively less weight at each weighing than at the one before. Its ADG during the last 4 wk of the treatment period was lower ($P < 0.05$) than that during the first 2 wk of the treatment period.

During the posttreatment period, 18-30 September, all the three groups lost weight, with the weight loss being greatest in group A. However, the differences in weight loss among the three groups were not significant.

The first decrease in the weight gains of the three groups of steers occurred during the first 2 wk of the treatment period and coincided with the first incidence of black fly activity that continued at the high level for 6 days of the 1st wk of August (Fig. 3). During the 2 wk, the PDA, which had never been above the medium level during the pretreatment period, occurred at the high level on 13 occasions. During these 2 wk, group A gained less weight than the other two groups probably because of increased black fly activity from which, unlike the other two groups, it had no protection.

After the first 2 wk of the treatment period, group A probably developed a tolerance to the comparatively low level of black fly activity that prevailed during the rest of the treatment period. This might have helped the group in acquiring compensatory growth resulting in an overall ADG for the treatment period that was not significantly different from its ADG for the pretreatment period.

Group B outgained group C during the entire treatment period, probably because the combination of a chemically charged backrubber and a shelter provided better protection from black flies and also from mosquitoes than the shelter alone. However, group B did not outgain group A after the first 2 wk of the treatment period. This was probably because, during the last 4 wk of the treatment period, 6 of the 20 steers in group B were suffering from infectious keratitis and the pasture used by the group was deteriorating faster than the one occupied by group A.

The weight loss in group C was caused probably by gradual deterioration of its pasture and the increasing pressure of black fly attacks during the later part of the treatment period. After 16 August, the PDA was recorded at the high level 10 times around group C and five and two times around groups A and B (Fig. 3).

The effects of deteriorating pastures became particularly noticeable when the three groups were mixed together and rotated through the three pastures from 18-30 September. During this period, all the three groups lost weight, with Group A losing the most (Table 6).

CONCLUSIONS

From 1971 to 1974, experiments were conducted to develop methods of protecting cattle from black flies. The objective of the experiments was to develop a method that would adequately replace the traditional method of controlling black flies - killing their larvae with pesticides applied to the rivers. The protective measures were directed against the high levels of black fly activity as the low level of activity were not of much concern to the stockmen.

Black Fly Activity

In the first experiment, the activity level was determined by 'sight and sound', but in the other three experiments, it was determined by the number of black flies caught per sweep of an insect net. The level was defined as low, medium, or high corresponding < 10, 10-20, or > 20 flies/sweep, respectively. The high level of activity was also associated with a buzzing sound, caused by swarming black flies, that was audible at a distance of 10-15 m.

The activity was highly variable not only from year to year, but also during a given year. In the first experiment, it was at the high level, whenever sampled. In the second experiment, the activity was highly variable, often reaching the high level after having remained as the low level for 1-2 wk. In the third experiment, the activity generally prevailed at the low level with occasional bursts of the medium and high levels. In the fourth experiment, the activity remained as the low level during June and July, but rose to the medium and high levels during August.

Four species of black flies, *S. arcticum*, *S. vittatum*, *S. venustum*, and *S. decorum* were collected in the area. *S. arcticum* was by far the predominant species and in some years constituted as much as 95% of all the black flies collected.

Protection of cattle

Use of pastures

A pour-on application of phosmet reduced the harrassment of cattle in pastures by black flies. In the first experiment, the treated cattle were able to graze in pastures during the periods of the high level of black fly activity, when untreated cattle either left the pastures or huddled together. These observations were confirmed in the following 2 yr as judged by the differences in weight gains between the treated and untreated cattle during the periods of high levels of activity.

Weight gains of cattle

Cattle treated with a pour-on application of phosmet either gained more weight or lost less weight than the untreated cattle during the periods of high levels of black fly activity. In the second experiment, the protective effect of a pour-on application of phosmet was reflected in improved weight gains in the treated group of cattle for 6 wk after treatment. During the first 2 wk of the period, when the black fly activity was at the high level, the treated groups of steers and cows and to a lesser extent, the treated group of heifers outgained their respective controls. Later, during the 5th and 6th wk of the period, when the black fly activity was again at the high level and all the animals lost weight, the weight loss was less in the treated than in the untreated steers, heifers, and cows. Similarly, in the third experiment, the treated steers outgained the untreated ones by 6.9 kg/head during a 9-wk posttreatment period.

