CONTROL OF BLACK FLIES IN THE ATHABASCA RIVER

EVALUATION AND RECOMMENDATIONS FOR CHEMICAL CONTROL OF *SIMULIUM ARCTICUM* MALLOCH

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FOREWORD

This publication 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.

This publication is based on 'Control of Black Flies in the Athabasca River: Technical Report' and related published material.

REPORT ACCEPTED BY THE

ALBERTA BLACK FLY COORDINATING COMMITTEE*

ALBERTA ENVIRONMENT

28 November 1979

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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.

ACKNOWLEDGMENTS

Principal scientific and technical participants in the Athabasca Black Fly Control Program have contributed the data base in a technical report (Haufe and Croome eds. 1980). In addition to this they have expressed valuable views from different fields of experience and personal interest for consideration in this publication. Gratefully acknowledged for their contributions in this respect are Professor J. R. Anderson, Dr. S. Beltaos, Dr. W. A. Charnetski, Dr. K. R. Depner, Mr. J. F. Flannagan, Dr. M. A. Khan, Dr. W. L. Lockhart, and Mr. J. A. Shemanchuk.

Criteria are notably nonexistant in principle for resolving basic environmental issues, particularly in the implication of a pesticide in large freshwater drainage systems. The data base in this publication has been consolidated from the results of multidisciplinary studies in which various methodologies have been employed, in some cases to reflect different concepts of the environmental characteristics of a river system. This has led to some conflicting views and contradictory interpretations of the environmental impact of operations. For practical purposes, the risks and benefits of methoxychlor need to be weighed conclusively for a technical position on its acceptability as a larvicide in river treatments for black fly abatement. Therefore, it has been necessary for the author to assume responsibility for judgment of the balance of all the data, along with the evidence from the available literature, in developing the final interpretations, evaluations, conclusions, and recommendations in this publication.

I am grateful to Mr. G. C. R. Croome for his expert editing of the final draft.

CONTENTS

1. 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 solution 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.

Anonymous. 1972. The black fly situation in Athabasca County and I. D. 18 Lac la Biche. Brief of the Livestock Owners' Committee to representatives of the Governments of Alberta and Canada, 13 July 1972. Grassland Community Centre, Grassland, Alberta. 7 pp.

Anonymous. 1973. Biting flies: Report of a work-planning meeting on biting flies and their control, 31 Oct.-2 Nov. 1972, Saskatoon, Saskatchewan. Agric. Can. 27 pp.

Freedeen, F. J. H. 1969. Outbreaks of the black fly *Simulium arcticum* Malloch in Alberta. Quaest. Entomol. 5: 341-372.

Hudson, A. (ed.). 1973. Biting fly control and environmental quality. Proc. Symposium at the University of Alberta, Edmonton, 16-18 May 1972. Defence Research Board, Ottawa. Rep. DR 217. 162 pp.

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2. 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.

3. 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.

4. 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.

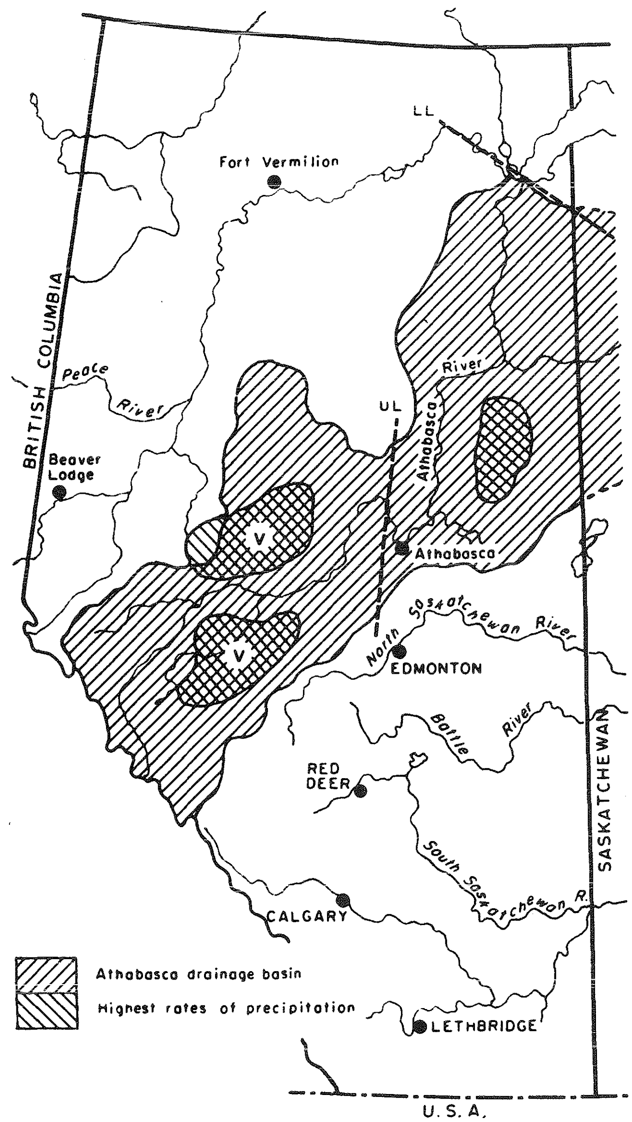

Fig. 1. The province of Alberta showing the Athabasca River Drainage System with the upper (UL) and lower (LL) limits of the study area and areas within the province having the highest rates of precipitation (Mean precipitation >560 mm/yr; days with precipitation >120/yr) and least annual variation (V)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

5. THE STUDY AREA

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 km² (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.

Of the drainage area, about 75,000 km² including Athabasca County and the downstream part of the Athabasca basin is covered by organic soils. These soils are

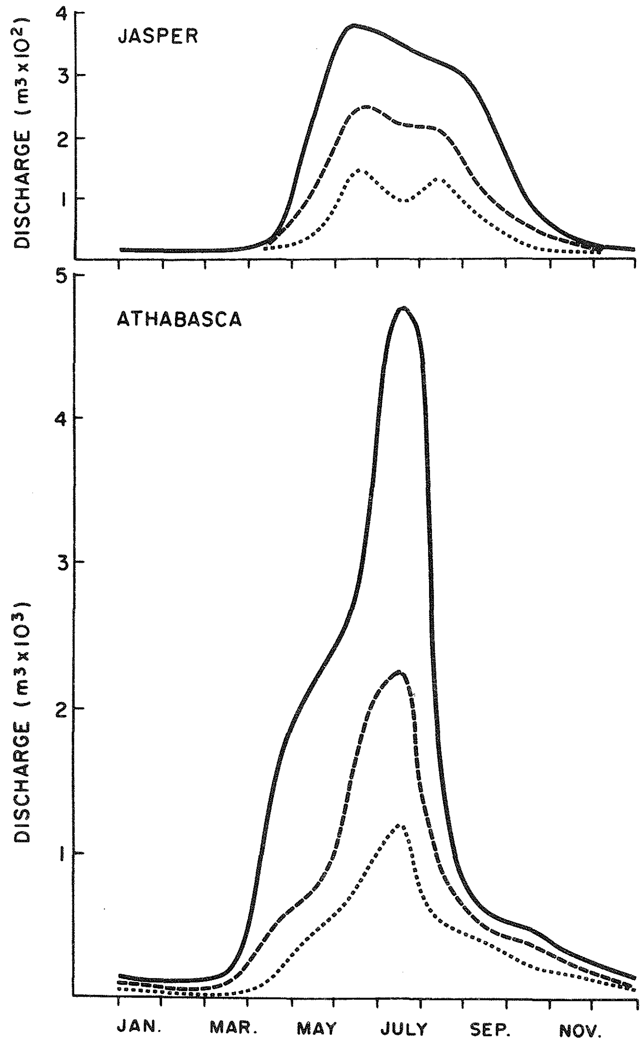

Fig. 2. Monthly variation in discharge of the Athabasca River as represented by the maximum (——), mean (---), and minimum (...) for the headwaters at Jasper (Station 07AA002) and for Athabasca (Station 07BE001 of Water Survey of Canada).

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 occurrence of infestations in the area.

6. SOURCE OF INFORMATION

A feasibility study (1973) and a 4-yr interdisciplinary research program (1974-1977) provided a data base for an evaluation of the effectiveness and environmental implications of the use of methoxychlor as a larvicide in river treatments to control outbreaks of the black fly *S. arcticum*. The interdisciplinary technical contributions to the research problem have been consolidated in a separate report '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' (Haufe and Croome 1980).

This report has been prepared from the data base in the technical report (Haufe and Croome 1980) and related publications (Section 13). It is an evaluation of available information on two questions of concern in an approach to the practical abatement of outbreaks of *S. arcticum*. The first concern is the effectiveness and environmental acceptability of methoxychlor as a larvicide for the control of *S. arcticum* in river treatments. The second is the socio-economic benefit of a strategy of controlling black flies at the source of infestations in river habitats as compared with the development of other options such as animal protection on farms.

7. PESTICIDE MANAGEMENT AND THE ENVIRONMENT - A CONCEPT OF EVALUATION

The Athabasca drainage basin, which comprises about one quarter of the land area in Alberta, is a highly complex environment for a diversity of life support systems. Ecological relationships are intrinsically subject to perturbations of natural origin through seasonal and episodal fluctuations in climate and consequent variations in river hydrology and the physical environment. It is against the range and frequency of perturbations of natural origin in the ecosystem that the consequence of any technological intervention must be evaluated. Even with an unlimited budget in this context, the design of a research program to cope with the complexity and magnitude of ecosystems will inevitably fall short of identifying and assessing all potenial perturbations that may accrue directly or indirectly with the introduction of a pest management practice. It is unrealistic and impractical, therefore, to design investigations within this scale of biological diversity for precise predictability of consequences.

A practical concept of program design is to achieve the means of operational accountability in detecting and avoiding unacceptable magnitudes of perturbations that may accrue with the immediate or long-term practice of a technological intervention in the environment of the ecosystem. The consequences of intervention in this case are evaluated within the natural range of variations exhibited and normally tolerated within populations of organisms. A technical intervention in pest management is environmentally acceptable if it is effective in controlling the target organism while inducing no measureable ecological perturbation in excess of natural ranges of variation in populations of non-targets. This concept implies that natural ranges of variation in populations are estimated in terms of behavioral patterns, phenology, and life cycles as well as chronological change in numbers.

The Athabasca Black Fly Control Program was designed primarily to evaluate the use of a pesticide in a large river according to the above concept. Emphasis was on the development of acceptable environmental accountability in the design and operation of an abatement program. Environmental and public accountability presupposes a scheme for the management of future abatement programs. In this scheme, essential parameters for control of treatments and for monitoring the environmental impacts are integral parts of continuing operations (Fig. 3).

The decision to implement a pest control operation involving the introduction of a pesticide to a large environmental system such as the Athabasca River is ultimately a political decision. The role of science and technology in contributing to this decision is confined to the process of developing, organizing, and communicating the available and pertinent information for this purpose. In accord with a concept of assessing environmental impact stated above, and also with a scheme of management and control for public accountability (Fig. 3), an evaluation of the research program and related available information is concerned with four objectives:

first, to provide a measure of the risks and benefits of the operation as clearly and completely as possible within the resources allotted;

second, to weigh the adequacy of available information;

third, to advise on procedures to detect injurious consequences and reduce risks in operations; and

fourth, in the event of a decision to implement the operation, to advise on further technical modifications and improvements that are feasible in maximizing advantages and in minimizing risks.

Since the consequences of technical interventions in large complex environmental systems are beyond precise prediction from the results of modest initial research programs, much of the risk has to be measured and minimized in the course of operations. The major requirement in an evaluation of this kind of intervention is provision of sufficiently sensitive monitoring procedures as an integral part of the operations to satisfy reasonable public accountability in detecting and in minimizing risks. The outline and conduct of the Athabasca Black Fly Research Program (Haufe and Croome 1980) has been based on this primary concern in an operational abatement program.

8. CRITERIA AND STANDARDS FOR ENVIRONMENTAL IMPACT STUDIES

Despite the large amount of research that has been recorded on the biota and its environment, there are still no definitive criteria or standards, even in general principle, that can be applied in assessing perturbations in ecosystems. The available knowledge of freshwater systems has been gained largely from studies of lakes and small streams. Large swift rivers such as the Athabasca have remained relatively unstudied in terms of populations, distribution, behavior, and life cycles of organisms. Consequently, there is very limited knowledge as background for the evaluation of environmental impact of pesticides in a large river system.

With insufficient available background information for large river systems such as the Athabasca in comparison with other freshwater environments, the research program was designed to achieve first approximations of environmental impacts based on physical as well as biological parameters of the system. For this reason, studies included hydraulics of the river for an appreciation of physical conditions as a common denominator to which all biological assessments, for both target and non-target organisms as well as water quality and river bed load, might be related. The major part of the methodology in the interdisciplinary projects was integrated in initial planning to facilitate this requirement for accountability in the final analyses of data. Unfortunately, some of the data on non-target invertebrates have been developed outside this framework. They are associated with conflicting interpretations that require consideration in greater detail in Section 9.4 of this report. Fish, because of their extreme mobility and frequent migrations in rivers and streams, present difficulty in devising a quantitative study of their response to the physical parameters of any treated part of the course of a river.

Since background descriptions of large river systems and their fauna are non-existent in the literature, criteria and standards in this evaluation have been developed largely without precedent. They are based on rationales supported by the limited program data base which, though highly indicative of the tolerance of a pesticide by the ecosystem, is still incomplete in some required details. In order to compensate for first approximations in this situation, criteria are applied as far as possible in terms that may be accountable for further refinement in the management and control of operations in any established abatement program. Thus, river hydraulics were included as an essential part of the program to serve as a reference for physical conditions and standards of treatment and for environmental assessments in future developments and reviews of operations.

9. SCIENTIFIC AND TECHNICAL EVALUATION

9.1 A Physical Model for River Treatments

In as much as the air is the medium for the development, dispersal, distribution, and survival of terrestrial organisms, so also is water for the comparable existence of aquatic taxa. The physical as well as the chemical characteristics and conditions of the life-supporting medium are fundamental to accurate interpretations of the effects of a pesticide on biological and environmental processes. In the concept of river treatment for black-fly control, effectiveness against the target and accountability for detection and reduction

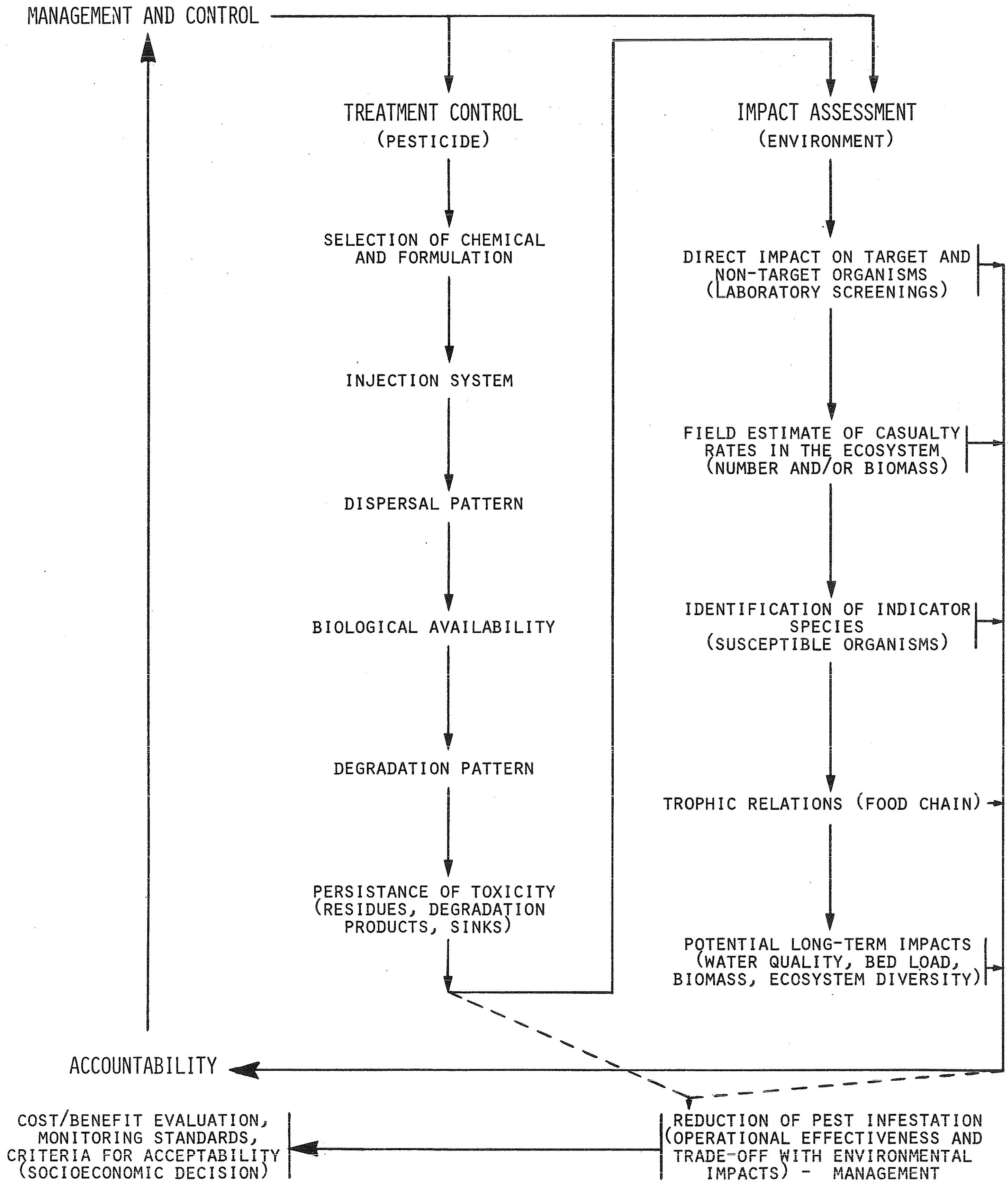

Fig. 3. Scheme for management and control of black fly abatement programs employing chemical treatment of rivers.

of hazards to non-targets and environmental quality are directly related to an understanding of the physical and chemical dispersal of the pesticide in moving water.

