

Rivers Research Branch
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March 1989

AQUATIC ASSESSMENT PROTOCOLS FOR OIL
SANDS AND HEAVY OIL OPERATIONS

PERD PROJECT #57205
Task 5.7

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INTRODUCTION

Aquatic impact assessment is a major concern of federal and provincial agencies, especially in areas where economic development occurs in the vicinity of a sensitive ecosystem, a commercial or sports fishery, or designated natural preserve. Proper assessment requires the development of protocols which take into account all appropriate parameters, and lead to policy decisions which reflect realistic estimates of risk. While environmental assessment has historically focussed on a managed resource, such as a fishery, there is increasing emphasis being placed upon functional analysis of the entire ecosystem, including chronic effects displayed at lower trophic levels.

The Rivers Research Branch (RRB) of the National Water Research Institute (NWRI) proposed a four-year research project under the aegis of the federal Panel for Energy Research and Development (PERD). The long term goal is to develop the knowledge base which can assist government and industry in the assessment of potential environmental impact of oil sands and heavy oil operations upon river systems, and to incorporate the knowledge base into a model which can be used to predict environmental sensitivity to various development scenarios. Using other data collected as part of our national program, we anticipate that this model may be transferable to other river systems where similar developments are planned. The lower reach of the Athabasca River and the Peace-Athabasca Delta provide an excellent laboratory for our program, since tar sands development has been ongoing for some time and future developments have been proposed.

This study is neither predicated on, nor motivated by any current complaint or specific concern. Rather, the study is motivated by the following factors:

- lack of knowledge surrounding the pathways, fate and effects of polycyclic aromatic hydrocarbons (PAHs) and their metabolites in natural river systems;
- consequent inability of industry and government to plan for and develop appropriate levels of waste treatment technology for tailings pond fluids and process stream byproducts which would enable surface discharge at acceptable levels of environmental risk;
- lack of understanding of the environmental impacts of the heavy oil industry relative to other industry groups such as current and planned pulp and paper discharges into the Peace-Athabasca system.

We have assembled a multi-disciplinary team within RRB to carry out the various scientific tasks necessary to achieve our overall goal. This team consists of expertise in the following disciplines: environmental chemistry, geochemistry, biochemistry, fish biology, ecotoxicology, microbiology, sediment transport, watershed modelling, and riverine physical processes. In addition we have in-house access to experienced technical assistance in field sampling and logistical support. We intend to involve private sector or other government agencies for assistance whenever a specialized capability is needed which is outside our own realm of expertise.

The Athabasca tar sands in northeastern Alberta contain a substantial part of Canada's oil supply, and may become increasingly important in the future as the world's supply of conventional oil reserves dwindles. From the environmental point of view, PAH emissions and contamination from synthetic fuel plants have long been a focus of concern. Recently, interest in heterocyclic PAHs has increased. A number of nitrogen-, sulfur- and oxygen-containing PAHs (N-PAHs, S-PAHs and O-PAHs) as well as their alkyl derivatives have been identified in tar sands plants process streams and emissions, as well as in other synthetic fuel operations. These compounds have also been identified in other media, such as marine sediments, tobacco smoke, urban air particulates and automobile exhausts. Some of these heterocyclic PAHs are potent mutagens and carcinogens. Very little is known about their persistence, fate and effects in aquatic environments. The anticipated increase in synthetic fuel production may significantly increase concentrations of N-PAHs and S-PAHs in the environment, because of the characteristically higher concentrations of organic nitrogen and sulfur in oil sands relative to conventional oil.

This study examines the persistence, fate and effects of chemicals which arise from upgrading operations in tar sands plants, and which may contaminate aquatic environments. The study includes chemical, physical and biological components which are expanded upon below. The prediction of downstream effects of these classes of compounds and of their principal metabolites is currently not possible due to unknown biogeochemical pathway characteristics both in the open water and under winter ice conditions.

Although the field site will be the Athabasca River in the vicinity and downstream of the two existing tar sand plants, the research is intended to have general applicability to other rivers and to other kinds of synthetic fuel operations in which substantial quantities of PAHs, N-PAHs, S-PAHs, O-PAHs may be produced and which may be discharged to lotic systems.

RESEARCH OBJECTIVES

Principal Research Objectives

- (i) identify PAHs, their derivatives and other chemicals which may contaminate aquatic environments as a result of tar sands mining and upgrading;
- (ii) determine their persistence and pathways of physical, chemical and biological distribution and transformation;
- (iii) determine effects of these substances on organisms in different trophic levels;
- (iv) generate predictive models which can be used in impact assessment of other heavy oil extraction and upgrading operations.

Other Applications

The study is expected to have direct relevance to the following issues:

- (i) water quality objectives for the Peace-Athabasca delta;
- (ii) options analysis for effluent management of tar sands operations;
- (iii) comparative evaluation of the impacts of bituminous sands and oil extraction relative to other known sources of toxicity (e.g., pulp and paper) on the Athabasca River.

The study has broader applications for:

- environmental assessment techniques
- aquatic monitoring protocol development
- broad relevance to spill assessment and risk evaluation
- general understanding of chemical transport in flowing water

STUDY TIMEFRAME

It is anticipated that this study will require four years. For planning, it has been organized into five subject areas (biological, chemical, ecotoxicological, biochemical, physical) and into three phases (1989/90 reconnaissance year, 1990/92 detailed study years, 1992/93 completion year). The activities are briefly outlined in Charts 1-3. Detailed study plans prepared by the investigator(s) in each subject area are included in the proposal.

STUDY MANAGEMENT AND COMMUNICATION

This Institute carries out research which has broad generic interest and this study is no exception. Because the work may have particular application to federal, provincial and industry concerns, we are especially sensitive to the needs for dissemination and comment on research findings by these three parties prior to publication of the research. The study will be managed by a small working group comprised of federal and provincial science managers. The final responsibility for the scientific content rests with the National Water Research Institute.

- Steering committee (DOE-C&P, Alberta Environment)
- Field program: NWRI staff
- Chemistry: NWRI staff
- some work, e.g., fish analysis will be contracted to selected private sector and university contractors

RECONNAISSANCE YEAR - 1989/90

The purpose of the reconnaissance year is to establish whether or not there is reason to believe that current licensed discharges, once mixed in the river, have ecological impacts or tainting potential beyond impacts associated with natural compounds or compounds associated with other industry groups. Part of the objective is to identify those classes of compounds which might be expected to accumulate or metabolize in fish or which might induce chronic or genotoxic effects on lower life forms.

LITERATURE REVIEW

A full literature review of PAHs and associated chemistry relevant to the heavy oil industry has been contracted under CEPA funding, and will be completed by March 31, 1989. It will cover these classes of compounds:

- PAHs, methyl homologues and metabolites
- hydroxylated PAHs (H-PAHs)
- polycyclic aromatic sulfur heterocycles (S-PAHs)
- polycyclic aromatic nitrogen heterocycles (N-PAHs)
- naphthenic acids

The subjects to be reviewed are:

- The chemistry of parent compounds and metabolites.
- Chemical methods for qualitative and quantitative analysis of these compounds in water, sediment and fish.
- What is known about the quantities and rates of release of these parent compounds into the river from tar sands operations, and how do these compare with natural release rates, if any?

- What is known about the toxicity of these compounds and their metabolites to native fish of the Athabasca system, and to laboratory organisms?
- Which of these compounds and their metabolites are known or likely to cause tainting of raw or cooked fish?
- What is known of the rates and processes of degradation of parent compounds once they enter receiving waters?

RECONNAISSANCE PROGRAM

The reconnaissance program will provide the following information:

