Urbanization and the Microbial Content of the North Saskatchewan River

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The effect of urbanization on the microbial content of the North Saskatchewan River was determined by following the changes in the numbers of total bacteria, total eosin methylene blue (EMB) plate count, and Escherichia coli as the river flowed from its glacial source, through parklands, and out into the prairies. Changes in physical parameters such as pH, temperature, salt concentration, and the amount and nature of the suspended material were also determined to evaluate their effect on the microbial parameters being measured. The level of all three microbial parameters studied slowly increased as the river flowed from its glacial source out into the prairies. The major effect of small hamlets, with or without sewage treatment facilities, appears to be to supply nutrients which supports the growth of the indigenous river flora but not E. coli. In contrast, the effect of a large urban center, with a population of approximately 500,000, which utilizes primary and secondary sewage processes in disposing of sewage, is to provide the nutrients and an inoculum of E. coli which results in a marked increase in the numbers of all three microbial groups studied. The effect of this urban center was still discernible 300 miles downstream. The river was also monitored for the presence of Salmonella sp. Only one positive isolation was achieved during this study, and this isolate was characterized as being Salmonella alachua.

Rivers are the repositories of both treated and untreated domestic and industrial wastes, and within limits they are self-purifying systems (12). In order to establish meaningful environmental regulations concerning the use of rivers as receiving bodies for society’s wastes, it is first necessary to establish what effect man’s activities have on a river’s normal microbial flora. Ideally, a river to provide a model system for such a study should be examined in an area where man has had little opportunity to alter its composition. It is also necessary to be able to observe the effect of wastes dumped into the river for a considerable distance downstream without large amounts of similar material being further added to the river. The North Saskatchewan River in western Canada provides a model system for such a study. It arises in Jasper National Park, Alberta, from a glacial source and flows relatively undisturbed for approximately 100 miles. There are only a few small towns and hamlets situated on its banks until it reaches Edmonton, a city of approximately 500,000 people plus petrochemical and assorted sustaining industries. For the next 250 miles, with the exception of Fort Saskatchewan, a town 25 miles downstream from Edmonton with approximately 7,000 people, there is very little habitation other than farmlands and occasional bridge crossings to interrupt its flow. The tributary systems draining into the North Saskatchewan River are restricted to one major river, the Brazeau, and several small creeks. The Brazeau drains on unsettled wilderness area, and the creeks drain barley farmland areas. There are no settlements on these tributary systems. Thus, this river is an ideal system for studying the effects of man’s activities on the microbiological activities and the capacity of such a river system to handle wastes.

This paper describes the experimental procedures developed as well as the changing patterns of selected groups of microbiological types and physical parameters (e.g., pH, temperature, and suspended material) as the river flows from its source, through Edmonton, out into the prairies.

MATERIALS AND METHODS

Sampling methods. Triplicate samples of surface water were collected at each location in sterile, wide-mouthed, 4-liter jars and immediately placed in
ice chests until used. All samples were taken during the period between mid-June and the end of July 1972. River locations were chosen so that straight stretches of at least 0.5 mile preceded the sampling site; thus abnormalities in flow rates brought about by curves were avoided.

Before taking portions of samples for analysis, the whole 4-liter sample was agitated for 5 min on a reciprocal shaker at 278 strokes/min. This was followed by a 5-min stationary period during which large particles settled out. The supernatant was then sampled at a depth of 6 cm, and suitable dilutions were made in cold 0.3 mM phosphate buffer (1). All dilutions were shaken 25 times before being plated in quintuplicate on prepared plates of various media previously warmed to room temperature (20°C). This technique facilitated the pipetting of samples and was without effect on the total numbers of bacteria determined as long as dilutions were made within 10 min of termination of the agitation period.

Microbiological analysis. Total counts were obtained by using a spread plate technique on tryptone yeast extract agar (TYA) with an incubation period of 4 days at 25°C. TYA consists of tryptone (Difco), 2.0 g; yeast extract (Difco), 2.5 g; sodium acetate, 0.2 g; agar (Difco), 15.0 g; and distilled water to 1 liter. The total eosin methylene blue (EMB) count is defined as those organisms which will grow on EMB agar (i.e., will use lactose or saccharose as carbon sources in the presence of EMB), and was obtained by using a spread plate technique on EMB agar (Difco), with an incubation period of 3 days at 30°C. Total Escherichia coli present were also determined on the EMB plates and represented those colonies which gave either a typical metallic green sheen or colonial coloration and morphology as described in the Difco manual (2), or both. This technique of determining total EMB count and E. coli was also compared with the presumptive standard total coliform (most probable number) procedure and the elevated temperature test.

