Bacteriological Assessment of Spoon River Water Quality

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Data from a study of five stations on the Spoon River, Ill., during June 1971 through May 1973 were analyzed for compliance with Illinois Pollution Control Board’s water quality standards of a geometric mean limitation of 200 fecal coliforms per 100 ml. This bacterial limit was achieved about 20% of the time during June 1971 through May 1972, and was never achieved during June 1972 through May 1973. Ratios of fecal coliform to total coliform are presented. By using fecal coliform-to-fecal streptococcus ratios to sort out fecal pollution origins, it was evident that a concern must be expressed not only for municipal wastewater effluents to the receiving stream, but also for nonpoint sources of pollution in assessing the bacterial quality of a stream.

Pathogenic bacteria indicators are used to determine the presence of disease-causing organisms originating from fecal pollution. Indicators such as total coliform (TC), fecal coliform (FC), and fecal streptococcus (FS) are used because of the laborious technique and equally expensive equipment required to isolate pathogenic bacteria and viruses from water.

The use of coliform bacteria as a measure of the fecal contamination of lakes and streams has been in practice for many years. The coliform group, however, includes a heterogeneous mixture of bacteria, many of which have little in common with each other except the fact that they are always present in the intestinal tract of humans and other warm-blooded animals. Thus the occurrence and densities of the TC group have been useful in assessing the sanitary conditions of water even though it is well known that some bacteria in the group have origins other than fecal material.

More recent developments have shown that the use of FC as an indicator of pollution from warm-blooded animal feces is a more precise bacteriological tool for assessing water quality, and the Illinois Pollution Control Board (10) (IPCB) has adopted rules requiring adherence to certain limitations on bacterial quality in waters of the state measured by the occurrence and density of fecal coliforms.

One of the weaknesses of the FC test is its inability to distinguish between whether or not the contributing sources are human or nonhuman warm-blooded animals. Geldreich and Kenner (2, 4) have reported upon the use of tests for FC correlated with tests for FS as a reliable procedure for differentiating sources of bacterial pollution. Their findings showed that FS densities were significantly higher than FC densities in all warm-blooded animals feces examined except that of humans. The application of these findings, within limits, should be useful in determining the comparative relationship of urban and rural areas as sources of fecal pollution in Illinois waters.

A 2-year water quality study of the Spoon River commenced on 1 June 1971. The stream’s waters were sampled at weekly intervals for bacteria and plankton enumerations as well as for major chemical constituents until 29 May 1973. The objectives of the study were (i) to determine the bacteria densities at selected sites on the main stem of the Spoon River and (ii) to ascertain if meaningful relationships exist between the densities and distribution of TC, FC, and FS.

MATERIALS AND METHODS

The Spoon River, with a drainage area of about 1,800 square miles, (4,660 sq. km) extends approximately 161 miles (260 km) in length from its confluence with the Illinois River in the vicinity of Havana, Ill. From its two sources, the East Fork and West Fork originating in Bureau and Henry counties, respectively, the Spoon River flows in a southerly direction through the counties of Stark, Peoria, Knox, and Fulton. In addition to its origin, the principal tributaries of the Spoon River are Indian, Walnut, Court, Cedar, and Big Creeks. The slope of the main stem of the river ranges from 4 feet (about 1.21 m) per mile (about 1.6 km) near its mouth (0.012 to 0.076%). The extent of the basin is shown in Fig. 1. There are 16 municipalities served by wastewater
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The largest communities are Kewanee and Canton with populations of 15,800 and 14,200 persons, respectively. Of the other 14 communities, seven have populations equal to or less than 1,500 persons, and the other seven have populations greater than 1,500 persons. None of these 14 communities have populations in excess of 3,200 persons.

For the purpose of the study, five sampling stations were established (Table 1). Their respective locations are shown in Fig. 1.

During periods of sampling, stream flows as measured at Seville varied from 18 ft³/s (about 5.4 m³/s) on 18 September 1971 to 16,000 ft³/s (about 480 m³/s) on 24 April 1973. These extreme flow ranges suggest the sensitivity of the Spoon River to runoff. Water temperatures varied from 0 to 29°C and ice cover prevailed during January and February. The temperature of the stream water, in general, increased as the water progressed downstream.