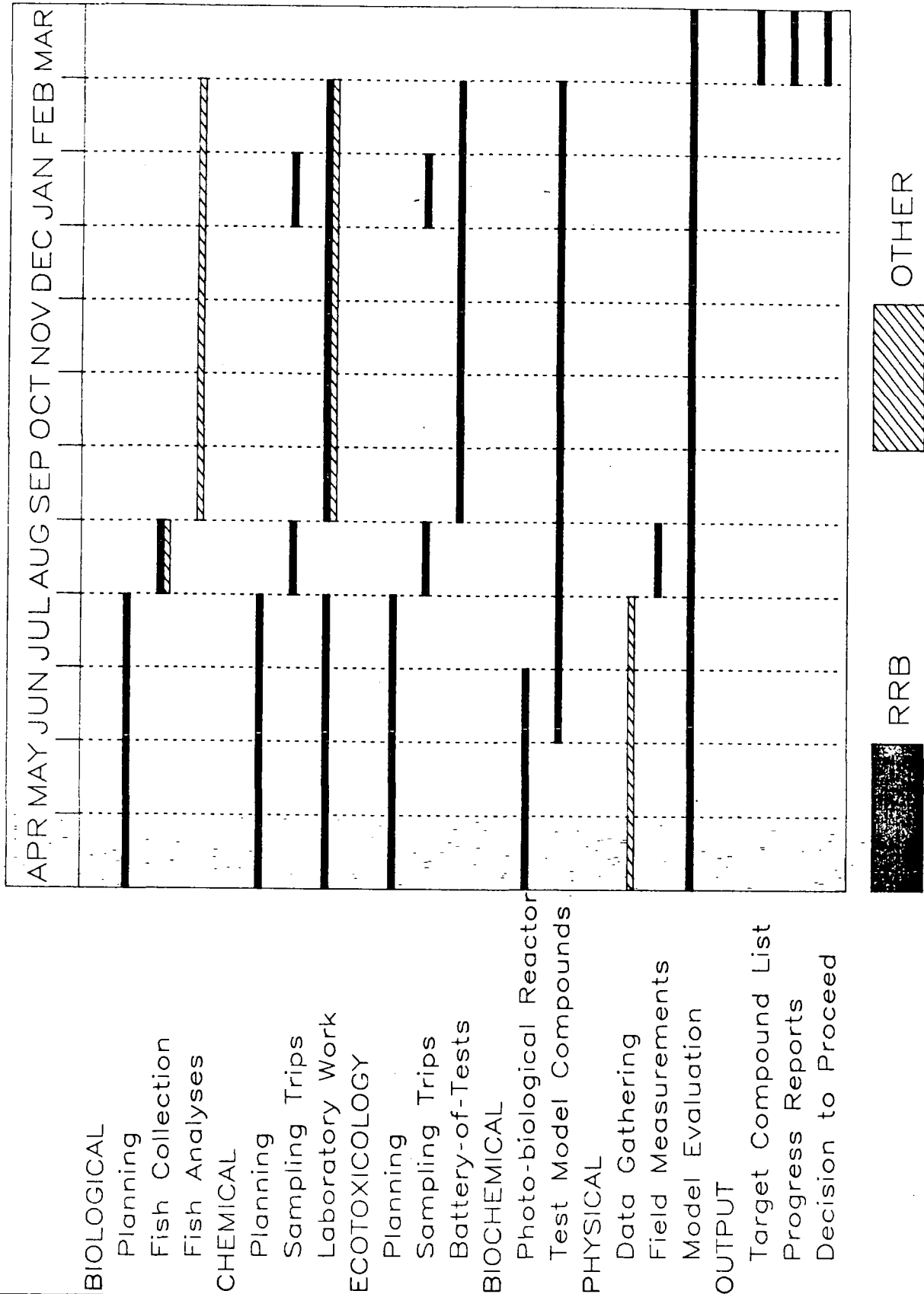
- What PAHs and related compounds can be detected in water, suspended particulate material and bed sediments in the lower Athabasca? Are these natural or anthropogenic?
- What PAHs and metabolites are found in fish and are there differences between sites? Are the (presumed) parent compounds for these metabolites also found in other environmental compartments?
- Are there concentration gradients of these compounds downstream from the tar sands operations?
- Is there evidence of sublethal, chronic or genotoxic effects which are above background?

This information will allow us to decide if there is sufficient reason to proceed with the rest of the study, and if so, will help to focus the study design for the detailed study years which follow.

Chart 1 shows how the activities in each subject area fit together and are to be coordinated. The primary activities of the biological and chemical components are parent compound and metabolite identification. Ecotoxicological work will concentrate on the response in a battery of tests to extracts prepared from the various compartments. This will be a preparatory year for the biochemical and physical components. At the end of this first year, we will be able to prepare a list of compounds and metabolites found in the various compartments, and the toxicological response, if any, of extracts tested. If, on the basis of this information, the decision is made to proceed with the project, this information will be used to plan sampling and analytical protocols for the detailed study years. At this point we will also be able to decide on candidate compounds for laboratory studies which will specify those physico-chemical and biochemical properties that are needed for pathway modelling.

A brief outline of the planned work in each subject area is given below. Full details are given in the individual work plans appended hereto.

CHART 1. WORK PLAN FOR 1989/90 RECONNAISSANCE YEAR



Biological, chemical and physical sampling will be done in August, 1989, when summer high flows should be receding. A chemical sampling trip is planned for January or February, 1990, to provide some under-ice data for comparison.

SITE SELECTION

Site selection (Figures 1a, 1b and 2) in the reconnaissance year is designed to provide sufficient resolution of spatial variability to permit detailed cross-sectional analysis of chemical fluxes in subsequent years. Using protocols developed in other studies, we propose the following:

- Single samples will be collected in the vicinity of Tar Island (miles 23, 24, 25 and 26 in Figures 1a, 1b)) to characterize any point source inputs of chemical leaching into the river.
- Transects of four or five samples across the river (Figures 1a, 1b) will be taken to delineate lateral mixing. This type of transect sampling should only be needed in the reconnaissance program. The transects chosen are:
 - (i) A benchmark transect at mile 16 (above Tar Island) to determine if upstream inputs such as the Clearwater River and Fort McMurray are well mixed.
 - (ii) Transects at miles 29, 31.5 and 34.5 (below Tar Island) to determine when lateral mixing of any point source inputs from the tar sands operations is complete.
- Midstream, near surface time-of-travel sampling (Figure 2) at miles 16 (upstream reference), and miles 34.5, 47, 69 or 73, 102 and 118, to detect downstream gradients in chemistry, biology, and ecotoxicology. These sampling sites are located at approximately equidistant intervals downstream at points where the river has a well defined channel, an absence of islands or permanent bars, and should be well mixed laterally. These sites are either immediately above or several kilometers downstream of tributaries.

Sampling Strategy

We have found in previous studies that seasonality plays a major role in chemical behaviour of rivers. We intend, therefore, to sample on the basis of time-of-travel (or as nearly as possible given logistics) in summer and winter during the reconnaissance stage. Open water sampling will be from a research vessel and winter under ice sampling by aircraft. Raw water will be processed using continuous-flow centrifugation for time-integrated bulk sampling of suspended material with on-board collection of large volumes of clarified water for subsequent chemical extraction. Past studies indicate that the <63 μm suspended material which contains most of the contaminants is fairly evenly distributed in the vertical section, therefore, we use a 0.3 m depth for sampling.

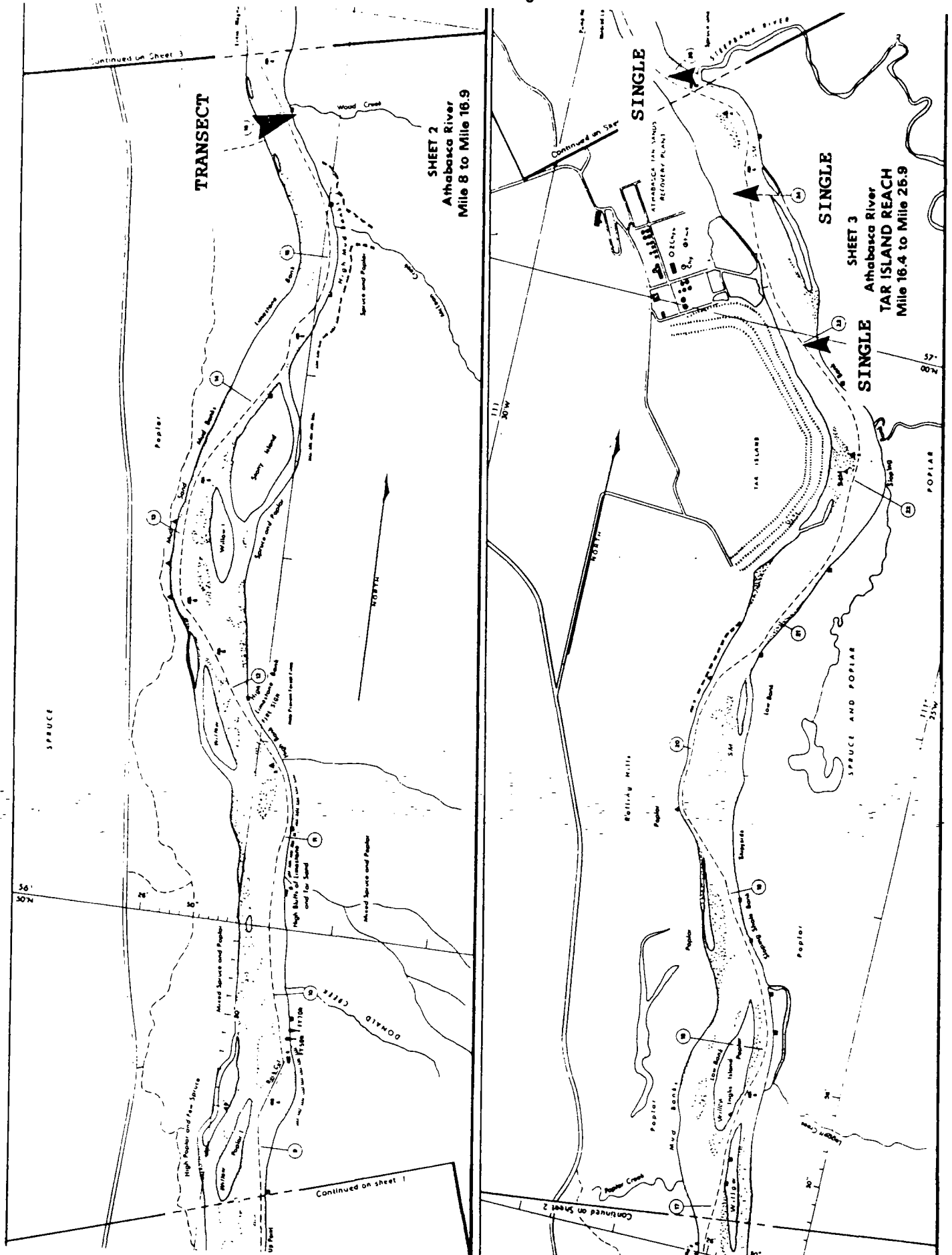


Figure 1A. Sampling sites for transects (▲) and single (○) samples.