Predictability and environmental control of a chemical introduced to flowing water is determined physically in the first instance by hydraulics. Hydraulic action influences dispersion and uniformity in concentration as well as movement downstream. Contact of the pesticide with aquatic organisms and the bed of the river is governed by hydraulic action. There is some assurance of accountability for chemical concentration and movement in water and for deposition and losses in environmental sinks when the fate of chemicals can be modelled in physical terms of river hydraulics.

In a study of the hydraulics of the Athabasca River, a model was developed from hydrometric measurements to account for substance-specific processes in the mixing of the pesticide (Technical Report: Beltaos, p. 97). Two hypotheses, sorption by suspended particles and losses to the channel boundaries, provide fair predictions of the downstream decline of the recovery ratio. Correlation of hydraulic parameters with data for larvicidal efficacy and for chemical residues in water indicate that quantitative prediction depends on three empirical coefficients that were determined to fit the observed variations in recovery ratio. The desired hydraulic model has been partially verified and some further research is required for its application in predicting detailed mixing characteristics including time-concentration curves for cross-sectional profiles in river flow. The complete verificiation of the model will be necessary in extending larviciding techniques to rivers other than the Athabasca River.

A simplified version of the hydraulic model developed from the program is based on one-dimensional theory for neutral substances such as tracers (Technical Report: Beltaos and Charnetski, p. 123). It accords closely with recovery ratios for pesticide residues in water in which the cross-sectional average concentration at any given instant is used as a satisfactory approximation to all other curves in the river flow. Since the mixing process and the appearance of concentration-time curves are influenced by the capacity of the channel boundaries to retain methoxychlor, the simplified version of the model provides rough predictions of average concentration with time based on coefficients related to the reaches of river studied in the research program. Its application is limited to operations on the Athabasca River between Athabasca Town and Fort McMurray. In these operations, it will provide estimates of peak concentration and concentration curves for methoxychlor at designated sites downstream of the highway bridge at Athabasca.

A fully desirable basis in hydraulic engineering for development and management of a pesticide in river treatments was beyond the resources and outline of the experimental program. The application of hydraulic principles in interpreting the effectiveness of treatment and in accounting for the behavior of the pesticide in explaining variations in results of this program is a precedent for all previous larviciding studies for black flies. Although still incomplete for the extension of river treatments to large rivers other than the Athabasca, the preliminary modelling of a river system in hydraulic terms (Technical Report: Beltaos and Charnetski, p. 123) is a major step toward the objective of achieving full accountability in future development and use of pesticides in rivers and streams. The hydraulic parameters in the modelling process are primary considerations not only for the management of practical black fly control programs, but especially for the development of the appropriate formulations of any pesticide to optimize effectiveness and to reduce environmental risks. More definitive aspects of river hydraulics are identified in relation to other results of the program in recommendations for priorities in future research and development.

9.2 Larvicidal Control of Black Flies

Major production of *S. arcticum* larvae involved in outbreaks of flies in farming areas occurs in the reaches of the Athabasca River between the town of Athabasca and Fort McMurray. Variations in rate of hatching of eggs, still unexplained, and possible interrelations with velocity and levels of discharge in the river are reflected in large seasonal variations in rate of infestation of breeding sites, and also in large annual fluctuations in larval production. Monitoring of larval populations is required beginning immediately after spring break-up of ice at points below 100 km downstream from the town of Athabasca to determine the need for control operations to prevent a serious outbreak of flies in summer. With the use of cones developed as standardized artificial substrates in a monitoring procedure, it is estimated that larviciding is required when larval numbers exceed an average of 500 per cone beyond 100 km downstream of Athabasca.

Larvicidal treatments are effective with methoxychlor injected at a uniform rate to provide a concentration of 0.3 ppm in the river flow for 7.5 min. The effective range of treatments in the course of the river varies with rate of river discharge. The distance is in the order of 120 km if the rate of river discharge is less than 560 m^3/sec. At higher rates of discharge, range of effectiveness exceeds 160 km.

Method of injection of the pesticide is a critical factor in the effectiveness of treating large deep rivers such as the Athabasca (Technical Report: Depner et al., p. 21). Treatment dispensed from powered boats according to outlined procedures enhances dispersion and mixing of the pesticide to achieve uniformity of concentration within a reduced time scale. It also provides flexibility for optimum choice of injection sites in wilderness areas.

One spring or early summer treatment, optimally scheduled by monitoring the rate of buildup of larval infestations after spring break-up of ice in the river, will effectively control an expected outbreak of *S. arcticum* during the summer. A single annual treatment, however, has no observable effect on the potential for an outbreak from posttreatment buildup in a subsequent year. Therefore, a practical abatement program will require regular annual monitoring of larval infestations for 6-8 wk after spring break-up of ice every year.

Effectiveness of methoxychlor as a black-fly larvicide during 3 yr (1974-1976), combined with hydrometric interpretations and correlations of larval reductions with methoxychlor recovery and its variation in the downstream river flow, indicates that two injections are necessary in each annual treatment. The two injections are required to control the heavy infestations in the most prolific breeding sites downstream of Athabasca to Fort McMurray, the potential source of black-fly outbreaks in agricultural areas.

An important limitation in minimizing the reach of river treated to sites of infestation is the lag in required level of pesticide mixing downstream of injection points. Pesticidal efficacy in reducing larvae, the pattern of recovery of residues downstream, and an interpretation of concentration curves according to hydrometric parameters show that 95% mixing is achieved within 20 km from the injection point. Injection from boats to provide an essential transverse linear deposition of the pesticide concentrate with river flow at the injection point is a major improvement over stationary injection in promoting advective and turbulent mixing downstream. Further improvement in injection techniques to reduce the mixing time for uniform concentration is still required to eliminate the need to treat excessive reaches of river above breeding sources for efficient and environmentally desirable control of infestations.

The results of the program have identified aspects of operations such as injection procedures, methods of accounting for the hatching of eggs, and appropriate formulation of pesticides within hydrometric and physico-chemical parameters for efficient mixing in river flow as potential areas for technical improvements. The advantages of relating technical research on these aspects to an accountable abatement operation, even to the point of integration, are obvious and receive further consideration in recommendations. Notwithstanding the desirable potential for technical improvements, the current design of treatments is highly effective, economic, and sufficiently accountable to be acceptable in the short term for practical control of *S. arcticum* in the Athabasca River.

9.3 Impact on Fish

Fish are the most mobile of organisms of animal populations in a river system. Their mobility creates practical problems in the design of adequate sampling methods to measure the effects of any intervention or episode in the river environment. Therefore, in studies of fish, the sampling of natural populations in the experimental reach of the river has been supplemented by monitoring the effects of treatments on caged samples, and by testing species in the laboratory for response to ranges of methoxychlor toxicity comparable to river treatments. In both cases of using caged fish and testing of species in the laboratory, there is no certainty that environmental conditions for measurements are completely representative of those pertaining to natural free exposure to the pesticide in a river system. Nevertheless, all the studies conducted are considered to provide reasonable estimates of the risks to fish populations in larviciding operations with methoxychlor.

Major concerns for the impact of methoxychlor treatments on fish include direct toxicity during exposure to the larvicidal pulse moving downstream, trophic interference in food chains supporting the fish population, and objectionable residues of the pesticide in fish tissues that might enter higher levels of the food chain including human consumption. Studies have been documented in the Technical Report with reference to toxicity (Lockhart, p. 183; Sebastian and Lockhart, p. 197), to trophic relations (Lockhart, p. 183), and to tissue residues (Charnetski and Currie, p. 75; Lockhart, p. 183).

There is no evidence that concentrations of methoxychlor comparable with river treatments were either seriously toxic or lethal to fish. Experimental poisoning of several species in laboratory tests indicate that tissue residues in fish exposed to the river treatment in 1974 approach to within a factor of 10 those causing gross morbidity and death. Risk in this margin is reduced in effective larvicidal treatments in 1975 and 1976 in which the time of potential exposure to the same range of concentration was half that in 1974. These results, in combination with failure in field observations to detect any evidence of fish in difficulty during and after injections of concentrate, indicate that risk of toxicity of methoxychlor to fish is acceptable for larviciding operations at the rate of 0.3 ppm for 7.5 min. Laboratory tests indicate that, in exposures determined as a constant product of time X concentration, short-term high concentrations are likely to produce higher residues than long-term low concentrations. With this relationship for concentration X time in toxicity, there is no concern for fish exposure in the extension of the pulse in time as it moves downstream.

There is evidence that further developments in formulation of methoxychlor may have potential in reducing risk of toxicity to fish in future abatement operations. A particulate formulation of methoxychlor is indicated in preliminary studies (Technical Report: Sebastian and Lockhart, p. 197; Helson and West 1978) as being less toxic than an emulsifiable formulation to Rainbow trout while possibly enhancing its selectivity as a larvicide for black flies.

Examinations of fish have revealed no indication that river treatments have interfered significantly with their trophic position in the food chain. Gut contents in samples suggest that fish suffered no deprivation of food. Low blood protein values were identified with one sample of four white suckers captured in July 1974 near Calling River. Low protein values may be induced in fish by a number of factors, one of which has been demonstrated in the laboratory as starvation for 8-16 wk. Although the reduced protein in the one sample is consistent with an interpretation of starvation, it does not indicate clearly that river fish were starving or that the observation was related to treatment. All samples of the same species captured after treatment the next year had normal blood protein values. There is no evidence from the accumulated laboratory analyses and field observations during the program that river treatments pose any serious risk for the trophic relations essential to the food chain for fish.

9.4 Impact on Invertebrates

One of the program objectives was to generate data for an analysis of the impact of river treatment on invertebrates as the most populous, highly diversified, and possibly the most biologically complex and dynamic component of the aquatic ecosystem. As an important component of the river biomass in terms of trophic relations, invertebrates were also considered to reveal the most obvious direct and indirect effects of methoxychlor as an intervention in ecological balance of the food chain, and consequently to indicate risks for environmental quality. Therefore, the analyses involve consideration of standing crop as well as aberrations in the biodynamic distribution and displacement of invertebrates in the river environment.

The pertinent data have been generated in three program operations. Two of these have been closely integrated in a sampling scheme developed in direct relation to the analysis of methoxychlor concentrations in water and bedload. Along with the methoxychlor residue analyses, they have also been designed within a framework of hydrometric parameters that govern the physical environment and that are applied in a hydraulic model for river treatments. Consequently, these parts of the studies are identified precisely with surveyed sampling sites for common reference to physical and hydrometric parameters of the river (Technical Report: Introduction, p. 1). The third operation (Technical Report: Flannagan et al., p. 131, 151) was developed independently of all other studies and consequently locations and methodology have not been identified within the common program framework of river studies including hydraulics.

Results of studies have been presented in the Technical Report with highly conflicting interpretations of the impact of methoxychlor on invertebrates. In the interest of reaching a conclusive assessment of the program, and in view of dissociation of the development of some results from an integrated framework for design of sampling and analysis, it is necessary to examine conflicting results and interpretations in this section with some clarification of methodology essential to hydrometric and biological parameters of the system. Resolution of differences must be considered on the basis of the available and relevant published knowledge as well as the validity of the methodology in justifying interpretations.

Flannagan et al. (Technical Report: p. 131, 151) contend that river treatments with methoxychlor are environmentallly unacceptable. They base their contention on an interpretation of their data in which methoxychlor causes 'catastrophic' drift that is detrimental to the maintenance of the standing crop of invertebrates. They contend further that the reduction in standing crop of invertebrates is demonstrated by their data on a scale that would deplete the food supply of fish.

The secondary contention that fish are deprived of food has not been borne out in related studies in the program. Studies on fish, as well as other observations during the course of treatments in 3 consecutive yr, have shown no evidence of starvation in fish specific to river treatment or even that fish samples on examination are lacking in gut contents. Therefore, conflict in interpretation of effects of treatments on invertebrates have to be considered *prima facie* in terms of the biological significance of what Flannagan et al. have defined as 'catastrophic' drift and how it relates to the contention that standing crop is seriously reduced. Resolution of differences depends on two requirements: first, that estimates and interpretations are in quantitative rather than qualitative terms; and second that interpretations and methodology are in accord with established knowledge of the nature and limits of the systems concerned.

9.4.1 Definitions.

The published information on the drift of stream insects was reviewed comprehensively by Waters (1972). The literature pertains to studies in small streams, but the concepts in terms of biological systems adapted to environments in flowing water are relevant in principle for consideration in large rivers. Therefore, while the functions and limits of biological systems in small streams may not be quantitatively relevant to large rivers for reasons of hydraulics, the qualitative definitions describing drift should be equally applicable.

In his review, Waters (1972) defined three qualitative types of drift that are distinguished by the cause of the downstream displacement.

1. 'Catastrophic' drift (Minckley 1964) results from the physical disturbance of the bottom fauna, usually by flood and consequent bottom scouring, but also by other factors such as drought, high temperature, anchor ice, pollution, and insecticides.

2. 'Behavioral' drift occurs during consistent periods of the day as a result of a behavior pattern characteristic of certain species.

3. 'Constant' drift constitutes the continuous stream of representatives of all species, in low numbers and occurring at all times.

From his review of related literature, Waters states "It is, of course, not always possible to distinguish among the three types for they overlap to some extent and also interact, but the effects may be decidedly different. For example, in respect to the effect on insect populations, catastrophic drift may have a decimating effect; behavioral drift, although in large quantities, may be density-dependent and serve only to keep populations at optimal levels; and constant drift probably has no effect. It is behavioral drift, involving sometimes large quantities and having the interesting aspect of rhythm involvement that has received the greatest scientific attention."

It is evident that a large literature already exists for small stream studies to indicate the implication of behavioral systems in the extreme variations that may be expected in numbers of drifting organisms. Accountability of behavioral patterns is a prerequisite, therefore, in establishing a background range of variations for a valid interpretation of either 'catastrophic' or 'constant drifts and their consequences for standing crop.