Although tests for TC and FC bacteria were performed at weekly intervals during the 2 years of

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**Table 1. Sampling stations used**

| Station | Mile point | Drainage area (sq. mi.) |
|---------|------------|------------------------|
| Havana  | 2.5 (1.6)  | 1,806 (704.0)          |
| Seville | 37.7 (23.4)| 1,600 (624)            |
| London Mills | 68.4 (42.4) | 1,070 (417.3)    |
| Elmore  | 113.7 (70.5)| 569 (221.9)           |
| Modena  | 141.2 (87.5)| 154 (60.1)            |

* River miles above mouth. Numbers in parentheses indicate kilometers.
* Numbers in parentheses indicate square kilometers.
sampling, tests for FS were limited to the second year. All samples for bacterial examination were collected several inches below the surface of the water at midchannel, in sterile 250-ml glass bottles, and placed on ice immediately. Bacterial examinations were performed on the morning after the day of collection.

Membrane filter techniques for TC, FC, and FS were performed in accordance with Standard Methods (1). The previous studies (5, 6) suggest that the membrane filter procedure is comparable to the multiple-tube method for TC, FC, and FS determinations in the river waters. TC counts were made with the M-Endo agar LES two-step procedure. M-FC broth and M-Enterococcus agar were used for FC and FS enumerations, respectively. Three duplications for each sample were filtered through 0.45-μm membrane filters for each test.

RESULTS AND DISCUSSION

Bacteria density. From June 1971 through May 1973, total coliform densities varied randomly from a minimum of 160/100 ml to a maximum of 13,000,000/100 ml. Both of these extremes occurred at Seville. FC densities ranged from 16/100 ml at London Mills to 160,000/100 ml at Modena, and FS counts reached a minimum of 17/100 ml at Havana and a maximum of 42,000/100 ml at Modena.

The mathematical distribution of the bacterial density data was determined by plotting the data on log probability paper. Figure 2 shows a typical pattern of distribution for the first year's data at two stations. Since a straight line can be drawn with some confidence through each set of plotted points, the data reflect the characteristics of a log-normal distribution with the geometric mean at the 50% quantile. The central tendencies and dispersion of log-normal distributed data can best be expressed in geometric terms, i.e., geometric mean and geometric standard deviation. The slope of the line reflects the variability of the data, and the geometric standard deviation (variability) is larger for the Havana data (Fig. 2).

The yearly ranges, geometric means, and geometric standard deviations of the bacterial densities observed at each of the sampling sites are summarized in Table 2. An inspection of the geometric means for FC and FS in the table

![Fig. 2. Log-probability plot of fecal coliforms densities in the Spoon River, June 1971 through May 1972.](image)
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Table 2. Statistical data of indicator bacteria counts per 100 ml at the Spoon River

| Station       | Density | Range | Mₜ | αₑ |
|---------------|---------|-------|----|----|
| Modena (MP-141.2) | 6.10-20.0 | 1.300-2.400 | 1.500-2.100 | 4.900-6.100 |
| Elmore (MP-113.7) | 1.50-3.00 | 5.10-10.00 | 9.000-15.000 | 20.000-30.000 |
| Spoon River (MP 2.5) | 0.50-1.00 | 0.200-0.350 | 0.500-0.700 | 1.000-1.500 |
| Havana (MP 37.7) | 0.50-1.00 | 0.200-0.350 | 0.500-0.700 | 1.000-1.500 |

generally suggests a higher concentration of organisms in the upper reaches, with lower concentrations in the downstream sectors. However, after applying statistical tests to the data, it was determined that there are no significant differences between the geometric means for the stations at Modena and Elmore, a distance of approximately 31 miles (50 km); similarly, there was no difference between the geometric means at London Mills and Seville, a distance of about 28 miles (45 km). Since it is unlikely that FC and FS experience regrowth in the stream, and considering the fact that the organisms do die off, it is probable that the lack of differences in bacterial densities between the stations is due to bacterial loadings originating from nonpoint rural sources of pollution along the intervening distances between stations.