All water samples were checked for the presence of Salmonella sp. by inoculating 5 ml of double strength Selenite broth (Difco) with 5 ml of water sample. Such tubes were incubated for 48 h at 37°C, after which 0.1-ml samples were used to streak SS agar (Difco) plates which were incubated at 41°C for 2 to 3 days. Suspect colonies were tested with Salmonella O polyvalent antiserum (BBL).

Physical analysis. The temperature of river samples was taken at the time of sampling. The pH and salt concentrations (conductivity) of the corresponding samples were determined when dilutions were made for microbial analyses. The dry weight of samples was determined by drying three 10-ml samples to constant weight ± 0.1 mg accuracy (12 h at 80°C) and weighing the residue. The organic matter concentration was determined by the chromic acid oxidation method (1), and the results were expressed as milligrams of organic matter per liter of the original sample.

Statistical analysis. Data from samples, i.e., values obtained from each location replicate, were subjected to the Nalimov test (7), which rejected data outside of 95% confidence limits. All values obtained were then subjected to analysis of variance, and product-moment correlation coefficients were calculated (10). All statistical analyses were done with an IBM 360 computer.

RESULTS

Parameters affecting microbial counts: media and incubation conditions. The data presented in Tables 1 and 2 indicate that the use of EMB agar and a temperature of 30°C for determining total coliform and E. coli levels of river water samples yielded values closely comparable to those obtained by the standard methods, presumptive and elevated temperature tests. The data are comparable for most samples at the 95% confidence level and for all samples at the 65% confidence level. Since higher values were obtained by the EMB method for those samples which did not agree at the 95% level, the data reported in this paper represent maximal values.

Sampling sites. Locations on the river were chosen so that the effects of mountains, park-

### Table 1. Comparison of total EMB count and total coliforms

| Sample | EMB ± 2 SD | MPN* |
|--------|------------|------|
| 1a     | 8.1 ± 4.8  | 9.3 × 10^4 (1.5/38.0) |
| b      | 5.1 ± 3.8  | 9.3 × 10^4 (1.5/38.0) |
| c      | 7.0 ± 2.5  | 2.3 × 10^4 (0.4/12.0) |
| 2a     | 2.9 ± 0.8  | 1.1 × 10^4 (0.15/4.8) |
| b      | 3.5 ± 0.6  | 4.6 × 10^4 (0.7/24.0) |
| c      | 2.2 ± 1.7  | 4.3 × 10^4 (0.7/21.0) |

* Triplicate samples of river water at two different locations. All samples except 1c showed overlap at the 95% confidence level.

* Most probable number; upper/lower limits at 95% confidence level.

### Table 2. Comparison of total E. coli counts by EMB and elevated temperature test

| Sample | EMB ± 2 SD | Elevated temperature |
|--------|------------|----------------------|
| 1      | 2.8 ± 1.7  | 3.3 × 10^4 (1.1/9.3) |
| 2      | 1.5 ± 0.5  | 7.9 × 10^4 (2.5/19.0) |
| 3      | 2.3 ± 0.6  | 2.4 × 10^4 (0.7/7.5) |
| 4      | <1         | 2.0 × 10^4 (7.0/0.5) |
| 5      | <1         | 0.02                 |

* Five different storm sewer samples. All samples except 2 and 5 showed overlap at the 95% confidence level.

* Upper/lower limits at 95% confidence level.
lands, and cultivated land drainage and of storm and domestic sewage influents on the various parameters under consideration could be measured. A brief description of the river and surroundings at the 20 sampling sites plus their distance from the glacial source and a site number for later reference are presented in Table 3.

