MICROBIAL POPULATIONS IN THE ATHABASCA RIVER

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ABSTRACT

The direct epifluorescence method has been adapted for counting bacteria in the sometimes turbid water of the Athabasca River and this method has been used to quantify planktonic bacteria. Monthly samples over an annual cycle beginning in May 1976 showed this population ranged from 1×10^5 to 2×10^6 cells per millilitre.

A statistical analysis of site-to-site variations and averages of bacterial numbers from sites upstream and downstream from Fort McMurray and the GCOS plant site have shown there is no discernible effect on the bacterial populations by either facility. Further, there is a definite site-to-site variation in the bacterial numbers as well as seasonal variations at each site.

The direct microscopic examination, including scanning electron microscopy, has shown that the planktonic bacteria are generally free-floating with some colonization of organic detrital materials. Silt particles are generally free of bacteria.

The statistical analysis of the ATP measurement showed that this method for estimation of bacterial biomass could not be used in the Athabasca. When bacterial enumeration data were compared to flow, total organic carbon, nitrogen (Kjeldahl), and conductivity, there was no correlation. However there was a slight negative correlation of bacterial numbers with turbidity and total unfilterable residue.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

The majority of the Athabasca River is presently being utilized as receiving water for wastes of many types. There is, however, little information available on the condition of the Athabasca River or how man's manipulations affect the river ecosystem. A paucity of information causes, in part, a lack of understanding of the principles governing this river ecosystem.

This study addressed itself to the following general objective: the assessment of both free and silt-associated bacteriological populations in the Athabasca River upstream from the Athabasca Oil Sands area to provide baseline data; and the examination of bacterial populations at sites downstream from various sites of input into the river to determine the effect of these perturbations on the Athabasca River bacterial populations.

Specific objectives for the project included the establishment of meaningful sampling sites on the Athabasca River in the Alberta Oil Sands Environmental Research Program (AOSERP) study area. Epifluorescence microscopy was applied to direct bacterial counts at the various sites and scanning electron microscopy (SEM) was used to support observations that bacteria were also detritus associated. Additionally, adenosine triphosphate (ATP) concentrations were determined to examine the possibility of using ATP measurements for bacterial biomass estimations. Lastly an attempt was made to establish correlations between bacterial numbers and the various physical and chemical parameters which were assessed.

The rationale for studying bacterial populations is based on the premise that microorganisms take up organic compounds from the aquatic environment. A survey of the literature led Sepers (1977) to the conclusion that the uptake of dissolved compounds in the environment is primarily a bacterial process. Because changes in the Athabasca River, which might be brought about by urban or industrial developments, would clearly be largely based on the introduction of the organic compounds in sewage and in other urban and industrial waste waters, we would expect these influxes to have

their first effects on the bacteria within the ecosystem. Included in the appendices is a brief bibliography of papers related to bacterial activity in aquatic ecosystems.

Accordingly, sampling sites were selected to assess the effects of Fort McMurray sewage discharge and of Great Canadian Oil Sands Ltd. (GCOS) waste water discharge and dike drainage on the bacterial population in the river. While a small number of industrial effluents have been shown to reduce bacterial populations by toxic effects, the usual pattern is one of stimulation of bacterial growth by the provision of organic nutrients. This stimulation of bacterial growth has the effect of removing the nutrient (pollutant) and most systems are maintained in equilibrium by this process. However, pollutant addition to the river can be said to have exceeded the river's capacity to accept waste material without detrimental effects, that is the assimilative capacity, when reductions of inorganic ions (NO_3, PO_4) and/or dissolved oxygen limit bacterial activity and numbers. Thus it becomes important to first assess the size of the bacterial populations in the river and to establish their relationship to various physical and chemical parameters which may affect them.

2. STUDY AREA

2.1 SELECTION

The sites used in this study are briefly described in Table 1 and located on the map of the AOSERP study area in Figure 1. A detailed description of the sampling sites are located in the Appendices (Section 9.1).

In order to assess the effects of urban development at Fort McMurray on the total bacterial numbers, Site 1 was established above the town on the Clearwater River. Site 2 was located 1 km above Fort McMurray on the Athabasca River.

Sites 3 and 4 were located 5 and 29 km, respectively, below Fort McMurray; these sites were designed to assess the cumulative effects of the presence of the town on the bacterial population of the river. Site 4 also served as the upstream control site for our assessment of the effects of the presence of the GCOS operation, which is located on the west bank of the river. Site 5 was located 3.2 km downstream from the putative center of the GCOS operation and, when a careful chemical and biological transect analysis showed marginal differences in samples taken at the west bank, Site 5a was defined at this location. Sites 6 to 10 were located 9.6, 17.6, 45.1, 93.2, and 116.8 km downstream from the GCOS operation to yeild data on immediate and long-range effects of the GCOS operation on the bacterial populations of the river. Site 7a was defined on the Muskeg River 100 m above its confluence with the Athabasca River to assess the chemical and microbiological contribution of this relatively pristine river to the main Athabasca River system and to provide a preliminary assessment of the bacterial population in a typical tributary of the study area.

Table 1. Brief description of sample sites.

Station No.	Station Description	Distance from GCOS in km[a]
1	Clearwater River 5 km upstream from Fort McMurray	+ 41.6
2	Athabasca 1 km upstream from Fort McMurray	+ 35.2
3	Athabasca River 5 km downstream from Fort McMurray	+ 29.0
4	Athabasca River at upstream end of Tar Island, 5 km above GCOS	+ 4.8
5	Athabasca River at Lower Syncrude 3 km downstream from GCOS	- 3.2
5a	Same transect as Site 5 but at the west bank	- 3.2
6	Athabasca River near Saline Lake 9 km downstream from GCOS	- 9.6
7	Athabasca River 300 m upstream from Muskeg River	- 17.6
7a	Muskeg River 100 m upstream from Athabasca River	- 17.6
8	Athabasca River 2.5 km upstream from Bitumount	- 45.1
9	Athabasca River 2 km upstream from Firebag River	- 93.2
10	Athabacas River at township 102 (mile 97 chart 6301)	-116.8

[a]Symbols: + = Below GCOS operations; - = Above GCOS operations.

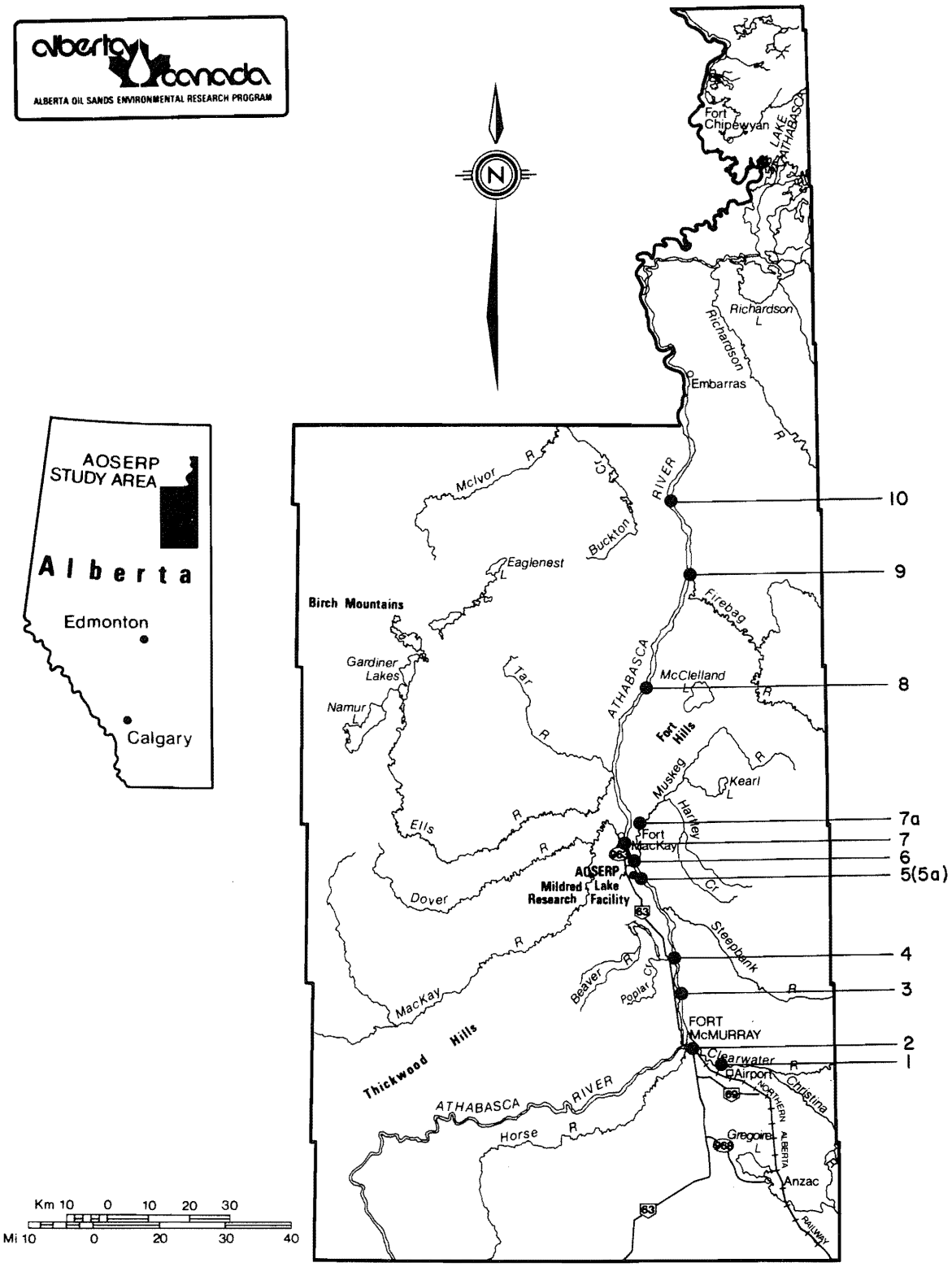

Figure 1. Location of sampling sites within the AOSERP study area.

3. CURRENT STATE OF KNOWLEDGE

Bacterial enumeration by total counts can be obtained by the use of the Petroff-Hauser counting chamber, but this method requires cell concentrations greater than 1×10^7 cells per millilitre (Collins 1957). This restriction excludes this method for enumerating bacteria in most natural waters without centrifugation or filtration of large volumes of water. The silt-laden nature of Athabasca River water makes it virtually impossible to differentiate bacteria and detritus by direct microscopy counts of concentrated samples.

Viable cell counts necessitate the growth of bacteria and the formation of viable colonies on solid media. This can require up to five weeks incubation time to obtain optimal counts (Francisco et al. 1973). The greates failing of techniques which require growth is that there is never any assurance that the growth medium selected will support colony formation of all viable cells from a mixed population. Additionally, microcolonies of as many as 1000 bacteria produce only one countable colony on agar plates. Classical plate counting methods reportedly understate the number of organisms by factors of 6 to as much as 700,000 when compared to counts made by direct microscopic examination (Jannasch and Jones 1959; Perfil'ev and Gabe 1969; Zobell 1946). It appears, then, that plate counting data in general do not reflect the biomass of the microbial populations in the environment.

Use of fluorescent vital stains, such as acridine, has made it possible to differentiate bacteria from detrital materials (Daley and Hobbie 1975; Jannasch and Jones 1959). The use of reflected light rather than transmitted light led to the use of epifluorescent microscopy to observe bacteria in the natural environment (Daley and Hobbie 1975; Francisco et al. 1973). Samples of 0.5 to 3.0 ml are all that is needed to obtain statistically valid total bacterial counts (Francisco et al. 1973). This technique was incorporated into our study of the Athabasca River system.

Measurement of total extractable adenosine triphosphate (ATP) has also been used as a measurement of bacterial biomass as well as activity (Holm-Hansen 1973). We, therefore, included ATP analysis in our study to determine its applicability in the determination of bacterial biomass in the Athabasca River.