Prevention of black fly anaphylaxis

Acute or fatal anaphylaxis could be prevented by bringing 'naive' cattle into black fly infested areas before the fly activity reached and prevailed continuously for several days at the high level. The observations in experiments 2, 3, and 4 indicated that 7 June should be observed as the deadline for importing 'naive' cattle into the black fly infested areas of the County of Athabasca.

A pour-on application of phosmet prevented fatal anaphylaxis in 'naive' cattle suddenly exposed to the high level of black fly activity in experiments 2 and 3. However, the results of these experiments need to be confirmed as, in experiment 2, only a small number of animals were involved and, in experiment 3, the first encounter of 'naive' cattle with the high level of black fly activity lasted only for a few hours.

Breed tolerance to black flies

Charolais cattle appeared to be more tolerant of black fly attacks then the Angus or Hereford breeds. In the second experiment, four Charolais-cross yearlings, two of which were given no protective treatment against black flies, survived acute anaphylaxis caused by sudden exposure to medium and high levels of black fly activity. Similar exposure to black flies had killed an Angus bull earlier in the season on the same farm where the Charolais yearlings were maintained. Furthermore, in the third experiment, Charolais bulls, whether treated with phosmet or not, outgained comparable groups of Angus and Hereford bulls.

Because of the small number of animals used in the second experiment and the low levels of black fly populations encountered in the third experiment, futher studies are needed to confirm the tolerance of the Charolais breed to black flies in the third experiment.

Effectiveness of shelters

Two types of shelters were used: one equipped with a backrubber (shelter I) at its entrance, and the other without a backrubber (shelter II). Both shelters, particularly shelter I, were effective for protecting steers from black flies and the steers used the shelters freely during the periods of high levels of black fly activity. The black flies did not pursue the steers into the shelters, but most of the flies that had already landed or were feeding on their hosts were carried into the

shelters. The number of black flies collected daily from shelter I was nearly 72% lower than that collected daily from shelter II. Similarily, the number of black flies collected from the steers in the pastures was lowest from the group using shelter I followed in the ascending order by those collected from the group using shelter II and the control group.

During the first 2 wk of the black fly activity at the high level, the two groups with access to the two shelters outgained the control group, with no difference between the weight gains of the two groups. For the entire experimental period, 9 July-30 September, the average weight gain per steer in the group with access to shelter I was 6.9 kg/steer more than that for the group with access to shelter II and 3.8 kg/steer more than that for the control group.

The shelter with backrubber appeared to protect the steers from mosquitoes also. Mosquitoes usually followed their hosts into the two shelters. However, the number of mosquitoes collected from shelter I was 90.7% lower than that collected from shelter II.

Shelters equipped with a chemically charged backrubber would appear to be a promising means of protecting cattle from black flies and, to some extent, mosquitoes as well. Shelters would also help in developing animal management practices that would reduce losses from black flies, particularly in the young and newborn calves and in 'naive' cattle. Shelters could be used not only for housing the young calves during the black fly season, but also as calving pens to encourage early calving in the infested areas. If shelters were available to protect the young calves from inclement weather, the calving season could be advanced to the later part of March and April. Calves born during this period would be better able to withstand black fly attacks than the calves born from 4-6 wk later as older calves, unlike the younger ones, would not have to depend entirely on mothers' milk, particularly during the first half of the black fly season. The nursing potential of cows is greatly reduced during the black fly season as milk production drops in the debilitated cows and suckling becomes painful because of black fly bites on the teats.

With early calving, early breeding would become feasible. The cows could be bred before the height of the black fly activity, which seems to suppress reproductive activity.

Shelters could also be used to acclimatize 'naive' cattle imported into the infested area during the black fly season. The animals could be kept protected from black flies and exposed to them gradually to help build tolerance for black fly attacks.

SUMMARY

These investigations began in 1971 when the black fly population was at the high level. The next year, the activity was variable and often reached the high level after 1-2 wk spells of the low level. In 1973, the activity was lower than during the previous 2 yr and the sustained high level of activity prevailed only on 2 days in the season. In 1974, the activity remained at the low level during the first half of the black fly season, but rose to the medium and high levels during the second half of the season.