Monthly geometric means of TC and FS bacteria densities are shown in Fig. 3 and 4, respectively. It is apparent from Fig. 3 and Table 2 that TC densities for the first year of the study were much lower than that for the second year. Stream flows were considerably higher during the second year. There was not a general pattern, suggesting seasonal variations in bacteria densities (TC and FS) at any of the stations sampled. Generally, however, there were decreases in TC densities with downstream movement (Table 2).

An exception to this general rule occurred during January through April 1973 (Fig. 3) for the Havana station. An examination of the Illinois River recorded pool stages for that period suggests that the sampling station on the Spoon River in the vicinity of Havana was significantly influenced by the floodwaters of the Illinois River. It is quite probable during this period of high water that the Illinois River was receiving inadequately treated sewages upstream of the Havana area to the extent that higher than normal TC densities were found in its backwaters in the Spoon River.

Comparison of FC standards. The general rule for bacterial quality, adopted by the Illinois Pollution Control Board (10) and applicable to the most Illinois streams including the Spoon River, is Rule 203(g), which states:

"Based on a minimum of five samples taken over not more than a 30-day period, fecal coliforms shall not exceed a geometric mean of 200/100 ml, nor shall more than 10% of the samples during any 30-day period, exceed 400/100 ml."

The FC densities, recorded for the Spoon
River at five locations from June 1, 1971 to May 29, 1973 were evaluated in terms of this rule using a programmable Wang 720 calculator (Fig. 5 and 6). There were some 30-day periods for which five samples were not available for evaluation. These omissions are indicated on the abscissa of the figures. Also depicted on the figures are the FC limits adopted by the IPCB, i.e., the geometric mean of 200/100 ml that must not be exceeded.

It appears that only during the latter part of October and the month of November 1971 was acceptable bacterial quality achieved at all stations (Fig. 5). Acceptable bacterial quality,
as measured by the geometric mean, occurred at some stations during the period December 1971 through March 1972. Ice cover prevailed during the months of January and February.

It is apparent that satisfactory bacterial quality was not achieved at any of the five stations during the 12-month period, June 1972 to May 1973 (Fig. 6). As mentioned earlier, the bacterial quality observed during the second year of the study was substantially worse than that found for the first year of the study. This is probably due to the above-normal precipitation events resulting in excessive rural and urban runoff during 1972 through 1973, compounded by the necessity to bypass sewage treatment facilities at frequent intervals.

A comparison of the observed FC densities with water quality requirements is summarized in Table 3. There were periods of compliance with the IPCB rule (Fig. 5). However, on an overall basis (Table 3), only in about one of every five periods of 30 days was a geometric mean of 200/100 ml or less achieved; and only about one period in 12 periods of 30 days met the conditions of the rule pertaining to FC densities not exceeding 400/100 ml for more than 10% of the samples.

It would appear that the portion of the rule
limiting geometric mean densities is not the
governing factor in assessing the bacterial qual-
ity of the Spoon River. Rather the limiting factor
is that portion of the requirement whereby no more than 10% of the samples shall exceed 400/100 ml. Whether or not this is the case for other Illinois streams remains to be
determined.

**FC/TC ratio.** The historical record of bacte-
rial examinations in Illinois streams is com-
posed principally of total coliform data. It
seemed worthwhile, therefore, to determine FC/
TC ratios with the thought in mind that a FC
baseline record might, at sometime, be derived
from the TC record of previous years.

We used the arithmetic mean in evaluating
the FC/TC ratios. The ratios developed for the
five stations during the period June 1971 to May
1973 are summarized in Table 4. The ratios
varied considerably, ranging from 0.0001 to
0.657 with a 2-year overall average of 0.095.
In other words, 9.5% of the TC consisted of FC.

This overall average for the Spoon River is
higher than that observed on the Upper Illinois
Waterway (7) (8.8%) and lower than that
reported for the Ohio River (9) (14.0%). The range
of the ratios for the Spoon River was greater
than that of the Upper Illinois Waterway (0.002
to 0.38) and the Ohio River (0.004 to 0.45).