Fluctuations in microbial populations are always in response to environmental changes. Factors governing bacterial growth include dissolved oxygen (D.O.), total organic carbon (TOC), phosphate (PO_4), and nitrogen (N). Additionally, factors such as pH, temperature fluctuations, and conductance can affect microbial populations (Brock 1970). Thus, these parameters were included in our study.

4. MATERIALS AND METHODS

Information on the techniques used for fixation, counting and ATP measurements, as well as those used for the chemical and physical analyses, will be included in this section. In the following sections, an attempt is made to integrate the data and provide a summation of the results.

4.1 SAMPLING AND IN SITU DETERMINATIONS

4.1.1 Depth Sounding

A metal sounding pole 4.7 m long was used for all depth measurements. Graduations were marked in black paint covered with shellac.

4.1.2 Flow Measurement

Flow measurements were carried out using a mechanical current meter (Price Meter). Measurements were made at the center of the transect. Data are expressed as cubic metres/second.

4.1.3 Determination of pH, Dissolved Oxygen, Temperature and Conductance

A Hydrolab "surveyor" equipped with Sonde attachments was used to determine the above parameters.

4.1.4 Microbiological and Chemical Sampling

Samples were taken for the vertical transects by using a Kahl Scientific (Model 003WA-100) sterile sampler mounted on a pole to preclude drifting. The horizontal transect consisted of three samples, taken 0.3 m below the surface. The horizontal transect included the upper sample of the vertical transect (the middle of the river) and samples taken two-thirds of the distance from this point to either bank.

4.2 EPIFLUORESCENCE COUNTING

Samples were collected in sterile containers and 1 to 10 ml were immediately filtered through sterile 0.2 µm Nucleopore filters (Figure 2). Duplicate samples were taken at all locations and membrane filters that had been manipulated through all of these procedures, but not exposed to river water, were used as controls. These controls were used intermittently in later samplings because they were uniformly negative.

In the laboratory, membrane filters were cut into quarter sections for processing so that counts could easily be repeated if deemed necessary. A Zeiss microscope equipped with an epifluorescence illuminator was used for all microscopy. Data are expressed as bacteria per millilitre.

4.3 SCANNING ELECTRON MICROSCOPY (SEM)

Samples of river water were collected in sterile containers and 1 to 10 ml were filtered within 5 min of collection. Samples were stored in gluteraldehyde for transport to the laboratory (Figure 3). Samples were critical-point-dried on a Technical Services Critical Point Drier and examined using a Cambridge Instrument Company Electron Microscopy (Model 140).

4.4 ADENOSINE TRIPHOSPHATE ASSAY (ATP)

Volumes between 5 and 10 ml were filtered in the field and filters were extracted in Trishydroxyethane hydrochloride (Tris-HCl) pH 7.0 (Figure 4). One millilitre of the sample is mixed with 50 µl of Firefly extract (Luciferin-Luciferase, SIGMA) and immediately placed in a Model 3375 Packard Scintillation Counter for photon counting. ATP, measured in µg/ml, is converted to biomass by multiplying by 250.

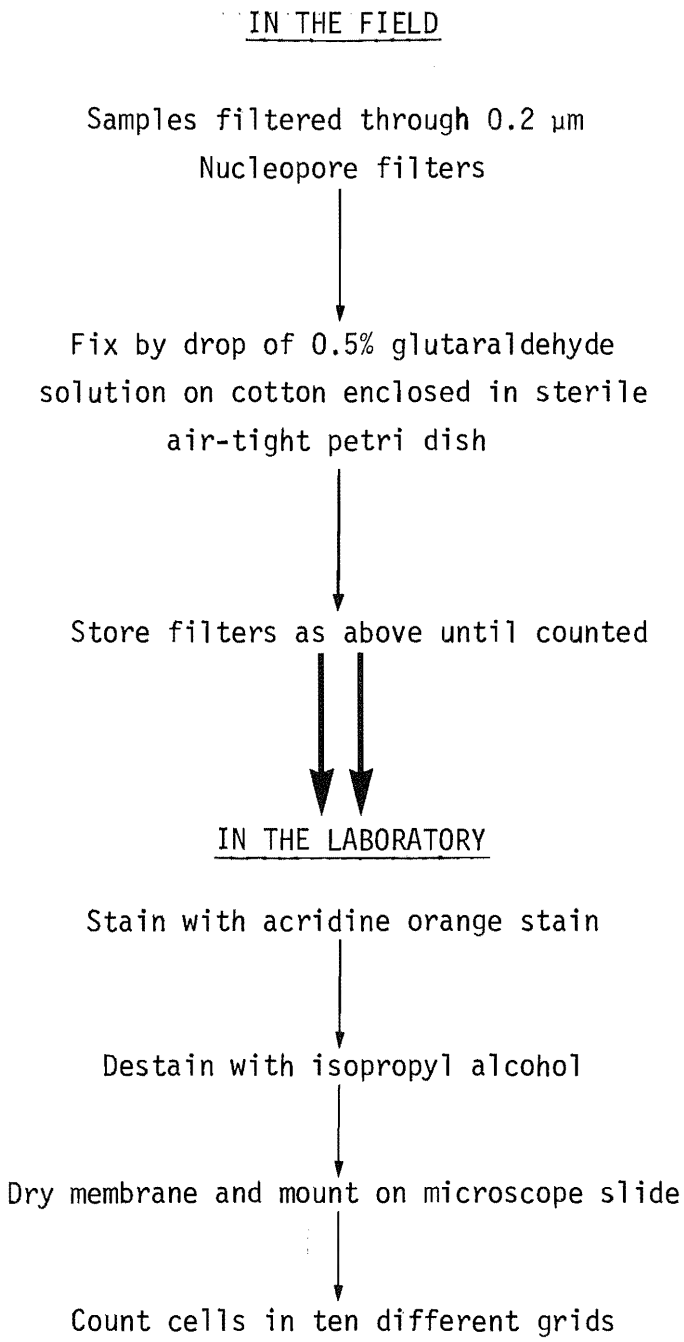

Figure 2. Procedure for preparation of samples for epifluorescence counting.

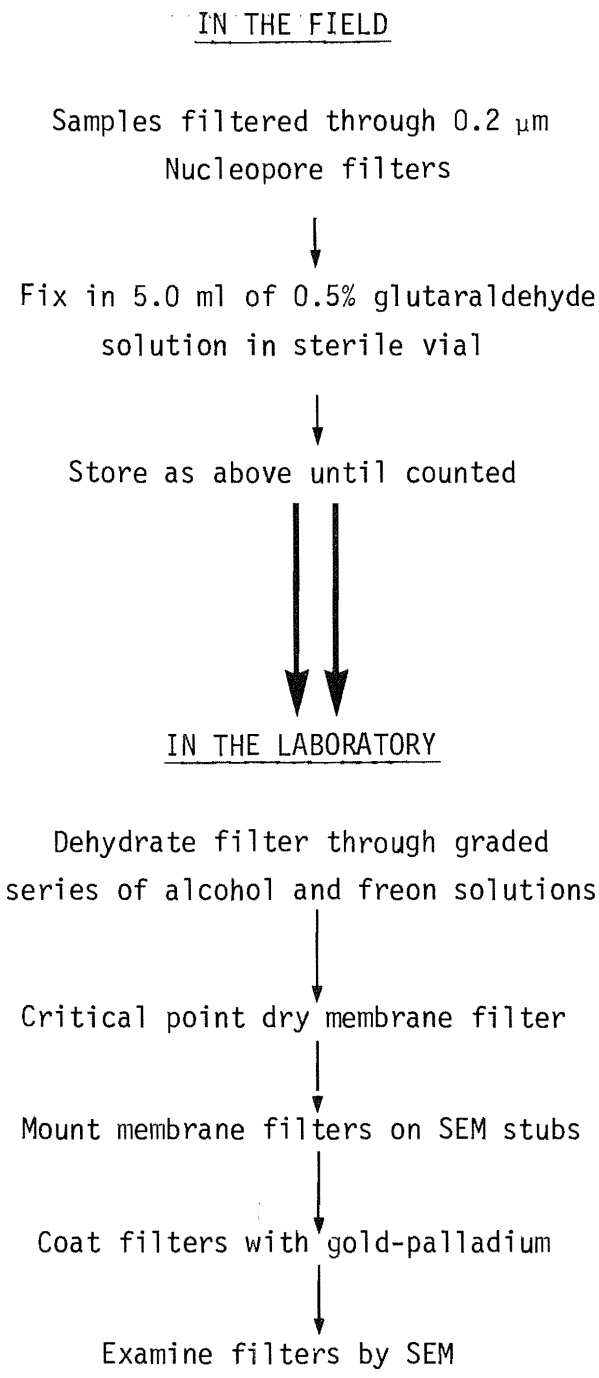

Figure 3. Procedure for preparation of samples for scanning electron microscopy (SEM).

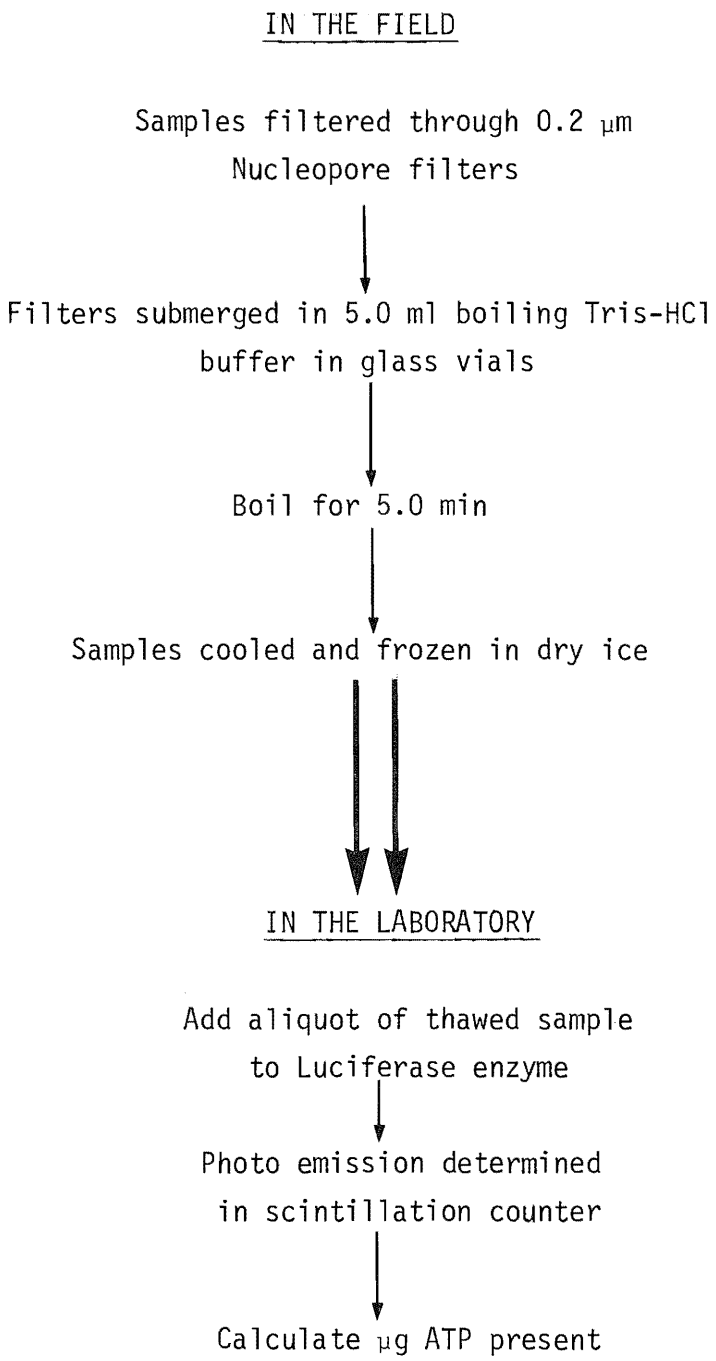

Figure 4. Procedure for preparation of samples for ATP analysis.