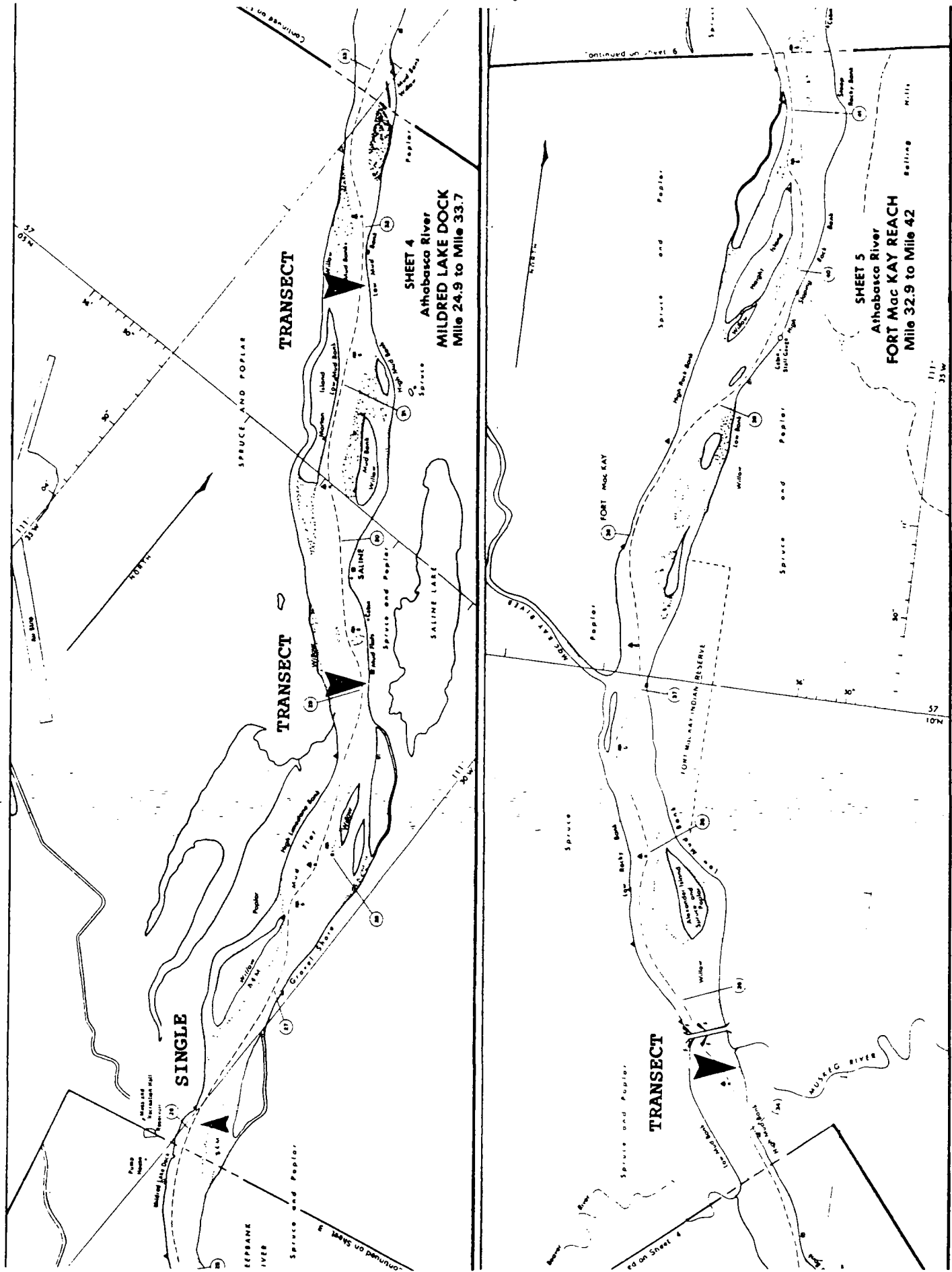


Figure 1B. Sampling sites for transects (▲) and single (▲) samples.

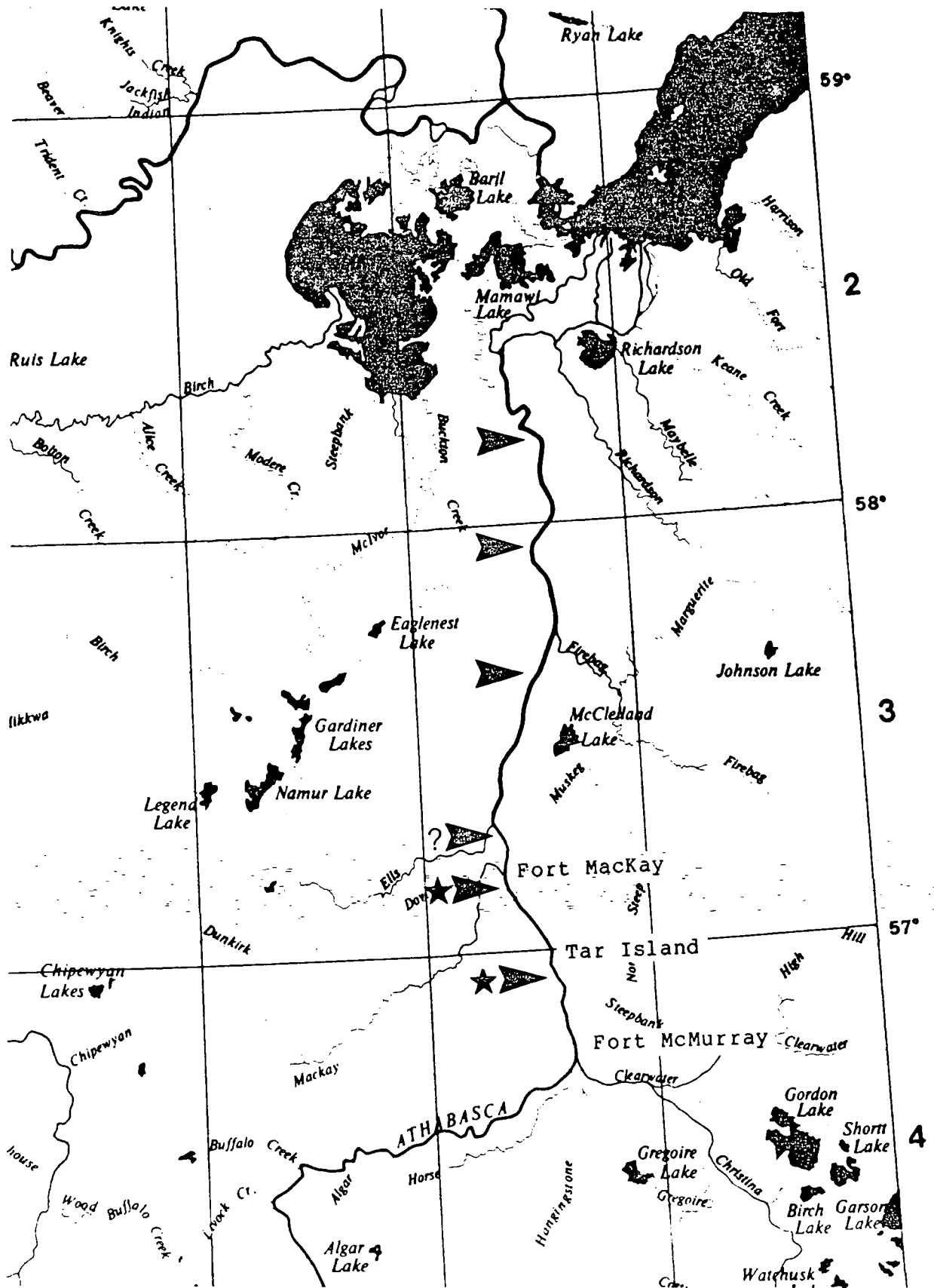


Figure 2. Midstream sampling sites (▲) for time-of-travel profile.
 ? Denotes possible relocation after reconnaissance year.
 ★ These locations are also transects in reconnaissance year.

Sampling Assumptions and Implications

This type of study must assume that ambient chemistry below Tar Island is typical of licensed effluent being discharged. The study is not designed to determine whether observed chemistry is atypical - i.e., representative of an abnormal condition pertaining to a plant upset. The study, therefore, can make no judgement on the quality, quantity or regulatory implications of observed chemistry. Fish chemistry represents long-term exposure and our findings may lead to options analysis for waste treatment. The study data are, however, nonjudgemental and are capable only of specifying the environmental implications of treatment options.

BIOLOGY

In the reconnaissance year the principal purpose of fish analyses is to establish presence/absence of parent compounds and/or metabolites which are associated with heavy oil effluents. The major chemical groups associated with typical process streams, and tailings ponds are generally known. The second objective is to establish whether observed chemistry in fish is significantly different from that derived exclusively from natural release and uptake of hydrocarbons from parent oil sands.

To keep analytical costs to a minimum, fish analysis can be limited to a single species. The species chosen should be a bottom feeder which is abundant, large enough to dissect for organ/tissue analysis, and well suited for histopathological studies. The species which best meets these criteria is white sucker (further detail can be found in the work plan of J.L. Metcalfe). To answer the primary questions, three sites are required: an unimpacted lake, the Athabasca delta, and the Athabasca River between Tar Island and Fort MacKay or preferably (subject to access) Mildred Lake or the Syncrude sedimentation ponds. The fish will be dissected to provide organ/tissue samples from ten individuals. PAH and metabolite analysis will be contracted out.