A pour-on application of phosmet protected cattle from black fly attacks to the extent that, during the 1st yr of investigation, the treated cattle continued to graze in pastures during the periods of black fly activity when the untreated animals were forced to leave the pastures and seek shelter in farm buildings. The effectiveness of the treatment was confirmed during the next 2 yr when the treated animals outgained the untreated animals during the periods of high level of black fly activity.

Fatal black fly anaphylaxis did not occur in 'naive' cattle imported into the area when the black fly activity was at the high level provided the cattle were treated with phosmet. Nor did the fatal anaphylaxis occur in 'naive' Charolais-cross cattle brought into the area when the black fly activity was high. However, further studies are required to confirm the prophylactic effect of phosmet against black fly anaphylaxis and the tolerance of the Charolais-cross cattle to it.

Black fly anaphylaxis could be avoided by importing cattle into the infested area before the black fly activity reached the high level. In the County of Athabasca, 7 June would be a practical deadline for importing naive cattle.

Partially darkened shelters, with or without a backrubber charged with 1% ronnel, effectively provided relief from black flies at the height of their activity. The shelter equipped with the backrubber was more effective than the one without it and also provided some relief from mosquito attacks.

The use of shelters could encourage such animal management practices as early breeding and early calving in black fly-infested areas. The former would eliminate losses from interrupted reproductive activity commonly reported in herds under black fly attacks, while the latter would prevent losses from retarded growth and death among calves born during or 3-4 wk before the height of the black fly season.

The unprotected cattle (deprived of the shelters or phosmet treatment) lost weight

when the black fly activity continued at the high level for the first time in the black fly season. However, the cattle made compensatory gains later when the activity dropped to the lower levels so that, at the end of the black fly season, no difference existed between the weight gains of the protected or unprotected cattle.

FURTHER STUDIES

The economics and effectiveness of shelters equipped with backrubber and preferably manufactured out of locally available lumber should be investigated. The protection provided by the shelters should be evaluated in terms of weight gains and reproductive performance in the adult cattle and the growth in the young calves. Animal management practices, such as early breeding and early calving, and the usefulness of shelters in developing these practices should be investigated for reducing the losses caused by black flies. Further studies should be undertaken to investigate the tolerance of the Charolais breed to black flies.

ACKNOWLEDGEMENTS

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CLINICAL STUDIES OF THE EFFECT OF THE BLACK FLY SIMULIUM ARCTICUM ON CATTLE

B. E. BECK

INTRODUCTION

A clinical study was conducted on the effect of black flies on cattle in 1973, a year of relatively low infestation after a severe outbreak in the previous year. The purpose of this report is to describe the clinical behavior of cattle affected with black flies, the postmortem findings on cattle killed by black flies, the pathogenesis of black fly bites, the immunologic response of cattle to the bites of black flies, and the possibility of protection through vaccination.

The clinical and pathological investigations were conducted under field conditions utilizing material that became available through natural black fly attacks. Laboratory procedure was limited to investigation of the immunologic response to the black fly antigen.

METHODS

Clinical Investigation

Six farms were visited in the Athabasca - Boyle area and clinical behavior observed in animals present on these farms. About 70 newly introduced heifers and 20 bulls were also observed on the experimental farm near Athabasca. The livestock growers were interviewed and impressions were gained from their observations.

Pathologic Investigation

Before this project, several postmortem examinations were conducted on animals that had died due to black fly attack and had been submitted to the Veterinary Services Laboratory in Edmonton. These cases are used for data because no animals died and no postmortems were performed during the survey conducted in a year of relatively low infestations.

Immunologic Investigation

Antigen Preparation

Adult *Simulium articum* flies were caught with a net and vacuum apparatus and killed by freezing. The thorax was removed manually under a dissecting microscope. A sample of thoraxes (1 g) was macerated with glass beads in 4 ml of sterile saline in a Waring blendor run at high speeds for about 5 min. During the blending, low temperature was maintained with an ice bucket. Solution obtained from this procedure was passed through a series of filters of 1.2, 0.8, and 0.45 µm. The filtrate was spun down in a refrigerated centrifuge at 1,500 rpm for 20 min. The supernatant was frozen in small vials and calibrated according to the number of black fly thoraxes present per unit volume.