4.5 STATISTICAL ANALYSES

All statistics were calculated by computer using the SPSS system at the University of Calgary.

4.6 TOTAL PHOSPHATE (Chemex)

Phosphate analyses were done using the Ascorbic Acid reduction method (Standard Methods for the Examination of Water and Wastewater, 13th ed. 1971:624), incorporated in a Technicon Autoanalyzer II. Data are expressed as milligram phosphorus per litre.

4.7 NITROGEN, TOTAL KJELDAHL (Chemex)

The Automated Phenate Method was used to determine the total Kjeldahl nitrogen (Naquadat No. 07015L). A Technicon Autoanalyzer II was used for all analyses. Data are expressed as milligrams nitrogen per litre.

4.8 TOTAL ORGANIC CARBON

Organic carbon was measured in a Total Organic Carbon Oxidizer (Chemex) using infrared analysis of a totally combusted sample (Naquadat No. 06001L). Data are expressed as milligrams carbon per litre.

4.9 TOTAL UNFILTERABLE RESIDUE

Nonfilterable residue was done by the filtration method (Method 224c, Standard Methods for the Examination of Water and Wastewater, 13th ed. 1971) using Whatman GF/C glass filters. A selected volume of sample was slowly filtered and rinsed three times with distilled water. The filter was then dried and weighed. Weight of residue is the final weight minus the initial weight of the filter. Data are expressed as milligrams residue per litre.

4.10 TURBIDITY

Turbidity was measured with a Hellige turbidimeter. Data are expressed in turbidity units.

5. RESULTS

This section is organized to respond to specific objectives as outlined for this study.

5.1 ESTABLISHMENT OF MEANINGFUL SAMPLING SITES AND METHODS

The study began with a careful analysis of horizontal and vertical transects at all ten sites with respect to total planktonic bacterial populations and living biomass (Table 2) and chemical and physical parameters measured *in situ* (Appendix 9.2). This transect study was repeated at least once at each site during the year study. The data were analyzed by analysis of variance, and there was no significant difference between the transect samples at any one site at the 95% confidence limit. Data are presented for bacteria counts at Site 8 (Table 3). When other parameters and sites were examined the F probability value was always smaller than the probability table value indicating homogeneous transects. Because of this homogeneity, subsequent samples and determinations were taken 0.3 m below the water surface at the middle of the river. The west bank of Site 5 seemed to be an exception to the general homogeneity and Site 5a was established there. Site 7a was added on 28 June to provide data on bacterial populations on the Muskeg River, a tributary of the Athabasca River.

5.2 APPLICATION OF EPIFLUORESCENCE TECHNIQUE TO BACTERIAL ENUMERATION

The raw data for bacterial counts at the 12 sites in the AOSERP study area from 11 May 1976 to 26 February 1978 are presented in Appendix 9.3.

Table 4 illustrates a statistical analysis of the site-to-site variations during the monthly sampling periods. When the F ratio is greater than F_s (from a table) value then the bacterial counts at the sites for that month are dissimilar. If the F ratio is smaller, then the bacterial counts are statistically similar at all sites. For example, counts obtained in February were compared

Table 2. Total bacterial counts on transects at 10 sites.

Date	Site	Location	Planktonic Bacteria (cells/ml)	Living Biomass (µg carbon/l)
11 May 1976	1	East Bank Surface	4.6×10^6	112
		West Bank Surface	4.8×10^6	112
		Middle Surface	2.3×10^6	112
		Middle 1.5 m	$2\ 0 \times 10^6$	112
		Middle 3.1 m	2.0×10^6	112
12 May 1976	2	East Bank Surface	1.3×10^6	75
		West Bank Surface	1.9×10^6	75
		Middle Surface	1.2×10^6	75
		Middle 1.5 m	1.1×10^6	112
		Middle 3.1 m	1.0×10^6	75
14 May 1976	3	East Bank Surface	2.5×10^6	112
		West Bank Surface	2.7×10^6	75
		Middle Surface	2.1×10^6	75
		Middle 1.5 m	2.0×10^6	112
		Middle 3.1 m	2.5×10^6	37
13 May 1976	4	East Bank Surface	2.0×10^6	40
		West Bank Surface	2.3×10^6	9
		Middle Surface	1.8×10^6	77
		Middle 2.1 m	2.1×10^6	21
		Middle 3.9 m	2.1×10^6	48
13 May 1976	5	East Bank Surface	1.8×10^5	26
		West Bank Surface	5.9×10^5	21
		Middle Surface	3.8×10^6	23
		Middle 2.7 m	3.5×10^6	50
		Middle 4.6 m	3.3×10^6	13
26 May 1976	6	East Bank Surface	1.6×10^6	273
		Middle Surface	1.4×10^6	114
		West Bank Surface	1.3×10^6	66
		West Bank 1.5 m	1.4×10^6	69
		West Bank 3.1 m	2.2×10^6	60

Continued ....

Table 2. Concluded.

Date	Site	Location	Planktonic Bacteria (cells/ml)	Living Biomass (µg carbon/l)
27 May 1976	7	East Bank Surface	9.7×10^5	23
		West Bank Surface	1.1×10^6	32
		Middle Surface	1.0×10^6	83
		Middle 2.3 m	1.4×10^6	57
		Middle 4.6 m	1.0×10^6	23
28 May 1976	8	East Bank Surface	1.6×10^6	33
		Middle Surface	1.2×10^6	36
		West Bank Surface	1.4×10^6	52
		West Bank 1.2 m	1.3×10^6	22
		West Bank 2.4 m	1.3×10^6	39
29 May 1976	9	East Bank Surface	2.4×10^6	50
		Middle Surface	1.7×10^6	110
		West Bank Surface 1.5 m	2.1×10^6	57
		West Bank 1.5 m	1.7×10^6	73
		West Bank 2.4 m	1.9×10^6	58
29 May 1976	10	East Bank Surface	2.5×10^6	168
		Middle Surface	2.0×10^6	257
		West Bank Surface	1.5×10^6	168
		West Bank 2.3 m	2.1×10^6	69
		West Bank 4.6 m	1.9×10^6	99

Table 3. The analysis of variance of the bacterial numbers for the transect study carried out at Site 8.

Source	Sum of Squares	Mean Squares	F_S Ratio	F Probability
Between groups	0.0608	0.0608	0.241	0.656
Within groups	2.2728	0.2841	N/A	N/A
Total	2.3336	N/A	N/A	N/A

Student-Newman-Keuls Procedure

Ranges for the 0.050 levels - 3.27

Number of subsets = 1.0

No significant differences in transect counts.

Table 4. Summary of analysis of variance table of bacterial numbers at AOSERP study area based on monthly comparisons.

Site	F Ratio	F Probability	F 0.05 Degrees of Freedom
SITES SIMILAR[a]			
February	2.215	0.116	[9, 10]
December	1.185	0.410	[6, 7]
September	2.683	0.070	[9, 10]
SITES DISSIMILAR			
January	8.752	0.001	[9, 10]
May	7.045	0.000	[9, 40]
June	4.490	0.014	[9, 10]

[a]Sites grouped into a homogeneous subset following the Student-Newman-Keuls procedure at P = 0.05.

together and the F ratio was 2.215. Since the F_s value was larger (3.06) at P = 0.05, the sites are not significantly different. Alternatively, the F ratio for May (8.752) is larger than the Fs value (5.02) found in the tables and thus there are significant differences in the bacterial counts at the various sites in May.

The statistical analysis of variations in bacterial counts from individual sites during the monthly sampling periods is illustrated in Table 5. As can be seen, there are significant differences in the seasonal counts taken at any one sampling site. These seasonal fluctuations fell into three major subsets: the subset containing counts from February, December and January had the lowest bacterial counts, $3.4 \pm 0.2 \times 10^5$ cells/ml; October and June made up the second subset with a mean value of $3.2 \pm 0.14 \times 10^6$; and a third subset consisting of the May sample only had $2.5 \pm 0.2 \times 10^6$ cells/ml.

The effects of Fort McMurray and the GCOS operations on the bacterial populations in the river were also examined. Data from Sites 2 and 3 were used to calculate effects of Fort McMurray and data from Sites 4 and 6 were used for the GCOS determination (Table 9). Analysis of variance showed that there was no significant difference in total bacterial numbers determined by epifluorescence microscopy at Sites 2 and 3, or 4 and 6 above and below Fort McMurray and the GCOS plant, respectively, during designated monthly sampling periods. Partial ANOVA tables are depicted in Table 6 for the monthly counts at these four sites. Data presented in Table 6 are based on duplicate counts collected within two areas of the transects at each site.

5.3 EPIFLUORESCENCE AND SCANNING ELECTRON MICROSCOPY OF FREE-FLOATING AND PARTICLE-ASSOCIATED MICROBIAL COMMUNITIES

During routine counting of bacteria on Nucleopore filters by epifluorescence microscopy, it was noted that very few bacteria were associated with clay particles (Figures 5 and 6). A more

Table 5. Summary of analysis of variance table for bacterial numbers at individual sites during monthly sampling.

Site	F Ratio	F Probability	F 0.05
1	8.777	0.010	[5, 6]
2	7.603	0.009	[6, 7]
3	31.236	0.000	[7, 8]
4	65.733	0.000	[7, 8]
6	51.408	0.000	[7, 8]
7	8.411	0.006	[6, 7]
8	15.677	0.000	[7, 8]
9	13.570	0.002	[6, 7]
10	33.868	0.000	[7, 8]

Table 6. Summary of analysis of variance comparing Sites 2, 3, 4 and 6 to each other during monthly sampling.

Month	F Ratio	F Probability	F 0.05
January	1.195	0.418	[3, 4]
February	2.524	0.196	[3, 4]
May	2.811	0.361	[3, 4]
June	0.647	0.625	[3, 4]
July	1.119	0.231	[3, 4]
August	2.868	0.691	[3, 4]
September	2.933	0.163	[3, 4]
December	1.050	0.462	[3, 4]

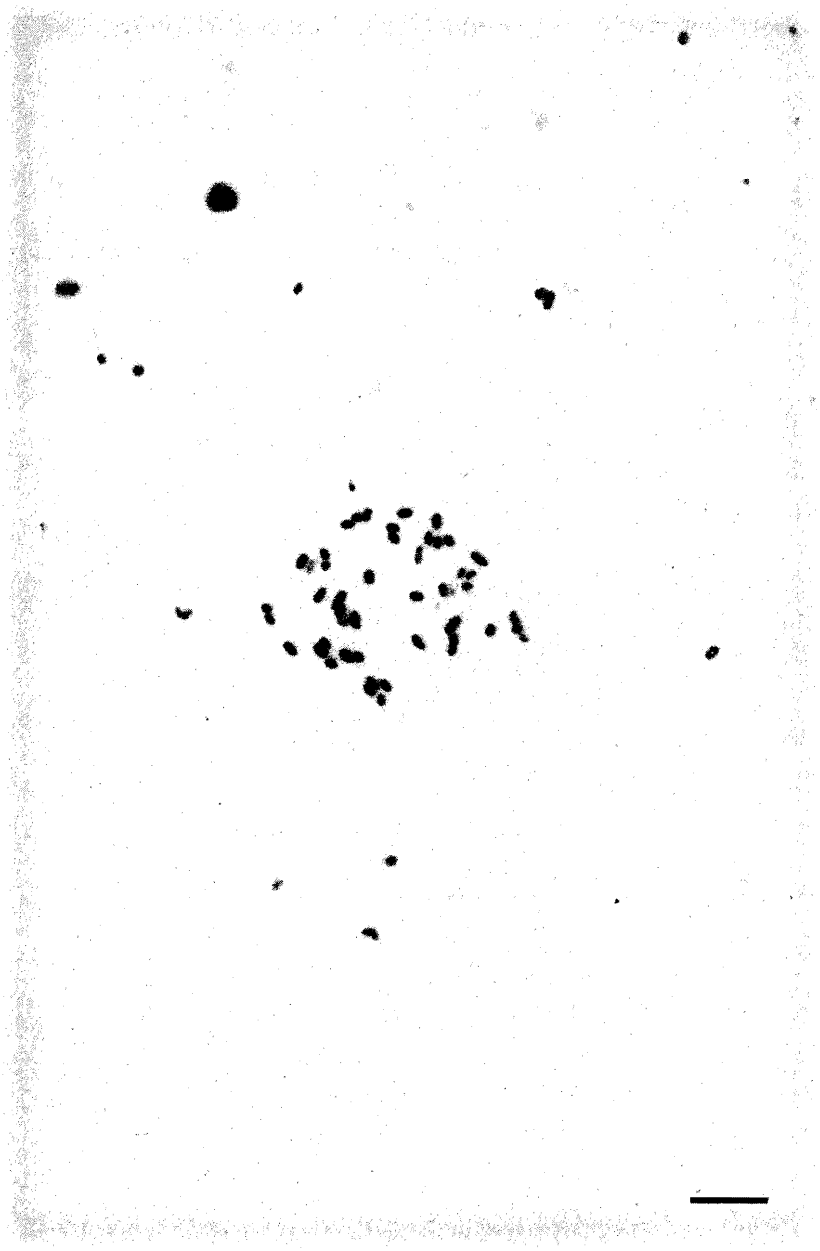

Figure 5. Microcolony of planktonic bacteria as seen by epifluorescence microscopy. 6000 x magnification. Bar represent 10 µm.