CHEMISTRY

The general requirement of the reconnaissance year is to:

- Characterize the levels and downstream gradients of target compounds. Target compounds are those identified in fish or for which there is evidence from the literature.
- On the bases of the above, nominate a candidate list for detailed investigation in the two subsequent years.

- Develop sampling, field extraction and laboratory analytical protocols for subsequent application (Ongley et al., 1988; Birkholz et al., 1989).

The theoretical chemistry of parent compounds and metabolites is well known, as is uptake and metabolism by caged fish in experimental conditions. The laboratory extraction and analytical procedures have been developed in recent years. What is not known is the pattern of occurrence of these compounds in natural environmental compartments.

Therefore, water, suspended particulate material, and bed sediments will be collected from a set of transects and nearshore sites extending from above Tar Island to Fort MacKay (Figures 1a and 1b). These same compartments will be sampled roughly according to time-of-travel at midstream sites from above Tar Island to Embarras (Figure 2). All of these samples will be analyzed for trace organic compounds and some of them for metals such as organic and inorganic forms of vanadium which is found in tar sands and which in some forms is toxic to fish. Several sets of replicate samples will be extracted by various methods to choose the most appropriate and effective sampling and extraction methods for the detailed study years.

ECOTOXICOLOGY

Sampling locations will be the same as for the chemical survey. Toxicity of water extracts of sediments will be determined using Ceriodaphnia and Daphnia tests. Water, suspended particulate, and bed sediment will be extracted by different methods to determine the best method for preparing extracts for the microbial "battery of tests". These results will permit the delineation of the impact zone and will be ranked relative to other areas in Canada which were included in a previous cross-Canada survey.

The role of bacteria in particle aggregation and contaminant transport will be studied using techniques such as cascade filtration, particle size distribution measurements (Malvern laser instrument), and contaminant binding.

BIOCHEMISTRY

This laboratory program will cover the area of photochemical and biological degradation rates. The coupling of the two processes will be studied by using a combined photo-biological reactor. This will provide the rates needed for environmental fate modelling. Activities in the first year will be construction of the photo-biological reactor and preliminary testing of model compounds.

PHYSICS AND MODELLING

A contract will be let to gather and synthesize available physical, chemical and biological data on the Athabasca River below Fort McMurray to aid in the development of hydrodynamic and toxic fate models. Different model formulations will be considered. Modelling strategy will be a major factor in study design for the detailed study years. The modelling work will be supported by research mentioned above on bacteria-particle interactions and photo-biological degradation, as well as other work in RRB on cohesive sediment transport and sediment-water partitioning of contaminants. The final model will use state-of-the-art toxic chemical model(s) combined with expert system and geographical information system techniques already in use by RRB modellers.

DECISION CRITERIA FOR GO/NOGO TO DETAILED STUDY YEARS

Since there are several possible outcomes from the reconnaissance survey, it is difficult to state exactly what combination of findings would justify proceeding with the next phase of the project. Clearly, if we find very few PAHs and related compounds in any of the compartments, then further work would be impractical.

The decision to proceed with the study will be based on:

- The number and concentration of chemicals found in the three compartments (water, sediment, fish).
- The presence of downstream concentration gradients in water or sediments.
- Relationship between compounds found in the fish and other compartments.
- Fish tainting potential of various compounds found in the river.
- Presence of metabolites in fish which can be attributed to tar sands operations.
- Detection of acute and/or chronic toxicity response in the ecotoxicological battery of tests.

DETAILED STUDY YEARS - 1990/92

The schedule for these two years is shown in Charts 2 and 3. The work can be conveniently divided into field and laboratory programs.

FIELD PROGRAM

Planning and study design for the detailed study years will be completed between April and July 1990. At this time, decisions will be made regarding the type of sampling and the number and location of sampling sites. The ideal is flow-weighted cross-sectional sampling at each site so that loadings can be calculated. However, it may not be possible to do this and also sample according to time-of-travel. An alternative is time-of-travel sampling in the midchannel of the river.

We anticipate that sampling a minimum of five and a maximum of seven sites will provide the necessary longitudinal resolution for modelling. Chemical analyses and ecotoxicological testing will be done in-house. The next set of choices will be the compartments to sample, the extraction methods to use, the analytical protocol(s) to follow, and quality control/quality assurance procedures to employ.

Past studies have shown that chemical transport varies considerably with discharge. Our sampling program is designed to cover all flow regimes. The tentative schedule for sampling is the following:

- August 1990. Summer low flow corresponds to minimum sediment transport, maximum biofilm productivity, and highest water temperatures.
- October 1990. Fall low flow.
- February 1991. Under ice. Minimum microbial activity. Concentration of volatile compounds and long range transport of chemicals should be at a maximum.
- Spring 1991. Spring high flow corresponds to maximum sediment transport, lower biofilm activity, and cold water temperatures.
- August 1991. Yearly variability by comparison to August 1990 results.

This part of the program will be providing information on concentration gradients, loadings, partitioning between compartments, sediment transport and flocculation, the role of bacteria-particle aggregates in contaminant transport, and microbial productivity.

CHART 2. WORK PLAN FOR 1990/91 DETAILED STUDY YEAR

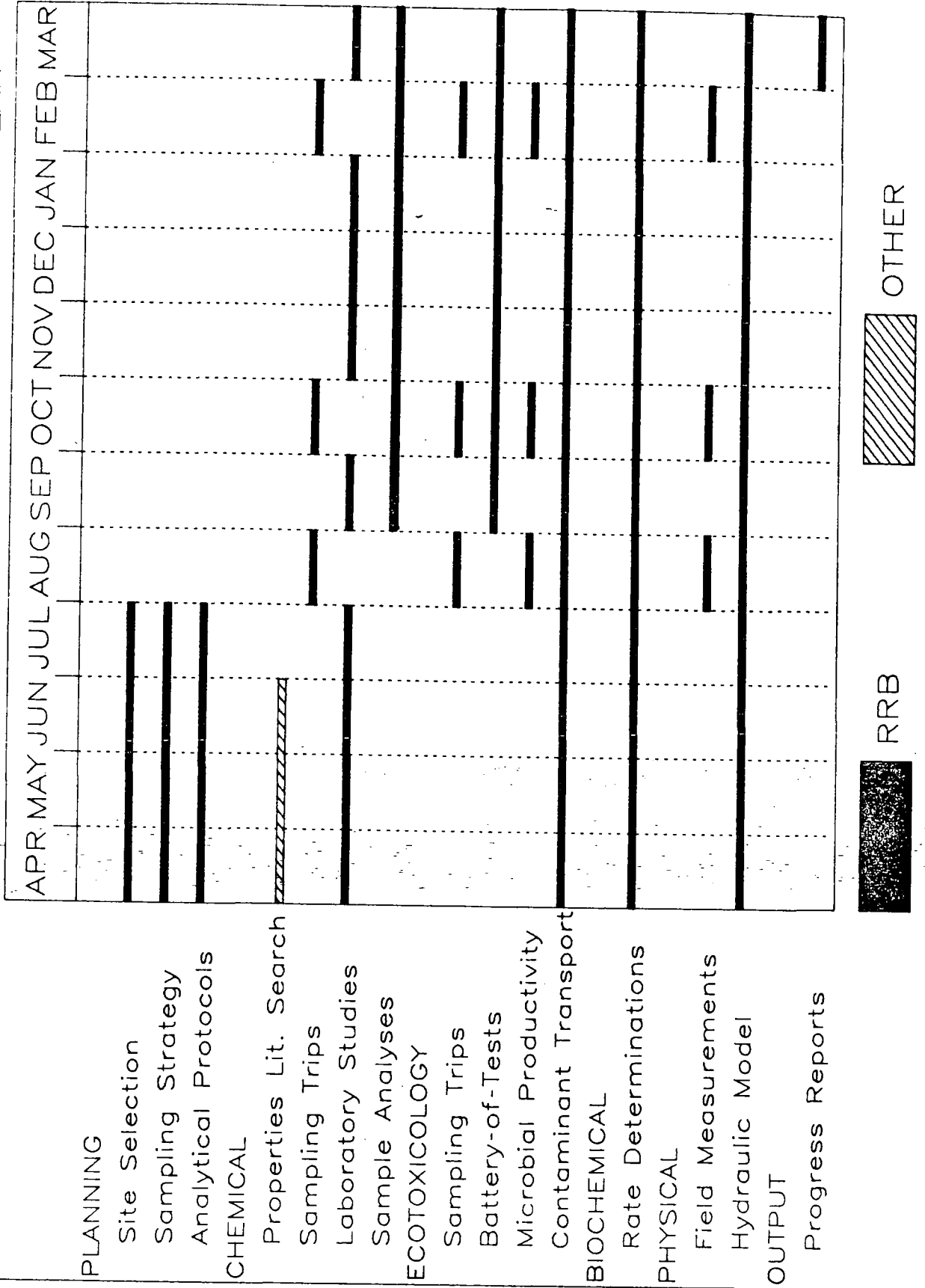
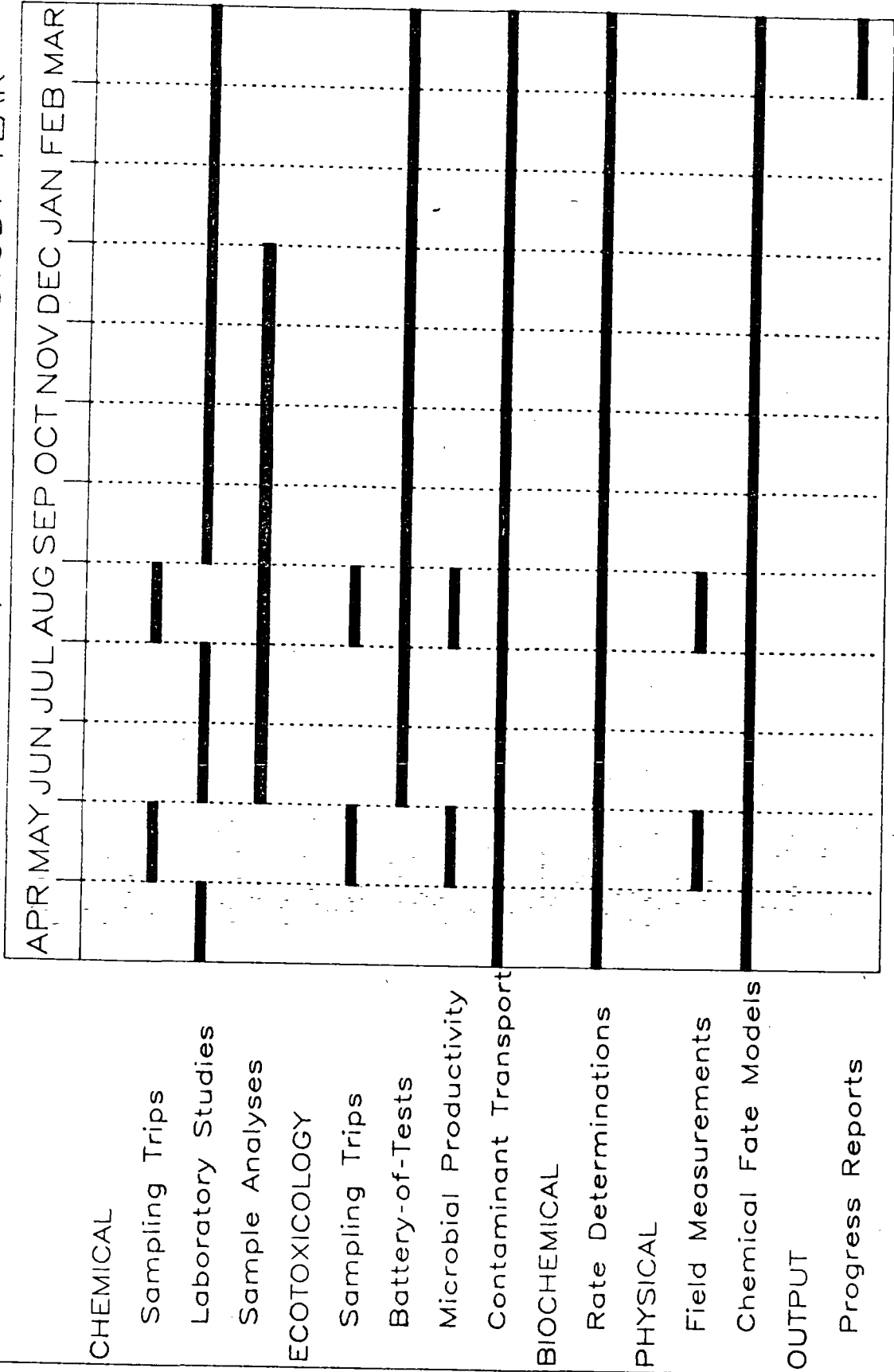