Animal Inoculation

All animals used were 3-mo-old mixed beef/Holstein calves.

Toxicosis - Two calves were injected with the equivalent of 1,500 black fly thoraxes by multiple subcutaneous inoculations in the cervical area. One calf was a normal control. One calf had been passively immunized with 1 liter of serum, obtained from an exposed indigenous cow in the black fly area, that presumably contained black fly antibodies.

Passive cutaneous anaphylaxis testing - The technique described by Wells and Eyre (1970) was used. Hair was removed over the cervical region and the skin intradermally injected with 0.2 ml of serum from an immune cow. The skin was injected 72 hr later with saline and normal sera. At the same time, 5% pontamine blue in isotonic saline was injected intravenously. A saline extract of black flies was injected intravenously 15 min later. Response was read in 45 min. A positive reaction was interpreted by the infiltration of blue dye into the skin area containing the immune serum.

Immunodiffusion - Detection of Ig G circulating antibodies was attempted in field cases of previously exposed adult cows and in the hypersensitized experimental calves. The technique of gel immunodiffusion was used.

RESULTS

Clinical Investigation

The following is a list of information considered most reliable from all available sources.

1. The most significant effect of black flies is severe nuisance and harassment of animals.

2. Effect on the animals is proportional to the number of attacking black flies.

3. Massive numbers of black fly bites can kill a recently introduced bull within 10-12 hr and up to 72-96 hr.

4. Newborn calves without antibodies may be killed before they obtain colostrum. After they have received colostrum, they may be severely affected but are sufficently resistant to avoid death.

5. Immune animals seem to be bothered less than non-immune animals.

6. Black fly bites cause a small but severe wound characterized by blood and serum exudation. On indigenous animals, these wounds are followed by large welts occurring 24 hr later.

7. Severly affected animals are characterized clinically by swelling in the ventral subcutaneous areas of the neck, head, and inguinal areas.

8. Some bulls that have been attacked are sick for as long as 6-8 mo after exposure. There are no specific symptoms but they fail to thrive. Bulls seem to be more susceptible than cows.

Pathologic Investigations

Postmortem examination of animals killed by black flies was characterized by massive numbers of small blood spots distributed over the skin, particularly the ventrum. There was extreme edema of the subcutaneous tissue of the head, neck, and thorax. The subcutaneous edema of the ventral cervical area was 5-7.5 cm thick. Pulmonary edema was marked. In a chronic case, a necrotizing vasculopathy was noted with thrombosis and myocardial infarction.

Immunologic Investigations

Toxicity - After injection of the black fly thoraxes, the unprotected calf became depressed. The body temperature was 40°C within 4 hr of inoculation. The injection site became hot and edematous with a swelling about 15 cm in diameter. In 12 hr, the animal had a rough hair coat. In 24 hr, it was slightly dehydrated, did not eat or drink, and walked stiffly. Over the next 24 hr, the signs abated and the animal returned to normal. The swelling required another 72 hr to disappear.

The passively immunized calf did not show any systemic signs of illness after injection but developed a similar edematous hot swelling at the site of injection.

Passive cutaneous anaphylaxis - No reaction took place, indicating a lack of reaginic antibody mediating the anaphylactic reaction.

Intradermal testing

The results are shown in Fig. 1.

Day 1 - Black fly antigen produced an immediate response with weal formation at the 2-hr interval that persisted for 8 hr. Histologically only edema was present.

House fly antigen produced an immediate response with slightly large weal formation which persisted for about 8 hr. Only edema was evident histologically.

Day 3 - Black fly antigen gave an immediate response with weal formation at 2 hr that persisted for 8 hr postinoculation. Histologically, the principle change was edema with small numbers of neutrophils and a few lymphocytes scattered diffusely in the edema fluid. There was slight edema of the vessel walls.

House fly antigen caused an immediate weal with a diameter 0.5 cm greater than the black fly weal. The only change histologically was edema.