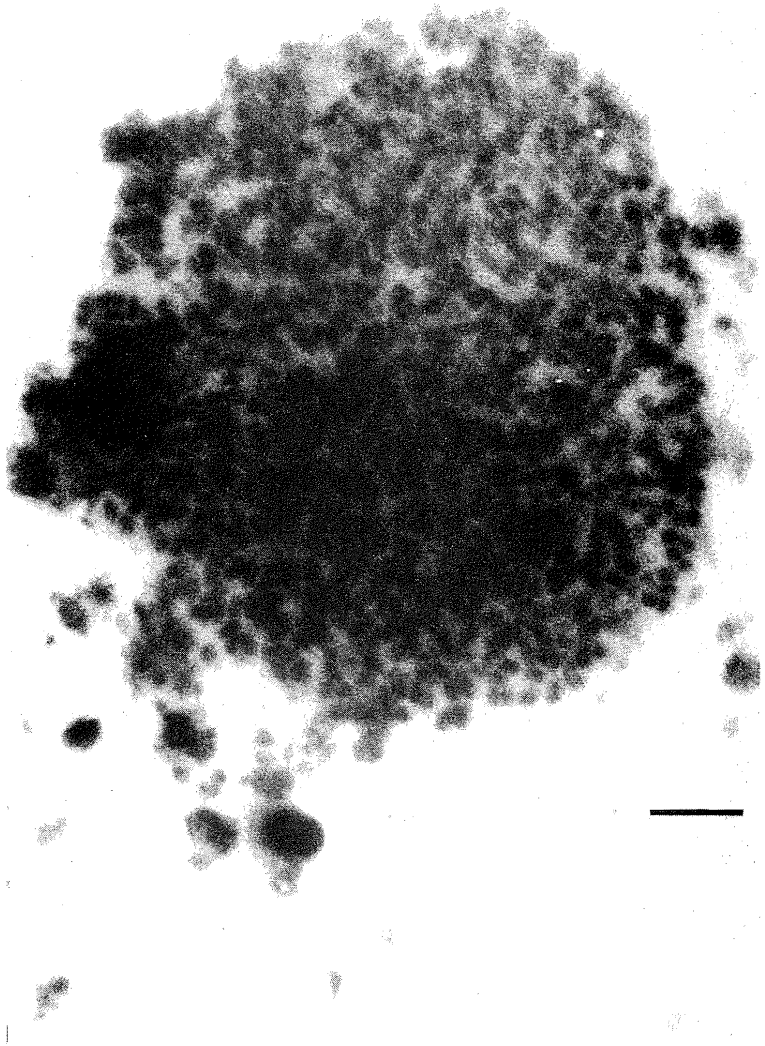

Figure 6. Large colony of planktonic bacteria seen by epifluorescence microscopy. 6000 x magnification. Bar represents 10 µm.

detailed examination of filters by scanning electron microscopy (SEM) revealed that a majority of the clay particles on the filters were devoid of bacteria (Figures 7 and 10) and the bacteria that were present were seen lying individually or in clumps on the filter (Figures 7 and 8). Numerous bacteria were seen to be attached to the occasional diatom found in this water and irregular detritus particles were heavily colonized (Figure 9). When the silt load of the river was reduced, larger volumes could be filtered for SEM analysis and bacteria were seen to be present singly and in clumps (Figures 10 and 11). The majority of the bacteria are rod-shaped, and thus resemble the bacteria in most aquatic systems. Fungal mycelia or algae other than infrequent diatoms were not found in any of the thirty samples observed by SEM.

5.4 ATP CONCENTRATIONS

The analysis of ATP concentrations at the sampling sites on the Athabasca River and tributaries is presented in Table 2 and Appendix 9.3. In all cases duplicate samples were examined in multiple determinations to test the consistency of the data. The high turbidity created many problems in the photometric assay of ATP. When the values for ATP analyses were compared by statistical methods (Table 7), the Pearson correlation coefficients ranged from -0.13 to 0.35. These values indicate there was no correlation between ATP measurements and epifluorescent counts of total bacteria.

5.5 COMPARISON OF BACTERIAL NUMBERS WITH PHYSICAL AND CHEMICAL DATA

The physical and chemical data obtained in this study are found in Table 2 and Appendix 9.2.

Since there was a large amount of data, we again used a statistical treatment of the data for comparison to bacterial numbers. These data are illustrated in Table 7. The results indicate that there are no significant correlations between bacterial

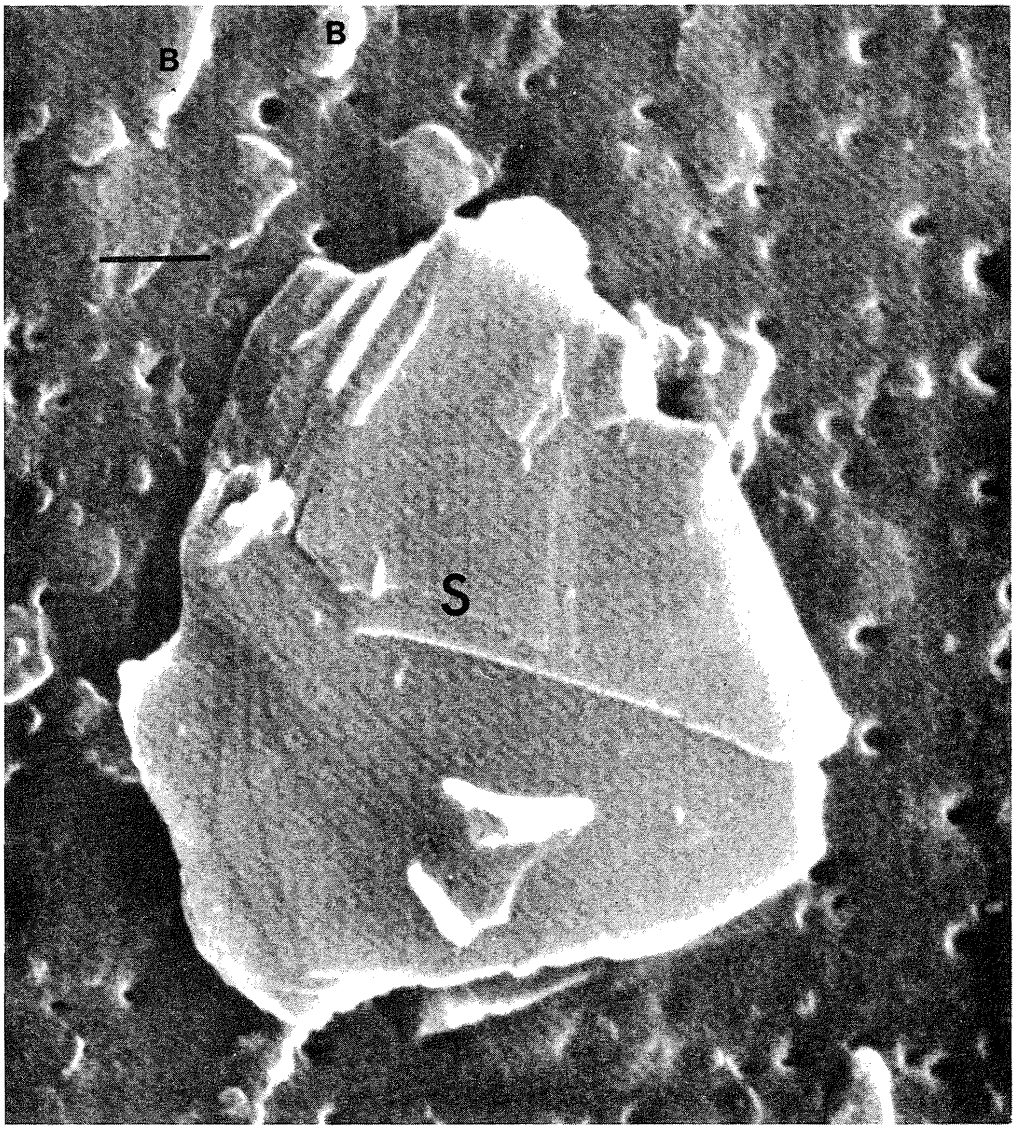

Figure 7. Uncolonized silt particle (S) and free floating bacteria (B) from Athabasca River laying on a 0.2 µm Nucleopore filter. 14,000 x magnification. Bar represents 1 µm.

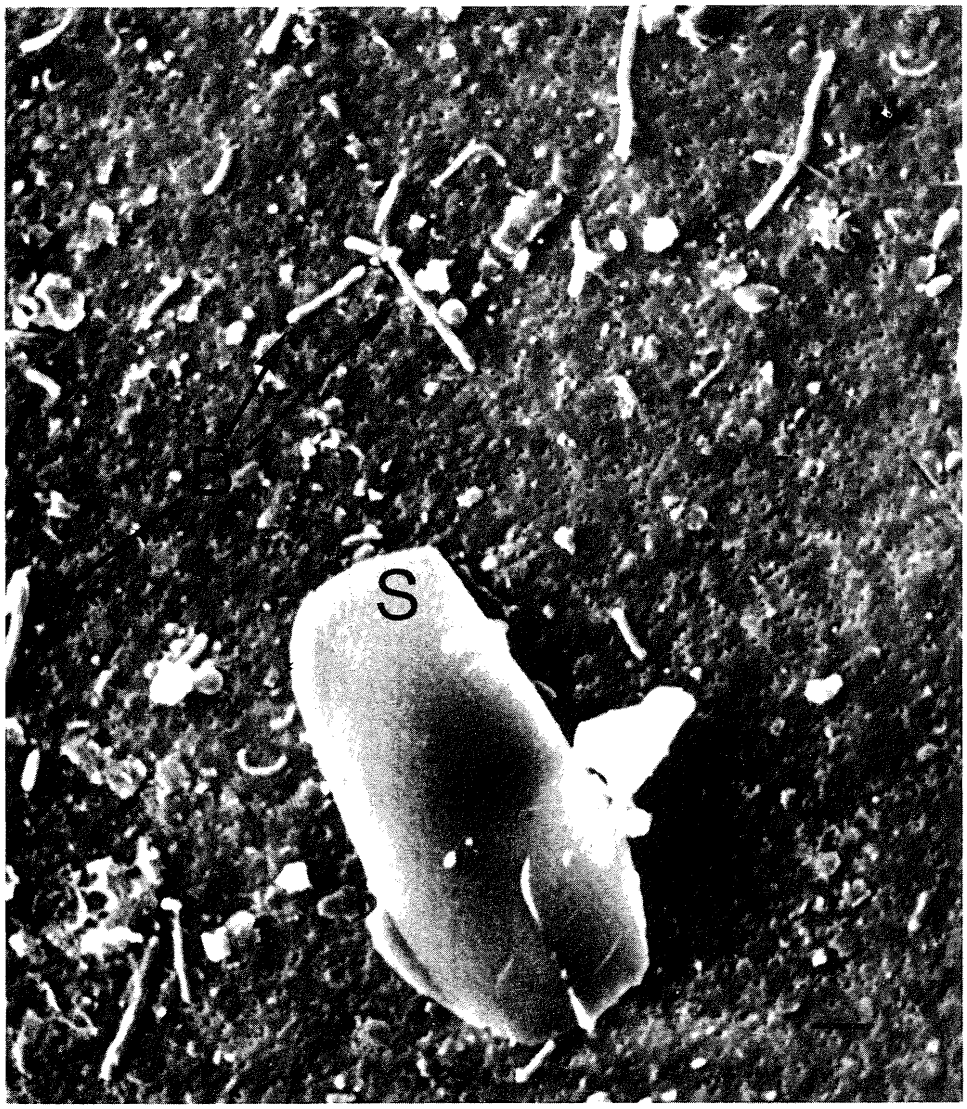

Figure 8. Free bacteria (B) and silt particles (S) from the Athabasca River laying on a 0.2 µm Nucleopore filter. 17,000 x magnification. Bar represents 1 µm.