| Sample site | Location | Miles from source | Description |
|-------------|----------|-------------------|-------------|
| 1           | Canyon Mouth | 2                 | Glacial melt water, river is 100 feet from Sun-Wapta Pass highway, ice-bound for 7 months. |
| 2           | Wild Horse Creek | 37                | Small stream tributaries from mountain slopes, highway 0.5 mile from river, no human habitation, ice-bound for 7 months. |
| 3           | Saunders   | 94                | More tributaries from mountain slopes, one very small settlement upstream from this location with no sewage effluent draining to the river, ice-bound for 6 months. |
| 4           | Pre-Rocky Mountain House | 138          | Same as 3. |
| 5           | Post-Rocky Mountain House | 140         | Similar to sample 4 but with the addition of one tributary and the anaerobic lagoon sewage effluent of a town of 3,141. Ice-bound for 6 months. |
| 6           | Rose Creek | 204               | One major tributary plus the drainage of parkland, some farmlands, and oil fields. Ice-bound for 6 months. |
| 7           | Drayton Valley | 218              | Similar to sample 6. The river passes within 4 miles of a town. |
| 8           | Berry Moor Ferry | 235         | Similar to sample 7. |
| 9           | Genesee Bridge | 271              | Now receiving drainage from almost entirely farmlands and oil fields. Ice-bound for 6 months. |
| 10          | Pre-Devon  | 297               | Similar to sample 9. |
| 11          | Post-Devon | 299               | Similar to sample 10 but with the addition of sewage effluent from a town with population of 1,502. Sediment is settled and passed through a commercial biofilter, chlorinated, and discharged to the river. A small petroleum refinery is located about 1 mile from the river banks. |
| 12          | Edmonton-156 Street | 313         | This location is just before the river enters Edmonton, a city of 441,530. Ice-bound for 5 months. |
| 13          | Edmonton-Quesnell Bridge | 316     | Similar to sample 12 but with the addition of storm sewer drainage. Ice-bound for 5 months. |
| 14          | Edmonton-Low Level Bridge | 323    | Storm sewer drainage plus the addition of two small streams. Channel open all year. |
| 15          | Edmonton-Clover Bar | 332     | This location is 3 miles down-stream from the sewage effluent for Edmonton. The sewage is secondarily treated and discharged. Channel open all year. |
| 16          | Fort Saskatchewan | 348            | Similar to sample 15 but with the addition of some effluents from the petrochemical industry. Ice-bound for 5 months. |
| 17          | Vinca Bridge | 365              | The river now passes through more farmlands and oil fields. Two more tributaries drain to the river, both from farmlands. Ice-bound for 5 months. Anaerobic lagoon effluent from Fort Saskatchewan a population of 6,756. |
| 18          | Shandro Bridge | 427              | Similar to sample 17 with no tributaries. |
| 19          | Elk Point  | 489               | Similar to sample 18. |
| 20          | North Battleford | 633            | Similar to sample 19, just upstream of a small city. |
tary, the Brazeau river system. Cultivated farmland is drained into the river between sites 9 and 10, whereas site 11 represents the river after receiving the tertiary treated sewage effluent from a town of 1,502 people. Sites 12 through 14 represent the passage of the river through the major portion of the city of Edmonton, which has a population of 441,550. The city's secondary treated sewage is discharged to the river between sites 14 and 15. Petrochemical and related industries line the river from site 15 to just downstream from site 16, at which point a town of 6,756 discharges anaerobic lagoon-treated domestic sewage to the river. From sites 16 to 20 the river is surrounded by prairie farmlands, with the addition of two minor tributaries.

**Sediment composition.** The data presented in Fig. 1 show similar patterns of change of total microbial count in samples of sediment and surface water. The expression of the counts on a volume basis magnifies the numbers found in the sediment as opposed to surface waters. The difference in these counts is not as marked when counts are expressed on a weight basis. Since difficulty was experienced in obtaining a satisfactory uniform sediment sample because the river bed varied from a sand sediment to one containing rocks of all sizes, it was decided to sample surface waters where the river was approximately 3 feet (about 0.9 m) deep and the location at least 0.5 mile from the last curve. Furthermore, since the sediment suspended in the river varied from "glacial flour" at its head waters to organic material from the sewage discharges in urban areas, the results are expressed on a volume basis. The count per weight parallels the count per volume (Fig. 1). The correlation coefficient between these two lines is 0.925, which indicates a high degree of linearity (critical value = 0.576 at 95% confidence).

**River flow rate.** Variations in river volume flow rates introduce another variable into these studies. Sampling for the major portion of the study took place during late June and July 1972, during which time the mean flow rate at Edmonton was 31,900 and 22,000 cubic feet/s, respectively. Although no restriction could be placed on the flow rates, it was felt that sampling during this period would minimize its effect, since flow variations were minimal. During late May and early June, break-up occurs, and flow rates at Edmonton peak at around 110,000, whereas peak August flow is down to 20,000 cubic feet/s (11).