Day 5 - Black fly antigen produced an immediate weal that developed to 1 cm in

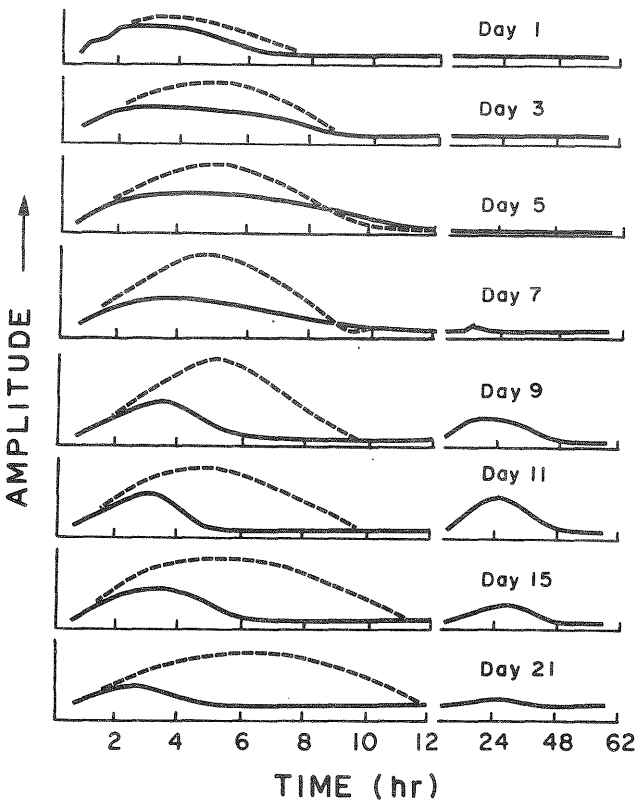

Fig. 1. Amplitude and duration of reaction to intradermal injections of black fly (---) and house fly (——) antigen.

diameter and persisted for 12 hr. Histologically, there was edema and moderate cellular infiltration of neutrophils and lymphocytes with a tendency to aggregate around the vessels. There was some edema of the vascular walls.

House fly antigen gave an immediate weal that developed to 1.5 cm in diameter and persisted for 10 hr.

Day 7 - Black fly antigen caused an immediate weal that developed to 0.75 cm in diameter and persisted for 10 hr. At 24 hr, a small nodule reappeared at the injection site. Histologically, the nodule at 24 hr showed edema, edema of the vessel walls, and cellular infiltration consisting of equal numbers of neutrophils, lymphocytes, and macrophages.

House fly antigen caused an immediate very edematous reaction that produced a weal 1.75 cm in diameter. Histologically, there was edema and very scattered, occasional, cellular infiltrate.

Day 9 - Black fly antigen caused an immediate weal that lasted only 6 hr but was followed by a prominent nodule 0.75 cm in diameter at 24 hr that persisted till 48 hr. Histologically, there were increasing numbers of macrophages, many lymphocytes, and a fewer neutrophils. Most of the cellular infiltrate was perivascular.

House fly antigen gave a prominent edematous reaction that regressed in 10 hr. Histologically, there was only edema.

Day 11 - Black fly antigen produced an immediate weal that lasted only 4 hr, but recurred at 24 hr and persisted until 48 hr. Histologically, there was little edema and principally perivascular cellular infiltrate consisting of macrophages and a few eosinophils. There was slight necrosis on the surface.

House fly antigen gave an immediate reaction that lasted 10 days and consisted of edema.

Day 15 - Black fly antigen caused immediate response that was smaller than the weal caused by day 11 but persisted for 6 hr and was followed by another nodule in 24 hr that lasted till 48 hr. Histologically, the response was similar to Day 11 reaction. The weal was small in diameter.

House fly antigen gave an immediate edematous reaction that lasted about 12 hr. Histologically, there was mild cellular infiltrate into the edema fluid.

Day 21 - Black fly antigen caused an immediate weal that was 0.5 cm in diameter but the delayed weal, 24 hr later, was only just detectable. Histologically, there was only a mild diffuse macrophage infiltration.

House fly antigen produced a persistent edematous reaction of 2 cm diameter that persisted for 12 hr. Histologically, there was edema and slight cellular infiltrate consisting of neutrophils, eosinophils, and a few lymphocytes.

Immunodiffusion

This techique did not demonstrate the presence of precipitating antibodies.

DISCUSSION

During the summer of 1973, when this investigation was conducted, black fly numbers were unusually low. As a result, no animals died from black fly attack during the study period. A detailed pathologic description of lesions of animals dying from black flies was not possible. Postmortem information was gained only from field material submitted to the Provincial Veterinary Diagnostic Pathology Laboratory before and after the study period.