CHART 3. WORK PLAN FOR 1991/92 DETAILED STUDY YEAR



If the fish analysis and histopathology work from the reconnaissance year are successful, then further fish sampling may not be necessary. Sampling of other biota such as clams or mussels, and sensory analysis of fish tainting may be done.

LABORATORY PROGRAM

One of the main data requirements for chemical fate modelling will be physical and chemical properties of compounds selected for modelling as well as rates of hydrolysis, photolysis and biodegradation. To minimize the amount of laboratory work required, a literature search will be carried out under contract to find out what information is already available.

Most of the laboratory work will be carried out during the detailed study years. Candidate compounds from the reconnaissance year will be studied to determine volatilization, photolysis and biodegradation in laboratory systems. Further work will be done to identify metabolites and transformation products. Partition coefficients between water, dissolved organic matter, and suspended particulate matter will be determined. Ecotoxicological response will be further examined by the "battery of tests". Flocculation and bacteria-sediment aggregates will be investigated in laboratory systems.

These studies will provide the quantitative information and conceptual understanding on which the modelling work will be based.

MODELLING

Modelling will begin with a hydraulic model for the lower Athabasca. As rate and partitioning data are provided by the laboratory work, and chemical concentrations become available from the field work, chemical fate models can be tested and calibrated.

COMPLETION YEAR - 1992/1993

Physical and chemical data sets will be completed. These data will be applied to chemical pathways models, including expert systems approaches to handle decision frameworks for aquatic management.

Final reporting is scheduled. This will include all chemical information, physicochemical pathways analysis and river models, recommendations for assessment criteria and ambient monitoring for application to oil and gas development elsewhere.

OUTPUTS/MILESTONES

- 1989/90 Progress report of initial reconnaissance study
- 1990/91 Progress report on low flow characterizations
- 1991/92 Progress report on under ice and high flow characterizations
- 1992/93 - Completion of physical and chemical data sets and development of models for effluent impact assessment and spill management
- Final Report, including recommendations for:
 - 1) Environmental Impact Assessment
 - 2) Monitoring needs and protocols
 - 3) Policy implications (if pertinent)
- Four scientific publications in journals

REFERENCES

- Birkholz, D.A., R.T. Coutts and F.M. Pasutto. 1989. Aquatic toxicology of heavy oil. Environ. Toxicol. Chem. (submitted).
- Ongley, E.D., D.A. Birkholz, J.H. Carey, and M.R. Samoiloff. 1988. Is water a relevant sampling medium for toxic chemicals? An alternative environmental sensing strategy. J. Environ. Qual. 17:391-401.

BUDGET

SOURCE OF FUNDS
PERD NWRI Short
-fall

1989/90

Person Years	4.0			
<hr/>				
Capital (\$K)	100		100	
Operating (\$K)				
- Field logistics	54			
- Fish collection	10			
- Fish chemistry analysis (contract)	84			
- Physical model data (contract)	5			
- NWRI laboratory costs	40		40	
Total (\$K)	293	40	140	113

1990/91 (Projected)

Person Years	5.0			
<hr/>				
Capital (\$K)	80		80	
Operating (\$K)				
- Field logistics	60			
- Chemical model lit. search (contract)	20			
- NWRI laboratory costs	85		48	
Total (\$K)	245	117	128	nil

1991/92 (Projected)

Person Years	6.0			
<hr/>				
Capital (\$K)	30		30	
Operating (\$K)				
- Field logistics	40			
- NWRI laboratory costs	135			
Total (\$K)	205	175	30	nil

1992/93 (Projected)

Person Years	5.0			
<hr/>				
Capital (\$K)	30		30	
Operating (\$K)				
- Expert system development (contract)	30			
- NWRI laboratory costs	135		8	
- Travel re consultations	10			
- Report preparation	8			
Total (\$K)	213	175	38	nil

NWRI LABORATORY COSTS

COST ESTIMATE FOR FY 89/90 (\$K)

- Laboratory operations, supplies, expendables	40
Total (\$K)	<u>40</u>

COST ESTIMATE FOR FY 90/91 (\$K)

- Laboratory operations, supplies, expendables	55
- Contract personnel	<u>30</u>
Total (\$K)	85

COST ESTIMATE FOR FY 91/92 (\$K)

- Laboratory operations, supplies, expendables	55
- Contract personnel	<u>80</u>
Total (\$K)	135

COST ESTIMATE FOR FY 92/93 (\$K)

- Laboratory operations, supplies, expendables	55
- Contract personnel	<u>80</u>
Total (\$K)	135

TRAVEL AND FIELD COSTS

BASIS FOR COSTS

- airfare and transporation, more than one week in field, per person	\$1,000
- airfare and transportation, one week or less in field, per person	1,300
- per diem while in Fort McMurray, per person	100
- ski plane rental, per day	1,000

RECONNAISSANCE YEAR - 1989/90

Cost Estimate for August, 1989 (\$K)

- Technical Operations	16.0
- Fish collection	4.0
- Travel for RRB staff	
- three persons for three weeks	9.0
- one person for two weeks	2.5
- three persons for one week	6.0
- less per diem adjustment for time on boat	-2.0
- Vehicle rental	2.0
- Miscellaneous (fuel, air freight, etc.)	2.5
Total (\$K)	40.0

Cost Estimate for February, 1990 (\$K)

- Technical Operations	6.0
- Travel for RRB staff	
- two persons for one week	4.0
- Vehicle rental	0.5
- Miscellaneous	0.5
- Ski plane rental, three days @ \$1,000	3.0
Total (\$K)	14.0

Total for FY89/90 (\$K) 54.0

FIRST DETAILED STUDY YEAR - 1990/91

Cost Estimate for August, 1990 (\$K)

- Technical Operations	12.0
- Travel for RRB staff	
- three persons for two weeks	7.5
- less per diem adjustment for time on boat	-2.0
- Vehicle rental	0.5
- Miscellaneous	2.0
Total (\$K)	20.0