9.4.2 Interpretation and Evaluation of Drift.

It is clear from Waters' review (1972) and from related literature that 'catastrophic' and 'constant' drifts as related to live organisms are the result of physical and chemical factors interacting with behavioral drift. Since 'behavioral' drift is an integral function of biological systems, daily rhythms and the phenology of its occurrence in life cycles must be considered to establish a range of background variations before any part of the drift can be interpreted as a catastrophic effect of an episode. In a study particularly concerned with interpretation of drift in streams, Waters (1965) states "We must differentiate between drift that occurs as a result of some behavior characteristic of animals that respond to changes in light intensity, which causes a diurnal periodicity in drift, and drift that occurs as the result of floods or other physical disturbance." He also states "... upstream areas apparently are not depleted by behavioral drift as indicated by the present results in the standing crop-drift relation ...." Müller (1954) states clearly that depletion of upstream areas does not occur even where he observed extremely high drift rates. Consequently, Waters (1965) suggests that it is not necessary to postulate upstream movements as a replacement mechanism to accept downstream displacement by behavioral drift. He asserts rather that such high behavioral drift appears to occur as a form of density-dependent removal under conditions of high rates of production (Waters 1961). On the other hand, upstream movements have been observed after floods or exceptionally heavy flow where the movements appear to function as a mechanism of replacement of catastrophic drift (Allee 1929; Stehr and Branson 1938; Minckley 1964), following a drought when desiccated stream areas are recolonized by upstream movement (Stehr and Branson 1938), and to colonize temporary newly filled tributaries (Neave 1930).

Waters (1961) also studied the standing crop and drift of stream-bottom organisms. He came to the conclusions that "The distribution of drift of invertebrate animals among five Minnesota trout streams compared favourably with a ranking of expected productivities made on the basis of surrounding geology, water alkalinity, and available trout population data. The distribution of standing crops of the bottom fauna among the five streams was not at all similar to the ranking of expected productivities, nor to the distribution of drift rates, until the standing crop samples were qualitatively limited to groups of organisms having similar longevities. When the standing crop samples were limited only to those organisms having two or more generations per year, the distribution was similar to the ranking of expected productivities and remarkably close to the distribution of drift rates."

With further reference to the standing crop-drift relation, Waters (1965) states that "Drift rates may be similar at different locations, whereas standing crops vary widely indicating that the drift rate at any given location in the stream is not a function of the bottom density at that location, but rather a function of factors existing throughout a much longer distance upstream from the nets.

The quantitative relationship between drift rate and population density and the stream bottom upstream from the point at which drift is measured cannot at this time be determined. Results suggest a daily distance of 50 to 60 m and this indicates that not the entire stream up from the nets is serving as a source. Hypothetically, the drift rate at any one point is some function of the area upstream serving as the source of drifted organisms, the population density on that area, and the relative rates of production and other forms of mortality."

The literature relating to drift of organisms, while rather extensive for small streams, is confined to biological considerations. Outside the Athabasca Research Program, there appears to be no record of studies referring to the influence of hydrometric parameters on biological systems. Particularly in the case of large turbulent rivers, hydrometric parameters may very well be the overriding factor of the physical environment influencing or even limiting the recognized biological mechanisms that stabilize the distributions of aquatic organisms. Notwithstanding the lack of studies on this aspect of the system, a rationale may be drawn from the analogous concept of distributions of terrestrial invertebrates that are relatively well studied.

Just as the distributions and behavior of aquatic organisms are subject to physical limitations and aberrations in a fluid medium, so also are terrestrial forms in an atmospheric medium. The issue is basically whether certain qualitatively designated displacements in the life-supporting medium are extraordinary to the range of variations that, with appropriate detailed studies, may be found to be within the limits of behavioral mechanisms. The analogy between the two life-supporting media may be related directly to the issue of behavioral vs. 'catastrophic' drift in flowing water.

In detailed studies of mosquitoes in extensive areas of prolific breeding and adult infestations characteristic of the sub-Arctic, a base seasonal level of flight activity (corresponding with stream drift) measured by a standardized trapping device for density per unit space was in an order of less than 10^2 for the summer season (Haufe 1952, 1966). This base level is maintained by diel behavioral rhythms in the pattern of activity during which very small parts of the standing crop are displaced by an interaction of physical factors in the medium (air currents) and active dispersal for short distances. This displacement corresponds with 'constant' drift in an aqueous medium in which an interaction of behavioral and physical factors (water currents) results in a steady displacement of very small parts of the standing crop for short distances. Waters (1972), in referring to the interpretation of invertebrate drift, says for example "We may further define the constant drift of occasional individuals of all species present that, for one reason or another, adventitiously lose their hold on the bottom and drift in low numbers without regard to any diurnal periodicity." In the terrestrial case for the analogy, the daily density of airborne mosquitoes in behavioral activities occasionally reach an order of 10^4 - 10^5 (Haufe 1966). These episodes are associated with the influence of major weather systems and, to use the qualitative definitions for drifting organisms in streams, might be classified as 'catastrophic' displacement on the grounds of the magnitude of members. The fact is, however, that in the studies of the distributions of mosquitoes, these occasional high densities do not deplete the standing crop and the base level is still maintained during intermediate and subsequent days. The occasional very high densities of airborne mosquitoes are obviously still associated with displacement within short distances so that infestation levels (standing crop) are maintained within the sampling area. High densities are the result of reinforcement of behavioral activity in a large proportion of the standing crop during one cycle of the rhythmic pattern by a physical episode (weather disturbance) in the environmental medium. Waters (1972) attaches corresponding significance to the 'qualitative' definition of 'catastrophic' drift of stream organisms when he associates it with floods and other forms of physical disturbance.

The point of the analogy here is that qualitative definitions in a highly dynamic biosystem are subjective and incapable of conclusive verification. Irrespective of the relevance of a qualitative definition as a description of an episode, an unacceptable technological intervention in a biosystem can only be identified in a quantitative measure of the disturbance exceeding characteristic variations and limits of biological mechanisms. An issue of conflicting interpretations then has to be resolved in the final analysis as a reevaluation of available data within the full concept and knowledge of the system. If there is a lack of correspondence in the data, then the methodology must also be subject to examination for appropriateness in what is already known of the system.

9.4.3 Evaluation of Differences.

The recorded knowledge outlined above has been developed from a large number of studies on small streams. It established a comprehensive concept of the variety and function of biological mechanisms that are accepted in principle as interacting to maintain a standing crop of organisms in flowing water. There is a noteable lack in previous studies of any procedures to relate functions of biological mechanisms to hydrometric considerations of the aquatic environment. There is little reason to doubt, however, that evolved biological mechanisms described for small streams apply in principle to large rivers. The variations and limits of the mechanisms, on the other hand, are likely to be different, and also characteristic of species adapted to the influence of hydraulic conditions in the physical environment, especially in large turbulent rivers.

In the face of conflicting interpretations of the impact of river treatments on invertebrate taxa, the claims are resolved in two contexts:

1. The validity of interpretations in relation to the present state of knowledge of functions of biological mechanisms known to comprise the system.

2. The adequacy of methods and procedures and their relevance to known parameters not only in the biological system but also in the physical environment.

The claim by Flannagan et al. that river treatments with methoxychlor are unacceptable is the only contention counter to a favorable recommendation for a black fly control program. Some aspects of their data as well as the interpretation of data are inconsistent with those in other studies relating to the same treatments. Specific aspects of interpretation and data are reexamined therefore within the whole concept of the river system and treatments to determine whether claims are substantiated in concept, methodology, and interpretation. In my view, some specific aspects of the claims by Flannagan et al. are questionable on grounds of scientific interpretation, methodology to substantiate theroretical contentions, and accountability of results in conflict with other studies of the same river treatments. These aspects are itemized separately with comments as below.

1. Interpretation of 'catastrophic' drift. As pointed out from a review of the literature, the term 'catastrophic' drift is defined as a qualitative description of displacement of organisms caused by a physical or chemical disturbance in the environment. The question for technological purposes is not whether the *quality* of the drift is detrimental to the standing crop of invertebrates; it is whether the *magnitude* and *distance* of the observed drift is sufficiently detrimental to seriously dislocate or reduce the standing crop or its potential to regenerate. Flannagan et al. use the term and all it may imply to the uninitiated reader without any quantitative substantiation of their claim for the consequences of their interpretation.

2. Impact of methoxychlor. Some taxa are sensitive to methoxychlor, and numbers in the drift increase with the arrival of a treated pulse of water. This response is shown by all studies in the program. Some caution is required in interpreting the consequences of this sensitivity. First of all, it is well known that methoxychlor, like DDT, stimulates hyperexcitability in various animals (Gardner and Bailey 1975). The effect of even sublethal amounts of active ingredient and formulating constituents in stimulating activity has been widely observed. Of concern in all measurements of drift associated with river treatments is whether this increased drift is of sufficient magnitude and distance to jeopardize the standing crop irrespective of whether it is called 'catastrophic' drift or 'behavioral' drift. Increased drift in this case may be an amplification of organisms participating in a diel cycle of the behavioral drift that is of brief duration over short distances. If so, it is of trivial consequence to the distribution of standing crop. Such an episode would also be of minor significance in comparison to the effects of flood conditions to which biological functions are undoubtedly well adapted.

Flannagan et al. in their interpretation of drift data contend that the treated pulse imposes a massive sweep of taxa over long distances downstream. This interpretation is not supported by results from similar sampling of drift coincident with both treatments in 1976. Otherwise, with the application of their methods and modifications of their equipment for operation in all parts of the river cross-section (Technical Report: Haufe et al., p. 159), the two treatments in 1976 had different effects on the drift than treatments in 1974 and 1975. The 1976 data are in marked contrast with data of Flannagan et al. in three significant aspects. First, the duration of amplified drift density for all taxa in both treatments in 1976 was confined to periods of no more than 6 hr in comparison to several days in Flannagan et al.'s studies. Secondly, the amplified drift in the 1976 studies were dramatically associated with the leading edge of the methoxychlor pulse. This supports the interpretation of the widely observed stimulation of hyperexcitability in taxa as an initial behavioral response to methoxychlor even for sublethal concentrations. Thirdly, with the exception of Plecoptera, drift densities of taxa returned to and were maintained in the same order of magnitude after the passage of the methoxychlor pulse as were observed preceding the pulse. The reduction in densities of some Plecoptera may be accounted for by mass emergence observed on the shoreline opposite riffles before and during passage of the pulse. In fact, Flannagan et al. omit any consideration of phenology in their interpretation of results. For example, the emergence of the most abundant genera of Plecoptera are closely synchronized phenologically with the stage of development of black flies that is optimal for effective river treatment.

Flannagan et al. are extremely obscure in details of sampling locations. They provide only a passing indication that their samples were obtained near the left bank at all four sampling sites. Despite the need for interdisciplinary and inter-project assessment of program results, they have not responded to a request for identification of sampling sites (Technical Report: Introduction, p. 1) corresponding with all other studies in the program. This situation obviates a reasonable understanding of methods, procedures, and environmental conditions pertaining to their results in comparison with those recorded for other related studies. Relative to interpretations of impact at this point, however, there is cause from the overall knowledge of stream drift of invertebrates to suggest for two reasons that their data do not reflect 'constant' drift and displacement in the main flow of the river, but do represent to considerable extent the behavioral drift very near the shoreline. Haufe et al. found that the equipment could not operate in swift currents between the thalweg and half the distance to the ebb-current shore without modification. Flannagan et al. mention all three downstream sites to be near the left bank in 1974, but provide no references to river cross-section for samples in 1975. Yet, without any recognition of *qualitative* distinctions clearly established in the literature (Waters 1972) for 'catastrophic', 'behavioral', and 'constant' drifts, Flannagan et al. assumed an estimate of 2.5 billion animals in catastrophic drift in the cross-section of the river for 4 hr. Again for reasons of valid methodology to be noted below, there are no grounds for this estimate based as it is on unreplicated samples in the cross-section of the river.

The lag in mixing of methoxychlor in the course of the downstream displacement of the pulse after injection is a technical problem. In 1974, stationary point injection from the bridge resulted in a displacement of over 50 km for near uniform mixing. Transverse linear injection in the cross-section in 1975 and 1976 reduced the distance for mixing to the order of 20 km for the same treated stretch of river. It is during the mixing stage of treatment that non-targets are at risk in exposure to pockets of high concentration of methoxychlor in the pulse. Flannagan et al. state (Technical Report: p. 151) "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." If this observation is to be significant in relation to their contention that standing crop is depleted by massive displacement in the drift, then it is critically important to measure level of mortality, immobility, and disabling behavior associated with the drift to support conclusions. These measurements were carried out by Haufe et al. (Technical Report: p. 159) for both treatments in 1976 in relation to hydrometric parameters and the monitored passage of the pulse. Highly variable and sporadic casualty rates in the drift at different points in the river cross-section indicate the risk to non-targets of insufficient mixing in pockets of the current immediately downstream from the injection site. Casualties were confined to a small number of sensitive genera, particularly *Cheumatopsyche* and *Hydropsyche* in the Trichoptera. They did not exceed a maximum of about 40% in the range for individual samples in the cross-section. In terms of reproductive potential of invertebrates and the mechanisms for distribution of the standing crop, these casualty rates within the limited range of the mixing zone of the river are not considered to have any serious consequence in the maintenance of the invertebrate food chain. If an average of casualties in all samples within the cross-section is taken as a measure, the rates for both treatments in 1976 are below 23% for any of the genera. The above casualty rates, nevertheless, must be considered in the trade-off with benefits of black fly control in river treatment. It is not realistic to expect that any formulation of a pesticide can be used in pest control programs without some element of risk to part of a large array of non-targets.

In the event of river treatments for black fly abatement, there is evidence of potential for technical improvement both in methods of injection and selectivity for the target organism. Research emphasis is needed on pesticide formulation as a potential means of reducing risks for non-targets in both mixing efficiency after injection and adsorption to particulate washload in the river.

Flannagan et al. (Technical Report: p. 151) interpret samples of organisms from the benthos to show that the methoxychlor treatment, even at the reduced dose in 1975, had major effects on the invertebrate fauna of the river. As with their analyses of invertebrate drift, they have ignored phenology in the comparison of samples within seasonal time series. Their conclusions are subject to the same kind of omission cited above for stream drift. They state "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." Certainly in the phenology of some Plecoptera, and possibly also in other Orders, the major emergence of mature taxa from the river occurs in late May and early June. While Flannagan et al. use the phenology of hatching of the young of most species in June and July, which is correct, to adjust results for their contentions based on drift samples, they ignore the effect of major emergence on benthic populations. In his review of the literature on drift, Waters (1972) refers to high levels of drift resulting from pre-pupation and pre-emergence activity. Accordingly, the time-series decline at Flannagan et al.'s control station is exactly what is expected from the literature on other studies. In fact, if one compares Flannagan et al.'s fig. 4 (Technical Report: p. 151) for Ephemeroptera, Plecoptera, and Trichoptera with the baseline study of invertebrate drift in 1977, a year with no treatment (Technical Report: Haufe at al., p 169) in which the study site corresponds approximately with Flannagan et al.'s site II, the relation of densities to phenology become obvious. Flannagan et al.'s claims for consequences of methoxychlor treatments on benthic populations are not substantiated convincingly when their data are carefully inspected in relation to established phenology and life cycles.

The tendency of Flannagan et al. to interpret data without reference to the broader context of ecological and biodynamic interrelationships recognized in literature reviews on stream insects, and insufficient outlines of their methods and procedures to interpret results relative to the river environment combine to obviate any clear resolution of their conflict with results of related concurrent studies on resident populations (Technical Report: Depner et al., p. 141). The studies of Depner et al. represent a complete regular time series spanning the treated reaches of river for the whole spring-summer season during two baseline years without methoxychlor treatment, 1973 and 1977, and three intervening and consecutive years with treatment, 1974-1976. If one inspects the variation in average monthly frequencies for key genera of non-target invertebrates both within years and between years for untreated and treated reaches of the river, there are no variations to indicate that methoxychlor treatments have jeopardized the standing crop. While some variations between May and June, i.e., at sites within the mixing zone in 1974, could be consistent with brief minor disturbance by the methoxychlor treatment, inspection of corresponding indices at sites in the untreated reach upstream of injections display variations of equal magnitude not associated with treatment. The same studies show clearly that diversity of genera in the sampling series increased each year between the first baseline year (1973) and the last (1977). There is a possibility from the literature on studies of density-dependent factors in population competition that river treatments might limit excess potential of dominant abundant species to the advantage of lesser species within the carrying capacity of the river bottom for standing crop. It is also possible, however, that efficiency in sampling techniques increased with practice to result in recovery of a larger variety of taxa. The indication of increased diversity is assuring that 3 consecutive yr of treatment have certainly not jeopardized the potential of any taxa in maintaining the standing crop.