**Water temperature.** Since the temperature of the river (Fig. 2) increased from 1 C at site 1 to 17 C near Edmonton, the initial total counts were carried out at both 5 and 25 C. The bacterial count data (Table 4) show that similar counts were obtained at both temperatures; therefore, since only limited facilities were available at 5 C, the survey for total counts was carried out at 25 C. The data in Fig. 3 suggest that the microbial types detected at the two temperatures are not the same and that the

![Fig. 1. Relationship between total counts per milliliter and per gram of the North Saskatchewan River from its source to North Battleford, Saskatchewan.](image-url)

**Table 4. Comparison of total bacterial counts of surface North Saskatchewan River water incubated at 5 and 25 C**

| Site | 5 C            | 25 C           |
|------|----------------|----------------|
| 1    | (6.61 ± 0.55) x 10^9 | (6.00 ± 2.50) x 10^9 |
| 2    | (7.20 ± 0.60) x 10^9 | (2.40 ± 0.27) x 10^9 |
| 4    | (2.40 ± 0.13) x 10^9 | (2.10 ± 0.16) x 10^9 |
| 5    | (1.70 ± 0.15) x 10^9 | (1.90 ± 0.13) x 10^9 |
| 10   | (1.70 ± 0.24) x 10^9 | (2.20 ± 0.39) x 10^9 |
| 16   | (1.80 ± 0.44) x 10^9 | (5.60 ± 0.21) x 10^9 |
| 17   | (7.60 ± 0.99) x 10^9 | (3.40 ± 0.36) x 10^9 |
| 18   | (1.40 ± 0.53) x 10^9 | (2.70 ± 0.66) x 10^9 |
percentage of pigmented bacteria detected was greater at 5 than at 25 °C. It is also possible that pigmentation is induced in a culture by growing at low temperatures. The content of the pigmented bacteria also decreases as the river flows out into the plains. During the counting of the winter plates from site 13 samples, it was estimated that the percentage of pigmented bacteria was about 40 to 50%, or close to the level observed near the rivers source (see Fig. 3). Fifty to sixty percent of the pigmented bacteria growing at 4 °C and in the winter sample from site 13 were tentatively identified as being members of the genus *Cytophaga*.

**Sectional analysis of sample site.** Table 5 shows a comparison of the bacterial counts obtained from surface water samples taken across the width of the river in a straight and curved section of the river. However, statistical analysis of the data indicated that the results were significantly different only at the 95% confidence level on the south side of the curved section of the river compared with the other locations. Although this cannot be considered as a significant difference, sample sites were chosen in straight stretches of the river which were free of sand bars to minimize possible abnormalities brought about in local changes in flow rates. Other workers have shown that the water in a river is homogenous with respect to microorganism distribution (13).

**Storage of samples.** Samples were all stored at 4 °C during transportation and in the laboratory until used. The data presented in Table 6 indicate a varied response to storage of the three microbial populations studied. At the 95% confidence level, sample 13 showed a significant increase in total count and a significant decrease in total EMB count after 24 h of storage at 4 °C. In contrast, the populations in sample 15 remained stable during this period. The *E. coli* count appeared to be unaffected by storage at 4 °C over the 2-day period, whereas the other populations measured decreased significantly by the end of the storage period. It has previously been shown that, in refrigerated water samples, *E. coli* did not significantly change in numbers when stored at 4 °C for 72 h (8). Therefore, in order to minimize such variations, all the data reported in this paper were obtained from samples which had been stored for no longer than 24 h.

**Analysis of the river.** The information presented in Table 7 and Fig. 4 shows the sample number and the total microbial, EMB, and *E. coli* counts per milliliter of water. The temperature, pH, and salt concentration are presented in Fig. 2, whereas dry weights of sample and organic matter, and ratio of the two, are presented in Fig. 5.

**Microbiological analysis: viable counts.** The changes in total, EMB, and *E. coli* counts as a function of distance from source are presented in Fig. 4. The data show that there is a differential response to the populations studied as the river flows out of the mountains onto the prairies. The discharge of small settlements like Rocky Mountain House and Devon resulted in a