Cost Estimate for October, 1990 (\$K)

- same as August, 1990	Total (\$K) 20.0
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Cost Estimate for February, 1991 (\$K)

- Technical Operations	8.0
- Travel for RRB staff	
- three persons for one week	6.0
- Vehicle rental	0.5
- Miscellaneous	0.5
- Ski plane rental, five days @ \$1,000	5.0
Total (\$K)	20.0

<u>Total for FY90/91 (\$K)</u>	60.0
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SECOND DETAILED STUDY YEAR - 1991/92

Cost Estimate for May, 1991 (\$K)

- same as August, 1990	Total (\$K) 20.0
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Cost Estimate for August, 1991 (\$K)

- same as August, 1990	Total (\$K) 20.0
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<u>Total for FY91/92 (\$K)</u>	40.0
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INDIVIDUAL WORK PLANS

FISH STUDIES.....	J.L. Metcalfe
CHEMISTRY	R.A. Bourbonniere,
	B.G. Brownlee and
	Y.K. Chau
BIOCHEMISTRY	D.L.S. Liu and
	R.J. Maguire
ECOTOXICOLOGY	B.J. Dutka,
	S.S. Rao and
	K.K. Kwan
PHYSICS/MODELLING	W.G. Booty,
	Y.L. Lau and
	S. Beltaos

FISH STUDIES
(J.L. Metcalfe)

PURPOSE

Indigenous fish will be the focus of an intensive study in the reconnaissance year and will be used in two ways:

1. as a monitoring medium to identify target chemicals (parent compounds and their metabolites) of concern which are associated with heavy-oil development. These chemicals will then become the focus of subsequent detailed fate and effects studies.
2. as indicators of the environmental impact of heavy-oil developments on aquatic ecosystem health.

These two aspects will be addressed concurrently using the same individual fish, and will identify or at least suggest possible cause/effect links between the occurrence in fish tissues of chemicals originating from the tar sands operations and the incidence of pollution-related diseases in feral fish.

BACKGROUND

The accumulation of PAHs and related compounds in the bile of fish has been well-documented in the literature, although little work of this nature has been conducted in Canada. To date, much attention has been given to monitoring for persistent lipophilic chemicals, whereas there have been few innovations in the area of monitoring for potentially hazardous chemicals which have lower bioaccumulation potentials. A lack of bioaccumulation in fatty body tissues such as the liver does not preclude toxic effects, but makes the link between exposure and effects difficult to establish.

The approach under these circumstances is to look for tissues which sequester non-lipophilic compounds. In fish, soluble compounds are conjugated with glucuronic acid and excreted into the bile in high concentrations prior to elimination; therefore bile can be used as a monitoring medium. We are currently evaluating fish bile as a monitoring medium for some of the more water-soluble pesticides and their conjugates in a watershed contaminated with agricultural pesticides in Quebec. The Athabasca study will contribute to our overall evaluation of fish bile as a monitoring medium for the environmental occurrence of contaminants with low bioaccumulation potentials. We propose to collect indigenous fish from a number of locations, dissect them into organs (including gall bladder, liver, muscle and possibly other organs such as gonads, kidneys and spleen) and analyze these organs for the contaminants of concern. By selecting a variety of organs, we will increase our chances of detecting all of the major chemicals of concern, including both highly lipophilic and relatively soluble compounds.

In addition to using fish as a monitoring medium, we will also assess the impact of contaminants on fish health. Several fractions and specific chemicals produced at various stages of the tar sands extraction process have been shown in earlier work to be toxic or mutagenic by the Microtox and Ames tests, respectively. Some of the PAHs and related compounds which accumulate in fish bile are also suspected of being carcinogenic, and have been implicated in the induction of cancers in bottom-dwelling fish species in other areas. To our knowledge, no histopathological studies have been conducted on fish from the Athabasca watershed; therefore, it is not currently known whether tar sands operations have an effect on native fish populations.

SPECIES SELECTION CRITERIA

For both aspects of the study, which will be conducted concurrently as previously mentioned, we require a species which is:

1. Common and abundant throughout the basin and also common elsewhere in Canada, in order to facilitate comparative studies in other areas.
2. Large enough to be dissected into organs which are themselves large enough to be analyzed individually.
3. A bottom-feeder, which will be most likely to come into contact with contaminated sediment and benthic invertebrates and which therefore provides us with the best possible chance of detecting contamination.
4. Non-migratory, or at least having restricted movements during known times of the year. This allows us to be confident that the fish are representative of the locations at which they were collected.
5. Likely to be found in both the main river and in lakes being considered as control sites.

The most suitable species for study is the white sucker, Catostomus commersoni, as it best satisfies the above requirements. The Athabasca River supports a cold-water cisco-based fishery consisting mainly of far-ranging migratory species. Migration is a major problem, as it confounds the relationships between sources of contaminants and their accumulation in, and effects on fish. White suckers move from the main river into the tributaries in May to spawn. After spawning, they distribute themselves throughout the system in areas where habitat and food availability are suitable, and their movements essentially cease until winter when they draw back towards the delta. By August, when we plan to sample, fish will have been living in the locations where they are caught for at least 2-3 months, and this is adequate for our purposes. The only reasonable alternative species is the slimy sculpin Cottus cognatus. This species is ideal in that it is common and likely to be quite abundant, non-migratory, and a bottom-feeder. However, adults are only 3 inches long; therefore organ dissections would not be feasible for two reasons:

1. Organ samples would have to be composited. This means the loss of much information, especially the ability to statistically analyze our data. Furthermore, it impacts greatly on the histopathological aspect of the study (discussed below).
2. Where organs are very small, cross-contamination of tissue samples is inevitable. The results would therefore be less conclusive.

Burbot (Lota lota), another large and abundant fish, is also a possibility. However, little is known of its movements and even less of its biology.

White suckers are ideal candidates for the complementary histopathological study. With the possible exception of lake trout and of bullheads in warm water fisheries, white suckers are the best known freshwater fish histologically and in terms of the presentation of pollution-related diseases. Local expertise is available within another government agency which is currently conducting fish health surveys in the Great Lakes using white suckers. To enable us to correlate the level of contamination of an individual fish with its health status, organ samples should NOT be pooled for contaminant analysis. The fish health aspect of the study is described in more detail below:

1. The livers from a minimum of 20 white suckers from each location will be examined histologically for signs of cancer and other diseases.
2. The levels of hepatic enzymes, such as mixed function oxidases, in these fish will be measured in order to detect signs of abnormal PAH metabolism which might increase the risk of developing cancer.
3. The mutagenic activity of samples of fish bile will be assessed and correlated with pathological changes.

SITE SELECTION

1. A site immediately downstream of the tar sands operations and/or Mildred Lake will provide data which maximize the probability of observing chemical accumulation. Captive fish populations in Mildred Lake or the riverine sedimentation ponds (Syncrude) would be ideal.
2. The lower river near the delta (but not IN the delta, to avoid mixing lake and river populations which are believed to be separate) will also be sampled to establish presence/absence of gradients.

3. The control site of choice would be a lake situated on bituminous sand but remote from the plants, to permit the comparison of background contamination and effects due to natural oil seepage with the results of industrial activities.

White suckers are known to be present in Mildred Lake, the Athabasca River, and are likely to be found in remote lakes in the area as well. Sculpins would not be found in lakes, but could be collected from unimpacted tributaries for comparison.

STUDY DESIGN AND CHEMICAL ANALYSIS

Two study designs are under consideration. The simpler and less costly design is for analysis of three separate organs/tissue from ten individual fish from three sites (90 samples). If funding permits, then four separate organs/tissue from ten to twelve individuals from four sites could be analyzed (160-192 samples). Both designs permit complementary histopathological studies.

For analysis, frozen tissues will be ground with dry ice, Soxhlet extracted with dichloromethane, and cleaned up by gel permeation chromatography (Birkholz et al., 1988). The extracts will be analyzed by capillary gas chromatography with flame ionization detection. Positive samples will be further analyzed by low resolution gas chromatography-mass spectrometry. One organ/tissue from each site will be subjected to derivatization and high resolution gas chromatography-mass spectrometry for confirmation of compound identification.

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GEOCHEMICAL STUDIES IN SUPPORT OF AQUATIC ASSESSMENT PROTOCOLS
FOR OIL SANDS AND HEAVY OIL OPERATIONS

(R.A. Bourbonniere, B.G. Brownlee and Y.K. Chau)

INTRODUCTION

The production of synthetic crude from tar sands is the result of many complex chemical processes which fundamentally alter the nature of the original bitumen. Generally, synthetic crude contains a high proportion of lower molecular weight, volatile, water soluble, and saturated components compared to the parent bitumen. Some of these may be easily distinguished as anthropogenic in origin (i.e., related generally to operations of synthetic crude plants), while others can have a dual natural and anthropogenic origin. We will attempt to distinguish between or apportion the natural and anthropogenic origin of compounds of interest identified by the chemical surveys conducted during the reconnaissance year. This is important in the modelling effort as components of natural origin can enter downstream of the plants.

The approach will be that commonly used in organic geochemical studies - the biomarker approach (e.g., Brooks et al., 1988; Payzant et al., 1985a,b; Strausz, 1984). More traditional chromatographic analyses of bitumen fractions and other long-standing organic geochemical techniques will supplement as necessary. We expect to pay special attention to more polar water soluble materials (Birkholz et al., 1987; Payzant et al., 1985c).