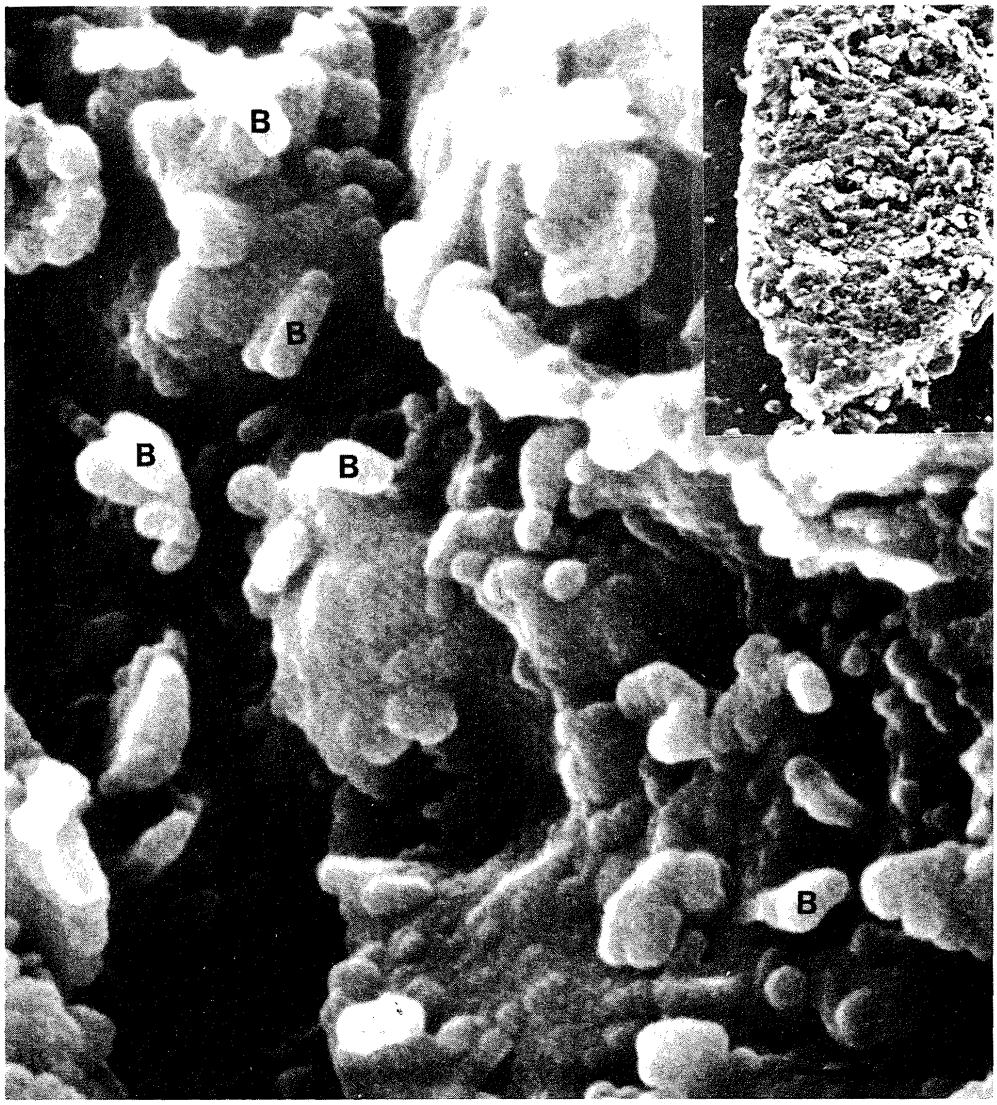

Figure 9. Detritus particle (insert, 5000 x magnification) from Athabasca River. This 7,500 x magnification shows complete colonization of surface by bacteria (B). Bar represents 2 μm.

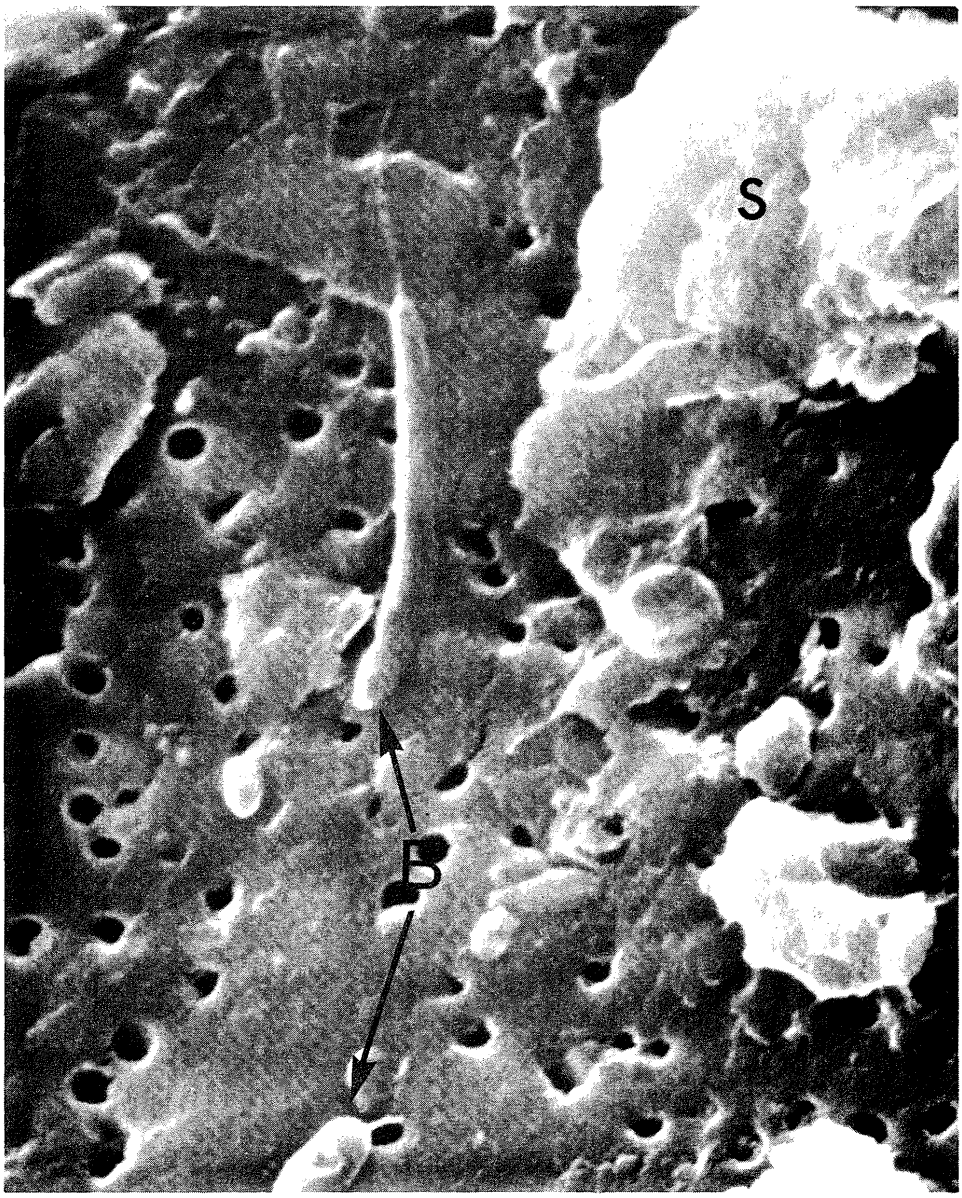

Figure 10. Filtered sample from January sampling period. Note uncolonized silt particle (S) as well as several unattached bacteria (B). 6000 x magnification. Bar represents 2 μm.

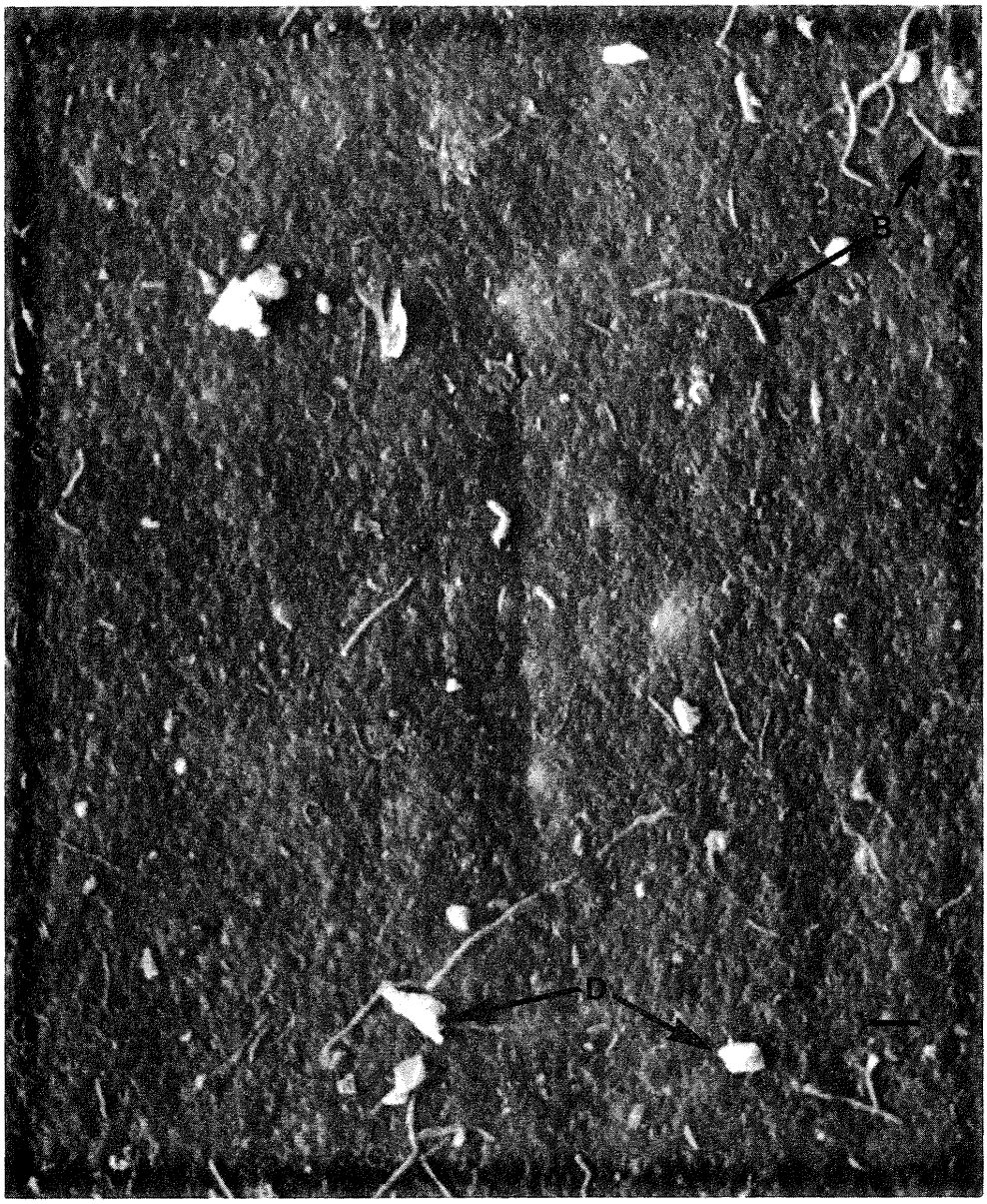

Figure 11. Filtered samples from winter sampling period. Note small detrital particles (D) and many individual bacteria (B). 3000 x magnification. Bar represents 2 μm.