### Table 5. Comparison of the total and EMB counts across the width of the North Saskatchewan River on a straight and curved section at site 13 and 1 mile downstream from site 13

| Location on lateral section | Bacterial count/ml ± 1 SD | Straight section | Curved section* |
|-----------------------------|---------------------------|-----------------|-----------------|
|                             | Total                     | EMB             | Total           | EMB             |
| A (north bank)              | (9.06 ± 1.89) x 10^4      | (1.13 ± 0.15) x 10^4 | (2.54 ± 0.09) x 10^4 | (4.84 ± 0.40) x 10^2 |
| B                           | (9.03 ± 2.03) x 10^4      | (1.19 ± 0.95) x 10^4 | (2.86 ± 0.51) x 10^4 | (3.78 ± 1.05) x 10^2 |
| C (midpoint)                | (6.54 ± 4.30) x 10^4      | (1.13 ± 0.19) x 10^4 | (2.89 ± 0.56) x 10^4 | (4.38 ± 0.49) x 10^2 |
| D                           | (8.29 ± 4.56) x 10^4      | (8.66 ± 0.18) x 10^4 | (2.33 ± 0.72) x 10^4 | (4.06 ± 0.37) x 10^2 |
| E (south bank)              | (9.38 ± 0.99) x 10^4      | (8.49 ± 0.06) x 10^4 | (5.03 ± 1.31) x 10^4 | (1.18 ± 0.33) x 10^2 |

*Approximately one-half way through curve; north side represents inside of the curve, the south side represents the outside of the curve.
Table 6. Effect of storage time at 4 °C on the total, EMB, and E. coli counts of two different surface samples of North Saskatchewan River water

| Site  | Hours at 4 °C | Bacterial count/ml ± 1 SD | Total | EMB    | E. coli |
|-------|---------------|---------------------------|-------|--------|---------|
| 13    | 4             | (1.05 ± 0.10) x 10⁴      | (2.14 ± 0.19) x 10⁴ | (4.04 ± 1.26) x 10³ |
|       | 28            | (1.54 ± 0.26) x 10⁴      | (1.65 ± 0.05) x 10⁴ | (3.70 ± 0.36) x 10² |
|       | 54            | (7.19 ± 0.75) x 10⁴      | (1.46 ± 0.17) x 10⁴ | (3.76 ± 0.73) x 10² |
| 15    | 3             | (2.45 ± 0.24) x 10⁴      | (7.56 ± 0.29) x 10³ | (2.06 ± 0.11) x 10³ |
|       | 27            | (2.61 ± 0.08) x 10⁴      | (7.12 ± 0.37) x 10³ | (1.86 ± 0.81) x 10³ |
|       | 51            | (1.41 ± 0.13) x 10⁴      | (2.58 ± 0.05) x 10⁴ | (1.00 ± 0.00) x 10³ |

* Samples were taken separately, approximately 1 month after sampling for major survey.

Table 7. Total, total EMB, and E. coli counts of North Saskatchewan River water

| Site  | Bacterial count/ml ± 1 SD |
|-------|---------------------------|
|       | Total count | Total EMB | E. coli |
| 1     | (4.81 ± 1.10) x 10²  | (4.80 ± 0.90) x 10¹  | (1.00 ± 0.00) x 10⁰ |
| 2     | (7.26 ± 1.20) x 10²  | (4.50 ± 1.30) x 10¹  | (5.00 ± 2.00) x 10⁰ |
| 3     | (1.16 ± 0.05) x 10²  | (3.80 ± 0.60) x 10¹  | (6.00 ± 3.00) x 10⁰ |
| 4     | (1.47 ± 0.02) x 10²  | (1.11 ± 0.13) x 10¹  | (9.00 ± 3.00) x 10⁰ |
| 5     | (7.66 ± 1.57) x 10²  | (1.62 ± 0.23) x 10¹  | (1.00 ± 0.00) x 10⁰ |
| 6     | (7.66 ± 1.29) x 10²  | (1.98 ± 0.34) x 10¹  | (1.30 ± 0.30) x 10⁰ |
| 7     | (6.84 ± 1.01) x 10²  | (1.86 ± 0.19) x 10¹  | (1.00 ± 0.00) x 10⁰ |
| 8     | (1.10 ± 0.21) x 10²  | (7.56 ± 1.20) x 10³  | (1.50 ± 0.50) x 10⁰ |
| 9     | (1.27 ± 0.17) x 10²  | (5.20 ± 0.47) x 10²  | (1.30 ± 0.50) x 10⁰ |
| 10    | (7.70 ± 3.49) x 10²  | (6.91 ± 0.42) x 10²  | (1.00 ± 0.00) x 10⁰ |
| 11    | (1.25 ± 0.01) x 10²  | (6.35 ± 0.77) x 10²  | (1.80 ± 0.30) x 10⁰ |
| 12    | (6.92 ± 0.39) x 10²  | (2.07 ± 0.22) x 10²  | (1.00 ± 0.00) x 10⁰ |
| 13    | (4.85 ± 0.41) x 10²  | (1.73 ± 0.17) x 10²  | (3.10 ± 0.90) x 10⁰ |
| 14    | (2.13 ± 0.12) x 10²  | (1.99 ± 0.17) x 10²  | (2.10 ± 1.00) x 10⁰ |
| 15    | (4.02 ± 0.93) x 10²  | (9.15 ± 3.19) x 10³  | (1.03 ± 0.28) x 10⁰ |
| 16    | (3.61 ± 0.78) x 10²  | (1.32 ± 0.19) x 10⁴  | (1.02 ± 0.18) x 10⁰ |
| 17    | (1.59 ± 0.14) x 10²  | (3.84 ± 0.41) x 10⁴  | (2.89 ± 1.25) x 10⁴ |
| 18    | (3.39 ± 0.16) x 10²  | (5.59 ± 0.60) x 10⁴  | (4.48 ± 0.52) x 10⁴ |
| 19    | (1.78 ± 0.50) x 10²  | (1.08 ± 0.07) x 10⁴  | (4.00 ± 1.15) x 10⁴ |
| 20    | (9.83 ± 0.75) x 10²  | (1.42 ± 0.16) x 10⁴  | (2.03 ± 1.52) x 10⁴ |