Even though black flies were not overwhelming, the recently introduced experimental bulls incurred many thousands of bites and these pests clearly created a considerable nuisance. Their activity could limit the grazing habits of animals, even to the point that cattle would not leave the vicinity of protective smudge fires to pursue normal grazing and cud chewing. Under such circumstances, average weight gains could not be achieved.

The black fly is a biting insect that saws or slices the skin with its sharp mouth parts creating a small pool of blood. The insect adds anticoagulant substances to this blood and lacerated area as it engorges on the blood meal. Besides the sharp pain of the initial bite, these anticoagulant chemicals also cause various tissue reactions. The black flies contain these secretions in their thorax. Only histamine has been identified as a component of these secretions but they probably contain a mixture of other amines and proteinaceous compounds.

It has been indicated that these secretions are toxic and may be fatal if injected in sufficient quantity. Material contained in 50 black flies was reported in the Russian literature as sufficient to kill or severely affect a bovine. In this trial, administration of material from 1,500 black flies seemed far from possessing life-threatening capability although it did elicit a severe localized edematous reaction. These results seem more in line considering that, under natural circumstances, multitudinous bites of swarms of black flies are necessary to kill an animal.

The toxin was not isolated or purified and no attempt was made to characterize or identify the toxic components in black fly venom. Based on the extremely localized edema with the injection of this toxin and the extreme edema in the subcutaneous tissue in animals dying of black flies, it would appear that the principle mode of action is through a vasoactive substance. Certainly histamine is a well known vasoactive compound and sufficient histamine injected into an animal could cause the same reaction.

Death due to anaphylaxis is commonly assumed with black fly attack. Whenever foreign protein is introduced parenterally, there is always a chance of anaphylaxis but to apply this generally to black fly deaths is inaccurate if the following definition of (Humphrey and White, 1970, p. 436) anaphylaxis is considered.

"Anaphylaxis is a reaction of antigen with preformed cellular attached Ig E antibody which releases a series of enzymes leading to the release of pharmacologic agents which produce physiologic effects. It is characterized by a period of sensitivity and the ability for small amounts of antigen to produce dramatic effects in 15-20 min. or less."

In this study, no Ig E was demonstrated, the effect of black flies was dose related, prior sensitization appeared to offer protection, and the course of the fatal disease course lasted for 24 hr or more.

In addition to the toxic reaction caused by the introduction of vasoactive amines, a further deleterious reaction takes place mediated by adverse immune reactions of the body. Intradermal testing revealed the existance of two of these adverse immune reactions. One of these reactions is delayed hypersensitivity and the other is type III cytotoxic reaction.

Delayed hypersensitivity was demonstrated by a weal or welt appearing on the skin 24 hr after regression of an immediate weal from the intradermal injection of black fly antigen into a sensitized animal. This delayed weal or lump persists for 24 hr or more, is hot, pruritic, and sore. This reaction is responsible for the hot and swollen scrotum of bulls. There is probably sufficient heat of inflammation present to account for the temporary sterility reported to occur in bulls so affected. Humans bitten by other species of *Simulium* are familiar with the sharp painful bite that goes away only to recur later and cause considerable discomfort by prolonged itchiness.

Type III cytotoxic immune reaction results from the stimulation of humoral Ig G antibody circulating throughout the blood stream and the body. This Ig G antibody forms immune molecular complexes that precipitate in the artery wall. These precipitates activate complement and cause an inflammatory reaction characterized by the infiltration of inflammatory cells that constitutes vasculitis. The pattern of inflammatory cell infiltration found in the skin biopsies confirmed the presence of this reaction. This reaction accounts for the extended recovery time noted in some severely affected animals. In the occasional animal, the vasculitis can be sufficiently severe to cause a collapse of major blood vessels with resulting loss of blood flow. This had occurred in the coronary artery of one cow examined and ischemic vascular myopathy resulted in her death.