Table 7. Comparison of bacterial numbers to measured physical and chemical parameters. Values of the Pearson-product-moment coefficient given for bacterial counts at ten[a] Athabasca River sites.

Month	Turbidity[a]	TOC	Flow[a]	Kjeldahl N	ATP	PO_4	Total Unfilterable Residue
May	-0.17	-0.36	0.04	-0.03	-0.13	-0.61	-0.03
June	-0.41	0.08	0.16	0.07	0.46	0.44	0.04
July	-0.42	0.63	0.23	0.23	-0.05	-0.75	-0.55
Aug-Sept.	-0.85	0.53	-0.10	0.90	0.35	0.58	-0.60
Sept.-Oct.	N.D.[b]	0.34	0.33	0.25	N.D.	-0.12	-0.30
December	-0.59	0.53	0.21	0.72	-0.25	0.51	0.20
January	-0.41	-0.41	0.40	0.26	0.15	0.07	0.67
February	-0.66	0.08	-0.04	0.16	N.D.	0.21	-0.68

[a]Turbidity and flow data obtained once each month at Embarras Airport.

[b]N.D. = not determined.

numbers determined by epifluorescence counting and TOC, Kjeldahl N, ATP, PO_4 or turbidity. There does appear to be a trend in the relationship between total unfilterable residue and bacterial numbers, however. The higher the turbidity values the lower the total bacterial counts become. Thus it appears that except for suspended solids, none of the parameters measured, including ATP, can be used to monitor or predict accurately bacterial numbers in the Athabasca River.

6. DISCUSSION

This section will concern itself with a discussion of the data in terms of the specific objectives set up for this study.

6.1 ESTABLISHMENT OF MEANINFUL SAMPLING SITES AND METHODS

These specific sites (Figure 1) were chosen to allow us to establish baseline data on the microbial populations in the Athabasca River. As well, we examined the population in two tributaries of the Athabasca River. These data will be discussed in subsequent sections. These sites were also established to allow us to assess the effects of various perturbations on the microbial populations in the river and have also been used by other researchers within AOSERP.

The use of statistical methods was extremely useful in the analysis of data obtained in the transect studies (Table 2 and Appendix 9.2). The analysis of variance program is tailor-made to determine the relationship of various samples, whether they were the same or not. It can be concluded from our analyses of data obtained for the vertical and horizontal transects that each site was homogeneous (except 5a), and that there was no significant difference in the five samples taken. This homogeneity then allowed us to take only duplicate water samples at each site, and be assured we were getting representative samples.

6.2 EPIFLUORESCENCE MICROSCOPIC EXAMINATION OF ATHABASCA RIVER BACTERIAL POPULATIONS

Acridine orange epifluorescence microscopy has become a well established method for counting bacteria, and thus is a useful technique for determining biomass of the population (Francisco et al. 1973; Costerton, Geesey, Ladd, in prep.). Most other methods for determining biomass of bacteria have been found to be of limited usefulness (Costerton and Colwell 1978).

The planktonic bacterial populations of the Athabasca River are higher than most of the 83 other rivers and streams we have studied in Alberta (Costerton et al. 1978). The three major subsets of counts obtained from the Athabasca River had averages ranging from 3.4×10^5 to 3.2×10^6 cells/ml. Zeikus and Brock (1972) found only 1×10^4 to 4×10^4 bacteria/ml in the Firehole River in Wyoming, while Daley and Hobbie (1975) found 8.7×10^5 cells/ml in an estuarine system. Thus, the Athabasca River resembles more the robust and active estuarine ecosystem than the rather pristine streams of Alberta and Wyoming.

Additionally we examined the bacterial populations in two tributaries of the Athabasca River (Table 2 and Appendix 9.2). Counts on the Clearwater were in the range of 2.2×10^5 to 3.3×10^6 bacteria/ml and the Muskeg was within this same range. Since only a limited number of samples were taken at these sites it is difficult to make a more critical comparison to the Athabasca at this time.

The most significant point to emerge from this study is that there is little if any effect on the bacterial population by the GCOS operation or Fort McMurray (Table 6). The analysis of variance data indicate that there is no statistical difference between counts at the four sites (2, 3, 4, 6) during the monthly surveys taken for this project. A careful examination of Tables 2 and 9 shows that even during periods of low flow (December, January, February) there is no perceptible effect of Fort McMurray sewage or GCOS effluents on the total bacterial numbers in the river.

It is clear that the Athabasca River contains a large (10^6 bacteria/ml) bacterial population at certain times of the year and that this population is maintained at a relatively high level (10^5 bacteria/ml) even throughout prolonged ice cover. In searching for an explanation for this large population, one can look for peculiarities of this river in relation to other systems which have been examined. The high silt load and the passage of the Athabasca River through the oil formations are such particularities. There is no correlation between total unfilterable residue (silt load) and bacterial numbers (Table 7). Thus the passage of the river through the oil sands may be the answer. Large amounts of organic material are leached from oil banks in river systems. With the high organic levels and sufficient D.O., which the Athabasca River has, one would expect a large bacterial population. The high bacterial counts in the Muskeg and Clearwater rivers, which also flow through oil sands, seem to substantiate this concept. Further analysis of these rivers outside the oil sands area would be needed to fully support the above contention, however.

6.3 SCANNING ELECTRON MICROSCOPY OF FREE-FLOATING AND PARTICLE-ASSOCIATED BACTERIA

Initial expectations with respect to the Athabasca were that the majority of the bacteria in the water column would be associated with silt particles as they are in other systems (Balkwill and Casida 1973). This was clearly not the case in the Athabasca River waters. Appendix 9.2 shows a slight trend indicating that the more total unfilterable residue and turbidity in the water (an indication of silt load), the less bacteria were found. Further proof of the absence of bacteria on silt is found in Figures 6 through 10. Figures 7, 8 and 10 show uncolonized silt particles with several free-floating bacteria on the filter. It appeared that amorphous and irregular debris was colonized, however (Figure 9). It is possible that the geometry of the silt (clay),

a planar, crystalline surface, causes extensive scraping by neighbouring clay particles, and bacterial colonization is minimized as a result. Truly sessile bacteria may occur in the sediments where the silt particles are undisturbed.

6.4 ATP CONCENTRATIONS

An attempt was made to apply the ATP method of measuring bacterial biomass to the silt-laden Athabasca River waters. A careful and extensive trial of comparisons of ATP and total cell numbers was conducted (Tables 2 and 9). Computer analysis indicated there was no correlation between bacterial numbers and ATP concentrations (Table 7). Except in a few specialized cases, the measurement of ATP was rarely found to indicate true biomass of bacterial populations. It has been discontinued as a tool for the measurement of biomass (Costerton and Colwell 1978) by most researchers in the field of microbial ecology.

6.5 COMPARISON OF BACTERIAL NUMBERS WITH PHYSICAL AND CHEMICAL DATA

The significant seasonal and site-to-site fluctuations in planktonic bacteria (Tables 4 and 5) suggest the populations may be responding to physical and chemical changes in their environment. Table 7 illustrates the statistical comparison of total bacterial numbers with turbidity, TOC flow, Kjeldahl N, ATP, phosphate and total unfilterable residue. There is no correlation between any of these factors and cell number with the exception of turbidity mentioned above. It is clear that sampling only comprises "windows" into a complex and dynamic relationship between bacterial numbers and various parameters. It is apparent that the factors governing bacterial growth in the Athabasca River are sufficiently complex to resist analysis without more comprehensive physical and chemical data.

7. CONCLUSIONS

In conclusion, the following brief summaries can be made.

1. The epifluorescence technique for direct counting of bacteria has been adapted to the determination of bacterial numbers in the Athabasca River and its tributaries.
2. It has been shown that the Athabasca, Clearwater, and Muskeg rivers support a large planktonic bacterial (2×10^6 bacteria/ml) population at some times of the year and support a smaller population at all times (2×10^5 cells/ml).
3. There are significant variations in bacterial numbers from site to site, as well as from month to month at individual sites.
4. There is no significant effect on the microbial numbers by either Fort McMurray or the GCOS operations.
5. The ATP method for measuring bacterial biomass cannot be used in the silt-laden waters of the Athabasca River.
6. The bacteria of the Athabasca River are not adherent to silt particles but do colonize detrital particles. Most of the bacteria are free-floating and sometimes found in colonies.
7. Bacterial populations are not correlated to flow, total organic carbon, Kjeldahl nitrogen, phosphate, or ATP. Samples having high turbidity and total unfilterable residue tended to have lower bacterial numbers.

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9. APPENDICES

9.1 SAMPLING SITE DESCRIPTION

1. Site 1 was located on the Clearwater River 5 km upstream from Fort McMurray. The main channel was 3 m from the west (south) bank and the maximum depth was 12 m. The vertical profile was made in mid-channel at the surface, 1.5 m, and 3.0 m. The horizontal profile was made midway between mid-channel and the east and west banks.
   Latitude: $56^{o}41'25"$. Longitude: $111^{o}18'45"$.
2. Site 2 was located on the Athabasca River 5 m upstream from the mouth of Horse River. The main channel was midstream and the maximum depth was 6 m. The vertical and horizontal profiles were the same as for Site 1.
   Latitude: $56^{o}43'15"$. Longitude: $111^{o}24'0"$.
3. Site 3 was located on the Athabasca River approximately 5 km downstream from Fort McMurray. The main channel was 5 m from the east bank and the maximum depth was 6 m. The vertical and horizontal profiles were the same as for Site 1.
   Latitude: $56^{o}47'0"$. Longitude: $111^{o}24'50"$.
4. Site 4 was located on the Athabasca River at the upstream end of Tar Island Pond. The main channel was midstream and the maximum depth was 6 m. The vertical profile was made in the main channel at the surface, 2 m and 4 m. The horizontal profile was the same as for Site 1.
   Latitude: $56^{o}59'30"$. Longitude: $111^{o}28'0"$.
5. Site 5 was located on the Athabasca River at the AOSERP dock. The main channel was 3 m from the west bank and the maximum depth was 6.5 m. The vertical profile was made in the main channel at

the surface, 3 m and 5 m. The horizontal profile was made midway between the mid-channel and the east and west banks.
Latitude: 57°04'45". Longitude: 111°33'30".