greater stimulation in the total and EMB counts than in the E. coli present. However, a large urban center like Edmonton introduces a large number of E. coli into the river along with the nutrients sufficient to stimulate the total and "coliform" population as well. These stimulations are also reflected in increases in those counts in the bottom sediments of the river (authors' unpublished data).

Statistical analysis of these data indicates that the stimulation of the total and EMB counts by Edmonton sewage effluent persists for at least 300 miles downstream from Edmonton, whereas the E. coli count is starting to return to normal within 100 miles of Edmonton. In general, there is a significant difference between pairs of means at 95% confidence levels by t-test for the following groups of microorganisms:

Fig. 4. Total, total EMB, and E. coli counts in the North Saskatchewan River as a function of distance from its source.
between samples 1 and 11 and 12 and 20 for total count; between samples 1 and 14 and 15 and 20 for total EMB; between 1 and 14, 19 and 20, and 15 and 18 for E. coli. These results objectively express what is seen in both Fig. 4 and Table 7, that is, that Edmonton contributes significantly to the bacterial population.

Correlations between all measured parameters are given in Table 8. There was a high correlation between total count, total EMB count, and E. coli. This is expected but statistically not valid since the three microbial populations overlapped, that is, E. coli and total EMB were a fraction of the total count. There was no significant correlation between any of the microorganisms and salt concentration, at least during the time of the study. The temperature and pH gave a negative correlation, which was probably fortuitous since the temperature rises after leaving the glacier and the high pH of limestone-saturated water is modified by the solution of carbon dioxide. A similar correlation but to a lesser extent appeared between temperature and all other parameters with the exception of salt concentration, which gave a high value (0.9006).

**Effect of physical parameters on viable counts.** The most marked effect on the temperature of the river (Fig. 2) was noted during its first 140 miles, where the temperature increases from 1 C (ice-water mixture) to about 14 C. During the next 500 miles, the temperature only increased another 3 C. The pH of the river (Fig. 2), except for sample 1, changed very little, i.e., only 0.3 units during its 600-mile course. The salt concentration (Fig. 2) continuously increased during the first 200 miles and then, except for slight variations where the river flows through Edmonton, remained relatively constant.

The dry weight of the samples (Fig. 5) with the exception of sample 1 remained relatively constant during its first 280 miles until Edmonton was reached, when it increases about fivefold. This value was reduced to the upstream Edmonton value during the next 35 miles. The high values at sites 19 and 20 were probably an artifact, since the samples were taken during a period when the North Saskatchewan River was turbulent in that area. The organic matter content (Fig. 5) remained at a relatively low value until site 5 was passed and then continued to increase to a value of around 15 mg/liter as the river flowed east through an increasing number of small hamlets. Once the river had passed through Edmonton and Fort Saskatchewan (sample 16), it contained in excess of 20 mg/liter, and this value does not appear to decrease during the next 160 miles. The relationship between organic matter and inorganic sediment is better shown in Fig. 5, where the ratio is plotted as a function of distance from the source. This figure suggests (i) that there is

![Graph](image1)

**Fig. 5. Relationship between total dry weight, organic matter, and the ratio of organic matter to total dry weight of the North Saskatchewan River water between its source and North Battleford, Saskatchewan.**