From the detailed examination of conflicting results above in relation to available published information, the contra-indications by Flannagan et al. for environmental acceptability of river treatments with methoxychlor must be discounted in terms of incomplete or unsubstantiated interpretations of data. On the balance of all the program results and their relation to pertinent published knowledge of concepts and biological mechanisms for small stream organisms, there is no convincing evidence that perturbations from methoxychlor treatment are seriously detrimental to standing crop of invertebrates.

3. Methodology. Methodology is the key to valid interpretations of complex dynamic systems involving biological mechanisms. Scientific and technical evaluation of the kind of conflict in evidence presented in the Technical Report for impact of methoxychlor on invertebrates is resolved in the final analysis in terms of validity of procedures and methods used to measure the contentious issues. It is necessary, therefore, in view of the overall assessment above, to document the inadequacies in methods related to questionable interpretations and results.

Conflict involves two basic issues. One is whether results and interpretations indicate, *and substantiate*, that displacement of organisms in the drift is of sufficient magnitude to potentially disturb the distribution of standing crop in relation to the carrying capacity of the river bed. The other is whether standing crop, as measured by samples from the benthos, is actually changed as a result of river treatments with methoxychlor.

With reference to the first issue, there is no practical method of making direct measurements to quantify displacement *per se*. An acceptable method would involve some means of labelling organisms and recapturing them downstream in relation to time and distance. Available methods, including those applied in this case, are indirect and depend on interpretations of the nature of the drift. The measurements in this case are dimensionally confined to changes in density of drifting organisms with time. They infer variation in the participation rate of benthic populations in the drift at the sampling site; but they provide no grounds for any claim of displacement for other than the shortest distances from the sampling site. As indicated earlier in the interpretation of invertebrate drift in streams, Waters (1965) concluded from his own and other studies that the daily distance does not exceed 50-60 m.

As a result of conflicting interpretations of results in interim reports of the program (1974-1975), additional studies were conducted in association with the treatments in 1976 (Technical Report: Haufe et al., p. 159). These studies were designed to analyze variation in the density of the drift within the cross-section of the river, and to relate interpretations to hydrometric parameters and time-concentration curves for methoxychlor in the passage of the pulse. These studies and the baseline studies without treatment in 1977 (Technical Report: Haufe et al., p. 169) define the distribution of the drift within a cross-sectional plane of the river. They distinguish comparative densities in the 'behavioral', 'constant', and so-called 'catastrophic' drifts in relation to the thalweg and ebb-current sections of the river flow. They show clearly that drift densities measured near the ebb-current shore and in backwaters represent 'behavioral' drift and cannot be used to represent either 'constant' or 'catastrophic' drift as defined in 'qualitative' terms, much less as estimates of downstream displacement of organisms. Although Flannagan et al. refrain from providing exact information on sampling locations in their reports, it is obvious that they are basing unsubstantiated interpretations on data representing ebb-current conditions. They provide no evidence that the variations that they are attributing to 'catastrophic' drift have been evaluated against inherent variations associated with phenology and 'behavioral' rhythms, both of which are fundamental to natural temporal variation in invertebrate systems. Irrespective of contradictory results from other integrated studies in the program, their sampling design and methods of analysis are clearly inadequate in relation to existing published knowledge to substantiate their interpretations and claims.

Serious questions also arise from the methods and experimental design used by Flannagan et al. in their sampling of invertebrates in the benthos. They dismiss other benthic sampling methods in favor of 'artifical substrates' because the "grab sampling methods were much more variable than the other two" (Technical Report: Flannagan et al., p. 156). This decision is reported without any evidence of an analysis to compare the different methods or to explain why variations in samples are not in fact a reflection of the natural variability in the systems that are being measured. From the point of view of hydrometric conditions in a swift turbulent river, 'artificial substrates' are above the bed and do not represent the benthos. In fact, they act as another trapping device for measuring the drift. Misinterpretations by Flannagan et al. are amply demonstrated by their own data. For example, referring again to the previously mentioned quotation from their report which goes on to say (Technical Report: p. 156) "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 stations 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 Station II and III coincident with the treatment, usually followed by at least partial recolonization in July and August." They imply that their own data at the control station for the Plecoptera and Ephemeroptera are anomalous to their concept of natural events. They then use the same reasoning to turn the application of this data that is inconsistent with their interpretation to an argument that their other data for downstream sites are biased against their claim for the effects of the pesticide. Their control data are in fact consistent with events and counter to their interpretation. The baseline study of drift densities with no treatment (Technical Report: Haufe et al., p. 169) in 1977 covers the same period, i.e., May-July, with sampling in uniform time series as that of the first three of Flannagan et al.'s four sampling intervals. The phenological variation in drift for indicator genera in the orders Plecoptera and Ephemeroptera have patterns identical to those in the data from Flannagan et al.'s control station. This indicates, counter to their interpretation to support their conclusion, that their control station data are not anomalous but a real reflection of seasonal phenology. Phenological correspondence between the artificial substrate and drift sampling methods indicate also that the artificial substrates are in fact indicators of drift rather than of resident benthic populations.

Flannagan et al. also mention a contrast between 1974 and 1975 in Ponar samples, but provide no data for comparison with the 'artificial substrate' results. This omission is curious in the light of their interpretations. They provide Ponar sample data for Chironomids and total taxa, which are entirely consistent with the expected phenological pattern, but not for the Plecoptera and Ephemeroptera which are primary orders in their contention that standing crop is depleted.

Irrespective of the validity of sampling methods, Flannagan et al. base all of their interpretations of sampling data related to standing crop on a gross misconception of phenological variation within life cycles. In the month of May, the total biomass of invertebrates is in the aquatic environment of the river. With advancing maturity and the beginning of mass emergence of many taxa in late May and June, a very large part of the biomass moves from the river to a terrestrial environment. It is inconceivable that this does not result in a very large reduction in the standing crop in the benthos during June and July until reproduction begins to replete aquatic populations in late summer and fall. As is to be expected, the phenological variation in density of drift during a year with no treatment (baseline study in 1977, Technical Report: Haufe et al., p. 169) reflects the seasonal change in standing crop of the benthos consistent with an appropriate recognition of life cycles. Flannagan et al. ignore this elementary established fact of life cycles and, as quoted, assume an *increase* in the standing crop of the benthos during the period of river treatment, which coincides with the beginning of seasonal mass emergence. In fact, the reduction in standing crop that they are attributing to the effect of treatment, at least in a large part of the measure, is merely the phenological variation associated with the basic systems of life cycles.

Statistical inferences in reports by Flannagan et al. are also open to question. For example, the presentation of statistical probabilities without any mean numbers or ranges for practical interpretation (Technical Report: Flannagan et al., p. 151, table 3) have little significance in demonstrating a quantitative measure of annual changes. Statistical procedures in this case are of little consequence in interpreting the results unless they are substantiated in clearly outlined procedures and sampling design.

Several aspects of design and equipment in sampling procedures employed by Flannagan et al. raise questions on conclusions and interpretations either because they have not been fully described and explained, or because they do not take biological complexity and hydraulic parameters into an account of the aquatic environment. For example,

1. Replication at sampling sites for drift is inadequate for the scope of their interpretations and conclusions.

2. Locations of sites and deployment of equipment with reference to the cross-section of the river are undefined.

3. As the later studies on drift have shown, the unmodified drift sampler could only function satisfactorily outside the main currents of the river.

4. Even though combinations of techniques for bottom sampling were obviously changed, numbers of taxa were compared between years without a clear indication of what samples were related and to what extent they were pooled.

5. Analyses appear to be based on excessive pooling of taxa, i.e. within taxonomic orders, so that it is difficult or impossible to relate results to what is already known within concepts of life cycles and phenology for the river system.

6. 'Artificial' substrates were placed above the normal level of the river bed. Despite the implications of this design for hydraulic relations in the habitats and behavior of benthic taxa, no comparative analysis of techniques were provided, including those discarded for reasons of variability. Notwithstanding these procedures, statistical conclusions were drawn from the sampling data.

9.4.4 General Assessment

In summary, it should be noted in this section that some results obtained somewhat independently of the interdisciplinary program plan are in serious conflict with other results from a closely integrated sampling system designed within hydrometric considerations of the river system. These results have been critically examined (Section 9.4.3) and found to be insufficiently substantiated in many identified instances as a consequence of incomplete consideration of the dynamics and life cycles involved, inadequate methodology and procedures to justify the claims being made, and incomplete or insufficient cognizance and interpretation of the available published literature on aquatic biology. The environmental impact of river treatment on non-target invertebrates has been assessed therefore on the balance of all relative results and information.

1. Some of the non-target invertebrate taxa are chemo-receptively sensitive to very low concentrations of the methoxychlor formulation. A treated pulse of water stimulates activity, particularly at the leading edge, and temporarily increases the density of drifting organisms as it moves downstream. This effect is clearly demonstrated by all related studies of the program.

2. The claim that the increased density of drifting organisms is 'catastrophic' in its consequences and that it seriously interferes with the distribution of the standing crop is not substantiated by a convincing description of methods or by convincing interpretations of available knowledge of aquatic bio-systems used to support the claim. Other detailed studies based on hydrometric parameters of the river provide evidence in fact that the magnitude of displacement *per se* of activated organisms is insufficient to cause any serious downstream dislocation of the standing crop. Therefore, on evaluation of all results and information, the transient increase in drift density of organisms associated with the movement of the treated pulse downstream is considered to be an amplificaion of natural drift behavior and of no serious consequence in altering the general distribution of benthic populations.

3. Numbers of some benthic taxa are observed at some sampling sites of the treated reach of river to be lower in June than in other months. They coincide with the first few weeks following treatment and, without reference to other sampling data, would be consistent with a minor disturbing effect of the pesticide. However, lower numbers of the same relative order of variation are also observed in June at control sites for treatment years and for a year with no treatment. These low numbers in June are consistent with the known life cycle for taxa having a terrestrial adult stage, in which mass emergence in late May and June may be expected to reduce populations in the benthos. Therefore, the claims for immediate posttreatment effects of the pesticide on the benthic populations based on data and sampling techniques without reference to natural phenological variation are unsubstantiated. The conclusion on all consolidated data along with the ecological knowledge of aquatic invertebrates is that river treatments with methoxychlor at a concentration of 0.3 ppm for 7.5 min have no serious effect on the standing crop in the benthos.

4. The risk of most concern for aquatic invertebrates in river treatments is related to the efficiency of pesticide mixing immediately after injection before acceptable uniformity of concentration is reached in the pulse. Rate of mixing of the pesticide depends on river hydraulics as the pulse moves downstream. During this initial stage of treatment, some of the aquatic taxa are exposed to pockets of high concentrations of pesticide before mixing is completed in the flow. This risk was reduced by about 50% in modifying injection from stationary points in 1974 to a transverse linear pattern from boats in 1975 (Technical Report: Depner et al., p. 141). The maximum casualty rate in treatments with the modified injection for pockets of exposure during mixing was measured in the constant drift in 1976 and ranges below 40% for the most sensitive taxa (Technical Report: Haufe et al., p. 159). The average casualty rate at any time in the pulse is less than 23% of the active part of populations of the most sensitive genera drifting through the river cross-section. It is associated with a small upstream part of the total reach of the treatment. This, in addition to the fact that the taxa concerned have very high rates of reproduction to accommodate low rates of survival in life cycles due to natural causes, is considered to be an acceptable risk in the context of a reasonable socio-economic environmental trade-off. This risk, while acceptable as a trade-off in an abatement practice for the short term, is not esthetically desirable for the long term since technical improvements are feasible to reduce it with very little additional expense in further development work. Therefore, this risk is the subject of a recommendation for further study in a later section.

5. A treatment in spring to prevent a severe outbreak of *S. arcticum* from excessive early hatch and development of larval populations has acceptable level of risk to nontarget invertebrates. Life cycles and phenological patterns of development in taxa indicate, however, that the same level of risk should not be assumed for additional follow-up treatments in late spring or early summer. The object of pesticidal treatments should be consistent with the concept of integrated control in which the capacity of natural predators of black fly larvae is preserved to maintain optimum predation. This predation is essential to control the less abundant but intermittent infestations occurring from later hatches likely to be determined by increased frequency and duration of flooding in late spring and summer.

Although diver techniques were unsuccessful in accommodating ecological observations on target and nontarget substrates in deep water, the nymphs of some taxa such as plecopterans and free-living trichopterans are biologically adapted for predacious grazing on organisms such as black fly larvae that inhabit the scoured river bed in swift currents. Normally, a propitious spring treatment will be scheduled toward the end of, or after, mass exodus of maturing plecopterous nymphs from the river. Later treatments will include the risk of toxicity to newly hatched nymphs from eggs deposited by adults from the spring emergence. Invertebrates are generally more susceptible to toxic chemicals in initial than in later stages of immature development. Therefore, excessive frequency of treatment within one season could prove to be counterproductive in a continuing abatement program. Some late treatments may jeopardize the capacity of the new seasonal generation of plecopterous taxa to 'catch-up' with infestations from late hatches of black fly eggs and exert full potential of natural predacious control during summer and autumn. Reduced potential for predacious control in summer and fall is likely to lead to outbreaks of black flies in late summer or early autumn and possibly also to increased annual need to cope with more frequently excessive infestations in early spring.

Pesticidal treatments developed in the program have been designed to prevent unacceptable outbreaks of black flies from excessive hatch of eggs and rapid developments of larvae in spring. They compliment natural predacious control since they reduce the production of black fly larvae in spring until the seasonal predatory potential of new predacious generations in the standing crop can adjust to later infestations. Indiscriminant frequency of treatment in late spring and summer should be contra-indicated for long-term effectiveness of pesticides until its effects are evaluated more conclusively in terms of phenology and life cycles of predacious nontarget taxa. This is particularly important for some Plecoptera that are ecologically most specialized in northern regions.

9.5 Impact on Water Quality

Methoxychlor was injected in river treatments as an emulsifiable formulation. The Athabasca River carries variable concentrations of suspended particles and silt in which high proportions of washload are associated with high velocity of flow and flood conditions. Dispersion of methoxychlor in the flow is characterized by two overlapping phases in the mixing of the injected formulation. In the initial phase, the methoxychlor is dispersed as an emulsible suspension in the water. In the second phase, methoxychlor is dissociated from the emulsifiable state of the formulation and is adsorbed to particulate material in the washload. Analysis of larvicidal effectiveness for black flies and of residual concentrations in water and washload show the association between efficacy in pest control and the second phase of methoxychlor dispersion in the downstream flow (Technical Report: Depner et al., p. 141; Charnetski et al., p. 39).

With increased adsorption to particulate material in the washload as the treated pulse moves downstream, methoxychlor is lost to the moving or static bed of the river (Technical Report: Charnetski et al., p. 63). The amount of methoxychlor retained in the water in the course of displacement downstream is a function of time (displacement distance) and velocity of the flow. The first parameter relates to the exchange of adsorbed methoxychlor between the water, including washload, and the moving or static bed of the river. The second is related to the carrying capacity of the river for methoxychlor adsorbed to particulate suspended materials since the amount of washload in the flow depends on flow velocity and turbulence. River conditions during treatment determine the time-concentration relation for the retention of methoxychlor within the downstream river flow.

An important aspect in management and control of treatments of large rivers is physical delineation of the distribution of methoxychlor in water downstream after injection. The delineation of methoxychlor distribution is important not only to define the range of larvicidal effectiveness for black flies, but also to define the impact of the treatment on water quality in downstream parts of the drainage system. The resultant maximum concentration of methoxychlor in the water and associated washload after treatment at 300 ppb for 7.5 min above Pelican Rapids will range below 3 ppb at Fort McMurray depending on flow velocity and distance of the injection upstream. The upper limit in this case is reasonably reliable since it is based on the Pelican Rapids treatment in 1976, which was conducted during flood conditions. A rapid rate of loss of methoxychlor from water and its associated washload occurs in the course of hydraulic mixing and particulate adsorption over relatively short distances downstream from point of injection. Generally, for treatments of the Athabasca River between the town of Athabasca and Pelican Rapids at the recommended rate for larvicidal operations, this rapid rate of loss occurs within the order of 80 km with flow velocities above 1 m/sec at injection as compared with 40 km at velocities below 1 m/sec.