It was attempted to confirm the presence of circulating Ig G antibodies by identifying these antibodies in gel immunodiffusion. Unfortunately, the levels of Ig G are small and gel immunodiffusion was unable to demonstrate such micro-quantities. It is suggested that serologic techniques of hemagglutination are satisfactory. Ig G may be considered a blocking antibody and is capable of preventing the adverse immune reaction and apparently some of the initial toxic effect of the venom. This phenomenon is commonly referred to as densensitization.

As this technique of densensitization is commonly practiced in human and small animal medicine, the possibility remains that cattle and more particularly newly introduced, highly prized, breeding bulls could be similarly protected. From the results of these experiments, it would seem entirely possible to achieve protection by transfusion with hyperimmune serum or using a series of densensitizing injections. Even though it is possible, it is probably impractical because of the extended period required for multiple densensitizing shots and the great difficulty in obtaining and processing the antigen. On-farm management and husbandry procedures, such as dark housing during the day, buying animals during low risk period, and insect repellents would appear more practicable. Hyperimmune serum harvested at slaughter from immune animals would be advisable for veterinary use in treating animals affected by black flies.

CONCLUSION

Black flies generally cause a severe nuisance to livestock management and, during severe outbreaks, may cause serious long-term, or even fatal, disease. Black flies inject vasoactive compounds, principally histamine, that cause an acute toxic reaction. This may be followed by several adverse immune reactions that lead to greater discomfort and an extended recovery period. The buildup of antibodies causes a blocking or desensitizing reaction that affords an animal some immunity or protection. It is possible to artifically immunize animals but this procedure would appear to be impractical. Hyperimmune serum may be used for treating sick animals.

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DIVERS AND TELEVISION FOR EXAMINING RIVERBED MATERIAL AND POPULATIONS OF BLACK FLY LARVAE IN THE ATHABASCA RIVER

K. R. DEPNER AND W. A. CHARNETSKI

INTRODUCTION

Sampling the biota of large rivers, such as the Athabasca in Alberta, is necessary to evaluate population and control studies. At present, no reliable quantitative methods exist. The difficulties in large rivers are due to the depth and velocity of water and to the turbidity.

Methods of sampling now available can be used only to obtain population indices. In the Athabasca River, sampling for black fly larvae has been accomplished in deep water by using a boat to place artificial substrates for larval attachment. Resident populations of non-target organisms living on or in the bottom were sampled by disturbing the bed material and catching the released organisms. However, investigators are limited to depths in which they can safely stand for the period required for sampling.

The technique of using artificial substrates for estimating larval populations is limited because it measures drifting populations. Even though this is an index of the sessile populations, the exact location and size of these populations cannot be determined precisely. Thus, it was felt that a technique of scanning attached larvae under natural conditions and correlating these population levels and locations to those identified using artificial substrates was required.

The feasibility of using closed-circuit television operated by a professional diving team to scan the riverbed was investigated in an attempt to locate sessile black fly larvae in the Athabasca River. This evidence would have been useful in pinpointing areas of black fly larval attachment in the river for correlation with other sampling methods in estimating the effect of control studies on black flies and other organisms.

MATERIALS AND METHODS

The tests described here were conducted on the Athabasca River. River velocity varied from 0 to 2 m/sec with a flow rate of about 570 m^3/sec and turbidity at >14 JTU (Jackson Turbidity Units) on 8 and 9 May 1975. The weather was generally clear with air temperature of 12°C and minimal wind.

Two significant major requirements are necessary for conducting studies of this nature on large rivers. First, trained professional divers and second, a maneuverable boat or platform from which to operate. A crew of three professional divers complete with self-contained underwater breathing apparatus (Scuba), the necessary safety equipment, and direct boat-to-diver audio communication equipment was contracted. The aluminum boat used in the operation had a 7-m hull and a 350-hp inboard engine, which powered a Berkely jet drive unit. Such a craft has the necessary stability, carrying capacity, and maneuverability in fast-flowing water. In addition, the jet drive allows access to shallow areas if necessary. In all situations, when divers were working in the water, the boat was securely anchored.

A three-diver team is the minimum for such an operation; one man dives, one controls the safety line, and the third is responsible for diver-boat communication.

Diver Examination of Bed and Sample Collection

By means of audio connection and by sense of touch, the divers were able to describe bottom topography and composition of the riverbed (i.e. mud, sand, rock, sizes of rocks, etc.) in highly turbid water. In clear or very slightly turbid water, an underwater camera or television assembly could be used.