### Table 8. Correlation coefficients among all measured parameters of North Saskatchewan River water*

| Parameter          | Temp | pH    | Salt conc | Ratio (organic material/dry wt) | Total count | Total EMB | E. coli |
|--------------------|------|-------|-----------|---------------------------------|-------------|-----------|---------|
| Temp               | —    | —     | —         | 0.5941                          | 0.4708      | 0.3952    | 0.3225  |
| pH                 | —    | —     | —         | −0.7115                         | −0.4822     | −0.3735   | −0.2957 |
| Salt conc          | —    | —     | —         | 0.6520                          | 0.5093      | 0.5410    | 0.5439  |
| Ratio (OM/DW)      | —    | —     | —         | 0.9085                          | —           | —         | 0.8442  |
| Total count        | —    | —     | —         | —                               | —           | —         | —       |
| Total EMB          | —    | —     | —         | —                               | —           | —         | —       |
| E. coli            | —    | —     | —         | —                               | —           | —         | —       |

* Critical value = ±0.2900.
in general a continual increase in organic matter as the river flows from the wilderness area to an area of maximal habitation, i.e., the Edmonton area, and (ii) there is some variability in the organic material concentration especially around Edmonton. This inflated level of organic matter does not return to a normal level until it has flowed approximately 180 miles downstream from Edmonton (sample 19).

The data presented in Table 9 show that the normal microbiological flora is greatly reduced under winter conditions as one would expect, and thus the effect of Edmonton’s effluents on the river are greatly magnified. The site 13 winter sample also indicated a shift back toward a pigmented bacterial population.

Occurrence of Salmonella species. During the period of sampling of the river, both upstream and downstream from Edmonton, only one isolation of a member of this genus was obtained. This was from a water sample obtained from site 17 and was classified as Salmonella alachua. It is possible that more successful Salmonella isolations would have been obtained if other methods or media, or both, had been used for enrichment and isolation.

DISCUSSION

A river can be considered as a two-phase continuous fermentor consisting of (i) the aerobic, moving surface water containing suspended matter, and (ii) the fixed sediments which provide an anaerobic environment. The inflow of nutrients is not uniform and is dependent upon both surface and subsurface drainage waters, the degree of habitation, and land use practices of man. The flow rate and drainage channel are the chief determining factors upon the rate of sedimentation and mixing of components added to the river. There is, in general, no feedback of nutrients and microorganisms upstream, and thus individual sections of the river can be considered as batch fermentors, the size of the fermentor being directly related to the flow rate and volume of the river (2).

In our preliminary study of this river, parameters were chosen which could be accurately and easily measured so that the usefulness of the sample type as an indicator of the effect of urbanization on the North Saskatchewan River could be readily assessed.

The composition of the microbial population of a river is dependent not only upon the microorganisms being carried, but also on the nature of materials and microorganisms being added to it via natural run-off and sewage effluents. The data suggest that the major effects of small settlements like Rocky Mountain House are probably on the total and “nonfecal coliform” content. That is, the added organic matter (Fig. 5) is potentially a source of nutrients for the growth of microorganisms present in the water. In contrast, the effect of the wastes of a large city, i.e., Edmonton, which has and uses secondary sewage treatment processes in handling wastes, is not only to add nutrients permitting growth, but also to add sufficient E. coli to yield a 300-fold increase in the content of this microorganism within 100 miles downstream (see Fig. 4). The fact that the increase occurs primarily (Table 7) within 3 miles of the point where Edmonton’s sewage effluent enters the river suggests that most of these E. coli are added in the sewage plant effluent (output averages 40 million gallons per day). That some growth does take place, however, is indicated from the increase in bacterial numbers observed downstream from Fort Saskatchewan, an area where only barley farmland drainage occurs. The elevated levels of E. coli started to decrease before any effect on the total EMB count was noted (sample 19, Fig. 4). This observed difference in survival ability of different groups of microorganisms under natural environmental conditions has been well documented in many systems (1, 5–7).