In addition to reduction of methoxychlor in water and associated bed load through losses to the moving and static bed load in the downstream flow, concentration is also reduced in association with the extension in time and distance of the length of the treated pulse of water. The initial assumed uniform concentration of 300 ppb at injection decreases to a range below 3 ppb at 400 km downstream for all conditions of treatment. This decrease is associated with the extension of the treated pulse in flow time (and length) from 7.5 min to the order of 60 hr in 400 km of downstream displacement. Therefore, recommended treatments above Pelican Rapids are considered to have biologically insignificant impacts on water quality for the river in the vicinity of Fort McMurray.

Analysis of the dose-mortality relationship for methoxychlor in the downstream course of treatments for larvicidal efficacy against black flies also indicates water quality for effective abatement (Technical Report: Charnetski et al., p. 39). Dose-mortality calculated as total weight of active ingredient specified that about 16.5 kg of methoxychlor uniformly dispersed is required to achieve larvicidal control above 90%. This figure is an important reference in future operations and abatement development for improved efficiency in pesticide injection. Amounts injected above this figure to accomplish satisfactory control represent, at least in major part, the inefficiency in injection measured as amount of excess material used in the operation. More efficient management and control of the treatment process in accordance with hydraulic processes in the river flow have significant potential in reducing environmental risks related to biological availability of methoxychlor as well as water quality. These important relationships receive further consideration in the recommendations for research and development that follow in this report.

It is concluded on the basis of recovery ratios for methoxychlor in relation to hydraulics of river flow that required larvicidal treatments for black flies in the Athabasca River can be applied without any significant risk to quality of water and its associated washload. However, in the event of any future added dependence of industrial processing and community water supply on water resources downstream of treatments, re-evaluation will be necessary in relation to new patterns of water use.

9.6 Impact on Bedload

The major reduction in the concentration of methoxychlor in the water and its associated washload is the result of loss to the moving and static bed of the river in the course of the flow downstream from injection. This loss occurs within 40-80 km from the site of injection with variations depending on rate of discharge and other river conditions at time of treatment.

Under hydraulic conditions characteristic of the Athabasca River, methoxychlor losses from the water and associated washload are generally subject to a continuing displacement downstream (Technical Report: Charnetski and Depner, p. 63). This displacement is associated with the moving bed load. Concentrations in the moving bed load decrease rapidly with time so that, for injections to provide 300 ppb at uniform dispersion in the water flow, they are generally reduced to the order of 10 ppb within 60 days after treatment. Variable hydraulic conditions in the river are such that temporary sinks occur at certain sites in the river in which some deposits of methoxychlor are trapped in static components of the bed such as mud in backwaters and sand bars. Deposits in these sinks are still subject to subsequent movement and redistribution within the bed load during intermittent increases in river discharge. Intermittent movement of the temporary sinks and re-entry of methoxychlor into the bed load account for some infrequent exceptions at localized sites in which residues may exceed 10 ppb after 60 days.

Residues of methoxychlor in the bed load may reach 5,000 ppb at certain sites during or immediately after the passage of the treated pulse. Generally levels are rapidly reduced from the peak within 10 days to about 25 ppb or less at all sites. This posttreatment level in the bed load corresponds with the residue levels found in the static bed (mud) 10-75 days after injection.

Results of analyses show conclusively that methoxychlor residues do not stabilize or persist in the moving or static bed of the river (Technical Report: Charnetski and Depner, p. 63). No residues could be found in either bed load or mud 17 mo after the 3 successive yr of treatment to reach or exceed a determinable level of 0.1 ppb. Therefore, it is concluded that river treatments with methoxychlor can have no irreversible or extended impact on the quality of the river bed.

9.7 Biological Availability of Methoxychlor

Methoxychlor must necessarily be biologically available for larvicidal control of black flies in treatments for a short interval of time in the course of the river flow. Essential biological availability is identified with the water and its associated washload. It is transient, of sufficiently short duration, and at a concentration in the particle adsorption phase to pose no serious impact on non-target organisms. Adverse essential biological availability is confined to a relatively short distance in the flow immediately downstream of injection before methoxychlor has been uniformly dispersed in the flow. The risk for casualties in the invertebrate taxa is considered acceptable as having no significant effect on the standing crop. However, fully integrated analyses of all results of the program indicate that further improvements in the treatment process are feasible to greatly reduce this risk. These are reflected in specific recommendations for further research and development (Section 11).

Biological availability of methoxychlor as a factor in quality of the river environment for both the short and long term is associated with the moving and static bed of the river. The bed of the Athabasca River is subject to continuous and intensive scouring by variably high rates of discharge and flow velocity. Except for occasional transitory sinks, methoxychlor residues are rapidly displaced downstream as in a chute. As a result of the known degradability of methoxychlor, residues do not persist at any given significant level in the bed of the river after treatments. All determinable residues were cleared from the river system by scouring and degradation within 17 mo after the last of four successive treatments spanning 3 yr.

As a result of the hydraulic conditions prevailing in the flow of the Athabasca River, the long-term biological availability of methoxychlor after river treatments is identified in the Athabasca delta, which becomes the ultimate sink for water, washload, and the continuously eroded river bed. An extensive systematic sampling and chemical analysis of the static and moving bed of the delta in 1977 disclosed no determinable residues of methoxychlor resulting from the river treatments.

9.8 Evaluation of Pesticides in an Integrated Approach to Control of *S. arcticum*.

In the context of options that are economically viable at present, control of *S. arcticum* for the protection of new and expanding livestock production in the drainage basins of major rivers such as the Athabasca and Peace Rivers in northern Alberta is highly dependent on continued use of environmentally acceptable larvicides. The results of the Athabasca Black Fly Research Program, although unprecedented in terms of multidisciplinary studies to evaluate methoxychlor in an extensive highly complex aquatic ecosystem, emphasizes not only the potential for selective use of chemicals, but also the need for a more thorough understanding of the dynamics of drifting and colonizing behavior in invertebrate populations of large rivers.

The physical dimensions of velocity, turbulence, and volume of discharge in large rivers such as the Athabasca offer little scope for the effectiveness, not to mention manipulation and management, of biological controls as economic or practical alternatives to larvicides. It is obvious, with the high potential for massive dispersal of flies from relatively well defined breeding sources, that livestock protection depends heavily on development of more sophisticated larviciding procedures as an essential part of an approach to integrated pest management.

Accurate evaluation of larvicides in large river systems is hindered by a critical need for information on the trophic status of aquatic invertebrate populations and their importance to the food chain and to the fish community. The relationship of standing crop and drift patterns of invertebrates to such components as larval survival, growth, fecundity, and body condition in the life cycle of the river fauna is insufficiently understood for knowledgeable management of rivers in the long term. These studies are essential to the development of adequate criteria for environmental acceptability and intelligent use and formulation of pesticides in rivers and streams. In combination with greater adherence to hydraulic parameters, this kind of information affords yet undeveloped approaches in ecological chemistry to exploit degradable pesticides to advantage in environmental compatability.

New integrated forms of quantitative methodology and correspondingly appropriate sample systems are needed to resolve conflicting interpretations from too meagre analysis of aquatic systems. Concepts of a quantitative ecological approach to balance in patterns of natural systems (Williams 1964) in conjunction with more comprehensive approaches to the graphic and mathematical analyses of biotic communities in rivers and streams (Wilm 1972) should encourage more extensive data bases for the evaluation of larvicides in integrated pest management of black flies in large rivers. In this respect, the Athabasca Black Fly Research Program has produced an unprecedented bank of data and samples for more detailed analyses of environmental impact along these lines of study. Computer analyses of about 200,000 generically collated samples of invertebrates from regular time-series sampling systems of the drift and the benthos in the Athabasca have been partially completed (Haufe, unpublished). These analyses with a mathematical model to represent Williams' concept have already shown clearly that invertebrates in the Athabasca River have maintained the taxonomic balance demonstrated in concept by Williams (1964). Further analyses are required to evaluate similar relationships for numbers of individuals distributed among the taxa as a potential criterion for larvicidal impact on ecosystems with reference to baseline studies with no treatment. Preliminary results from these unpublished detailed studies in addition to the consolidated general analyses of all published studies in the Athabasca Program support the conclusion that methoxychlor can be managed in large rivers as an environmentally acceptable larvicide.

A major requirement still remaining from the Athabasca Black Fly Research Program is a clear resolution in methodology of the relation between drift and standing crop of invertebrates. With a satisfactory understanding of this relation, drift measurements may become an extremely convenient economic means of monitoring larviciding programs for public, administrative, and operational accountability.

10. RECOMMENDATIONS

10.1 River Treatment as an Abatement Practice

10.1.1 Operational Effectiveness

River treatment with an environmentally acceptable pesticide is the most effective and the most economical method that can be applied in the immediate short term to prevent outbreaks of *S. articum* from the Athabasca River. Methoxychlor is considered to be environmentally acceptable for this purpose until further improvements in treatment techniques or equally effective and practical alternatives are developed. A single injection, properly applied, will eliminate the source of an outbreak from at least 160 km of infested river downstream from the point of injection. Two injections will be required to control sources of *S. arcticum* that contribute to the severe outbreaks experienced in agricultural areas adjacent to the Athabasca River below the town of Athabasca. The first of two injections is recommended at the head of Pelican Rapids to be followed by the second below the bridge at the town of Athabasca.

Two injections are recommended to achieve maximum benefits from an annual treatment. A downstream injection is necessary to control potential sources of heavy infestation affecting the northern and eastern areas of Improvement District 18. It also restricts the long-range infiltration of flies into Athabasca County from downstream with the result that infestations on farms are reduced by 70% as compared with 50% after a single injection at the town of Athabasca.

10.1.2 Environmental Acceptability

Despite some conflicting claims for the effects of treatments on non-target invertebrates, a comprehensive review of all the available data from the program and from the published literature indicate that a concentration of methoxychlor at 0.3 ppm for 7.5 min produces no seriously detrimental impact on standing crop of any non-targets or their aquatic environment. There is some risk to non-target invertebrates immediately after injection and before mixing of the pesticide in the water approaches uniformity throughout the pulse. The casualty rate associated with this risk is well within the reductions common to natural episodes and also within the range of natural variations observed in phenologically related densities of populations. Only 8 of about 100 genera of invertebrates known to inhabit the river are sensitive to the treatment. All of the sensitive genera have high reproductive potentials to accommodate highly variable survival rates common to the life cycles of these taxa. Therefore, the risk for these genera may be considered acceptable in a trade-off for cost-benefit in environmental impact provided that their populations are not severely depleted for other reasons before larvicides are applied. It is recommended, however, that accountability for this risk be incorporated as an integral part of black fly abatement operations in monitoring the effectiveness and quality of all treatments.

10.1.3 Operational Specifications

Present knowledge of infestation patterns for *S. arcticum* in the Athabasca River indicates that larval populations build up to levels for severe outbreaks once in every 2 or 3 yr. Therefore, it is recommended that treatments should not be scheduled as a continuing annual practice. Treatments should be applied only as indicated within an established annual monitoring procedure for the river in spring subject to the following general guidelines.

1. Standardized artificial substrates for *S. arcticum* should be used in a monitoring operation, beginning with the clearance of ice from the river in spring, to assess the rate of build-up of larval populations at regular weekly intervals.

2. Sites beyond 100 km downstream from the town of Athabasca must be used as indicators of a serious outbreak in summer.

3. A larviciding operation should be organized when larval numbers exceed an average of 500/cone (artificial substrate) at the indicator sites.

4. A transverse linear injection of larvicide from boats is essential for effective application in the Athabasca River. Injection from stationary points may be acceptable for shallow rivers but results in inefficient mixing rates in deep rivers.

5. Methoxychlor must be injected in quantities and at rates to achieve a uniform concentration of 0.3 ppm in the river flow for 7.5 min.

6. Injection sites for effective treatment of identified river sources of infestations must be determined from prevailing rates of river discharge. Effective range of the recommended treatment is in the order of 120 km for rate of discharge less than 560 m^3/sec. It exceeds 160 km at higher rates.

A detailed outline of guidelines, specifications and schedules is provided as Appendix I for operational use in abatement operations.

10.1.4 Operational Costs

Operational cost of an effective treatment of the Athabasca River will depend on whether the abatement program is assigned to an existing government agency or to contract. Activity during the monitoring period for infestation level after spring break-up of ice is intermittent and involves a professional biologist and assistant for about 2 days/wk for up to 8 consecutive wk in a uniform time schedule. This requirement is met economically by permanent personnel in a government agency but is considerably more expensive under a contract arrangement. The basic time-rated costs of personnel, equipment, and supplies for the recommended two injections will be less than $25,000. As a guideline for general organization of an annual program, basic costs using 1977 values may be estimated (Table 1).

Short-term and intermittent employment of personnel, annual rental of all necessary equipment, and extra administrative overheads increase costs in contractual arrangements. An abatement program under annual contract should be expected to range from two to three times the basic agency-oriented cost.

Table 1. Estimated costs of an annual control and monitoring program

Infestation Monitoring -		
Professional biologist (2 days/wk, 9 wk)	- $2,400	
Assistant (2 days/wk, 9 wk)	- 1,200	$3,600
Permanent equipment (capital cost 1st year)		5,000
Annual supplies		1,200
Larviciding operation -		
Rental of 3 boats with drivers (2 days)	- $2,000	
Six drum handlers $6.00/hr (2 days)	- 250	
Larvicide for treatment (140 gal.)	- 1,400	3,650
Environmental monitoring (minimum for treatment)		
Professional biologist (2 wk)	- $1,100	
Three assistants (2 wk)	- 1,350	
Equipment (capital cost, 1st year)	- 2,000	
Supplies	- 550	
Taxonomic analysis	- 2,000	$7,000
Total basic costs		$20,450

A budget of basic costs responsive to the recommendation of treatments only when indicated by spring monitoring should make resources available according to a contingency plan (Table 2).

Table 2. Budget of basic costs for contingency plan

Infestation monitoring (every year)	$9,800
Treatment contingency fund (used in 1 of every 2-3 yr	3,650
Environmental monitoring for accountability of treatments (used in 1 of every 2-3 yr	7,000

10.1.5 Technical Improvements

As a result of the final analysis of all data from the experimental program, it is evident that further improvements can be made in the effectiveness and safety of larviciding procedures, in some cases at nominal expense in further research and development. These potential improvements are concerned with more efficient injection and mixing of the pesticide in flowing water. Although they are outlined among other desirable requirements (Section 11), they are emphasized for the immediate benefit of river treatment as an abatement practice. It is recommended that they receive the highest priority in support of future development work. In addition to benefits in increasing effectiveness and further reducing environmental risk for sensitive non-target invertebrates, the recommendations for improved injection and formulation of pesticides for particulate adsorption and mixing in river water are considered to be important factors in reducing the present cost of treatments.

10.2 Environmental Monitoring (Requirements and Procedures)

10.2.1 Operational Requirements

Pesticidal treatment of a large river such as the Athabasca involves an assessment of risk for the quality of a highly complex and very extensive life-support system and its aquatic environment. It is recommended that the above specifications for effective control of black fly infestations are also environmentally acceptable for a reasonable level of risk in cost-benefit trade-off.

The risk in this case is for eight identified genera of non-target invertebrates that are relatively sensitive to methoxychlor. It is recommended that a minimum level of environmental monitoring be an integral part of any continuing abatement operation. Environmental monitoring in this case should serve accountability of the abatement practice for two purposes - (1) To control the standard of operational practices for continued effectiveness and environmental safety of each treatment; and (2) To detect any increase in environmental risk that may occur with continued long-term use of the insecticide.

It is recommended that operational accountability be provided within the following general guidelines.

1. A minimum monitoring procedure should be incorporated with the sampling schedule for evaluation of black fly control at each injection of pesticide.