6. Site 6 was located on the Athabasca River at the cabin on the east bank near Saline Lake. The main channel was 5 m from the west bank and the maximum depth was 3.5 m. The vertical and horizontal profiles were the same as for Site 1.
Latitude: 57°04'45". Longitude: 111°31'55".
7. Site 7 was located on the Athabasca River 300 m upstream from the Muskeg River. The main channel was midstream and the maximum depth was 6.5 m. The vertical and horizontal profiles were the same as for Site 1.
Latitude: 57°7'50". Longitude: 111°36'0".
8. Site 8 was located on the Athabasca River approximately 2 km south of Bitumount. The main channel was 2 m from the west bank and the maximum depth was 2.5 m. The vertical profile was made in the main channel at the surface, 1 m and 2 m. The horizontal profile was the same as for Site 1.
Latitude: 57°22'30". Longitude: 111°38'45".
9. Site 9 was located on the Athabasca River approximately 2 km south of the confluence of the Firebag River. The main channel was 2 m west of the channel marker and the maximum depth was 4 m. The vertical profile was made mid-channel at the surface, 2 m and 3 m. The horizontal profile was the same as for Site 1.
Latitude: 57°44'25". Longitude: 111°21'45".
10. Site 10 was located on the Athabasca River at mile 97 (chart 6301). The main channel was off the west bank approximately 2 m and the maximum depth was 6 m.

The vertical profile was made at mid-channel at the surface, 2 m and 5 m. The horizontal profile was the same as for Site 1.
Latitude: 57°44'30". Longitude: 111°22'0".

11. Site 7a was located on the Muskeg River 100 m above its confluence with the Athabasca River. The main channel was midstream and had a maximum depth of 5 m. The vertical and horizontal profiles were the same as for Site 1.
Latitude: 57°8'0". Longitude: 111°36'20".

9.2 BACTERIAL COUNTS, BIOMASS ESTIMATIONS, AND PHYSICAL AND CHEMICAL DATA

The chemical and physical data for the transect are presented in Table 8. The bacterial counts, biomass estimations and physical and chemical data at 12 sites are presented in Tables 9 to 11.

Table 8. Chemical and physical data for transects at 10 sites.

Date	Site	Location	*In situ* Temperature (°C)	*In situ* Conductance (μ mho/cm)	*In situ* Dissolved Oxygen (ppm)	pH[a]
11 May 1976	1	East Bank Surface	13.0	200	N.D.	N.D.
		Middle Surface	13.0	200	N.D.	N.D.
		West Bank Surface	13.0	200	N.D.	N.D.
27 July 1976	1	East Bank Surface	18.0	180	8.1	N.D.
		West Bank Surface	17.5	210	8.1	N.D.
		Middle Surface	18.0	200	8.3	8.6
		Middle 1.6 m	18.0	215	7.9	N.D.
		Middle 3.1 m	17.5	215	8.0	N.D.
12 May 1976	2	East Bank Surface	15.5	265	N.D.	N.D.
		Middle Surface	15.5	265	N.D.	N.D.
		West Bank Surface	15.5	265	N.D.	N.D.
27 July 1976	2	East Bank Surface	19.0	205	9.1	N.D.
		West Bank Surface	19.0	200	8.5	N.D.
		Middle Surface	19.0	200	8.7	8.4
		Middle 1.6 m	19.0	200	8.6	N.D.
		Middle 3.1 m	19.0	200	8.7	N.D.

Continued ....

Table 8. Continued.

Date	Site	Location	*In situ* Temperature (°C)	*In situ* Conductance (μ mho/cm)	*In situ* Dissolved Oxygen (ppm)	pH[a]
14 May 1976	3	East Bank Surface	13.0	230	N.D.	N.D.
		Middle Surface	13.5	260	N.D.	N.D.
		West Bank Surface	13.5	270	N.D.	N.D.
28 July 1976	3	East Bank Surface	19.0	180	8.0	N.D.
		West Bank Surface	18.0	190	7.6	N.D.
		Middle Surface	19.0	210	7.6	N.D.
		Middle 1.6 m	19.0	200	7.8	N.D.
		Middle 3.1 m	19.0	200	7.8	N.D.
13 July 1976	4	East Bank Surface	14.5	170	N.D.	N.D.
		Middle Surface	14.5	190	N.D.	N.D.
		West Bank Surface	14.5	260	N.D.	N.D.
31 Aug. 1976	4	East Bank Surface	13.5	780	7.6	7.9
		West Bank Surface	15.0	970	7.7	7.6
		Middle Surface	14.0	840	7.8	7.6
		Middle 1.6 m	14.0	830	7.7	7.7
		Middle 2.2 m	14.0	830	7.6	7.7

Continued ....

Table 8. Continued.

Date	Site	Location	*In situ* Temperature (°C)	*In situ* Conductance (μ mho/cm)	*In situ* Dissolved Oxygen (ppm)	pH[a]
13 May 1976	5	East Bank Surface	14.0	250	N.D.	N.D.
		Middle Surface	14.0	260	N.D.	N.D.
		West Bank Surface	14.0	255	N.D.	N.D.
29 July 1976	5	East Bank Surface	18.0	210	7.4	N.D.
		West Bank Surface	18.0	170	7.7	N.D.
		Middle Surface	17.5	180	7.6	8.1
		Middle 1.6 m	18.0	200	7.0	N.D.
		Middle 3.1 m	18.5	210	7.4	N.D.
26 May 1976	6	East Bank Surface	17.0	260	9.7	N.D.
		Middle Surface	17.0	250	9.6	N.D.
		West Bank Surface	18.5	250	9.4	N.D.
29 July 1976	6	East Bank Surface	18.0	210	6.9	N.D.
		West Bank Surface	18.0	210	6.9	N.D.
		Middle Surface	18.5	210	6.9	8.3
		Middle 1.9 m	18.0	210	6.9	N.D.
		Middle 3.8 m	18.0	210	7.0	N.D.

Continued ....

Table 8. Continued.

Date	Site	Location	*In situ* Temperature (°C)	*In situ* Conductance (μ mho/cm)	*In situ* Dissolved Oxygen (ppm)	pH[a]
31 Aug. 1976	6	East Bank Surface	14.0	800	7.6	7.6
		West Bank Surface	15.0	880	7.3	7.7
		Middle Surface	14.5	800	7.6	7.6
		Middle 1.9 m	14.0	860	7.6	7.7
		Middle 3.8 m	14.0	850	7.6	7.7
27 May 1976	7	East Bank Surface	17.5	260	11.2	N.D.
		Middle Surface	17.5	260	10.8	N.D.
		West Bank Surface	18.0	260	11.0	N.D.
31 Aug. 1976	7	East Bank Surface	14.0	830	7.5	7.7
		West Bank Surface	15.0	970	7.6	7.7
		Middle Surface	15.0	920	7.6	7.7
		Middle 1.2 m	15.0	920	7.6	7.7
		Middle 2.5 m	15.0	920	7.5	7.7
28 May 1976	8	East Bank Surface	17.0	270	9.3	N.D.
		Middle Surface	17.0	270	9.3	N.D.
		West Bank Surface	17.0	270	9.6	N.D.

Continued ....

Table 8. Concluded.

Date	Site	Location	*In situ* Temperature (°C)	*In situ* Conductance (μ mho/cm)	*In situ* Dissolved Oxygen (ppm)	pH[a]
3 Sept. 1976	8	East Bank Surface	15.0	940	7.6	7.7
		West Bank Surface	15.0	950	7.6	7.7
		Middle Surface	15.0	940	8.0	7.7
		Middle 0.8 m	15.0	950	7.4	7.7
		Middle 1.6 m	15.0	950	7.6	7.7
29 May 1976	9	East Bank Surface	17.0	270	8.8	N.D.
		Middle Surface	17.0	280	8.9	N.D.
		West Bank Surface	17.0	235	8.8	N.D.
29 May 1976	10	East Bank Surface	17.5	270	9.1	N.D.
		Middle Surface	17.5	270	8.8	N.D.
		West Bank Surface	18.0	280	8.7	N.D.
3 Sept. 1976	10	East Bank Surface	15.0	980	7.3	
		Middle Surface	15.0	1050	7.3	7.7
		West Bank Surface	14.0	1150	6.9	7.6
		West Bank 1.9 m	14.0	1100	6.9	7.6
		West Bank 3.9 m	15.5	1100	6.9	7.6

[a]Symbol: N.D. = No data.

Table 9. Bacterial counts and biomass estimations for 12 sites.

Date	Site	Bacteria (cells/ml)	Biomass (µg carbon/ml)[a]
1976			
11 May	1	2.3×10^6	112
12 May	2	1.2×10^6	75
14 May	3	2.1×10^6	75
13 May	4	1.8×10^6	77
13 May	5	3.8×10^6	23
26 May	6	1.4×10^6	114
27 May	7	1.0×10^6	83
28 May	8	1.2×10^6	36
29 May	9	1.7×10^6	110
29 May	10	2.0×10^6	257
28 June	1	3.3×10^6	6
28 June	2	2.8×10^6	121
28 June	3	1.7×10^6	1
28 June	4	1.8×10^6	28
29 June	5	2.1×10^6	14
29 June	6	2.1×10^6	55
29 June	7	1.8×10^6	41
29 June	7a	2.3×10^5	41
30 June	8	8.8×10^5	1
30 June	9	1.1×10^6	7
1 July	10	1.4×10^6	15.0
27 July	1	2.2×10^5	13.8
27 July	2	2.9×10^5	1.0
28 July	3	4.9×10^5	5.5
28 July	4	2.8×10^5	N.D.
29 July	5	4.6×10^5	4.5
29 July	6	1.0×10^5	5.8
30 July	7	2.5×10^5	5.5
30 July	7a	8.6×10^5	2.8
30 July	8	9.9×10^5	6.9
31 July	9	5.8×10^5	6.9
31 July	10	6.2×10^5	5.5

Continued ....

Table 9. Continued.

Date	Site	Bacteria (cells/ml)	Biomass (µg carbon/ml)
2 Sept.	1	N.D.	N.D.
2 Sept.	2	N.D.	N.D.
3 Sept.	3	2.7×10^5	14.9
31 Aug.	4	1.4×10^5	16.4
31 Aug.	5	6.8×10^4	14.9
31 Aug.	5a	8.0×10^4	14.9
31 Aug.	6	4.0×10^4	12.4
31 Aug.	7	7.2×10^4	< 10.0
3 Sept.	8	8.0×10^4	14.1
3 Sept.	9	6.6×10^5	13.5
3 Sept.	10	1.0×10^5	< 10.0
29 Sept.	1	1.6×10^6	N.D.
29 Sept.	2	1.3×10^6	N.D.
29 Sept.	3	1.5×10^6	N.D.
28 Sept.	4	1.5×10^6	N.D.
28 Sept.	5	9.7×10^5	N.D.
28 Sept.	5a	1.2×10^6	N.D.
28 Sept.	6	1.1×10^6	N.D.
28 Sept.	7	1.3×10^6	N.D.
28 Sept.	7a	1.2×10^6	N.D.
2 Oct.	8	9.6×10^5	N.D.
29 Sept.	9	1.1×10^6	N.D.
2 Oct.	10	$1\ 4 \times 10^6$	N.D.
	1	N.D.	N.D.
10 Dec.	2	5.1×10^5	5.72
10 Dec.	3	5.8×10^5	3.63
12 Dec.	4	7.4×10^5	6.68
12 Dec.	5	5.3×10^5	8.54
12 Dec.	5a	6.1×10^5	6.73
11 Dec.	6	6.5×10^5	6.74
	7	N.D.	N.D.
11 Dec.	8	3.6×10^5	7.68
	9	N.D.	N.D.
11 Dec.	10	6.2×10^5	5.51

Continued ....

Table 9. Concluded.

Date	Site	Bacteria (cells/ml)	Biomass (µg carbon/ml)
1977			
23 Jan.	1	4.8×10^5	12.0
23 Jan.	2	1.7×10^5	17.6
22 Jan.	3	2.1×10^5	3.3
22 Jan.	4	3.5×10^5	8.9
22 Jan.	5	4.9×10^5	12.7
22 Jan.	5a	7.2×10^5	33.7
22 Jan.	6	3.0×10^5	19.2
22 Jan.	7	4.2×10^5	19.9
21 Jan.	8	4.7×10^5	
21 Jan.	9	7.3×10^5	17.6
21 Jan.	10	1.1×10^6	8.8
26 Feb.	1	2.2×10^5	N.D.
26 Feb.	2	3.4×10^5	N.D.
26 Feb.	3	2.2×10^5	N.D.
26 Feb.	4	2.1×10^5	N.D.
26 Feb.	5	2.4×10^5	N.D.
26 Feb.	5a	3.9×10^5	N.D.
25 Feb.	6	2.3×10^5	N.D.
25 Feb.	7	4.2×10^5	N.D.
25 Feb.	8	3.5×10^5	N.D.
25 Feb.	9	4.1×10^5	N.D.
25 Feb.	10	4.4×10^5	N.D.