Table 9. Comparison of bacterial counts during winter and summer at two locations of the North Saskatchewan River

| Site | Season | Counts/ml ± 1 SD* | Total | Total EMB | E. coli |
|------|--------|------------------|-------|-----------|--------|
| 13   | Winter | (1.14 ± 0.19) x 10^4 | (1.78 ± 0.46) x 10^4 | 0 |
|      | Summer | (4.85 ± 0.41) x 10^4 | (1.73 ± 0.17) x 10^4 | (1.02 ± 0.18) x 10^4 |
| 16   | Winter | (2.08 ± 0.14) x 10^4 | (7.81 ± 0.88) x 10^4 | (2.47 ± 0.43) x 10^4 |
|      | Summer | (3.61 ± 0.78) x 10^4 | (1.32 ± 0.19) x 10^4 | (1.02 ± 0.18) x 10^4 |

* All site 13 counts and site 16 E. coli counts showed significant differences between winter and summer counts at both 95 and 99% confidence levels by t-test. All other counts showed significant differences at 95 but not 99% levels.
It is to be noted that the counts of all three groups slowly increased as the river flowed from the mountains to parklands and the prairies. This slow increase in numbers is probably the result of the interaction of several factors, for example, the addition of microorganisms and nutrients to the river through surface and subsurface drainage and the reproduction of microorganisms, which factors have been previously shown (1, 5, 7). The contribution of a tributary should normally not affect the microbial numbers present in the receiving river except when it contains an abnormal load of microorganisms or substrates, or both. It was not possible to detect the effect of the Brazeau system on the microbial load of the North Saskatchewan River. A similar situation may occur when the river is in flood, but this was also not possible to detect by bacterial counts.

Variations observed in the physical and microbial parameters studied as the river flowed through an urban center such as Edmonton probably reflects, at least in part, the effects of storm sewers and the return of large volumes of industrial cooling waters to the river. Although precautions were taken in the selection of sampling sites within Edmonton to avoid such situations, the data suggest that we might not always be successful or that mixing in any given location is not uniform or reproducible. The latter hypothesis is more reasonable, since physical parameters are more uniform upstream from Edmonton (see Fig. 5, organic material).

The data presented indicate that the dumping of Edmonton’s wastes into the North Saskatchewan River alters its microbial composition to such a degree that its effect is still discernable 300 miles downstream from the city (sample 20). Not only are the total, total EMB, and E. coli counts increased by Edmonton, but the fraction of pigmented bacteria is decreased (Fig. 3). It was also noted that the bottom cover of the river changed from a natural leaf mold one upstream from where the effluent from the sewage plant enters the river to a black sediment smelling strongly of hydrogen sulfide downstream from the sewage treatment plant. The results also confirm Wuhrmann’s (12) view that although the river is an open continuous fermentor, it can be best studied in sections which can be isolated and treated as batch fermentors.

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LITERATURE CITED

1. American Public Health Association. 1971. Standard methods for the examination of water and wastewater, 13th ed. American Public Health Association Inc., Washington, D.C.
2. Blakebrough, N. 1969. Design of laboratory fermentors, p. 473-502. In J. R. Norris and D. W. Ribbons (ed.), Methods in microbiology, vol. 1. Academic Press Inc., New York.
3. Difco Laboratories. 1972. Difco manual, 9th ed. Difco Laboratories, Detroit, Michigan.
4. Geldreich, E. E. 1966. Sanitary significance of fecal coliforms in the environment. Federal Water Pollution Control Administration Publ. WP-20-3.
5. Geldreich, E. E. 1970. Applying bacteriological parameters to recreational water quality. J. Amer. Water Works Ass. 62:113-120.
6. Hendericks, C. W. 1972. Enteric bacterial growth rates in river water. Appl. Microbiol. 24:168-174.
7. Kaiser, R. 1971. Errors in chromatography. Chromatographia 4:123-127.
8. Lonsane, B. K., N. M. Parhad, and N. U. Rao. 1967. Effect of storage temperature on the coliforms in water samples. Water Res. 1:309-316.
9. McFeters, G. A., and D. G. Stuart. 1972. Survival of coliform bacteria in natural waters: field and laboratories studies with membrane filter chambers. Appl. Microbiol. 24:805-811.
10. Sokal, R. R., and F. J. Rohlf. 1969. Biometry, 1st ed. W. H. Freeman and Co., San Francisco.
11. Water Survey of Canada. 1972. Daily discharge record. Canadian Federal Government, Ottawa, Canada.
12. Wuhrmann, L. 1971. Stream purification, p. 119-151. In R. Mitchell (ed.), Water pollution microbiology. Wiley-Interscience, New York.
13. Witzenhausen, R. 1972. Aus welcher Wassertiefe soll die Wasserprobe für die bakteriologische Untersuchung entnommen werden? Zentabl. Bakteriol. Parasitenk. Infektionskr. Hyg. Abt. Orig. 156:373-382.