The monthly average ratios for each of the
five sampling stations are depicted in Fig. 7.
The period of relatively low ratios occurred
during January through March 1972 and
November 1972 through May 1973. To produce low
ratios, either the FC densities must decrease or
the TC densities must increase. During the two
periods of low ratios, the FC densities did not
significantly decrease (Fig. 5 and 6). On the
other hand, TC densities did increase signifi-
cantly during these periods (Fig. 3). It can be

**Table 4. Statistical results of FC/TC values of the
Spooner River**

| Station (MP) | Study period | Range | M* | σ* |
|--------------|--------------|-------|----|----|
| 141.2        | 6/1971-5/1972| 0.002-0.530| 0.115| 0.130|
|              | 6/1972-8/1973| 0.001-0.300| 0.064| 0.063|
|              |              | 0.001-0.473| 0.054| 0.065|
|              |              | 0.001-0.451| 0.071| 0.086|
|              |              | 0.001-0.400| 0.131| 0.117|
|              |              | 0.0001-0.295| 0.060| 0.073|
|              |              | 0.002-0.429| 0.110| 0.106|
|              |              | 0.001-0.188| 0.057| 0.055|
|              |              | 0.083| 0.089|
| 113.7        | 6/1971-5/1972| 0.004-0.391| 0.113| 0.103|
|              | 6/1972-5/1973| 0.001-0.473| 0.054| 0.065|
|              |              | 0.001-0.451| 0.071| 0.086|
|              |              | 0.001-0.400| 0.131| 0.117|
|              |              | 0.0001-0.295| 0.060| 0.073|
|              |              | 0.002-0.429| 0.110| 0.106|
|              |              | 0.001-0.188| 0.057| 0.055|
|              |              | 0.083| 0.089|
| 68.4         | 6/1971-5/1972| 0.003-0.567| 0.143| 0.139|
|              | 6/1972-5/1973| 0.001-0.451| 0.071| 0.086|
|              |              | 0.001-0.400| 0.131| 0.117|
|              |              | 0.0001-0.295| 0.060| 0.073|
|              |              | 0.002-0.429| 0.110| 0.106|
|              |              | 0.001-0.188| 0.057| 0.055|
|              |              | 0.083| 0.089|
| 37.7         | 6/1971-5/1972| 0.001-0.473| 0.054| 0.065|
|              | 6/1972-5/1973| 0.001-0.451| 0.071| 0.086|
|              |              | 0.001-0.400| 0.131| 0.117|
|              |              | 0.0001-0.295| 0.060| 0.073|
|              |              | 0.002-0.429| 0.110| 0.106|
|              |              | 0.001-0.188| 0.057| 0.055|
|              |              | 0.083| 0.089|
| 2.5          | 6/1971-5/1972| 0.002-0.473| 0.110| 0.106|
|              | 6/1972-5/1973| 0.001-0.188| 0.057| 0.055|
|              |              | 0.083| 0.089|

* M, Arithmetic mean.
* σ, Standard deviation.

concluded that the lower ratios on the Spoon
River are due to increasing TC densities rather
than decreasing FC densities.

Strobel (11) reported that the relationship
between FC and TC varied with the sources of
pollution, level of sewage treatment, character-
istics of the receiving waters, and precipitation
on the watershed. Since so many factors may
influence the overall value of FC/TC ratios, it
would seem unwise to rely on overall average
values based upon a year or more of observa-
tion. In fact it would be preferable to limit
judgment to only those ratio values obtained
during stable stream flow conditions. However,
ON the basis of the results shown in Fig. 7, the
monthly or seasonal mean might be useful.

The ORSANCO Water Users Committee (9)
suggests that higher FC/TC ratios might indi-
cated the proximity of inefficient wastewater treatment operations or conditions where treatment facilities are being bypassed during storm runoff. Low ratios (<0.20) are most likely caused by aftergrowths of *Aerobacter aerogenes* resulting in abnormally high TC densities (9). In the Spoon River, 437 samples of 494 (88.5%) produced FC/TC ratios less than 0.20. This is indicative of *A. aerogenes* aftergrowths in the stream.

**FC/FS ratio.** The use of FS in conjunction with FC was first suggested by Geldreich et al. (10). They felt the use of a ratio, FC/FS, would be a more valuable informational tool for assessing pollution sources than relying solely on FC densities. In applying the FC/FS ratio to a natural stream system, best results are obtained if the stream samples are collected within a 24-h stream flow time of a pollution source.