The emphasis of the reconnaissance sampling program will be to bracket all possibilities so that important sites will be identified for more intensive study in the following detailed study years and may include tributaries and the Peace-Athabasca delta area. In the reconnaissance year we will produce an inventory of natural and anthropogenic organic compounds from which to select candidate compounds and allow a focusing of the work for the detailed study years. It is expected that the subset of compounds identified by this process, combined with important metabolites identified in the biological component of the research program will become the candidate list for the modelling effort and photobiological degradation studies.

RECONNAISSANCE YEAR - 1989/90

- (i) Determine spatial distributions of tar sands related organic compounds in the lower reach of the Athabasca River, upstream of, adjacent to, and downstream from a synthetic crude oil plant.
 - Develop methodology to determine the relative importance of operationally-defined physical compartments in the transport and fate of organic compounds in the Athabasca River. The proposed definitions include; suspended particulates (by centrifuge), "fine particle-colloidal-DOM-associated" (by filtration of centrifuge effluents), and dissolved (filtrate).
 - Produce an inventory of organic compounds found in the various physical and biological compartments of the Athabasca River environment from which selections will be made for further detailed study.
 - Determine spatial gradients for the organic compounds studied in the various compartments.
- (ii) Characterize by class the natural bitumen, natural non-bituminous and synthetic fractions in the following compartments: water, suspended particulates and colloidal (DOM-associated) material. Sediments, soils, biota, and surface microlayer may be sampled at selected sites to provide ancillary information.
 - Determine the natural signature of bitumen-related organic compounds.
 - Determine the natural signature of non-bituminous watershed-related sources of organic compounds to the Athabasca River.
 - Determine the anthropogenic signature of synfuel upgrader plant related sources of organic compounds.

An ambitious list of classes of organic compounds which will be scanned in the reconnaissance year appears below along with reasons that each class may be important to the study. It is intended that the list be substantially reduced in subsequent years to only a relatively small number of important compounds.

- PAHs - prevalence in bitumens, synfuel waste streams, local combustion sources, toxicity, carcinogenicity - some priority pollutants;

- Saturated Hydrocarbons - prevalence in synfuel and waste streams, natural bituminous, and non-bituminous sources - many potential source indicators and biomarkers included in this class - some toxic components;
- Naphthenic Acids - prevalence in water soluble fraction of synfuel plant wastes and presence in natural bitumen, toxicity, biodegradability;
- Fatty Acids - indicators of natural non-bituminous origin, high concentrations in natural sources;
- Aromatic Hydrocarbons - water solubility, prevalence in synfuel and synfuel plant wastes and natural bitumen, toxicity, volatility, some priority pollutants;
- N-PAHs and S-PAHs - possible toxicity, mutagenicity, and carcinogenicity; water solubility, some priority pollutants

METHODOLOGY

Chemical samples will be taken at a series of single points and transects, and along a longitudinal (time-of-travel) profile as discussed previously and shown in Figures 1 and 2. This should result in about 50 samples from each compartment.

Water samples will either be filtered water or the centrifugate from suspended sediment dewatering. Water samples of 18-20 L will be batch extracted in the field with dichloromethane at pH 11-12, and then at pH 2-3. The preferred order is high pH first to generate a base/neutral fraction and a separate acid fraction which can be derivatized later. Also, Maguire and Tkacz (1988) observed higher recoveries of chlorinated hydrocarbons from Niagara River water when the extractions were carried out at high pH.

Suspended sediment samples will be collected by continuous-flow centrifugation, stored at low temperature, and Soxhlet extracted at NWRI using dichloromethane and/or hexane-acetone. More polar solvents will be used to extract portions for ecotoxicological testing. Bed sediment samples will be collected with a grab sampler and treated the same as the suspended sediment samples.

The extracts from these three compartments will be analyzed by capillary gas chromatography using flame ionization, nitrogen-selective, and sulfur-selective (flame photometric) detectors. Selected samples will then be analyzed by gas chromatography-mass spectrometry for compound identification. Quality assurance/quality control will be monitored using traditional laboratory standards and appropriate standard reference materials from the AOSTRA Oil Sands Sample Bank.

Approximately 20 samples of water, suspended sediment, bed sediment, and fish tissue will be analyzed for heavy metals (V, Cr, Ni, Cd, Pb, and Cu).

DETAILED STUDY YEARS - 1990/92

Specific details of the sampling, methodology, etc., are given elsewhere in this proposal. The general goals of the geochemical research elements are outlined below. They will be focused by the results of the reconnaissance year studies.

- (i) Seek out unique indicators of natural and anthropogenic sources of organic compounds. Produce and test algorithms for apportioning natural and anthropogenic sources to any given sample from the Athabasca River.
- (ii) Apportion natural non-bituminous, natural bituminous and synthetic fuel sources to the organic components determined in compartments of interest to the modelling effort. This will result from analyses of indicator classes determined necessary from the results of the reconnaissance year studies.
- (iii) Test the relative significance of three physical compartments for selected compounds throughout the flow/seasonal cycle of the Athabasca River watershed, with particular emphasis on the effect of ice conditions on the concentrations of more volatile components.
- (iv) Apply this information to laboratory studies in support of the modelling effort (e.g., sediment-water partition coefficients, volatility studies, contaminant-DOM associations).

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PHOTODEGRADATION AND BIODEGRADATION OF CONTAMINANTS
IN THE ATHABASCA RIVER SYSTEM
(D.L.S. Liu and R.J. Maguire)

INTRODUCTION

The hazard posed by a toxic substance in water or sediment is a function of its toxicity, concentration and persistence in water or sediment. In particular, the persistence is a function of physical, chemical and biological removal mechanisms. Physical removal mechanisms include volatilization, adsorption to suspended solids and sediment and advection. Chemical removal mechanisms include all pathways of chemical and photochemical transformation. Biological removal mechanisms include, but are not limited to, microbiological transformation.

An examination of the literature indicates that photo- and biodegradation of PAHs will be among the most important pathways of transformation, and that in some circumstances, volatilization will be important. We propose to study, for selected PAHs and derivatives, these pathways in the laboratory, where more rigid control of experimental variables will facilitate metabolite identification and mechanism of degradation. The identification of metabolites is essential for estimating environmental impact, since sometimes the metabolites are found to have considerable toxicity relative to the parent compound (e.g., Revzin, 1969).

METHODOLOGY

Biodegradation

For each test chemical, the biodegradation experiment generally involves the use of 6 cyclone fermentors, which are made of glass and Teflon to avoid the problem of adsorption and contamination. Three of the fermentors are operated under aerobic conditions and another three in an anaerobic environment. Two fermentors serve as controls (aerobic and anaerobic), containing microbial inoculum, the test chemical, and mercuric chloride (microbial inhibitor); another two fermentors contain only inoculum as a cell control; the two test fermentors include inoculum and test chemical. At various time intervals, samples are withdrawn from each fermentor for analysis of the test parent compound and the possible metabolites. To assess the impact of the test chemical on the fluvial system, a rotating flume (Y.L. Lau) will be used in the later study of biodegradation.

Photodegradation

Aqueous solutions of the test chemical will be irradiated in a Rayonet "merry-go-round" photochemical reactor by using RPR 3500-A lamps. These irradiations will be conducted in the presence of hydrogen peroxide and at selected time intervals, aliquots of the irradiated solutions will be assessed by GC, GC/MS, HPLC and UV/VIS.

Photobiological Degradation

The sequential degradation of selected organic contaminants (e.g., naphthalenes, methyl naphthalenes, polycyclic aromatic sulfur and nitrogen heterocycles) by photolytic and microbial degradation will be conducted in the Biodegradation Laboratory of the Rivers Research Branch. This laboratory has extensive experience in petroleum biodegradation and has been involved in several international research activities on biodegradation, such as the OECD Ring Test on Biodegradability. In fact, the cyclone fermentor test developed by D. Liu of this laboratory is one of the OECD official biodegradation tests.

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BATTERY OF SCREENING TESTS APPROACH

A variety of test methods, procedures and criteria have been developed internationally to assess the ecological impact of domestic and industrial effluents/discharges. However, with the increasing awareness of the long term effects of chemicals discharged into aquatic systems, research efforts have been directed at short-term bioassay tests to alert monitoring agencies, as well as dischargers, of the presence of toxicants in effluents and the aquatic ecosystem. Application of these short term bioassays to environmental samples soon revealed that there was no single test which was responsive to all conditions. This realization led to the concept of using a battery of tests to ascertain the ecological impacts of effluents and discharges.

The battery of tests we propose to use contains tests for toxicant (acute and chronic) activity and indicators of fecal pollution. We believe the presence of either contaminant is potentially detrimental to the health of the ecosystem and man. The battery of tests we propose to use in this study are: Microtox, Toxichrome, SOS chromotest, microbics, Black Mutant test, Spirillum volutans, ATP-Tox System, Algal-Tox, Daphnia, Ceriodaphnia, coliphage, Clostridium perfringens and A-1 fecal coliform test.

CONTAMINANT/PARTICULATE TRANSPORT AND RELATIONSHIP

To understand contaminant transport in rivers and streams, and to try to develop contaminant transport models, the knowledge of partitioning of contaminants between suspended particles including bacteria and the dissolved phase is essential. Another goal of the Project is to try to understand this process and contribute to the development of contaminant transport models.