2. A minimum monitoring schedule involves sampling on 5 successive days for each treatment in which the treated pulse is estimated to arrive during the 3rd day.

3. Sampling should be confined to the 'constant' drift in the thalweg of the river flow as the most economic design for acceptable estimates of impact from minimum number of samples.

4. Since the constant drift of most taxa is either rhythmic or relatively stable according to the 24-hr clock within weekly periods, the daily sampling period may be confined to 12 hr provided that it is regular for each day, i.e., 0600-1800 hr.

5. The regular daily sampling period must be determined by the time of arrival of the treated pulse estimated from flow velocity measurements. For example, the treated pulse must arrive within the 12-hr sampling period during the 3rd day.

6. Samples must be sorted on site to distinguish and quantify casualty rates in the drifting taxa as a practical measure of toxicological impact.

7. The sampling site must be located 15-20 km downstream from the injection point. This condition is important since the risk in treatment is related to the mixing of pesticide in the river flow. Maximum casualty rates will occur in the constant drift at this distance to reflect extraordinary exposure to pockets of high concentration and hence, also, unacceptable rates of mixing in the river flow.

Minimum sampling-set design and additional details of procedures recommended for operational use are provided in Guidelines, Specifications, Schedules, and Procedures (Appendix II).

10.2.2 Environmental Indicators

Of about 100 genera among the aquatic invertebrates of the Athabasca River, eight have been identified as taxa sensitive to methoxychlor. These genera are *Cheumatopsyche* and *Hydropsyche* in the Trichoptera; *Baetis*, *Heptagenia*, and *Ephemerella* in the Ephemeroptera; and *Isogenus*, *Isoperla*, and *Hastaperla* in the Plecoptera. All these genera appear in the 'constant' drift of taxa in the river for convenient practical monitoring in a minimum sampling-set design. It is recommended that these genera be used as indicator genera for environmental quality related to continued use of methoxychlor in river treatments.

10.2.3 Criteria for Pesticide Safety

Two criteria are recommended to ensure that continued use of methoxychlor in river treatments is confined to acceptable limits in maintaining the quality of the Athabasca River environment.

1. The casualty rate in the 'constant' drift of invertebrates associated with the treated pulse should be recorded for each injection of methoxychlor as a measure of the operational impact of treatments. It should not exceed 40% at 15-20 km from the injection point for any of the taxa in an individual 4-hr sample. The objective with continuing practice and development of improved injection equipment and technique should be to reduce this measure of risk, which is associated with the mixing of the pesticide. Excessive casualty rates will indicate unacceptable operational standards

or unacceptable formulations of pesticide. Specific attention to the eight identified indicator genera of taxa is essential in this measure during the recommended environmental monitoring procedure for river treatments.

2. Methoxychlor is degradable. All residue sampling data indicate that it is cleared satisfactorily from water, river bed, and organisms in the river system after treatments. As a result of high velocity, turbulence, and frequent flooding, the Athabasca River functions as a massive chute for movable organic and inorganic material that is ultimately deposited in the delta of Lake Athabasca. The long-term safety of methoxychlor is measurable in terms of residues deposited in the delta. No significant residue attributable to river treatments could be found in extensive sampling of the delta in 1977 following four injections of methoxychlor in the previous 3 yr. It is recommended that long-term accountability for methoxychlor in river treatments be provided by an appropriate sampling and analysis of delta sedimentary deposits at intervals of 5 yr for comparison with methoxychlor and background residues at sites corresponding with the 1977 baseline. Any increase in residue levels should indicate the need for a reassessment of the long-term safety of methoxychlor use in conserving the present quality of the Athabasca River and delta environments.

10.2.4 Operational Costs

Environmental monitoring for accountability of river treatments, as incorporated with larviciding operations, is estimated at a basic cost of $7,000. Annual expenditure would be a contingency depending on the need for larviciding with an expected frequency of once in every 2 or 3 yr. It is recommended that the proposed minimum environmental monitoring be a condition for all authorized treatments with methoxychlor.

Five-year residue sampling operations and related laboratory analyses for reassessment of quality of sedimentary deposits in the Athabasca delta will be considerably more expensive. Actual costs are difficult to project but should not exceed $5,000 every 5 yr. It is recommended that these financial commitments should be seriously considered by agencies responsible for environmental quality on intitiation of black fly abatement programs in large river systems.

10.2.5 Environmental Surveillance and Accountability

An extension of the practice of river treatments to control infestations of black flies on a large scale represented by the Athabasca drainage system presents new dimensions of responsibility for the use of pesticides in complex environmental systems. Responsibility in this case must be satisfied within adequate measures for surveillance of practices and accountability of operations (Fig. 1). Adequate measures must accommodate detection and assessment of risk in practice and also identify needs for improvement in techniques and performance to maintain standards of environmental acceptability.

Two basic requirements are recommended for accountability and surveillance of operations.

1. Performance Records. Operators (service agencies, contractors, etc.) must be required to provide a performance record for each treatment. The performance record must include (A) results of monitoring procedures to measure pretreatment infestation levels - to account for the need of pesticidal treatments; (B) river conditions, date and time of treatment, identity and formulation of pesticide, actual amount applied and site of injection, efficacy of treatment in larval reduction - to justify cost-benefit considerations in socio-economic-environmental impact trade-offs; (C) posttreatment assessment of impact on invertebrates with special reference to indicator species - to verify operational standards in meeting criteria for environmental risk.

2. Environmental Surveillance. Performance records of operations in river treatments must be subject to inspection, review, or both by a designated agency responsible for the maintenance of environmental quality and prevention of pollution. A designated government agency in this case must have the added responsibility for periodic review, at intervals not less than 5 yr, of the impact of practices on the environmental quality of river systems that are subject to treatment practices. The review procedure must include analyses from the minimum monitoring schedule recommended for delta deposits in lakes and reservoirs.

3. Management and Control. Abatement of infestations of black flies in a large river is a large-scale pest control operation. Satisfactory accountability lies in the establishment of rigorous and reasonable management policies and procedures to accommodate continuing assessment of benefit and risk. It is essential, because of the scale of operations, that a single professionally competent authority be designated to specify and govern pesticide use (including formulation), application, and evaluation of performance in river treatments. This authority must provide management and control of abatement programs within a reasonable framework of ecological assessment, cost/benefit evaluation, monitoring standards, and criteria for environmental acceptability (Fig. 3).

10.3 Alternatives in Black Fly Abatement

Development of practices for control of black flies is confined to three feasible approaches to the problem. The approaches are (1) control of infestations at sources of breeding and development, (2) control of invasions of adult flies affecting problem areas, and (3) local protection of man and animals on farms and around human habitations. The benefits to be achieved from these approaches at the present time are very different in terms of operational effectiveness, status of current development of techniques, and cost-benefit ratio in the economy of operations and environmental impact.

10.3.1 Operational Effectiveness

The Athabasca Black Fly Research Program has demonstrated that treatment of black fly infestations at the source in rivers is an operationally effective method of achieving a measurable reduction of infestations on farms. Operations are also subject to sufficient technical control to be accountable in terms of acceptable risks for maintenance of environmental quality in the river system. By comparison, the alternatives at the present time are operationally ineffective in achieving the level of animal protection required in agricultural areas. In contrast to the knowledge available on immature stages of *S. arcticum* to manage the problem, there is no basic knowledge of adult behavior and dispersal patterns to develop effective methods of controlling adult fly invasions within designated areas of agricultural production.

Experimental work on repellents indicates some promise for the future in developing control methods for human and animal protection on farms and around human habitations. This alternative is an important supplementary requirement, not only to protect livestock from *S. arcticum* on a smaller and more flexible scale, but also to relieve man and animals from infestations of a greater diversity of species of biting flies which, though of lesser individual importance, exert a serious impact through their collective abundance and attack. Repellents under experimental development are effective for periods up to 10 days. At present, it is inconceivable that practical applications with clearance for toxicology and residues in animals will be achieved in less than 5 yr.

Biological control agents are a promising alternative to chemical pesticides in current developmental work for control of mosquitoes. However, irrespective of their effectiveness for use in static aquatic environments against mosquitoes, there is no prospect in the foreseeable future for their effective application for black flies in small streams. There is no conceivable reason that they can ever be considered for large rapid rivers in which biota are subject to hydraulic conditions under which the river bed is intensively and continuously scoured.

It is concluded that river treatment with methoxychlor is the only method available with proven effectiveness to be acceptable for immediate application.

10.3.2 Development Status

River treatment for larvicidal control of *S. arcticum*, as demonstrated by the experimental Athabasca River program, has been developed with an unprecedented measure of environmental impacts. Risks for environmental quality and non-target biota have been extensively evaluated and found acceptable on reasonable ecological terms for immediate development of an effective black fly abatement program. Methods, standards, and criteria have been developed to provide accountability and management control by responsible agencies for the performance and safety of operations in the short and long terms. With implementation of recommendations for surveillance by designated responsible agencies, techniques and procedures are considered adequate to satisfy present conceivable concerns for effectiveness and environmental safety.

10.3.3 Economic Assessment

The Athabasca Drainage Basin is a major focus in Alberta at the present time for new and expanded development of natural resources, industry, agriculture and recreation. The solution of problems of biting flies is a primary factor in the future socioeconomic viability of human interests and activities in the area. The immediate serious threat to development is in the established livestock industry, especially at this time in Athabasca County and Improvement District No. 18.

The livestock industry in the two census divisions (12 and 13) associated with areas of major infestations of biting flies in the Athabasca Drainage Basin was comprised primarily of more than 480,000 cattle in 1978 (Alberta Agriculture, Statistics Branch, Cattle Numbers (1), 26 Feb. 1979). Even more important than the present economic viability of this industry is the potential future expansion of enterprises into additional infested areas that are suitable for grazing and forage operations to meet increasing demand for animal protein food. The gross value of animals in this area alone is likely to increase from a current conservative estimate of about $96 million exclusive of related and dependent agricultural and business enterprises. The requirement for methods of protecting livestock in areas infested with biting flies as a whole is justified substantially by the livestock industry irrespective of other unknown estimates related to other industries and human enterprises and activities.

Surveys of cattle within the study area of the research program in 1977 provided an estimate of the numbers seriously affected by outbreaks of *S. arcticum* alone as distinguished from other infestations of biting flies. The total as a conservative estimate exceeded 80,000 or about one-sixth of the actual cattle census for divisions 12 and 13. The base cost of river treatment for protection of this part of the cattle population from *S. arcticum* infestations is less than $0.30/head. Although the actual costs of the most promising alternatives are still unknown for practical purposes, they are cetain to exceed $1 and may be as high as $10/head. River treatment is not only a fully developed method for proven effective and immediate application, but is now and will probably continue to be the most economic option. In the event of an expanding livestock industry the cost of treatment per animal will in fact decrease in relation to alternatives developed for use on farms.

Experiments by Steelman et al. (1972) showed that steers exposed to mosquito attack gained 0.32 kg/day/head less on low-energy rations and 0.14 kg/day/head less on high energy rations in comparison with screened steers on the same rations. These results correspond with the lowest baseline losses in rate of gain of yearling cattle exposed to horn flies on pasture (Haufe 1979). Results of experiments with horn flies and mosquitoes are considered to represent losses common to various infestations of biting flies including black flies, which inflict additional losses through occasional deaths of animals during severe outbreaks. If these measured losses are applied to an estimate of economic returns in animal production from river treatment, the cost per animal is equivalent to less than 2 days gain. On the basis of only 2 mo exposure during the most severe part of an infestation of an outbreak the cost-benefit ratio will be better than 1:30 as a conservative estimate of actual total losses.

The economic significance of *S. arcticum* on cattle production has a high probability of increasing with an expansion of the industry in the Athabasca Basin. Reproductive capacity of blood-sucking flies depends, among other factors, on the success of adult females in obtaining blood meals to reach their biological potential in egg laying. *S. arcticum* is highly selective in attacking cattle as a source of blood for this purpose. This indicates that with an expansion of the cattle industry in the future, the pest will have a high probability of increasing the frequency and intensity of outbreaks in proportion to the numbers and distribution of cattle available. A recent study in the USSR indicates that the abundance of larvae and pupae of black flies depends on the number of attacking females (Jankovsky 1979). It follows that this population parameter, combined with a ready source of blood meals and a river environment highly favorable for larval production, will increase the biological potential of the pest. This probability emphasizes the present importance of economically effective methods of controlling *S. arcticum* in the interests of a viable cattle industry in the Athabasca Basin.

11. PRIORITIES FOR FURTHER RESEARCH AND DEVELOPMENT

11.1 Techniques for River Treatment

The consolidated results on black fly control (Technical Report Depner et al., p. 21), on residues of methoxychlor in water and associated washload (Technical Report: Charnetski et al., p. 39) and on the modelling of hydraulic dispersion of the pesticide in the river (Technical Report: Beltaos, p. 97) indicate a potential for improved technology in pesticide injection during river treatments. Feasible improvements will increase the effectiveness and selectivity of treatments for black fly larvae, reduce the risk to non-target invertebrates and fish, and also provide economy in the use of toxic materials in river environments.

The risk to non-target organisms is associated with the mixing phase of the pesticide immediately after injection. It was reduced by about half with a transverse oscillatory pattern of injection from power boats in 1975 and 1976 instead of a stationary point injection from a bridge as in 1974. However, injection in both cases is confined to the surface of the river. To reduce the time for hydraulic mixing still further, the dispersal pattern must be improved within the vertical as well as the horizontal plane within the cross-section of the river. With modest engineering of the outlet apparatus on the larviciding drums, simultaneous injection at controlled rates can be achieved at sub-surface levels. Extrapolating from experience with mixing rates for pesticide application at the surface, it is estimated that simultaneous injection at one- and two-thirds of the depth in the river cross-section may decrease the time for 90% mixing to about one-sixth of that currently achieved. In terms of distance travelled by the treated slug, 90% mixing may be expected within 2-3 km as compared with 15-20 km in 1975 and 1976 and 40-50 km in 1974.

The significance of improved injection methods for treatment of deep rivers such as the Athabasca is indicated by an interpretation of Charnetski et al.'s data on residue levels in water and associated washload (Technical Report: p. 39). It is clear (their fig. 4) that black fly control is being achieved for up to or exceeding 160 km with a dose below 20 ppb hr after mixing of methoxychlor in the water and its adsorption to particulate material in the washload. The advantage of more efficient mixing with injection to reduce both mixing time and amount of pesticide to achieve black fly control is an important consideration for future applications in deep-river treatments.

Distribution of methoxychlor in the river after injection is evidently related to three processes. The first is physical and mechanical mixing during injection followed by hydraulic mixing of a uniform concentration within the downstream flow.

The second is the emulsifying action of the formulation of methoxychlor. The third is physical adsorption to particles in washload and bed load. The interaction of these processes is interpreted in Fig. 4. Initial loss of methoxychlor from water and associated washload is rapid and related to rate of break-down of the emulsible formulation (A_1, A_2) within the first 75 km of flow. As methoxychlor dissociates from the emulsible formulation, it adsorbs to particles in the washload to establish a relatively more stable concentration (B_1, B_2) for the remainder of its displacement downstream. This state in the methoxychlor distribution contributes to efficacy of the treatment in reducing infestations of *S. arcticum* larvae and it constitutes the essential process in river treatment. Physical and mechanical mixing during injection influences time and distance downstream for river hydraulics to achieve 95% of a uniform concentration throughout the pulse. With stationary-point injection on the surface, it is in the same order as the rate of break-down or dissociation in the emulsible formulation and is achieved within about 50 km. The improved pattern of surface application from boats reduces hydraulic mixing to the order of 15-20 km (C_2). An ideal mixing distance would be in the order of 2-3 km to minimize the risk to non-target organisms (C_3).