The divers were equipped with a coarse mesh bag for collecting larger bulk samples. This bag was connected to a separate line to allow for independent retrieval of collections. For collecting biological material, the coarse mesh bag was replaced by one with a fine mesh (12 strands/cm) which permitted the retention of organisms as small as second-instar black fly larvae. Sample collection was attempted at several locations in both shallow water (1.3 m deep) and in deep water (up to 5 m) at velocities up to 1 m/sec at slow-water sites, and above 1 m/sec at faster flowing sites. In shallow water, only snorkel equipment was used, whereas in deep water Scuba equipment was necessary.

Underwater Television for Riverbed and Insect Examination

A small portable Sony television camera in a waterproof case, connected to a video-tape recorder and monitor on the boat was used in this test. Light source consisted of four flood lamps attached to the camera case. Power was supplied by a 1,500-W portable gasoline-powered generator in the boat.

The equipment was evaluated in several locations along the river in shallow and deep water of varying velocities.

RESULTS AND DISCUSSION

Diver Examination of Riverbed and Sample Collection

The reaches of the Athabasca River located beyond 100 km downstream of the town of Athabasca are known to have high populations of the black fly *Simulium arcticum* and, for this reason, attempts at sample retrieval were made at three points in this area. It was found at every site that the diver could maneuver successfully only in relatively quiet water (<1 m/sec). The parts of the river in which these conditions exist are, however, not the conditions under which the larvae of *S. arcticum* are found. Attempts to have the diver work in the deep channels and rapids where the water flows swiftly and where it was hoped that black fly larvae could be obtained, failed for two reasons. First, it was almost impossible to anchor the boat securely in fast water and, secondly, the diver was unable to control his attitude and movements underwater. In one instance at a point 200 km downstream, the boat was anchored in relatively quiet water at the edge of a fast channel. The diver was allowed to move back on his safety line to a point 60 m behind the boat. At that point, he attempted to move laterally into the fast water of the channel. Each of several attempts was unsuccessful as he was immediately swept back into quiet water with no more than minimal and momentary penetration of the faster water. These attempts were at the expenditure of much human energy, and also resulted in severe buffeting of the diver.

After this, attempts were made to obtain samples by wading in chest-deep water. These attempts were in an area of high larval black fly populations, as indicated by the attachment of larvae to artificial substrates in other work that was going on at the same time.

In all situations, the rocks recovered by the diver were not clean but were covered with algae, and were therefore not suitable as attachment sites for *S. arcticum* larvae. It was evident in this section of the river that the area in which the rocks were scoured clean by high current velocities could not be reached. Other bottom-dwelling organisms were obtained, but numbers were low since many were carried away by the current during transfer to the sample bag.

Although the divers were not successful in faster waters, they were valuable in the identification of the riverbed material and in the selection of locations for the placement of sampling equipment. It is important that these are placed so as not to be influenced by abnormal hydrological phenomena that would bias any results obtained from such equipment.

We are confident that, through a cooperative effort, a towable underwater sled with controllable hydrofoils operated by the diver could be developed for use in fast flowing turbid rivers.

Underwater Television for Bed and Insect Examination

In above-surface tests, the television equipment functioned well and picture quality on the monitor was excellent. The resolution was sufficient to identify floating objects such as small sticks and bubbles. However, no resolution was attainable in the picture when the camera was submerged. The lack of visibility was uniform, whether working in the main current or in quiet shallow water, regardless of depth.

The turbidity of the water (14 JTU) was far too great for penetration by the artificial lights. In addition, significant reflection of light from the water-borne silt particles effectively blinded the camera and registered on the monitor as a featureless flickering.

CONCLUSIONS

Highly turbid and fast flowing rivers pose significant problems to biologists and hydrologists in the systematic evaluation of phenomena that affect aquatic biology. Divers can be used successfully in identifying, by touch, characteristics of the riverbed at lower current velocities. However, research is needed to design equipment to make it possible for divers to work in faster flowing water. Similarly, procedures and equipment must be developed for recovery of insect material, especially black fly larvae, from riverbeds in deep, fast flowing water.

The use of closed-circuit underwater television is impractical in very turbid rivers because of reflection and lack of penetration of light from auxilliary sources.

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