The adsorption of contaminants onto suspended matter in aquatic systems is influenced by a variety of parameters such as particle size distribution, bacterial content, stream velocity, pH, etc. To gain a better understanding of the effect of particle size distribution and the bacterial content on the contaminant adsorption process, laboratory studies have been initiated using natural suspended matter obtained from rivers in widely separated areas of Canada. These river samples will be subjected to particle size distribution analyses. The different sized fractions from each river will be separated using fractionation techniques, tested for microorganism content, and studied for contaminant/particle interactions to establish the nature and extent of the contaminant binding efficiency.

Current data indicate that the 20-40 μm particle sized fraction may be the predominant component which also exhibits maximum contaminant binding efficacy. This active fraction also appears to be very rich in organic matter. Extension of these studies and findings, we believe, will help us better understand the mechanism of toxicant/contaminant transport in our rivers and streams.

6. Once the particulates have been separated into the various fractions, an evaluation of the toxicant activity of each fraction will be evaluated using one or more of the toxicant screening tests found in our battery of tests.
7. The diversity of phytoplankton will be studied to establish variability in relation to degree of impact as indicated by the battery of tests approach.

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AQUATIC ASSESSMENT PROTOCOLS FOR OIL SANDS
AND HEAVY OIL OPERATIONS
(W.G. Booty, Y.L. Lau and S. Beltaos)

SIMULATION MODELLING

Model Needs and Utility

To mathematically reproduce observable phenomena in aquatic systems, water quality models have utility in two broad areas: for water resource management and as research tools. Resource management applications include resource evaluations and protection of aquatic ecosystems and, ultimately, human health. As research tools models provide a means with which to synthesize data on complex systems so as to gain an understanding of ecosystem behaviour and to direct and integrate process and field experimentation.

For the Athabasca River study, the modelling effort will provide a research framework which can be used to evaluate these processes which control the persistence, fate and effects of chemicals released into the aquatic environment from upgrading operations in tar sands plants. The ultimate goal of the modelling effort is to produce a resource management tool which can be used with confidence to assist in addressing management options for acceptable chemical release into river systems.

Modelling Approach

An expert system or hierarchical modelling framework allows the integration of diverse data sets and knowledge, and identifies solutions according to a hierarchy of logic (artificial intelligence). This system would be coupled with a comprehensive model such as WASP (Ambrose *et al.*, 1984) which incorporates the essential physical and chemical processes, and range of dimensions which are required for toxic chemical modelling. Such a modelling approach should provide maximum flexibility in the model's range of application. Our recent review (Booty and Lam, in press) of the latest state-of-the-art toxic chemical models will assist in the selection of model structure and components. A data base management system will contain an indexed storage scheme for time-series data collected at numerous water chemistry and water flow monitoring stations along a river.

A map representation of the river system may be employed which takes advantage of recently developed GIS (Geographical Information System) capability, as is used in the RAISON model (Regional Analysis using Intelligent Systems on a Microcomputer [Swayne and Fraser, 1986]). A map representation of the river system is developed upon

which "snapshot" or "continuous action" contaminant levels are indicated by colours. A pull-down menu allows the user to select which contaminants and system components (suspended sediments, biota, dissolved) are to be considered in the stretch of river.

The modelling team is an integral part of the research effort in order to ensure that all of the necessary model coefficients and parameters which can not be obtained from the literature are determined for the Athabasca River via the field and laboratory studies. This interaction will include work in the following areas:

- i) Cohesive sediment transport: physics of cohesive sediment transport, including flocculation, are poorly known. Extensive laboratory programs are designed to produce the theoretical and empirical knowledge base now absent in sediment-contaminant transport models;
- ii) Microbiology-particle interrelationships: microbiology is a major controlling factor over flocculation and, most probably, chemical processing of adsorbed contaminants;
- iii) Biochemical: modelling contaminant pathways requires rate coefficients of metabolic processes;
- iv) Physico-chemical: all models require partitioning coefficients which are known to be equilibrium phenomena. These coefficients must be established over a range of physical conditions, including temperature and suspended sediment size, nature and concentration.

The modelling of the project will be carried out in the following phases:

- 1) Model development
- 2) Sensitivity analyses
- 3) Calibration of hydraulic segment of model to available historical flow data
- 4) Calibration of hydraulic and chemical model segments using data collected from the second and third years of the Athabasca River study

Reduction of the PERD program to four years precludes model confirmation/verification for the Athabasca; however, parallel work elsewhere will permit assessment of model reliability.

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STAFF QUALIFICATIONS

All staff are in the Rivers Research Branch, National Water Research Institute.

Dr. S. Beltaos

Dr. Beltaos, Chief of the River Modelling Project, received his Ph.D. in hydraulics-fluid mechanics from the University of Alberta. His research interests include river ice processes and dispersion of pollutants.

Dr. W.G. Booty

Dr. Booty is a hydrogeochemist with a background in soil chemistry and mathematical modeling of the transport and fate of pollutants in natural aquatic systems. He received his Ph.D. from McMaster University, and joined the Long Range Transport of Atmospheric Pollutants project following post-doctoral research at Clarkson University, New York. He has developed and applied computer simulation models for watershed acidification, acid lake and watershed liming, and organic contaminants in the Great Lakes.

Dr. R.A. Bourbonniere

Dr. Bourbonniere is an organic geochemist with the Contaminants Project. He has experience in oil pollution studies, the biogeochemistry of lipids and humic substances, and the character of dissolved organic matter and its interaction with aluminum. His current research interest is the transport and fate of contaminants in association with natural organics and particles. He obtained a Ph.D. in organic geochemistry from the University of Michigan.

Dr. B.G. Brownlee

Dr. Brownlee is a research scientist in the River Modelling Project. He received a Ph.D. in organic chemistry from the University of New Brunswick in 1971. Recent research has been in the area of transport and fate of herbicides and industrial chemicals in rivers. Earlier research activities have been in nutrient cycling in rivers and lakes, drinking water quality, surfactant biodegradation, and a major multi-agency study on the distribution of organic compounds from a kraft pulp mill in northern Ontario.

Dr. Y.K. Chau

Dr. Chau is a research scientist in the Contaminants Project. His research interests are on various aspects of the aquatic chemistry of metals and organometals, namely chemical and biological processes, transformation, speciations, and toxicity. He has published some 125 papers in scientific journals, including 11 book chapters, and edited 2 special journal issues on the above topics. His research publications have been selected in the archives of "Eminent Scientists of the Great Lakes Series" by the International Joint Commission of the Great Lakes in 1988.

B.J. Dutka

Mr. Dutka is the Ecotoxicology Project Leader. Present research is directed toward the development of an appropriate battery of tests and ranking scheme for waters and sediments which would be universally applicable and would aid in problem predictions and indicate restoration successes. B.J. Dutka obtained an M.Sc. from Queen's in 1964 in Microbiology-Immunology.

K.K. Kwan

Mr. Kwan is a biologist in the Ecotoxicology Project. He obtained his degree from the Lakehead University, Thunder Bay. He later obtained his clinical laboratory Q.C. certificate from Warner-Lambert, and a quality control diploma from Ryerson Polytechnical Institute. His primary research interests are in the field of ecotoxicology, methods development and evaluation, mutagenic, carcinogenic and genotoxicity testing of effluents, waters and sediments.

Dr. Y.L. Lau

Dr. Lau is a research scientist in the River Modelling Project. He received a Ph.D. in mechanical engineering from the University of Toronto. His research interest has been in the area of pollutant dispersion and sediment transport in river flows and recently in the area of fine sediment.

Dr. D. Liu

Dr. Liu is a research scientist of the Contaminants Project and associate professor of environmental toxicology of the Tulane Medical School in New Orleans. He obtained a Ph.D. in microbiology from the University of British Columbia. His primary research interests are in the fields of environmental toxicology, water quality and waste treatment. His international activities include: expert/consultant to FAO and WHO of the UN, as well as co-editor for Toxicity Assessment: An International Journal (John Wiley, New York).

Dr. R.J. Maguire

Dr. Maguire is Chief of the Contaminants Project. He obtained a Ph.D. in physical chemistry from the University of Alberta in 1972, and has extensive experience in the areas of enzyme kinetics and mechanisms of action, macromolecule-xenobiotic interactions and the environmental persistence and fate of organophosphorus, carbamate and pyrethroid pesticides and industrial chemicals such as PCBs, PAHs, amines and dyestuffs.

J.L. Metcalfe

Ms. Metcalfe is an aquatic biologist with the Contaminants Project. She has developed biomonitoring techniques for determining the distribution and bioavailability of environmental contaminants in fish and aquatic invertebrates, and is currently conducting studies to assess biological response at the organism, population and community levels to environmental pollution. She has a B.Sc. (Hons.) from the University of Manitoba.

Dr. E.D. Ongley

Dr. Ongley, the Director of Rivers Research Branch, is a former university professor who was recruited into the federal government to develop a research program focussed on rivers. He has led river research programs focussing on physical, chemical and toxicological processes in rivers across Canada. He serves as advisor for the U.S. Geological Survey water quality program, and routinely advises international agencies on riverine issues, and monitoring and interpretive technologies.

Dr. S.S. Rao

Dr. Rao is a research scientist in the Ecotoxicology Project. Present research is directed toward the development of appropriate methods to study contaminant-particulate matter interactions in fluvial systems and the role microbes play in the fluvial contaminant transport. Dr. Rao obtained his Ph.D. in zoology from the University of Mysore.