A large proportion of the methoxychlor is lost from the water and associated washload to the bed load during mixing and subsequent dissociation from the emulsible formulation. Lost material continues to be displaced downstream with the moving bed load in the wake of the treated pulse of water. Amounts lost to the bed load (A_1, A_2) are about one and three times of the stable amount (B_1, B_2) retained as the effective larvicidal dose in water and washload at the injected rates of 300 ppb for 7.5 and 15 min, respectively. This indicates that, with improved methods for

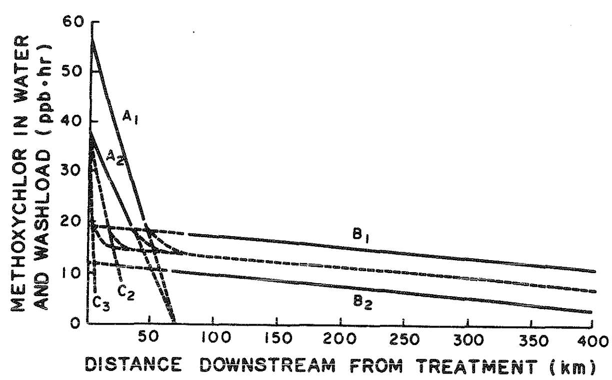

Fig. 4. Relationship between maximum exposure to methoxychlor and distance from injection for mixing phase (A_1 - 1974 and A_2 - 1975 and 1976) and for effective phase (B_1 - 1974 and B_2 - 1975 and 1976). C_2 represents present mixing efficiency and C_3 the feasible, optimum with improved injection apparatus.

mechanical mixing during injection and with appropriate formulation for dispersion by river hydraulics, an effective dose may be reduced to a concentration of 150 ppb. The total mass of suspended particles exposed to the formulated pesticide during the mixing process may prove to be critical in determining the subsequent and more stable concentration in water and washload downstream. If more efficient reduced mixing provides insufficient exposure to a critical mass of suspended particles, the required capacity for an effective larvicidal concentration could be maintained by extending the injection time at the lower rate. The advantages of reducing unnecessary losses to the bed load through feasible improved injection techniques and pesticide formulations are obvious in reducing risk to non-targets and in eliminating excessive use of pesticide for larvicidal effectiveness.

The integrated analysis of results from the research program reveals a comprehensive concept of the behavior of methoxychlor in river treatments with respect to river hydraulics, larvicidal efficacy for black flies, and impacts on non-targets and the aquatic environment. It identifies four important priorities as foci for further useful research and development.

1. <u>An engineering study to develop a modified delivery system for formulated pesticides</u>. The delivery system should be designed to disperse the pesticide in a vertical as well as a horizontal plane of the river to reduce mixing time and displacement distance for uniform concentration in the treated pulse. This innovation is essential for more effective and safer treatments of deep rivers.

2. <u>Chemical formulation of methoxychlor expressly for river treatments</u>. The methoxychlor used in the research program was formulated for general purposes other than river treatment. A formulation is required for compatability with river hydraulics and paticulate adsorption in the washload of turbulent water. Due consideration should be given to optimum mixing time and 'break' in the action of emulsifiers to minimize loss to the bed load and to economize on the amount required in the stabilized concentration for larvicidal efficacy against black flies.

3. <u>Particulate formulations</u>. Efficacy of emulsible formulations of methoxychlor as black fly larvicides is associated with availability of suspended silt particles as a substrate for adsorption in the river flow. A formulation of methoxychlor with a self-contained particulate substrate of optimum size and specific gravity for stable aquatic suspension will be necessary for effective use in rivers with clear or low-silt waters.

4. <u>Trophic status of aquatic invertebrate populations</u>. There is a critical need for information on the trophic status of aquatic invertebrate populations and their importance to the food chain of

the fish community in large rivers. In lotic ecosystems, benthic invertebrates contribute significantly to the energy maintenance of individual fish. The relationship of standing crop and drift patterns of invertebrates to such components as larval survival, growth, fecundity, and body condition in the life cycle of the piscine fauna is insufficiently understood for knowledgeable management of river systems. These studies are essential to the development of adequate criteria for environmental acceptability of pesticidal treatments in rivers and streams.

11.2 Alternatives to River Treatment

Alternatives to river treatment are limited by an acceptable cost-benefit ratio in practical application. For the foreseeable future, alternative options in controlling *S. arcticum* will be considerably more expensive than river treatments. Cost-benefit ratios will be more favorable for the development of alternatives that offer broad-spectrum control and that will protect man and livestock from a variety of black flies, mosquitoes, tabanids, and ceratopogonids. Although less significant than *S. arcticum* in numbers within individual species, their collective effect on human and animal productivity justifies more expensive methods of protection that are effective against mixed adult infestations of the variety of biting flies normally experienced in the Athabasca region.

Adulticides offer little economic promise until knowledge is available on behavior of biting flies to understand problems of displacement and dispersal of populations in control areas. Although present adulticiding methods are effective in control programs for some urban communities, they are neither practical nor economically feasible for application in agricultural areas.

Feasible development of economic methods for controlling infestations of adult biting flies is limited to chemical repellents. Future emphasis in research on local protection of man and animals in agricultural areas should be placed on the search for chemicals and their formulation to provide effective repellency for 10-20 days. Effective repellency in this order will meet an acceptable cost-benefit ratio for application on farms during peak infestations in severely affected areas.

12. ACHIEVEMENTS TOWARD OBJECTIVES

The Athabasca Research Program has been unprecedented in an integrated multidisciplinary study of larvicidal control of black flies in a large river. As such, it has provided the essential information to specify and to justify larviciding procedures with methoxychlor in the Athabasca River to prevent or reduce outbreaks of *S. arcticum* in Athabasca County and Improvement District 18. Of the six objectives outlined for the program, all were met satisfactorily for the Athabasca River problem with the reservation perhaps that more detailed development of quantitative environmental criteria is required for acceptable long-term impact of continued black fly larviciding on the management of a large river system. As indicated in Section 9.8, this requirement is relevant to the present concept of pesticide use as part of integrated pest management in a complex aquatic ecosystem.

The results of the program serve the concept of integrated pest management with an identification of hydraulic parameters in an analytical model of a river system. The elaboration of this model through further studies in association with future larviciding operations is needed to justify direct application of the Athabasca River recommendations to other large rivers. Through presently available approaches in ecological chemistry and within a complete hydraulic model, it will be feasible to formulate degradable larvicides and control their injection for predictable effectiveness and environmental compatability.

Incomplete integration of quantitative methodology and related sampling systems to conclusively resolve all conflicting interpretations of larvicidal impact on invertebrates was an unsatisfactory feature of the program. Consequently, more detailed analyses of the behavior of invertebrates in relation to standing crop are necessary to specify and to fully substantiate the recommended criteria for environemntal accountability in larviciding operations. The large bank of data and samples accumulated from the program (Section 9.8) is a promising basis for more detailed computer simulation studies to resolve conflicting interpretations without additional field studies. These analyses, not anticipated in the program budget and found feasible only after the consolidation of all program results, have been initiated at the Lethbridge Research Station through other resources. The final conclusions on their completion will appear in a later published report.

As a means of conclusively resolving conflicting interpretations of data from the program, it has been necessary to use Williams (1964) concept of balance in the pattern of nature as the only method in quantitative ecology presently available. Supplementary analyses in progress according to this concept are based on all the data accumulated for invertebrates by various methods in the program. The first part of the analysis has shown conclusively that taxonomic balance was maintained in invertebrate fauna throughout the 3 yr of treatment and the post-treatment baseline study in 1977. It also indicated conclusively that sampling methods based entirely on the drift of organisms do not represent the diversity of taxa in the ecosystem. The second part of the analysis is designed specifically to evaluate balance in numbers of individuals among the taxa, and also to identify any significant variations in numbers with treatments in a more detailed time-series analysis for standing crop. This part has been delayed until additional computer resources are available. The achievement of environmental accountability and acceptable criteria for larviciding operations as the fifth objective of the program remains to be determined more conclusively, therefore, on completion of the additional detailed analyses of the accumulated data bank.

13. RELATED LITERATURE

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14. APPENDICES

APPENDIX I: BLACK FLY LARVICIDING OPERATIONS: GUIDELINES, SPECIFICATIONS, SCHEDULES, AND PROCEDURES FOR LARGE RIVERS

K. R. DEPNER

The procedures and equipment given here were developed to accomplish population reduction of the larvae of the black fly *Simulium arcticum*, a pest of livestock breeding in large rivers in Western Canada. The experimental program was conducted in the Athabasca River in Alberta.

A typical larval control operation consists of infestation monitoring to locate the source and severity of populations, larviciding operations to reduce larval populations, and posttreatment monitoring to determine the effectiveness and environmental side effects.

Experimental procedures in the Athabasca program have shown that operations using fast, high-powered river boats in all phases have the best chance of success.

INFESTATION MONITORING

The need to treat any river system with larvicide to reduce populations of black flies is determined by the history of livestock attack by black flies in adjacent areas. Location of the area to be monitored in a known system, such as the Athabasca River, can be limited to areas of known high larval populations. In an unknown river system, location of areas of high population require more extensive monitoring, but can generally be expected to be to windward (prevailing) of areas where livestock are frequently attacked, and in sections of the river with rocks, rapids, and riffles and a high current velocity.

Infestation monitoring requires the services of a trained aquatic biologist, preferably one with river experience. A capable assistant is also necessary since most river operations require two persons. River operations should begin as soon as possible after spring ice break-up to monitor early larval hatches that are well underway by this time. There is usually less than 1 mo from spring breakup to larval maturity, therefore every week is important in larval population assessment. This period in the spring is usually one of rapidly fluctuating river levels and a corresponding increased chance of loss of sampling equipment and results.

Black fly larvae in large silt-laden rivers attach to rocks in deep, fast-flowing water and are, therefore, impossible to observe directly. An artificial substrate for larval attachment is thus needed to provide an index of population fluctuations. In working with *Simulium arcticum*, plastic cones with a surface area of 353.6 cm^2, were found to be satisfactory substitutes for natural substrates.

Infestation monitoring makes it possible to locate areas of high populations, keep track of the stage of development, and determine the exact date on which black fly larvicide should be applied to the system. The decision to treat or not treat can usually be made by mid-May. It is, therefore, important that the 2 wk after breakup of river ice are fully used in sampling.

The cones used as artificial substrates are suspended at two levels in the river, one near the surface and one at mid-water. These are left in the river for 1 full wk to allow larval attachment to stabilize. The apparatus used to suspend the cones is called a set and is described later under 'Procedures and Equipment for Monitoring Large Rivers'. In the week before treatment, the number of sets, generally two or three, must be doubled at each station to permit sampling immediately before and after treatment.

LARVICIDING OPERATIONS

In the Athabasca system, the decision to treat the river was based on the presence of 500 or more larvae on any one cone. Larvicide must be applied at least 15 km upstream from the point in the system where high larval populations begin so that complete mixing of larvicide is ensured.

Monitoring stations should not be more than 40 km apart. At least one, and preferably two, monitoring stations should be upstream of the larvicide injection point to serve as control or check stations.

The date of larvicide application to the desired area is decided on the basis of the stage of development of the black fly larvae. When a significant number have reached the seventh or final larval instar, treatment must be not more than 5 days later. The final stage of larval development of *S. arcticum* is indicated when larvae have reached a length of 6.3 mm, when pupal respiratory histoblasts are well developed, and when cervical sclerites can be seen on at least some of the larvae. Once the decision has been made to attempt population reduction of *S. arcticum* larvae, the actual injection point must be selected. It should, if possible, be located on a straight section of river (away from a curve) and have a uniform cross section, i.e. depths at various distances from the bank should be similar both sides of the river. Current velocity should be not less (preferably more) than 0.6 m/sec to ensure rapid and uniform mixing of larvicide and water after injection.

When the injection site has been selected, the type of larvicide, concentration, and duration of the injection must be decided. In the Athabasca program, 0.3 ppm of methoxychlor was applied as a 24% emulsifiable concentrate. This, applied for 7.5 min, effectively reduced populations of black fly larvae for 160 km when current velocity and silt levels in the wash load were high.

Cross-sectional measurements of the river must be made at the injection point to determine width, depths, and current velocity. Current velocity should be taken with a current meter and surface and mean velocities calculated.

Mean velocity may be calculated as follows:

(a) Two-point method - make observations at two- and eight-tenths of the depth below the surface. Average of the two is taken as the mean velocity.

(b) Three-point method - observations are made at two-, six-, and eight-tenths of the depth and the average of the three is taken as mean velocity.

Cross-sectional area and mean current velocity are necessary to calculate volume of discharge of the river and, therefore, the amount of larvicide required for treatment. The amount of larvicide should be sufficient to treat at the maximum flow rate at which treatment will be considered. If river discharge rates do not reach this level, there will be a surplus amount of larvicide. This is preferable to having insufficient for treatment.

In the method of application described here, all larvicide injections are made from boats. When the amount of insecticide to be used is known, the number of boats required for delivery and injection of larvicide may be determined. Under experimental conditions, no boat delivered more than 114 liters of 24% methoxychlor from two half-full drums of 114-liter capacity. This amount is sufficient to treat 209.97 m^3/sec of water from each boat at a concentration of 0.3 ppm. Less than full multiples of this amount of flow may be adjusted by equipping one boat with a smaller drum that delivers a lesser amount of larvicide in the same 7.5-min interval.

Drums on boats are emptied by a constant flow apparatus (Fig. 1) calibrated to deliver the amount in the drum in 7.5 min. This may be accomplished by enlarging the pre-drilled orifice (G) until the desired time interval is reached. Drums are held in position on boats by racks built from common lumber (Fig. 2). Boats can be levelled port to starboard by using the U-tube filled with colored liquid to a scribed level line. This levelling should be done with movable ballast after operational boat crews are in position.

Drums of larvicide to the number required to treat maximum flow should be prepared well in advance of the treatment date, together with a constant flow apparatus for each. This is necessary to permit rapid adjustment should the discharge rates in the river change.

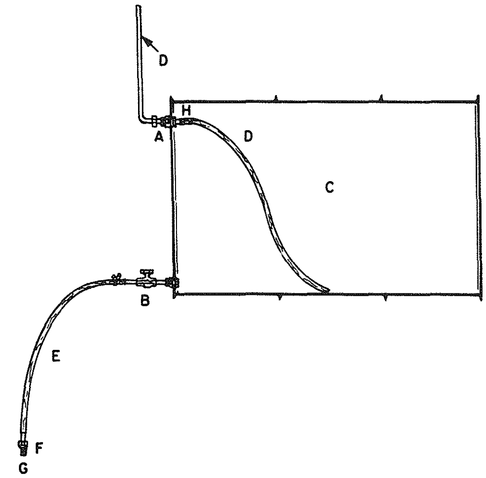

Fig. 1. Larvicide delivery apparatus. A - air inlet seal arrangement; B - oulet faucet; C - 114-liter drum; D - 0.95-cm ID copper tubing; E - 1.6-cm ID neoprene tubing; F - thin wall conduit and reducer to hold drilled orifice; G - drilled orifice; and H - 1.27-cm ID tygon tubing.

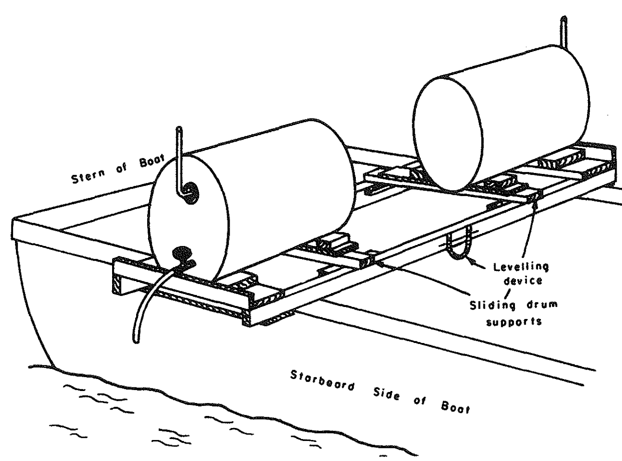

Fig. 2. Larvicide dispensing racks for boats.

During treatment, boats move synchronously back and forth in channels corresponding in width to the percentage of total discharge to be treated by each boat. Channels are marked by brightly colored buoys placed shortly before treatment.

As was previously indicated, monitoring sets are doubled in the week before treatment. Six sets, instead of three, are placed at each monitoring station. This arrangement permits half of the plastic cone substrates to be retrieved before treatment, and the other half after treatment. Sets at check stations should also be doubled.