From a series of studies (2, 4), it was determined that ratios greater than 4 were indicative of a pollution source primarily of human origin such as domestic wastewater, whereas ratios less than 0.7 suggest the likelihood of the pollution source to be that of waste from warm-blooded animals other than humans, i.e., livestock and poultry wastes. Table 5 summarizes the relationship of a range of FC/FS ratio values to their respective probable origins (2, 4, 8).

Determinations for FS densities were limited to the second year of the study which covered the period June 1972 through May 1973. This was a very wet year with excessive variability in stream flows and the computed ratios reflected this variability. The low value of 0.18 occurred at the Havana station; a high of 27.8 occurred at the Modena station. Both of these extremes occurred on 27 December 1972.

There was no distinguishable pattern in average monthly values and thus the yearly average values were meaningless. In an effort to evaluate the FC/FS ratios for comparison with the relationships set forth in Table 5, a cumulative frequency diagram was prepared (Fig. 8). A review of the figure suggests that the percentage of fecal bacteria originating from animal wastes other than human increased with downstream movements. This increase in occurrence of fecal bacteria from animal wastes is apparent from the values set forth in Table 6, if the summation of columns 1 and 2 are compared with the summation of columns 4 and 5. It is quite apparent from Table 6 that fecal bacteria in the upper reaches of the Spoon River originated primarily from humans during the period of study; from London Mills downstream, the shift in origin is toward other animal wastes with a significant change of bacterial origin occurring in the stretch of the stream between Seville and Havana. The data emphasize the importance of defining nonpoint sources of pollution in addition to point sources when assessing the bacterial quality of streams.

We draw the following conclusions from our data.

**Fig. 7. Monthly average of FC/TC values in the Spoon River.**

**Table 5. Relationship between FC/FS values and pollution sources**

| FC/FS - X range | Indicative source of pollution                      |
|-----------------|-----------------------------------------------------|
| X ≥ 4           | Human wastes                                        |
| 4 > X > 2       | Predominance of human wastes in mixed pollution     |
| 2 ≥ X ≥ 1       | Uncertain of interpretation                         |
| 1 > X > 0.7     | Predominance of animal wastes in mixed pollution    |
| 0.7 ≥ X         | Livestock or poultry wastes                         |
(i) Bacteria densities, although varying randomly in time, exhibited a log-normal distribution at each station permitting the central tendencies and dispersion of the data to be expressed in geometric terms.

(ii) Bacteria densities, in general, decreased with downstream movement.

(iii) During periods of high Illinois River stage, the bacterial quality of the lower Spoon River was influenced by the Illinois River.

(iv) From comparing fecal coliforms densities with the bacteria requirements of the IPCB, acceptable bacterial quality in the Spoon River was achieved about 8.3% of the time during June 1971 through May 1972. During the period June 1972 through May 1973, satisfactory bacterial quality was not achieved at any of the five sampling stations during periods of sampling.

(v) Since compliance with the IPCB was achieved about 20% of the time during 1971 through 1972 under that portion of the rule referring to a geometric mean limitation of 200 FC/100 ml, and only 8.3% of the time when considering the conditions of the rule pertaining to not exceeding bacterial densities of 400 FC/100 ml for more than 10% of the samples, it would appear that the latter condition is the governing factor in assessing the bacterial quality of the Spoon River.

(vi) To derive meaningful baseline fecal coliform data from historical records of total coliform measurements by current FC/TC ratios, it would be preferable to limit the data used to that obtained from stable stream flow conditions. However, monthly or seasonal values may be useful with proper judgment.

(vii) Although bacterial densities decreased with downstream movement, the decrease in total coliform was less dramatic because of the occurrence of A. aerogenes aftergrowths in the stream.

(viii) The use of FC/FS ratios indicated that fecal bacteria in the upper reaches of the Spoon River originated primarily from human wastes; from London Mills downstream the origin shifted to animal wastes with a significant change occurring between Seville and Havana.

(ix) The FC/FS ratios emphasizes the need to consider nonpoint as well as point sources of pollution in assessing the bacterial quality of streams.

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