[a]Symbol: N.D. = No Data.

Table 10. Physical data at 12 sites from May 1976 to February 1977.

Date	Site	Temperature (°C)	Conductance (μ mho/cm)	Dissolved Oxygen (ppm)	pH
11 May	1	13.0	200	N.D.[a]	N.D.
12 May	2	15.5	265	N.D.	N.D.
14 May	3	13.5	260	N.D.	N.D.
13 May	4	14.5	190	N.D.	N.D.
13 May	5	14.0	260	N.D.	N.D.
26 May	6	17.0	250	9.6	N.D.
27 May	7	17.5	260	10.8	N.D.
28 May	8	17.0	270	9.3	N.D.
24 May	9	17.0	280	8.9	N.D.
29 May	10	17.5	270	8.8	N.D.
28 June	1	21.0	170	N.D.	N.D.
28 June	2	19.2	210	N.D.	N.D.
28 June	3	19.5	200	N.D.	N.D.
28 June	4	19.2	200	N.D.	N.D.
29 June	5	19.5	200	N.D.	N.D.
29 June	6	19.2	195	N.D.	N.D.
29 June	7	19.5	80	N.D.	N.D.
29 June	7a	22.0	420	N.D.	N.D.

Continued ....

Table 10. Continued.

Date	Site	Temperature (°C)	Conductance (μ mho/cm)	Dissolved Oxygen (ppm)	pH
30 June	8	20.0	200	N.D.	N.D.
30 June	9	19.5	220	N.D.	N.D.
1 July	10	19.5	230	N.D.	N.D.
27 July	1	18.0	200	8.3	8.6
27 July	2	19.0	200	8.7	8.4
28 July	3	19.0	210	7.6	N.D.
28 July	4	18.0	190	7.8	N.D.
29 July	5	17.5	180	7.6	8.1
29 July	6	18.0	210	6.9	8.3
30 July	7	18.0	200	7.3	8.3
N/A	7a	N.D.	N.D.	N.D.	N.D.
N/A	8	N.D.	N.D.	N.D.	N.D.
N/A	9	N.D.	N.D.	N.D.	N.D.
N/A	10	N.D.	N.D.	N.D.	N.D.
N/A	1	N.D.	N.D.	N.D.	N.D.
N/A	2	N.D.	N.D.	N.D.	N.D.
31 Aug.	3	15.0	860	8.0	7.7
31 Aug.	4	14.0	840	7.8	7.6
31 Aug.	5	15.0	900	7.7	7.7
31 Aug.	5a	15.0	970	7.7	7.7

Continued ....

Table 10. Continued.

Date	Site	Temperature (°C)	Conductance (μ mho/cm)	Dissolved Oxygen (ppm)	pH
31 Aug.	6	14.5	800	7.6	7.6
31 Aug.	7	15.0	920	7.6	7.7
3 Sept.	8	15.0	940	8.0	7.7
3 Sept.	9	14.0	940	7.4	7.6
3 Sept.	10	14.0	1150	6.8	7.6
29 Sept.	1	11.5	100	10.4	8.1
29 Sept.	2	14.5	115	10.3	8.6
29 Sept.	3	14.5	115	10.3	8.35
28 Sept.	4	12.5	110	10.0	8.4
28 Sept.	5	13.0	120	9.9	8.4
28 Sept.	5a	13.5	120	9.9	8.45
28 Sept.	6	13.0	110	10.0	8.4
28 Sept.	7	13.0	110	10.0	8.45
28 Sept.	7a	10.5	180	11.2	8.65
2 Oct.	8	10.2	110	10.4	8.05
29 Sept.	9	12.5	120	9.9	8.0
2 Oct.	10	10.5	120	10.2	8.1

Continued ....

Table 10. Continued.

Date	Site	Temperature (°C)	Conductance (μ mho/cm)	Dissolved Oxygen (ppm)	pH
10 Dec.	1	0.75	90	13.4[b]	7.65
10 Dec.	2	0.25	160	14.2	8.4
10 Dec.	3	0.2	130	15.4	8.2
12 Dec.	4	0.4	160	13.4	7.15
12 Dec.	5	0.4	132	13.4	8.0
12 Dec.	5a	0.25	145	13.6	8.2
11 Dec.	6	0.25	115	12.8	8.3
11 Dec.	8	0.0	152	N.D.	8.5
11 Dec.	10	0.5	165	N.D.	8.3
23 Jan.	1	1.0	195	N.D.	7.25
23 Jan.	2	0.3	145	N.D.	7.8
22 Jan.	3	0.1	150	11.6	7.7
22 Jan.	4	0.1	155	11.4	7.7
22 Jan.	5	0.25	132	11.2	7.65
22 Jan.	5a	0.2	155	11.1	7.7
22 Jan.	6	0.5	140	10.6	7.8
22 Jan.	7	2.5	170	10.4	7.6
21 Jan.	8	0.1	157	10.4	7.5
21 Jan.	9	0.6	170	13.2	7.45
21 Jan.	10	1.5	180	13.6	7.85

Continued ....

Table 10. Concluded.

Date	Site	Temperature (°C)	Conductance (μ mho/cm)	Dissolved Oxygen (ppm)	pH
26 Feb.	1	1.2	155	N.D.	7.5
26 Feb.	2	0.6	185	N.D.	7.9
26 Feb.	3	0.6	185	N.D.	7.85
26 Feb.	4	0.5	175	N.D.	7.8
26 Feb.	5	1.2	160	13.4	7.7
26 Feb.	5a	0.75	185	11.6	7.9
25 Feb.	6	0.2	162	10.6	7.8
25 Feb.	7	0.3	166	11.5	7.75
25 Feb.	8	0.75	160	11.0	7.7
25 Feb.	9	0.5	179	11.2	7.6
25 Feb.	10	1.5	180	11.2	8.0

[a]Symbol: N.D. = No Data.

[b]These data were irregular due to the altitude changes involved in transporting the meter by helicopter.

Table 11. Physical and chemical data from May 1976 to February 1977.

Month	Site	Conductivity (μ mho/cm)	Total Unfilterable Residue (ng/l)	Flow	Turbidity (units)	TOC (mg/l)	Kjeldahl Nitrogen (mg/l)	Total Phosphate (mg/l)
January 1977	1	59	174	200	3.2	6.0	0.77	0.05
	2	151	186		48.0	13.5	1.21	0.03
	3	140	218		2.4	13.0	0.86	0.08
	5	217	208		2.3	8.0	0.77	0.03
	5a	136	225		1.8	7.0	0.80	0.04
	6	115	195		2.4	9.0	0.75	0.04
	7	130	216		2.1	7.0	0.72	0.23
	8	125	217		1.8	5.0	0.66	0.02
	9	129	251		3.9	6.5	0.88	0.04
	10	134	241		2.6	9.5	1.21	0.01

Continued ....

Table 11. Continued.

Month	Site	Conductivity (μ mho/cm)	Total Unfilterable Residue (ng/l)	Flow	Turbidity (units)	TOC (mg/l)	Kjeldahl Nitrogen (mg/l)	Total Phosphate (mg/l)
February 1977	1	59	164	200	5.8	5.0	0.65	0.05
	2	154	215		5.0	8.0	0.57	0.03
	3	154	203		5.8	11.0	0.67	0.19
	4	144	212		4.0	11.0	0.63	0.12
	5	107	199		4.2	8.0	0.63	0.03
	5a	143	225		3.2	9.0	0.75	0.03
	6	117	192		3.9	10.0	0.82	0.04
	7	120	198		1.4	9.0	0.82	0.20
	8	128	209		3.3	7.0	0.59	0.03
	9	128	235		2.1	8.0	0.61	0.03
	10	132	245		4.2	12.0	0.70	0.25
May 1976	2	108	164	680	26.0	12.0	0.28	0.166
	3	124	123		33.0	15.0	0.26	0.066
	±4 (right)	107	142		28.0	12.0	0.26	0.075
	±4 (left)	103	195		31.0	13.0	0.25	0.066
	10	109	163		27.0	13.0	0.3	0.07

Continued ....

Table 11. Continued.

Month	Site	Conductivity (μ mho/cm)	Total Unfilterable Residue (ng/l)	Flow	Turbitidy (units)	TOC (mg/l)	Kjeldahl Nitrogen (mg/l)	Total Phosphate (mg/l)
June 1976	1	61	124	1370	64.0	17.0	2.6	0.085
	2	107	144		255.0	19.0	3.19	0.125
	3	83	148		130.0	20.5	4.17	0.185
	4	90	120		155.0	16.5	3.74	0.208
	5	107	144		270.0	18.0	3.04	0.180
	5a	91	144		225.0	18.5	3.19	0.197
	6	97	132		230.0	15.0	2.89	0.192
	7	202	248		16.0	18.0	2.89	0.007
	7a	104	124		270.0	14.5	2.75	< 0.005
	8	93	140		218.0	20.0	2.75	0.157
	9	103	145		230.0	14.5	2.89	0.254
	10	100	156		270.0	16.0	2.89	0.173
July 1976	1	59	203	1150	18.0	15.5	1.29	0.08
	2	85	156		59.0	15.5	1.56	0.13
	3	72	127		43.0	15.5	1.44	0.112
	4	86	158		51.0	9.5	1.09	0.093
	5	85	132		56.0	30.0	1.27	0.062

Continued ....

Table 11. Continued.

Month	Site	Conductivity (μ mho/cm)	Total Unfilterable Residue (ng/l)	Flow	Turbidity (units)	TOC (mg/l)	Kjeldahl Nitrogen (mg/l)	Total Phosphate (mg/l)
July	6	79	121		43.0	12.5	1.01	0.110
1976	7	84	126		48.0	11.0	1.44	0.085
	7a	195	230		15.0	23.5	1.29	< 0.005
August-	1	60	89	1880	155.0	83.0	0.82	0.32
September	2	93	109		205.0	144.0	1.20	0.35
1976	3	60	88		168.0	61.0	2.70	0.35
	4	73	112		218.0	22.0	1.30	0.41
	8	87	107		218.0	23.0	0.70	0.29
	9	86	105		205.0	23.0	1.20	0.36
	10	92	135		218.0	22.5	1.60	0.37
September-	1	60	112	750		18.0	0.48	0.26
October	2	109	127			9.5	0.71	0.05
1976	3	107	130			14.5	0.74	0.05
	4	77	110			17.0	0.54	0.05
	5	99	126			10.5	0.38	0.05

Continued ....

Table 11. Concluded.

Month	Site	Conductivity (μ mho/cm)	Total Unfilterable Residue (ng/l)	Flow	Turbidity (units)	TOC (mg/l)	Kjeldahl Nitrogen (mg/l)	Total Phosphate (mg/l)
September-	5a	95	125			11.0	0.98	0.06
October	6a	107	155			22.0	0.68	0.07
1976	7	100	130			14.5	0.83	0.06
	7a	128	198			19.0	0.70	0.04
	8	95	123			11.5	0.51	0.05
	9		129			10.0	0.51	
	10	98	134			14.5	1.08	0.07
December	1	64	152	275	2.8	7.0	0.69	0.03
1976	2	194	240		5.1	11.0	0.59	0.05
	3	128	210		3.2	11.0	0.64	0.03
	4	161	236		3.2	13.0	0.59	0.03
	5	149	226		2.8	8.0	0.82	0.03
	6a	155	238		2.5	13.0	0.73	0.03
	6	126	193		4.1	24.0	0.68	0.07
	8	143	206		5.2	9.0	0.73	0.67

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