On the treatment day, one boat and crew is sent down river ahead of the treated section of water to pick up sets at each monitoring station. The treated section of river is 7.5 min long at the injection point but becomes progressively longer downstream. For example, in the Athabasca River where surface current velocity is about 4.8 km/hr, the front of the treated section of water reaches 40 km in about 8 hr, 80 km in 16 hr, and 160 km in about 32 hr. The back of the treated section, however, passes these same points at about 16, 32, and 64 hr after injection, respectively. In other words, the treated section of water is about 8 hr long at 40 km, 16 hr at 80 km, and 32 hr at 160 km. This must be taken into account when picking up post-treatment samples so that a true assessment of effectiveness of treatment can be made. Pre-treatment sets and cones are removed from the water entirely, but post-treatment sets are left in the river with fresh cones in place so that a post-treatment follow-up of hatches and mortalities can be made.

In the experimental program, eight monitoring stations were maintained in the downstream treated area, and two were upstream to serve as checks. For practical purposes, one station located 20 km below the treatment point would indicate immediate effectiveness of population reduction attempts, but better knowledge of effective distance downstream can only be obtained by further downstream sampling or monitoring stations. At least one monitoring station must be maintained upstream of the treatment point to serve as a check station.

PROCEDURES ON TREATMENT DAY

1. Pretreatment

1.1 Take river volume discharge readings long enough before treatment to give time to divide the river into channels.

1.2 Determine the exact amount of larvicide required at this rate of flow and adjust the number of drums of larvicide to coincide with this flow rate. If a table of amounts of insecticide required for various flow rates is made up in advance, this process takes very little time.

1.3 Divide the amount of larvicide among the boats available for treatment. It is preferable to have not more than two drums per boat.

1.4 Using highly visible buoys, divide the river into as many channels as there are boats, with the percentage of river discharge in each channel matching the amount to be treated by the boat assigned to that channel.

1.5 Treatment time should have been decided previously. Before this time, move loaded boats, with crews on board (one boat driver and two drum operators), into position with each boat facing upstream and positioned against its left-hand channel buoy. Time should be allowed for at least two practice runs before actual treatment so that accurate timing and synchronization of movements can be developed.

2. Treatment

2.1 Each boat moves to its left-hand channel marker buoy with motors adjusted to hold position against the current.

2.2 Trim boat for port-to-starboard level attitude using movable ballast. This may be easily accomplished using the U-tube level attached to the support racks. This level is filled with colored liquid to a scribed line (Fig. 2).

2.3 On signal, when all crews are ready, boats begin to move from the left-hand channel marker to the right. Simultaneously, applicator valves are opened fully to allow larvicide to begin to flow. Time to reach right-hand marker is 2.5 min.

2.4 Begin synchronized movement of all boats back to left-hand marker. Time 2.5 min.

2.5 Begin synchronized movement back to right-hand marker for the second time. If all adjustments and calibrations have been properly made, drums will empty as the right-hand marker is reached. Toward the end of flow, drainage of larvicide will be interrupted as drum empties. At this time, each operator should up-end the back of his particular drum to ensure complete drainage in the specified time.

2.6 Return boats to the dispatch point and unload to prepare for post-treatment duties.

3. Posttreatment

3.1 Dispatch one boat and crew to move immediately downstream to pick up pretreatment samples (entire sets must be removed from the river).

3.2 Dispatch a second boat to pick up pretreatment samples from check stations. The second boat can then move downstream as required to pick up posttreatment samples and reset cones for posttreatment follow-up monitoring.

3.3 Assemble data as quickly as possible so that results of treatment can be determined.

PROCEDURES AND EQUIPMENT FOR MONITORING LARGE RIVERS

An index of population levels of *S. arcticum* in large rivers can be obtained by the use of artificial substrates for larval attachment. These substrates are plastic cones made by Spencer-Lemair Industries in Edmonton, Alberta. They have a height of 17.5 cm and a basal diameter of 10 cm. The cones are made up into sets. Each set consists of 20 m of 0.5-cm polypropylene cord tied to a 12-kg concrete anchor at one end and 4.5-liter plastic jug as a float at the other. Rust-proof metal rings of 2.5 cm diameter are tied into the cord at 1 m and 10 m from the float. Plastic cones are tied to the end of a 24-cm long cord to which a small metal snap has been attached. These are then snapped to the metal rings, and when placed in the river, the cones will stream with the apex pointed upstream. The use of small snaps speeds up weekly replacement of cones.

Sets should be placed in the river at points where the current is vigorous but where there is some protection from high-water surface drift. Sets should be in the river for 1 wk at a time. Depth of water at the point where sets are placed should be between 1.3 m and 4 m. At depths of less than 1.3 m, substrate cones may be left on dry land if the river level should drop and, at depths greater than 4 m, sets can be pulled under by a rise in the river level. The extremely fast water of chutes and rapids should be avoided since current velocity is so great that sets are dragged under the surface and lost. The sets can be further secured against washout by high water if the anchors are joined by 10-m connecting lines. The inner anchor, i.e. the one closest to the river bank, should be tied to a point on the bank (tree or stake) by a long, weighted line. Sometimes, if sets are forced beneath the surface, these lines help in locating them. Weighting the connecting line sinks it and permits much of the drift material to pass over it without snagging.

Sampling should begin as soon as possible after the ice break-up in the spring to follow *S. arcticum* larval development through its seven stages. At least two sets, and preferably three, should be placed at each monitoring station.

Location of sampling or monitoring sites is determined by the length of the section of river to be monitored. Sampling stations should never be more than 40 km apart, but may be closer together depending on river conditions. The largest numbers of larvae, and the most uniform samples will be obtained by sets placed downstream from, but near, rapids.

TREATMENT OF SAMPLES

Every 7th day, cones should be removed from sets and new cones snapped in place. Retrieval of cones should begin by approaching the set from a downstream position. As the boat operator brings the boat slowly alongside the float, his assistant leans over the side and grasps it, either directly or with a hook.

As the line is lifted, the cone will be brought to the surface. Once the cone is clear of the surface of the water, it must not be allowed to dip back below the surface as this allows many of the larvae to release and escape. Each cone is unsnapped from the line and placed in an individual container for washing. Simultaneously, a new cone is snapped onto the ring and the float and cone passed over the side of the boat, which is moving slowly forward, until the next cone is reached. When the second cone has been replaced by a new one, the set is allowed to drop back into the river.

Cones must not be allowed to dry during handling. Black fly larvae should be washed from cones with alcohol in the container in which they have been placed. When all larvae have been detached from the cone, they are poured onto a 100-mesh cloth screen disk with a diameter of 9 cm, which is held open in a supporting ring. When water and alcohol are removed and the larvae are concentrated on the cloth, it is removed from its holder, carefully folded with the larvae inside, and put into a vial in 95% alcohol together with a clearly marked identification label. Labels for preservation in alcohol should be marked with an HB lead pencil for legibility. Accurate records of dates, locations, set number, and position on the set should be kept for each cone. When the larvae are returned to the laboratory, they should be counted, identified (species), and the degree of maturity (instars) determined. This may be most easily done under a stereoscopic binocular microscope with up to 100 times magnification.

CONCLUSIONS AND PERTINENT OBSERVATIONS

In previously monitored rivers where areas of high larval numbers are known, pre-treatment monitoring can be limited to areas of highest numbers, e.g. on the Athabasca River. Areas beyond about 80 km downstream of the town of Athabasca are known to produce high numbers of *S. arcticum* larvae, pupae, and adults.

In rivers in which population levels and breeding areas of *S. arcticum* are unknown, e.g. the Peace River, at least one season, and perhaps more, should be spent obtaining this information before attempts at control are considered.

Need for treatment is determined by per-cone larval numbers. Generally, if the average on cones in a set is over 500 larvae, treatment is indicated.

If the degree of population reduction of *S. arcticum* at downstream areas must be measured, then pre- and post-treatment sets must be placed in these areas.

There are indications that larval counts from sampling stations established just beyond the downstream ends of rapids are more uniform than those from upstream stations.

Treatments can usually be scheduled 1 wk after the first larvae reach the seventh instar.

River current velocities are best determined by using accurate current meters using either the two-point or three-point method described earlier. An approximation of mean velocity can be made in a large river by timing the drift of a floating object along a marked floating line anchored in the river. Mean velocity is about two-thirds of this calculated velocity.

If the treatment point is far removed from a permanent flow recorder, then volume of flow at different levels of the river at the treatment point should be determined and a temporary gauge installed.

Variations in river discharge rate may be compensated for by adding or subtracting drums of larvicide to keep larvicide concentration at the desired level. Preparation of one injector to deliver a partial drum in the required time will permit closer adherence to the desired concentration.

CAUTIONS TO BE OBSERVED

River fluctuations must be watched very closely. For example, rain in the drainage basin west of Fort Assiniboine can be expected to increase the flow in the Athabasca River at the town of Athabasca 3 days later, and at 160 km downstream a further 1 day later.

Since larviciding operations are usually in late May or early June, a hard frost is still possible and the larvicide should be protected from freezing. Furthermore, any surplus larvicide should be stored under conditions of uniform temperature to prevent deterioration.

During application of larvicide, boats must be kept in a level port-to-starboard attitude so that flow rates by both applicators are uniform. Levelling is best accomplished by moving ballast from one side to the other.

Treatment, and all river-holding operations, should always be made with boats pointing in an upstream direction and power adjusted to hold in the cross-section.

APPENDIX II: MONITORING PROCEDURES AND GUIDELINES FOR ENVIRONMENTAL ACCOUNTABILITY IN LARVICIDING OPERATIONS

W. O. HAUFE

Treatment of rivers with pesticides involves risk to non-target taxa and the quality of the aquatic environment. Operations necessarily cause perturbations in living systems and the potential consequences of impacts are proportional to the size of downstream drainage areas. The public interest in protecting the quality of the environment dictates that large-scale operations of this kind be accountable within certain standards and criteria for performance and effectiveness of the operation. Performance of the operation must be subject not only to the objective of efficient pest control, but also to a continuing means of detecting and evaluating environmental risks revealed within a highly complex and dynamic system.

Surveillance of environmental impacts of river treatments may be designed within two general concepts of the consequences of pesticide use. One measure is concerned with the long-term effects of the practice on environmental quality and on the ecological balance and diversity in living systems. The other is a measure of quality control in treatment operations to ensure that immediate environmental impacts are contained within predetermined limits defined by previous evaluations of risk. The former measure takes the form of a special study designed to re-evaluate the principle of a practice at periodic intervals in the long-term interest of change in environmental quality. The latter is an integral part of continuing pest control operations to provide a record of acceptable performance of technique. Guidelines and procedures to follow are designed to meet minimum requirements in a record of performance for larviciding operations in the Athabasca River.

ENVIRONMENTAL PARAMETERS

Experimental studies have identified the most sensitive taxa in the ecological system as indicators of excessive treatment or of unacceptable immediate impact on the standing crop of aquatic organisms. Impacts on these indicators must be shown to remain within certain limits as a measure of an acceptable standard of the black fly larviciding treatment.

PROCEDURES

Monitoring Site

Select a monitoring site within 15-20 km downstream of the point of injection for the pesticide. At this distance downstream, the maximum impact of the mixing phase of the pesticide on non-target invertebrates is detected as a casualty rate in the drift. Casualties resulting from exposure to high concentrations of unmixed pesticide are captured by the main current in the thalweg and appear with an increased density of the 'constant' drift coinciding with the passage of the treated pulse.

Control Site

Under some circumstances, it may be desirable to include measurements of density in the drift at a site upstream of the injection of the larvicide. It will serve as a 'control' to detect perturbations of short duration in the drift that are unrelated to the larvicide, but that may occur during the monitoring period due to industrial origin upstream. It will not serve as a 'control' for the monitoring site in terms of numbers of organisms in the drift or of distribution of taxa since the two sites cannot be assumed to be ecologically comparable in relation to the standing crop. The need for inclusion of a 'control' site would have to justify a doubling of the resources required to carry out the monitoring operation.

Sampling Equipment and Sample Processing

Use the river drift sampler (Burton and Flannagan 1976) as modified by Haufe et al. (Technical Report: p. 169) for operation in swift currents. Arrange a sampler set design as described by Haufe et al. (Technical Report: p. 169). Employ one sampler set at a monitoring site with two samplers, one at 50 cm below the surface and the other at mid-depth. Provide four samplers for operation of each set with the required rotation between sampling intervals. A spare sampler should be available at each monitoring site for replacement in the event of damage from floating debris during severe floods. Sets with the proper arrangement of buoys are easily recoverable during floods.

Use white enamel pans to sort organisms and organic matter washed from the drift samplers immediately after removal from the river. Sort active organisms from disabled or dead ones in river water in separate containers. Final sorting should be terminated 3 hr after samples have been removed from the river. At this time, preserve the separate samples with ethyl alcohol in sealed glass containers with labels to identify sample, site, date, and time for later taxonomic identification and evaluation in the laboratory.

Sampling Site

Locate the sampling site within the thalweg (T) of the river at a point where it is midway between the river banks in a normal cross section (X-Y) of the river flow (Fig. 1). It is essential that samplers operate in that part of the cross-section that carries the 'constant' drift of organisms. Locations at bends or irregular courses of the river should be avoided. The 'constant' drift, unlike the 'behavioral' drift, contains disabled and dead organisms that are captured and retained in the thalweg over long distances in the flow. Therefore, the casualty rate will be biased as an underestimate if the sampling site is in the ebb current near shore, and as an overestimate if it is in the rip current near the outside of a bend.

Sampling Schedule

Estimate the time of arrival of the treated pulse as accurately as possible from the average velocity of the river upstream to the point of injection. Design a 5-day sampling schedule to embrace the time of arrival of the treated pulse as nearly as possible at the mid-point of the sampling period, i.e. within the 3rd day. Round-the-clock sampling is desirable if labor is available to accommodate the schedule. Otherwise, sampling must cover the same minimum period of 12 hr in each of the 5 days. In the event of a 12-hr sampling period per day, more accuracy is required in estimating time of arrival of the treated pulse so that it occurs near the middle of

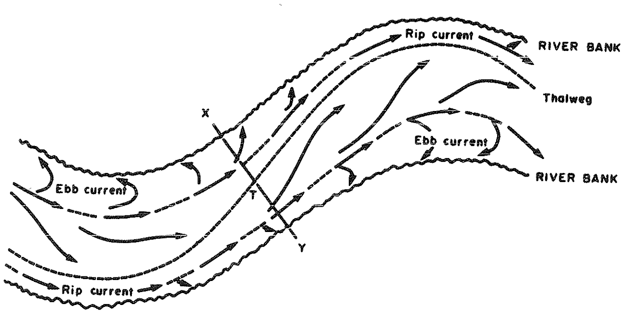

Fig. 1. Schematic representation of river flow showing ideal location for sampling across the river flow.

the sampling period. The length of the pulse will range from 1-2 hr and, in a reduced daily sampling period, must be preceded and followed by one full sampling interval.

Remove drift samples at regular 4-hr intervals on every day. This procedure is essential to avoid bias in daily comparison of densities in the drift due to the diurnal rhythm in behavior of organisms.

Criteria in Evaluation

Identify and ennumerate all individual organisms within indicator genera. The indicator genera represent three orders of invertebrates:

Trichoptera:	*Cheumatopsyche* spp. *Hydropsyche* spp.
Ephemeroptera:	*Baetis* spp. *Heptagenia* spp. *Ephemerella* spp.
Plecoptera:	*Isogenus* spp. *Isoperla* spp. *Hastaperla* spp.

No casualty rate for an indicator genus should exceed 40% of the density in the constant drift. With few exceptions, the level of 'constant' drift on days 4 and 5 should return to the same level as that on days 1 and 2. Exceptions will occur in some genera, such as those in the Plecoptera, if mass emergence of maturing forms coincides with time of treatment. In this case, densities in the 'constant' drift will decrease during days 4 and 5.

As a means of detecting mass emergence, turn over dead wood and other ground cover opposite riffles on shore at regular intervals in morning and evening to expose adult plecopterans.

REFERENCES

BURTON, W. and FLANNAGAN, J. F. 1976. An improved river drift sampler. Environ. Can., Fish. Marine Serv., Tech. Rep. 641.